Effect of Agroforestry and Intercropping Systems on Fodder Production in Rural Areas in South Africa

Report to the
WATER RESEARCH COMMISSION

by

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executive summary

1. INTRODUCTION

The major agricultural enterprises for small-scale farmers in the Upper Thukela region are livestock (mainly cattle) and crops (mainly maize and dry beans). These enterprises (cattle and crops) are the sources of their income and staple diets respectively. However, one of the major constraints in rural farming systems of the Upper Thukela region is the shortage of adequate and good quality forage during the dry winter season. Supplementation of feed using commercial supplements is expensive for resource-poor farmers and supplements are not easily available in remote areas. Provision of alternative sources of fodder such as tree leaves and pods can increase production. The introduction of tree species, particularly the leguminous fodder trees in combination with temperate pastures for fodder, should decrease the grazing pressure on the existing grassland. This will result in improved basal cover, decreased soil erosion and promote greater water infiltration. The leguminous fodder trees can also be used as alternative sources of high quality forage for livestock and can substitute for expensive dairy concentrates as they are rich in protein. Therefore the leguminous fodder trees can be used as supplements to grasses and can provide significant amounts of protein for ruminants particularly dairy cows.

2. PROJECT OBJECTIVES

The specific objectives of the project were:

1. To determine the effect of different agroforestry systems on increasing fodder production in rural farming systems.
2. To determine the effect of agroforestry practices on soil water availability to traditional crops (e.g. maize).
3. To determine whether the inclusion of trees in traditional cropping systems can enhance the infiltration of rainfall and prevent soil loss.
4. To compare the water use of an indigenous fodder tree (*Acacia karroo*) and an exotic fodder tree (*Leucaena*), in order to test the hypothesis that indigenous fodder trees are more conservative water-users than exotic tree species.

The objectives of the project were all achieved. However, the effect of trees on soil loss was not measured because of the flat aspect of the experimental site and the high basal cover.

3. STUDY AREA

The field trials were conducted on a small-scale dairy farm owned by Mr Simon Mbhele. The farm falls within a communal rangeland area in the Zwelisha ward of Bergville in the province of KwaZulu-Natal, South Africa. The area is bordered to the south west by Lesotho and to the north and north east by the uThukela River and Woodstock dam.

The vegetation of the area falls under Bioresource Group 12, Moist Tall Grassveld (Camp 1999). The characteristic feature of this BRG is the abundance of thatch grass, *Hyparrhenia hirta* and sparsely scattered acacias including *Acacia karroo*, *A. sieberana* and *A. caffra*. The grassland in the area is described as sourveld which provides palatable material only during the growing season (6-8 months of the year). The vegetation is therefore characterized by low palatability in the winter season.

The area falls into the summer rainfall region. The mean annual rainfall range of this BRG is 712-805 mm and the mean annual temperature is 17.1°C. Frosts are moderate with the occasional severe frost.

The soils of the study area are dominated by red soils (Hutton soil form) with good effective depth and drainage and to a lesser extent by grey soils (Westleigh soil form) which are poorly drained. Agricultural lime, as well as fertilizers, are essential for good crop growth and high yield.

The traditional farming system is based on the two main enterprises of keeping cattle and growing maize. In winter, following harvest and when the climatic conditions in the mountains are extremely cold, most of the cattle graze on the communal rangelands in the lowlands and on the maize stover. The maize stover remaining after harvest therefore provides a valuable winter feed for the cattle. During the summer and cropping season the herds are kept on the lower slopes and the oxen are driven up to the mountain tops. Milk cows and young calves are kept in the vicinity of the homesteads. In 2002 the farmer, Mr Mbhele, had a herd of approximately 12 cattle at his dairy within one kilometre of his homestead, and was able to sell his milk locally for R2.50 l^{-1}. The experimental trials were held at both the dairy site and the homestead site.

4. ALLEY CROPPING TEMPERATE PASTURE SPP. AND TREE LEGUMES

The problem of severe shortage of fodder faced by Mr Mbhele, a small holder dairy farmer, was confirmed by the low dry matter yields recorded from natural veld (1195-2728 kg ha^{-1}). The alley crop field trial demonstrated the high potential of the use of temperate grass species and tree legumes for small-scale dairy systems in the Upper Thukela region. For example, the dry matter production from the winter pasture species in spring 2008 (3390 kg ha^{-1}) indicated a 96% increase in fodder over the veld. Fodder production in alley crops ranged from a minimum of 4830 kg ha^{-1} in 2005 in *L. leucocephala* alley cropped with cocksfoot to a maximum of 8928 kg ha^{-1} in 2006 in *A. karroo* alley cropped with Tall fescue. The cafeteria trial showed that dairy cows preferred *L. leucocephala* tree fodder (97% intake) compared to *A. karroo* tree fodder (52% intake).

One of the negative factors in alley cropping agroforestry systems is the competition between trees and crops. However, throughout the trial trees had a positive effect on pasture production with highest values generally recorded 0.5 m from the trees. For example, in 2006 the total pasture dry matter yield of Cocksfoot was higher in alley plots (> 5318 kg ha^{-1}) compared to sole pasture plots (3703 kg ha^{-1}). Similarly, the Tall Fescue alley plots had a higher yield (>7193 kg ha^{-1}) than in the sole plots (<4212 kg ha^{-1}).

The field trial demonstrated high mean crude proteins values of *A. karroo* (14.65%) and *L. Leucocephala* (18.6%). Higher total inorganic nitrogen in alley treatments (145.78-181.45 ppm) compared to sole treatments (77.56-89.68 ppm) indicate that tree legumes can be used to supplement expensive concentrates. In addition, the temperate pasture species, Tall fescue (15.26%) and Cocksfoot (16.09%), were able to provide quality fodder during the dry winter season.

This is an indication of the importance of having silvopastoral fodder production systems in rural areas where shortages of fodder are usually experienced during winter.

5. INTERCROPPING MAIZE AND *DOLICHOS LABLAB*

The higher total fodder yield observed in the maize plus lablab treatment compared to maize only treatment showed the importance of intercropping maize with lablab for increasing feed quantity. Highest fodder production was obtained in 2007 from intercropping (12120 kg ha^{-1}) compared to sole maize cropping (7360 kg ha^{-1}).

The highest maize grain yield (4460 kg ha^{-1}) was recorded in the maize plus lablab treatment during the 2006 season. The yield was significantly higher than the maize only treatment (1490 kg ha^{-1}) ($p<0.01$). The results are in contrast to those obtained in the 2004, 2005 and 2008 seasons where the differences in grain yield between sole maize and intercrop were not significant ($p=0.440$).

The results from this study highlighted the importance of agronomic practices in achieving high yields. Maize grain yield from intercropping systems was reduced by entanglement, competition from weeds and foraging by animals during 2004, 2006 and 2008.

With very poor quality roughages (such as mature sourveld grasses with a high lignin content, and fibrous maize stalks and leaves) cattle cannot ingest enough feed for maintenance requirements. Intercropping maize with lablab improved the quality (crude protein) of maize leaves by 39% which will therefore enable the farmer to meet the maintenance requirements for his dairy cows.

6. WATER USE

An important objective of this of this study was to estimate the water use of the various agroforestry trees species in the trial. In the Zwelisha trial only the Acacia trees were large enough for sap flow measurements using the Heat Pulse Velocity technique. However, large trees of *Morus alba*, *Gleditsia triacanthos* and *Acacia karroo* were available at the initial agroforestry trial situated on Mr Mahlobo's farm and were chosen for the water-use measurements. The heat pulse velocity technique was selected as the most appropriate technique for the measurement of sap flow/transpiration rates in the selected trees. Seventeen access tubes for the measurement of soil water content, using the Diviner 2000 system of measurement were installed in each of the silvopastoral treatments. An automatic weather station was used to monitor the climatic conditions at Zwelisha.

The trend in the vapour pressure deficit (VPD), which gives a good indication of the atmospheric evaporative demand, showed that the most extreme climatic conditions occurred in August to September at the end of dry winter period in all years. During these periods VPDs of over 2 kPa were recorded, coinciding with very low humidity, high temperatures and high average and maximum wind speeds.

Temperature trends across the trial were measured from May 2006 to September 2006 using Hobo loggers. During the winter period regular frosts were recorded at the study site. Between 1 June and 15 July 2006, minima of -5°C were frequently recorded at the study site. Clear seasonal trends were found in the soil water content in the 2007 year, with the lowest water contents (±130 mm) being recorded in the winter (June and July) while the highest water contents (±260 mm) were recorded during the rainy season from November to February. In the bare soil areas water contents were over 100 mm lower than in the tree rows. It was concluded that this was a result of higher surface evaporation from the bare soil than from tree transpiration. This illustrates the importance of mulching in soil water conservation. In 2008 there were no clear seasonal trends in soil water between treatments. Unlike 2007, soil water values were consistently high (250-300 mm) in all months, probably as a result of regular irrigation of the plots.

The water use for *A. karroo* in this silvopastoral trial indicated that maximum sap-flow rates were between 20-25 l day^{-1} in summer, while the fast growing *G. triacanthos* tree averaged 25-30 l day^{-1}. The semi deciduous nature of the indigenous *A. karroo* trees resulted in water-use later into the winter months, although these values were low. Heavy frost in 2008 resulted in seasonal plant die back and reduced water use. The introduced *M. alba* trees had maximum sap-flow rates of 10 l day^{-1} in summer as a result of pruning and showed reduced transpiration in winter due to the dry conditions and the deciduous nature of the trees. The data showed that *M. alba* had a lower water use than either the *G. triacanthos* or *A. karroo* trees. The impact of pruning was evident in all the tree species and pruning made absolute estimates of undisturbed single tree water use impossible. The results of the water-use estimates of all three species in this trial were conservative when compared to other South African studies, but must be seen against the silvicultural practice of pruning, which clearly had a major impact on leaf area and water use.

7. TECHNICAL TRANSFER

Details of the technology transfer and capacity building that occurred in this study are outlined in Appendix 2. In this on-farm trial Mr Mbhele received training on the establishment and management of different fodder production systems for dairy farming. Farmers' days were used to disseminate the results from the trials and demonstrate the viability of the fodder technologies to the wider farming communities. These farmers' days provided an opportunity for Mr Mbhele the farmer, to share his experience, knowledge and views on the benefits of the fodder technologies with other smallholder farmers, and encouraged information exchange among the farmers. The farmers' day in 2005 was broadcast on SABC TV which created national awareness about the project. Mr Mbhele also gave a presentation at the annual Grassland Society of Southern Africa conference in 2008 which resulted in extensive dissemination of the trial results to wider communities across South Africa. Paper presentations were also given by Mr Mthembu at the International Commission on Irrigation and Drainage conference in 2007 and the GSSA conference in 2008.

It should be noted that a number of problems were experienced during the on-farm trials which negatively impacted the research trials. A major problem throughout the course of the on-farm trials was the grazing of pastures and browsing of fodder trees by livestock, in spite of fencing off the site. This contributed to the low biomass values recorded during various growing seasons. This was a problem that was difficult to control as the farmer prioritized feeding his cattle over quality of research data. In addition, neighbours cut the fence to give their cattle access to the high quality forage in the trial. This highlights the need for providing fodder during winter in sourveld communal areas.

In spite of these problems, the study showed clearly that agroforestry and intercropping technologies should be tested under local farming conditions through on-farm trials with farmer involvement. In this way smallholder farmers can acquire skills and knowledge to implement fodder conservation techniques.

8. RECOMMENDATIONS FOR FUTURE RESEARCH

The results from the alley cropping trials in this study clearly demonstrate that benefits of agroforestry are generally not realized in the first two seasons after establishment. The long-term nature of agroforestry systems necessitates the use of models to facilitate the planning and optimisation from the wide range of species and tree spacing options available for implementation.

- Farmers indicated the need to extend similar on-farm trials to wider farming communities in other climatic areas and provinces.
- Testing a wider variety of trees and crops will give farmers more options to select the most appropriate species.

9. DATA

All processed data have been catalogued and stored at the CSIR and UKZN, BEEH, P/Bag X01, Scottsville, 3209. All data can be supplied to researchers and managers on CD-R diskettes. *Contacts:* Prof CS Everson and Mr Mark Gush.

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CHAPTER 1: INTRODUCTION

Ruminant livestock play an important role in sustaining socioeconomic aspects of households in smallholder farming areas worldwide. Livestock production was reported by Kunene *et al.* (2003) to be an integral part of the communal farming system. The multiple benefits obtained from ruminant livestock (cash income, insurance against risks in difficult environments, draft power, source of capital, milk, manure, meat and socio-cultural uses) have been reported in many studies (Stur *et al*. 2002; Dovie *et al*. 2006; Rufino *et al*. 2007; Mapiye *et al*. 2009; Zingore *et al*. 2009). These benefits contribute to the major role of ruminant livestock in sustaining livelihoods in communal areas. However, the magnitude of these benefits is dependent on the health of the livestock which in turn is dependent on the quality of their feed.

Natural rangeland (veld) forms an important basis for animal production (Tainton 1999) as it provides the cheapest feed resource for livestock (Smith 1999; Kirkman 1999) particularly in small holder farming systems where resources are limiting. However, the seasonal shortages and low nutritional value of natural veld, particularly during the dry season, is a major constraint to livestock production in smallholder farming systems (Mpairwe *et al*. 2002; Everson *et al*. 2003).

It is important to note that the quality and quantity of feed from the veld vary according to veld type. In the sourveld regions of South Africa, which occur at high elevation in high rainfall areas, the growing season is short because of low early-spring and low-autumn temperatures. As a result, sourveld regions only provide quality grazing for six to eight months of the year (Kirkman 1999; Hardy 1999). The grass species become fibrous and have poor quality during the dry winter season. Poor quality grasses in sourveld may also be attributed to high leaching of bases that result in acidic soils with low plant nutrient status (MacVicar 1999). Thus, both the quantity and quality of the natural veld are low during the dry season and are major constraints to ruminant livestock production in communal areas (Hove *et al*. 1999).

Supplementation of feed using commercial supplements is expensive for resource-poor farmers and they are not easily available in remote areas. Crop residues, in the form of maize stover that become available after harvest, provide an important feed resource for livestock during the winter season in communal areas. Although livestock survive the winter period by grazing maize stover and the low quality natural grassland, this is not sufficient for dairy cows. For example, Nyaata *et al*. (2000) reported high levels of neutral detergent fibre (NDF 83%) and low levels of crude protein (CP 4.5%) of maize stover. The low nitrogen, mineral and vitamin content of crop residues make them inadequate even to meet the daily maintenance requirement of dairy cows (6% CP; Smith 1999), while the high fibre results in low voluntary intake and low digestibility (Bwire and Wilktorsson 2002). The nutrient requirements for maintenance of a dairy cow weighing 300 kg to 500 kg are 288 g to 423 g of crude protein per day respectively. A productive cow in the middle third of pregnancy weighing 350 kg to 450 kg will require 320 to 390 g of crude protein respectively. Thus during the dry season the veld and maize residues have low nutritional value so that cattle lose considerable weight and become more susceptible to diseases (Moritz 2008).

In communal areas the grazing land is frequently reported to be in poor condition because it is difficult to implement veld grazing systems (e.g. rotational grazing) due to the fact that the land is communally owned (Smith 1999). Veld management principles such as resting of veld and having periods of absence, which are key for successful veld management and keeping the veld in good condition, are rarely practised in communal areas. This leads to deterioration in veld condition. Reducing the grazing pressure on communal land through the production of alternative fodder resources therefore has the potential to improve veld condition.

One way to provide alternative fodder resources is through the introduction of agroforestry systems or on-farm tree establishment. An agroforestry system is defined as a land-use system in which woody perennials (e.g. trees, shrubs) are deliberately used on the same land management unit as agricultural crops or animals or both, either in some form of spatial arrangement or temporal sequence (Huxley and Van Houten 1997). Currently, there are a vast number of different agroforestry systems which provide socio-economic upliftment and conserve the environment. In these systems there are both ecological and economic interactions between the different components. 'Agroforestry' is a general term for different types of systems. For example, agrosilvicultural systems incorporate trees and crops while silvopastoral systems incorporate trees and pastures for grazing. Thus agroforestry is a set of integrated land use practices, combining trees, shrubs, forages, grasses, livestock and crops in innovative, flexible combinations tailored to the landowner's needs. The goal in agroforestry is to optimize production and conservation benefits. Properly designed and implemented agroforestry practices can:

- Increase crop production
- Diversify products and farm income
- Improve soil quality and reduce erosion
- Improve water quality and reduce damage due to flooding
- Enhance wildlife habitat and improve biodiversity
- Reduce pest management inputs

Agroforestry consists of five main systems:

1. Alley Cropping
2. Silvopasture
3. Riparian Forest Buffers
4. Windbreaks and
5. Forest Farming.

When designing and implementing any of the five practices, it is important to consider the compatibility of the species with the site, the compatibility between species, the farm equipment available and the potential markets. On-farm trials have value in addressing all of these issues. Two agroforestry systems which have potential to increase fodder in the communal sourveld Upper Thukela region are alley cropping and silvopastures.

Alley cropping is an agroforestry system that entails growing food crops between hedge rows of planted shrubs and trees preferable leguminous species. The hedges are pruned periodically during the crop's growth to provide biomass which when returned to the soil enhances its nutrient status and physical properties. Pruning also prevents shading of the growing crop (Winrock International 2009). Beetz (2011) defines alley cropping as an agroforestry system that involves growing crops like grain, forages and vegetables between trees planted in rows. However, the canopy density and sunlight requirements for the agronomic, horticultural crops or forage crop are the primary factors that determine which crops can be grown (Khanal 2011)

Silvopasture is an agroforestry system that intentionally blends management of trees, forage and livestock. The benefits of silvopasture include increased forage yields by providing shade and shelter to the forage crop, reducing evaporation and thus improving moisture efficiency. Silvopasture as an agroforestry system improves quality of associated pastures. Buergler *et al.* (2006) found in their study of evaluating nutritive value of cool-season pastures in response to tree species, that shaded plants often have greater concentrations of crude protein.

The agroforestry systems may offer some benefits in the crop-livestock farming systems that are normally practiced in the smallholder farming areas. Some of the benefits from alley cropping reported by Kang and Gutteridge (1998) are improved crop performance, provision of additional products such as forage and firewood, improvement in physical nature of the soil environment, reduction of the use of chemical fertilizer, improvement in weed control. The reported benefits are relevant to small holder farmers in South Africa in particular and in southern Africa in general as small holder farmers in these areas are resource poor and as a result their crops perform poorly and also these farmers generally suffer acute shortages of good quality fodder for their livestock.

Intercropping technology is another strategy that can be used to improve the quantity and quality of livestock fodder in communal areas where there is a problem of fodder scarcity and quality. Several studies conducted in some African countries and other parts of southern African countries (Mpirwe *et al*. 2002; Ngongoni *et al.* 2007; Gbaraneh *et al*. 2004) showed that intercropping cereals with legumes increased cereal crop yields and their crude protein content and therefore are more profitable than sole cereal crop (Rao and Mathuva 2000). Studies also demonstrated that intercropping technology improved total biomass yields and protein content over that of sole cereal crops (Titterton *et al.* 2002, Anwar *et al.* 2010) and increased feed intake of low quality diets and daily weight gains of ruminant livestock (Kanani *et al*. 2006). For example, a study conducted in Ethiopia on the effect of intercropping maize with lablab and vicia on grain and forage yield (Hassen *et al.* 2006) showed that intercropping increased forage yield. However, the same study showed that simultaneous planting of maize with forage legume depressed maize grain and maize stover yields.

The aim of this project was to establish an on-farm trial to determine the effect of agroforestry, intercropping and pasture systems on fodder production and assess their impact on soil water availability for a small-scale dairy farmer. The provision of alternative sources of fodder such as tree leaves, pods and temperate high quality pasture species can increase production in communal areas. The introduction of tree species for fodder should also decrease the grazing pressure on the existing grassland. The capacity of rural farmers will be built by involving farmers in the planning, implementation, management and evaluation of the trials.

The objectives of the project were:

1. To determine the effect of different agroforestry systems on increasing fodder production in rural farming systems.
2. To determine the effect of agroforestry practices on soil water availability to traditional crops (e.g. maize).
3. To determine whether the inclusion of trees in traditional cropping systems can enhance the infiltration of rainfall and prevent soil loss.
4. To compare the water use of an indigenous fodder tree (*Acacia karroo*) and an exotic fodder tree (*Leucaena leucocephala*), in order to test the hypothesis that indigenous fodder trees are more conservative water-users than exotic tree species.

CHAPTER 2: DESCRIPTION OF THE STUDY AREA

2.1 Location

The field trial was conducted on a small-scale dairy farm within a communal rangeland area in the Zwelisha ward of Bergville in the province of KwaZulu-Natal, South Africa. Zwelisha is a subward of the Amangwane Traditional Authority area (Figure 2.1). The total area of the ward is approximately 1000 km^2. The experimental site was located approximately 35 km north-west of Bergville at 28º 30' S, 28º 00' E. The area is bordered to the south west by Lesotho and to the north and north east by the uThukela River and Woodstock dam. The farm is situated approximately 1000 m from the Woodstock dam.

The area falls into the summer rainfall region. The mean annual rainfall range is 712-805 mm and the mean annual temperature is 17.1^{0}C. Frosts are moderate with the occasional severe frost.

2.2 Vegetation

The vegetation of the area falls into Bioresource Group 12, Moist Tall Grassveld (Camp 1997). The most extensive plant association in the Moist Tall Grassveld is *Themeda-Hyparrhenia* Grassland with *Hyparrhenia hirta* dominating much of the veld, particularly disturbed veld (Camp 1997). Sparsely scattered acacias including *Acacia karroo, A. sieberana* and *A. caffra* are also present. This grassland is described as sourveld as it loses palatability and nutritive value when mature and only provides quality grazing for between six and eight months of the year. The vegetation is of low palatability and poor quality during the dry season (Ellery *et al.* 1995; Kirkman 1999; Hardy and Camp 1999; Everson *et al.* 2003). In sour grassveld areas the decline in grass quality usually begins at the beginning of February and it is therefore essential that good-quality licks be supplied to livestock at this time of the year to ensure continued animal mass gains. However, new grass growth is highly nutritious and palatable to livestock (Hardy and Camp 1999). The well managed rangeland is dominated by Decreaser species of *Themeda triandra*. Long term overgrazing is indicated by a dominance in *Eragrostis curvula, Eragrostis plana* and *Sporobolus africanus* (Hardy and Camp 1999). The decline in fodder quantity and quality that commences in mid-autumn (April), and lasts until early spring season (October) may limit livestock production particularly dairy cows and is a major constraint facing smallholder farmers in sourveld areas.

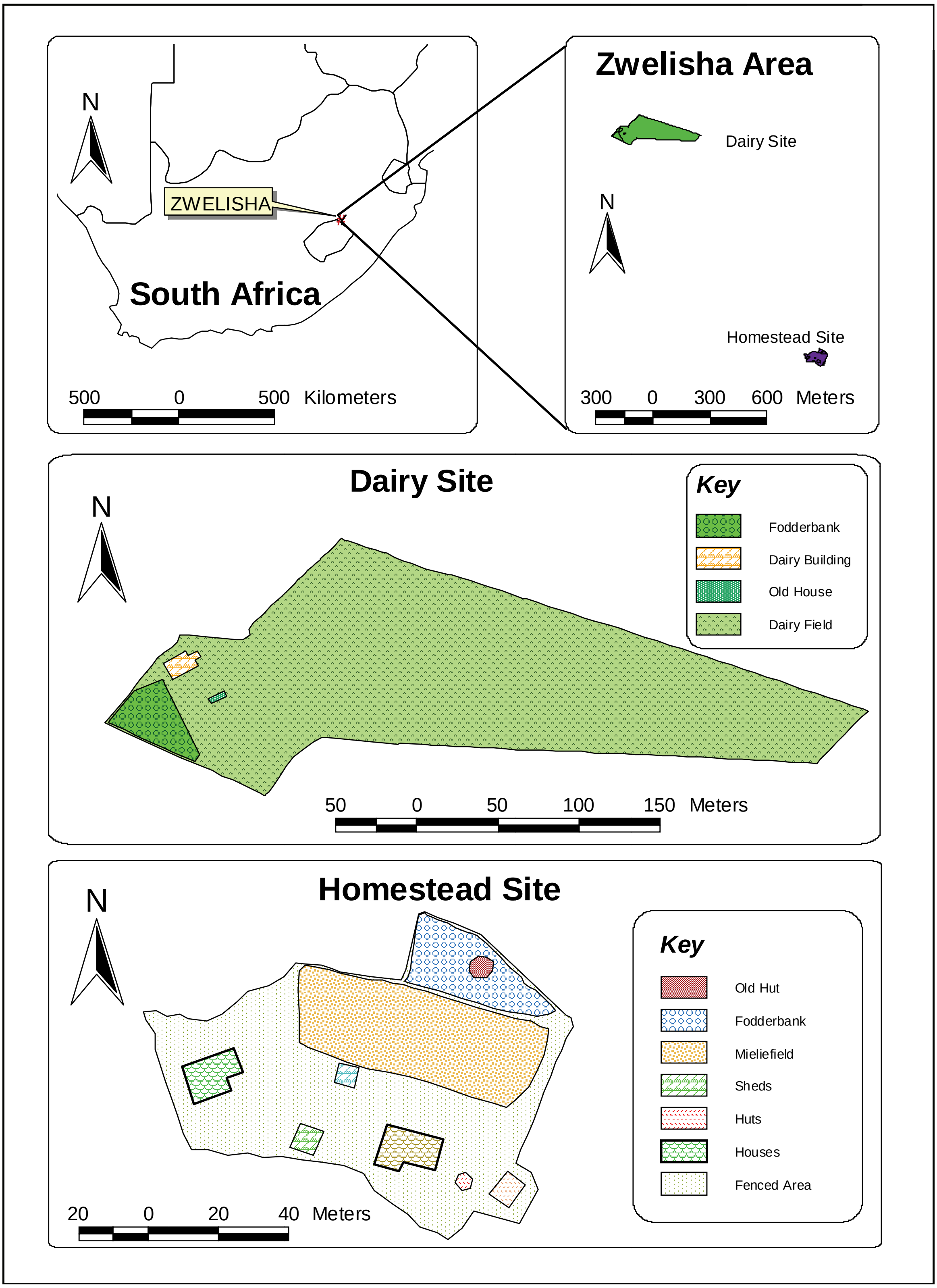


Figure 2.1 **Details of the study sites on Mr Mbhele's farm in the Bergville District**

2.3 Climate

2.3.1 Rainfall

The study area is characterized by relatively high rainfall which is in excess of 800 mm of rainfall per annum with a mean annual rainfall of 824 mm based on long-term average of approximately 35 years (Camp 1999). Most of this rainfall (about 51.6%) is received during the summer months (December to February) and only 4.7% of the total rainfall occurs during winter season (June to August). The area receives 18.3% and 25.4% rainfall in autumn and spring respectively. Most of the rainfall during summer, late spring and early autumn is usually in the form of high intensity thunderstorms (Camp 1999). This high intensity rainfall has low infiltration and high runoff and consequently a low proportion is utilized by plants. The seasonal distribution of rainfall indicates high variation of rainfall between and within seasons. This high seasonal variation in precipitation will cause fluctuations in forage quality and quantity in the study area. The implication is that there will be low quantity and poor quality forage from mid-autumn (April) through winter until September illustrating severe feed scarcity and possible high livestock mortality if no supplementary feeds are provided.

2.3.2 Temperature

The area experiences low temperatures during winter (June, July August), spring (September, October, November) and autumn (March, April, May) with minimum temperature ranges of 1.8 to 4.0ºC; 7.5 to 11.8ºC; 5.0 to 12.7ºC respectively with severe frost occurrence from May to August. Low temperatures coupled with frost have a detrimental effect on the production of subtropical species in spring and autumn (Rethman 1990) and will depress growth of natural pastures. In contrast, these temperature conditions at these times are ideal for temperate pasture production and therefore temperate pastures need to be considered as an alternative land use in the area.

The mean monthly temperature range of 18.8ºC to 19.5ºC coupled with heat units of 236 to 295 from November to March respectively, and relatively high rainfall during this period (615 mm) (Camp 1999), illustrate good potential for growing of cereal crops like maize. These conditions are ideal for growth of leguminous crops and summer pasture species.

2.4 Soils

With reference to the study site, Zwelisha, the soil types that dominate are well drained soils of Hutton soil form with bottomland position consisting of poorly drained soils of Westleigh and Katspruit soil forms. Hutton soils have good effective depth and are suitable for dryland and irrigated crops. These are high potential soils. However, acidity can be a limiting factor for plant growth and therefore application of lime and fertilizers are essential. Katspruit and Westleigh soil forms are of particular importance to smallholder farmers, who mostly cannot afford costs of irrigation, as these soils may serve as water storage during dry season thus reducing the amount of irrigation water. Camp (1999) reported that these soils can be used for irrigated temperate pastures.

2.5 Water resources

There is one perennial river (Khombe) in the study area (which is approximately 800 m from the study site) and one non perennial stream which is very close to the study site (20 m). The importance of having a non-perennial stream close to the study site is (1) the potential for it to be utilized as a source of irrigation water, provided a weir is constructed and (2) adjacent soil types, Katspruit and Westleigh, are suitable for irrigated temperate pastures.

2.6 Farming system

The trial was conducted on land belonging to Mr Simon Mbhele, a smallholder dairy farmer in the Zwelisha ward. This land is part of the communal area under the Amangwane Traditional Authority. The Traditional Authority controls the allocation, utilization and ownership of land in communal areas. Even if the person has permission to occupy the land (also known as PTO certificate) the Inkosi has all the powers to expropriate the land. For example, if the land allocated to the person is not utilized e.g. for planting, the Inkosi has the power to expropriate the land and allocate it to another person.

The farming system practised by Mr Mbhele is a crop-livestock system. The system involves growing field crops (maize and dry beans) under dry land conditions during summer. The average size of the land used for crop production is 20 ha. Maize is the major crop grown. Maize grain is milled and used for household food and for selling to the local communities. Dry beans are used for home consumption and selling will only be done if there is surplus. Part of the maize crop residue (leaf and stalk) is left on the land after maize grain harvesting and the dairy cattle are allowed to utilize them *in-situ*. Most of the dry beans stover is used for dairy cattle feed. However, these crop stovers (maize and dry beans) are of limited quantity and therefore only support livestock for a short period during the dry season. The limited quantity of maize stover and poor quality fodder from natural rangeland is a major constraint for Mr Mbhele to sustain his dairy enterprise. The fodder scarcity commences in May when the first frosts occur and the vegetation cures until October when the spring rains occur.

Generally in the Upper Thukela, smallholder farmers often prefer to keep the larger size dairy breeds (Friesland) compared to smaller size dairy breeds (Dairy Shorthorns, Jersey). Bebe *et al.* (2003) found in a study on breeding preferences and breeding practices that preference of larger dairy breeds by some of the smallholder farmers was because they attached greater importance to milk production and cash income. A similar trend was followed by Mr Mbhele where he used Holstein Friesland dairy breeds first before changing to smaller sized breeds (Dairy Shorthorn). His interest in Holstein Friesland was attributed to their high milk production.

Mr Mbhele reported several major constraints in using Friesland for dairy production. These include the feeding behaviour of Holstein Friesland cows which is less selective, the lower mobility (they do not like to walk long distances in search of fodder for grazing), they are highly susceptible to diseases and they have less preference of grazing in natural rangeland. He therefore had to try other dairy breeds that may adapt better to the environment where the natural rangeland forms the major feed provision to dairy cows.

The Dairy Shorthorn is the preferred breed that is presently used by Mr Mbhele. He stated that Dairy Shorthorn are able to graze and adapt reasonably well in natural rangeland compared with Holstein Friesland because they have good mobility and are able to search for the palatable grass species. Dairy Shorthorn cows are also more resistant to diseases than Holstein Friesland cows. On average Mr Mbhele owns five to six dairy cows, eight heifers and one bull. He reported that the heifers are kept within the herd and steers are sold because it is difficult to raise them. However, the feed scarcity remains the major constraint during the dry season and he reported that April, May, June, July, August, September and October are the critical months in terms of fodder quantity and quality. During these months the maize and dry beans stovers and commercial concentrates are used as dry season supplements. However, these crop stovers are inadequate and last for only two months while the commercial concentrates are very expensive and are not easily accessible at Zwelisha.

Mr Mbhele tries to reduce the costs of concentrates by preparing a dairy meal concentrate using the hand mixing method. He uses the following mixture to prepare a 19% CP dairy meal: 250 kg hominy chop, 50 kg Voermol Suiwer 50, 90 kg molasses, and 5 kg P12. Hominy chop is a by-product of maize milling, containing germ and maize husks (maize bran) with little endosperm. In summer Mr Mbhele uses 15% CP dairy meal using the same ingredients used to prepare the 19% dairy meal because the dairy cows get nutritious fodder from the natural rangeland. Each lactating cow is offered 1 kg of dairy meal per day. However, if the dairy cow produces more than 2 ℓ of milk per day it is offered 2 kg of dairy meal concentrate. He reported that the ingredients for dairy meal rations were difficult to afford because they were so expensive.

Another difficulty that Mr Mbhele encountered was that his dairy cows could not survive the dry season with only concentrates, and they still needed roughages which were very difficult to obtain during winter. Examples of roughages include maize silage, hay e.g. made from *Eragrostis curvula*. Roughages are necessary to stimulate ruminant digestion. Cattle on low roughage/high concentrate rations, or finely milled rations, chew less and consequently produce less saliva. The reduced saliva production can result in excessive acidity (acidosis) in the rumen leading to reduction in butterfat levels in the milk (Dugmore 2005). The major impact of good quality roughages is that they provide the cheapest way of supplying the dairy cows with their energy and protein requirements (Jones 2005). Mr Mbhele stated that July, August and September were the most critical months in terms of availability of roughages because it is during this period that the harvested maize and the *in situ* crop residues (that are used as supplements to natural rangeland) are no longer available as they had been already utilized by livestock. During the dry season period livestock mortalities occur especially if maize yields were low. Generally cattle graze on crop residues, especially maize stover after maize harvest and form a valuable fodder during the dry season. Mr Mbhele aimed to have a fodder production system that would provide adequate, good quality fodder for his dairy cows throughout the year.

CHAPTER 3: THE EFFECT OF ALLEY CROPPING TEMPERATE PASTURES (COSKSFOOT AND TALL FESCUE) AND TREE LEGUMES (*ACACIA KARROO AND LEUCAENA LEUCOCEPHALA*) ON FODDER PRODUCTION AND QUALITY

3.1 Introduction

One of the major constraints in rural livestock farming systems of the Upper Thukela is the shortage of adequate and good quality forage during the dry winter season. Supplementation of feed using commercial supplements is expensive for resource-poor farmers and they are not easily available in remote areas such as Zwelisha. Livestock survive the winter period by grazing maize stover and the natural grassland which has low quality. This, however, is not sufficient for dairy cows. The provision of alternative sources of fodder such as tree leaves, pods and temperate high quality pasture species can increase production in communal areas.

Several studies have been conducted on forage technologies that will provide solution to fodder shortages and have shown some degree of success. For example, a study by Tudsri *et al*. (1998) on the effect of feeding *Brachiaria ruziziensis* grass alone; *B. ruziziensis* mixed with *L. leucocephala* and *B. ruziziensis* supplemented with *Lablab purpureus* to dairy cows on milk production found that dairy cows fed with *L. leucocephala* or lablab in combination with *B. ruziziensis* produced higher milk yields (14.4 kg cow^{-1} and 13.6 kg cow^{-1}) than those which were fed pure grass alone (11.9 kg cow^{-1}). The milk yield increase is attributed to the high protein content of legumes (25% vs. 10.3%) compared to grasses. However, very little information is known about the effects of leguminous trees on pasture quality in smallholder farming systems in communal areas of South Africa where farmers are resource constrained.

The planting of grasses in combination with legumes have shown to increase fodder quantity and improve quality of associated grasses. Legumes have an important role in low-cost and sustainable agriculture because of their role in nitrogen fixation and their feeding value, benefits which are well recognized under grazing (Halling and Scholefield, undated). In smallholder farming areas where the farming systems is characterized by minimal fertilizer inputs, legumes can contribute to the crop phase by reducing the rate of soil fertility decline, enhancing crop yield and reducing the length of the fertility regenerating fallow period. Because of the initially higher levels of protein in the legume tissues, it takes longer for their protein content to fall to less than 6.5%, which is the lower protein threshold for animal maintenance (Tothill 1986). A study conducted in Ethiopia revealed that legume increased the yield of grasses (15.4 vs. 12.2 t ha^{-1}) and crude protein content of grasses when grown in combination with them compared to sole grass stand (Tessema and Baars 2006). In the same study, the mean crude protein values of 20.7% were recorded in *Panicum coloratum* when grown in combination with legumes compared to 17.9% CP recorded in sole *Panicum coloratum*. Another study conducted in Uganda on the effects of intercropping legumes with elephant grass, found that total dry matter yields of the elephant/legume intercrop was significantly higher (p=0.034) during the wet season (6488.72 kg ha^{-1} than in the dry season (5722.2 hg ha^{-1}) (Kabirizi *et al.* 2007).

Forage of good quality is one of the major limitations in livestock production in smallholder farmers. Forage quality, defined as the sum total of the plant constituents that influence an animal's use of the feed is determined by feed digestibility, intake, palatability and nutrient content. The quality of forage is analyzed by measuring crude protein content (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). Crude protein is essential for livestock growth and milk production and is needed by rumen bacteria that digest feed for ruminant livestock. NDF represents the structural or cell wall mineral. Forages with low NDF will have higher intake compared to those with higher NDF. The feed with low NDF is highly desirable. Acid detergent fibre represents highly indigestible plant material present in the forage. Low ADF values in the feed indicate higher energy values and digestibility (Eskandari *et al.* 2009).The high level of protein content in leguminous trees justifies their use in supplementing low quality diets like natural pastures. In communal areas of South Africa, including the study area, cattle graze natural veld and maize stover during dry season which are poor in nutritive value due to their low crude protein content and high fibre content. There is limited information available on the adaptability and performance of *L. leucocephala* and other leguminous trees and their impact on improving poor quality diets from natural veld and crop residues. Similarly very little information is available on the performance of temperate pastures in these communal areas.

Studies conducted by Fulkerson *et al.* (2008) proved that temperate pastures such as Cocksfoot and Tall Fescue have good performance during the dry season, thus providing fodder during this critical period, while kikuyu pasture provides valuable fodder during summer and autumn seasons. There is no research that has been conducted on the adaptability of temperate pastures and their ability to provide fodder during the dry season in the study area.

This project will therefore examine the potential of alternative fodder systems for small-scale dairy farmers in the Upper Thukela area and their impact on water availability. This on-farm study will determine the effect of agroforestry legume tree species and pasture systems on fodder production and assess their impact on soil water availability.

The aim of the study was to determine the effect of alley cropping temperate pastures (Cocksfoot and Tall fescue) with leguminous trees (*L. leucocephala* and *A. karroo*) to increase fodder productivity and quality. The main objective of the study was: to conduct an on-farm trial to assess the effect of growing temperate pastures in combination with leguminous trees (in the form of silvopastoral agroforestry) on pasture fodder yield, total fodder and quality in terms of crude protein and fibre content. It was hypothesized that alley cropping temperate pastures with leguminous trees would increase fodder production and increase their crude protein content.

3.2 Experimental design

The trial was laid out in a randomized complete block design (RCBD) in March 2003 with three replications (Figure 3.1). Each block consisted of 8 experimental plots of 5 m x 16 m size each. Treatments included two tree species, that is *Leucaena leucocephala*, and *Acacia karroo* and two pasture grass species, that is, *Festuca arundinacea* (Tall fescue) and *Dactylis glomerata* (Cocksfoot) with the following treatment combinations: *Acacia karroo* + Cocksfoot; *Acacia karroo* + Tall fescue; *Leucaena leucocephala* + Cocksfoot, *Leucaena leucocephala* + Tall fescue, sole *Acacia karroo* (control), sole *Leucaena leucocephala* (control), sole Cocksfoot (control), sole Tall fescue (control) resulting in 8 treatments. In summary the treatments were arranged into:

1. *Leucaena leucocephala* + Tall fescue (*Festuca arundinacea)*
2. *Leucaena leucocephala* + Cocksfoot (*Dactylis glomerata)*
3. *Acacia karroo* + (*Festuca arundinacea)*
4. *Acacia karroo* + Cocksfoot (*Dactylis glomerata*)
5. *Leucaena leucocephala*
6. *Acacia karroo*
7. Tall fescue (*Festuca arundinacea*)
8. Cocksfoot (*Dactylis glomerata*)

Block I		Block II		Block III	
2 m 1 AkCf	2 m 5 LlCf	3 m 9 Cf	2 m 13 AkCf	3 m 17 Tf	2 m 21 Ak
2 m 2 Tf	2 m 6 Cf	2 m 10 Ll	2 m 14 AkTf	2 m 18 LlCf	2 m 22 AkTf
2 m 3 LlTf	2 m 7 AkTf	2 m 11 LlTf	2 m 15 Ak	2 m 19 LlTf	2 m 23 Cf
2 m 4 Ll	2 m 8 Ak	2 m 12 LlCf	2 m 16 Tf	2 m 20 Ll	2 m 24 AkCf

Figure 3.1 A layout of 2 X 2 X 2 factorial experiment involving two tree varieties/species, two pasture grass varieties/species and two control methods in randomized complete block design (RCBD) with three replications.

Number of plots = 24
Plot Sizes: 16 m X 6 m
Block Size: 70 m X 14 m

Treatment combinations:
AkCf = *Acacia karroo X* Cocksfoot
AkTf = *Acacia karroo X* Tall fescue
LlCf = *Leucaena leucocephala X* Cocksfoot
LlTf = *Leucaena leucocephala X* Tall fescue

Controls:
Ak = *Acacia karroo X 0 (control)*
Ll = *Leucaena leucocephala X 0 (control)*
Cf = Cocksfoot *X 0 (control)*
Tf = Tall fescue *X 0 (control)*

3.3 Study site

The silvopastoral site selected was Mr Mbhele's dairy farm. The dairy site had potential for the establishment of a fodder bank as it was close to the dairy and thus easily accessible to the cattle for dietary supplements during winter. The area established was approximately 20 m by 45 m (900 m^2) in extent and had the advantage that it was already fenced on two sides. Additional fencing was erected to enable the trees to grow to a harvestable height without browsing by cattle or goats. Availability of water to irrigate the trees during establishment was not a problem as the river was accessible.

3.4 Agronomic Practices

Land preparation and planting

The site was measured and sprayed with roundup herbicide to eradicate weeds before ploughing in January 2003. Land was prepared using primary tillage (ripper, disc plough) and secondary tillage (disc harrow, rotovator) implements before planting in order to have a fine and firm, weed free, smooth and even seedbed (Bartholomew *et al*. 1991). *Leucaena leucocephala* and *A. karroo* tree seedlings were planted into a clean-tilled experimental plots in each replication i.e. 3 plots planted with *L. leucocephala* and the other 3 plots planted with *A. karroo* tree seedlings in March 2003 using the row spacing and intra-row spacing of 4 m and 1 m respectively. Twenty tree seedlings were planted in each plot with a lime, fertilizer and polymer mixture.

On the 25th of February 2003 an electric fence was erected around the fodder bank site to protect the planted trees from being grazed by the cattle as a temporary measure. The permanent protection of the fodder bank site was done by fencing the site with bonox wire during the first week of April 2003.

Planting of pasture grasses was done on the 26th March 2003 and 6 experimental plots in each block were planted. Cocksfoot (Cambria cultivar) and Tall fescue (Dovey cultivar) were the two pasture grass species used.

Planting Method: Three replicate plots were established with eight plots per block. Each type of pasture grass species was planted as an alley with each of the two tree species resulting in 4 plots. The remaining four plots comprised two plots planted with pasture grass alone and two plots planted with trees alone (both of these plots forming a control) in each block. Fertilizer (superphosphate and potassium chloride, 2.8 kg and 1.5 kg respectively) was hand broadcast on each plot. The plots were disked and harrowed in order to incorporate fertilizer in the soil. The pasture grass seeds were then evenly broadcast by hand in the 6 plots in each block. The pasture seeds had to be replanted on the 20th and 21st May 2003 as they did not germinate because of water stress. This was a result of the theft of the water pump, labour problems and non-payment of the previous electricity bill. The land was firstly harrowed with a hand petrol driven rotovator and raked by hand rake to achieve a fine seedbed. Tall fescue (Dovey cultivar) and Cocksfoot (Cambria cultivar) of 220 g and 200 g each were evenly broadcasted in each of the six plots per block respectively. The planted plots were then raked to cover the pasture seeds using a hand rake. The plots were irrigated for four hours using the sprinkler irrigation system to achieve 25 mm application of water.

Fertilization programme

Superphosphate and potassium chloride (KCl) fertilizers were broadcast and disked into the top 150 mm of soil in all plots with a basic dressing of 350 kg ha^{-1} and 187.5 kg ha^{-1} respectively in March 2003 prior to planting. The total amount of N required (100 kg N ha^{-1}) was applied in the form of limestone ammonium nitrate (LAN) in split equal dressings monthly to the entire plot area, commencing shortly after establishment. In addition to N, 10,5 kg P ha^{-1} and 9.4 kg K ha^{-1} were applied simultaneously with N dressings. These fertilizer dressings were applied monthly (four weeks interval) on the same day immediately after pasture harvest. These annual dressings support the recommendations made by Elliot and Reynolds (2002) that annual topdressings of all three major nutrients should be made as this practice will ensure that no nutrients become limiting over time. Fertilizer application trend was similar for the entire experimental period (2003 to 2009). Dolomitic lime was applied at the rate of 2000 kg ha^{-1} one month before planting based on soil test results.

Irrigation system

Following a decision made at a reference group committee meeting an irrigation system was installed to ensure the survival of tree seedlings during severe dry spells. A 40 mm irrigation pipe, 90 m hose pipe, 1500 litre storage tank with tap and hired petrol water pump were used as components of the irrigation system. A small weir was constructed in the stream below the dairy site. The water was pumped from the weir to the storage tank above the experimental area. The hose pipe was connected to the storage tank tap to collect water and then the planted tree seedlings were irrigated. The first irrigation started on the 11th March 2003 and was done every week. The hand irrigation system was not adequate for the large experimental site. An electrical system was therefore installed.

Electric Irrigation System: The electric irrigation system was installed on the 3rd April 2003. A 150 m electric cable was laid in a trench from the pump to the dairy where it was connected to the Eskom power source to supply power to the electric water pump. The 40 mm irrigation pipe was installed and buried in a trench from the stream to the middle of the experimental area. The three risers were connected to this pipe and the sprinklers were connected to these during irrigation. Although the installation of the electric irrigation system was done in April, the system was only functional on the 1st July 2003 because there were problems with outstanding electricity payments owed by the farmer. This was overcome by using a diesel generator to supply power to the water pump. This however, was very time-consuming and expensive as the generator had to be transported from Pietermaritzburg to Zwelisha (Bergville) every week as it was also used for other projects.

Soil sampling

Soil samples were taken over the entire experimental site before and during the establishment of the experiments. The soils were sampled randomly to a depth of 15 cm from each plot with the first samples taken on the 19th March 2003. Thereafter samples were taken after every harvest of the maize/lablab trial. In the silvopastoral and fodder bank trial soil sampling was done in May each year. Sampling of soils in the silvopastoral and fodder bank trials were done in zones of 0-0.5 m; 0.5-1.5 m; 1.5-2.5 m; 2.5-3.5 m; 3.5-4 m. The soils were analysed for total soil nitrogen.

3.5 Methods

3.5.1 Tree-height measurement

Tree height was measured at regular intervals at least once in three months throughout the growing season in order to determine the growth of the trees. The two tree rows in the middle of the plot were used for these measurements. These trees were cut to a height of 0.75 m from the ground towards the end of the growing season. The harvested biomass was weighed before sub samples were taken for dry matter (DM) yield estimates.

3.5.2 Tree Fodder harvesting procedure and sample collection

The harvesting of *A. karroo* and *L. leucocephala* tree species was done once a year in May/June to a height of 0.75 m from the ground. The border tree rows were pruned in each plot to standardize the treatment. It is important to note that only *L. leucocephala* trees were harvested in 2004 since *A. karroo* trees were still too small. This species was sensitive to any form of defoliation and had a slow growth rate after harvesting. All leaves from *L. leucocephala* and *A. karroo* leaves were weighed before sub samples were oven dried for dry matter yield estimates. These were ground for chemical analysis.

The harvesting technique was the same throughout the experimental period for both tree species except for *A. karroo* in 2009 where the cut branches of *A. karroo* were put in 50 kg bags and bags were left open to allow drying for easy separation of leaves from branches. The bags were beaten by sticks followed by shaking the leaves off the branches for effective separation of leaves from thorns. The beating technique is well known to the farmers as they also use it to separate dry bean seeds from pods after harvesting.

3.5.3 Pasture harvesting procedure and sample collection

Samples of pasture grass were collected from sole pasture and alley cropped pasture and natural veld once in every month using a quadrat of 50 cm x 50 cm. Harvesting of grasses in natural veld started in 2006. Pasture grasses within the 0.25 m^2 quadrat were clipped to a height of 5 cm above the soil surface. Sample collection in alley cropped plots was done at alley positions of 0.5 m, 1.0 m, and 1.5 m away from the tree row. A similar sampling procedure was conducted in sole pasture plots. The plots were mowed immediately to a height of approximately 5 cm after pasture sample collection using a brush cutter. The samples were put in paper bags and weighed for fresh mass determination immediately. These were then dried in an oven at a temperature of 60ºC for 48 h to determine dry matter yield. The samples were pooled within each of the four seasons (Autumn: March to May; Winter: June to August; Spring: September to November and Summer: December to February) and analysed for nutrient content.

3.5.4 Chemical analysis

The dried grass samples and tree samples were ground to pass through a 1 mm screen and analyzed for crude protein (CP), in a LECO FP2000 Nitrogen Analyser using the Dumas Combustion method following standard procedures of AOAC (1990). The Neutral detergent fibre (NDF) and Acid detergent fibre (NDF) were analysed on a Dosi-Fibre machine according to the method described by Van Soest, Robertson and Lewis (1991). Analysis of grass and samples were conducted at Cedara Agricultural Development Institute and some in the Department of Animal Science at the University of KwaZulu-Natal.

3.5.5 Data analysis

The effects of factors (grass species, tree species, tree plus grass species and season) and their interaction on dry matter yield were tested with analysis of variance (ANOVA) using the Statistical Package for Social Scientist (2008). Multiple comparisons of means were made by Least Significant Difference (LSD) test ($P<0.05$). The fixed effects model was used to detect the difference between the yields from tree plus pasture alley cropping and sole tree, sole pasture cropping treatments. Homogeneity of variance was tested with the Levene's test. The means were considered significantly different at $p<0.05$. In some cases letters of the alphabet were used to separate the differences among treatments where different letters indicate significant differences and similar letter indicate no differences (Mortimer *et al.* 2009). The standard deviations were used to indicate the level of differences in tree heights.

3.6 Results and Discussion

3.6.1 Constraints experienced during the experimental trial

A number of problems were experienced during the on-farm trial which negatively impacted the research trials.

- An electric irrigation system was installed in April 2003 to ensure the survival of planted trees and pastures. However, this was only functional in July 2003 because there were problems with outstanding electricity payments owed by the farmer. This was overcome with the use of a diesel generator to supply power to the water pump This proved to be very time-consuming and expensive as the generator had to be transported from Pietermaritzburg to Zwelisha every week as the generator was used for other projects.
- A ploughing problem was experienced during the initial start of the trial as it was difficult to get a suitable tractor and tillage implements. Since the area was virgin land with heavy soils it needed to be ploughed with a primary tillage implement e.g. a ripper first followed by a disc plough using a high power tractor. The land was eventually ploughed with a ripper and disc plough in February 2003 but it was observed that the land was not prepared in a fine form suitable for pasture establishment. Further tillage was necessary at the end of February 2003 using the disc plough and disc harrow.
- During the course of the trial, grazing of pastures and browsing of fodder trees by livestock was experienced in spite of fencing of the site. This contributed to low

biomass values recorded during various growing seasons. This was a problem that was difficult to control as the farmer prioritized feeding his cattle over quality of research data. In addition, neighbours cut the fence to give their cattle access to the high quality forage in the trial. The problem highlights the need of providing fodder during winter in sourveld communal areas.

- In the study area the theft of exclosures which were used to prevent grazing of pasture grasses and natural veld in the selected sampling areas was another constraint.

As a result of the problems outlined above, the results in this report are largely based on the 2008 and 2009 data.

3.6.2 Tree Growth

The establishment of the fodder trees in 2004 was initially slow and was linked to the severe frosts and high atmospheric evaporative demand measured at this site. *Leucaena leucocephala* appeared to have potential as a fodder species as it had the ability to die back in winter. *Acacia karroo* appeared to be frost sensitive in the establishment stage. In addition there was evidence that it was also not able to compete well with the vigorous growth of the pasture grasses.

Growth of tree species planted in combination with pasture grasses was suppressed due to interspecific competition compared to sole trees. For example, in March 08 tree height in alley cropped plots of *A. karroo* (<1.31 m) was 23.4% lower than *A. karroo* sole plots (1.53± 0.33 m) (Table 3.1). Throughout the trial the growth of *L. leucocephala* was higher than that of *A. karroo* except for September and December 08 when cattle entered the experimental area and preferentially defoliated *L. leucocephala.*

Table 3.1 Tree height (m) from December 2007 to September 2009. SD = standard deviation

Treat-ment	December 2007		March 2008		June 2008		September 2008		December 2008		March 2009		June 2009		September 2009	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AkCf	0.75	0.45	1.24	0.34	0.75	0.02	0.97	0.16	1.37	0.28	1.51	0.33	0.77	0.04	0.90	0.05
LlTf	0.53	0.18	1.15	0.24	0.74	0.01	0.75	0.06	1.03	0.05	1.52	0.13	0.77	0.08	081	0.01
LlCf	0.75	0.17	1.25	0.42	0.75	0.01	0.80	0.08	0.93	0.11	1.61	0.39	0.77	0.01	0.89	0.05
Ll	0.98	0.15	1.65	0.43	0.75	0.00	0.83	0.07	1.20	0.32	2.07	0.37	0.78	0.03	1.00	0.06
Ak	0.89	0.1	1.53	0.33	0.75	0.00	1.02	0.12	1.42	0.14	1.66	0.21	0.78	0.06	0.99	0.05
AkTf	0.87	0.41	1.31	0.28	0.73	0.03	1.06	0.11	1.31	0.09	1.29	0.28	0.74	0.04	0.87	0.04

Key:

AkC: *Acacia karroo* + Cocksfoot
LlTf: *Leucaena leucocephala* + Tall fescue
LlCf: *Leucaena leucocephala* + Cocksfoot
Ll: *Leucaena leucocephala*
Ak: *Acacia karroo*
AkTf: *Acacia karroo* + Tall fescue

3.6.3 Fodder Yield

2004 – Pasture yield

The first harvesting of pasture grasses was conducted in January 2004, ten months after seeding. The harvesting was done 0.5, 1.0 and 1.5 m away from the tree in order to see the effect of the trees on pasture production and compare the results with the control (no trees). In the Cocksfoot/*Acacia* trial, pasture yield increased from 954 kg ha^{-1} (control) to a maximum of 1229 kg ha^{-1} (15 cm from trees) indicating a positive effect of the trees on grass production (Table 3.2). This effect decreased with distance from the trees. A similar trend was observed in the Cocksfoot/*Leucaena* trial (Table 3.2) although the maximum increase was lower (23 kg ha^{-1}). The increased production of the pasture species closest to the trees may be due to the tree's nitrogen-fixing ability which supplies nitrogen resulting in improved growth conditions of the non-nitrogen-fixing perennial pastures. The highest pasture yield (1255 kg ha^{-1}) was obtained with the Tall Fescue/*Acacia* trial (0.5 m from trees). However, all other Tall Fescue combinations produced a lower yield when compared to Cocksfoot production.

Table 3.2 Dry matter production of the pasture species (kg ha^{-1}) per distance away from the trees in January 2004

Treatment	Distances (m)		
	0.5	1.0	1.5
AkCf	1229	1054	975
AkTf	1255	987	985
Cf		954	
Tf		912	
LlCf	977	893	819
LlTf	820	742	781

Key:
AkCf: *Acacia karroo* X Cocksfoot
LlTf: *Leucaena leucocephala* X Tall fescue
LlCf: *Leucaena leucocephala* X Cocksfoot
Cf: Cocksfoot
Tf: Tall fescue
Ll: *Leucaena leucocephala*

2004 – Tree biomass (area harvested: 2 rows in the middle = 10 trees = 40 m^{-2})

The results presented here are only for *Leucaena leucocephala* since the *Acacia karroo* trees were slow in establishing and did not produce enough biomass for harvesting. *Leucaena leucocephala* trees were harvested in each plot in April 2004.

The results (Table 3.3) indicated that 796 kg DM ha^{-1} of *L. leucocephala* fodder was obtained where *L. leucocephala* was planted alone (control) while only 97 kg DM ha^{-1} *L. leucocephala* fodder was obtained where there was combination of pasture grass and *L. leucocephala*. This difference in fodder yield indicates that pasture grass reduces tree growth. However, the low yield of *L. leucocephala* where it is planted in combination with pasture is offset by the fact that a higher pasture yield was obtained where pasture grass is planted with trees (Table 3.4). Thus total fodder production is highest with the tree/pasture combination.

Table 3.3 Dry matter production of *Leucaena leucocephala*

Treatment	Yield (kg DM ha^{-1})
Leucaena x cocksfoot	105
Leucaena x tall fescue	88
Leucaena (control)	796
***Leucaena* x pasture grass**	**Average Yield: 97 kg ha^{-1}**

2004 – Total fodder yield (pasture plus trees)

The total fodder yield (all the harvests in 2004) was significantly higher (6440-7553 kg ha^{-1}) from the alley crops and sole pasture plots compared to natural veld (1195 kg ha^{-1}; Table 3.4). The results indicate the high potential of pasture species for fodder production. Alley cropping leguminous fodder trees with pasture grasses was more beneficial compared to planting tree fodder species alone. For example, the total pasture dry matter (DM) yield of Cocksfoot was higher in alley plots (7205 kg ha^{-1}) compared to sole pasture plots (6440 kg ha^{-1}) (Table 3.4). Similarly, the Tall Fescue alley plots had a higher yield (7443 kg ha^{-1}) than in the sole plots (7293 kg ha^{-1}). This high pasture dry matter yield indicates that trees had positive effects on pasture production in all intercrops (Table 3.4) The establishment of the fodder trees was slow and low biomass was linked to the severe frosts and high atmospheric evaporative demand measured at this site. This indicates that when implementing on-farm agroforestry systems, farmers need to be made aware that potential benefits will be long term. In the establishment phase of the trees *L. leucocephala* appeared to have a higher potential than *Acacia karroo* as a fodder species which was frost sensitive. In addition there was evidence that it was also not able to compete well with the vigorous growth of the pasture grasses.

Table 3.4 Total dry matter fodder yield (kg ha^{-1}) in 2004

Treatment	Pasture biomass	Tree biomass	Total
**Acacia karroo* + Cocksfoot	7485		7485
**Acacia karroo* + Tall fescue	7334		7334
Tall fescue	7294		7294
Leucaena leucocephala + Cocksfoot	6925	105	7030
Leucaena leucocephala + Tall fescue	7553	88	7641
Cocksfoot	6440		6440
**Acacia karroo*			
Leucaena leucocephala		796	796
***Natural Veld*	1195		1195

** Acacia karroo biomass too low to harvest*
*** Sampling of natural veld only commenced in 2006. The 2006 data are used here for comparative purposes.*

The monthly dry matter yields for 2004 (Figure 3.2) indicated that with the exception of March and November, fodder yield was generally <1000 kg ha^{-1} month^{-1}. This highlights the fodder shortage problem faced by farmers in the Upper Thukela.

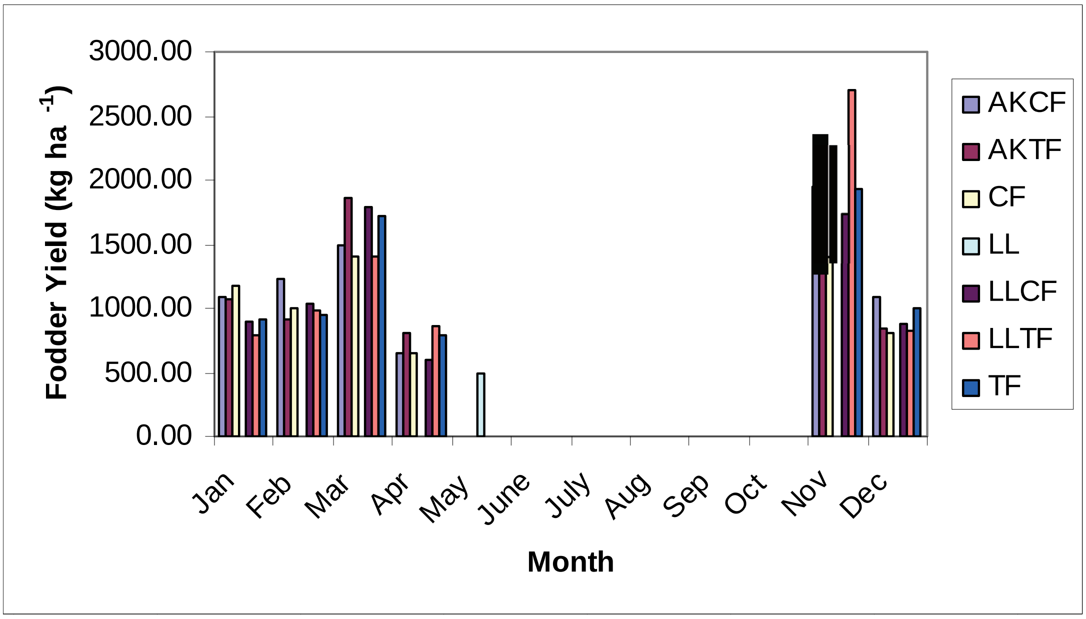


Figure 3.2 Monthly dry matter yield from various treatments in 2004

2005 – Total fodder yield (pasture plus trees)

Total DM fodder yield (pasture + tree fodder) from intercrops was lower than sole pasture plots in 2005 (Table 3.5). However, the total DM fodder yield from intercrops was significantly higher compared to pure tree plots of *A. karroo* and *L. leucocephala*.

Table 3.5 Total dry matter fodder yield (kg ha^{-1}) in 2005

Treatment	Pasture biomass	Tree biomass	Total
Acacia karroo + Cocksfoot	5196	230	5426
Acacia karroo + Tall fescue	5779	145	5924
Tall fescue	7398		7398
Leucaena leucocephala + Cocksfoot	4752	78	4830
Leucaena leucocephala + Tall fescue	6537	49	6586
Cocksfoot	5574		5574
Acacia karroo		1037	1037
Leucaena leucocephala		431	431

The total pasture dry matter (DM) yield of Cocksfoot was lower in alley plots (< 5196 kg ha^{-1}) compared to sole pasture plots (5574 kg ha^{-1}) (Table 3.5). Similarly, the Tall Fescue plots had a higher yield (7397 kg ha^{-1}) than in the alley crops (<6537 kg ha^{-1}). This effect can be contrasted to the previous year where grass production was higher in the alley plots (7000-7600 kg ha^{-1}). The lower pasture dry matter yield can be attributed to invasion of pastures by grasses and weeds as well as moisture stress.

In 2005 the total monthly pasture DM yield declined during October, November and December with most treatments yielding <500 kg ha^{-1} (Figure 3.3). This decline can be attributed to the loss of the pasture species and invasion by weeds caused by moisture stress. The DM yield reduction was severe when compared to the previous growing season. For example, in November the yield was reduced from an average of 1921.77 kg ha^{-1} in

2004 to 176.18 kg ha^{-1} in 2005, which is approximately a 90.8% yield reduction (Figures 3.2 and 3.3). The low biomass of pastures from April to September as a result of the irrigation problems prevented harvesting during this period.

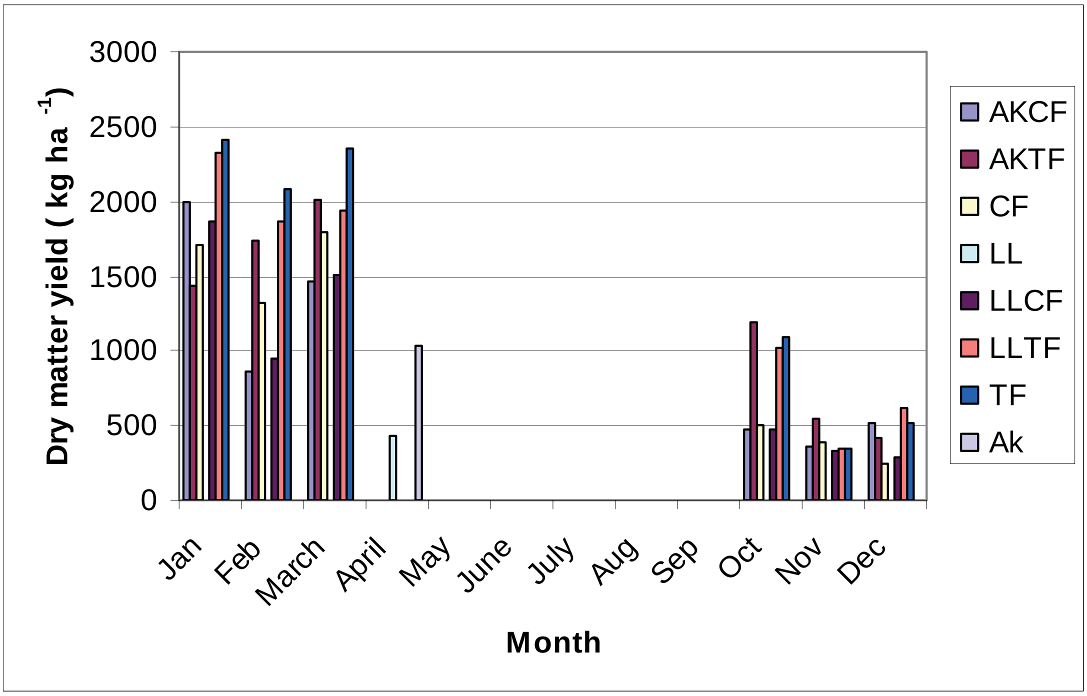


Figure 3.3 Monthly dry matter yield from various treatments in 2005

The trees had a positive effect on pasture production with highest values recorded 0.5 m from the trees (Figure 3.4). It is apparent that *A. karroo* had a more positive effect on pasture production closest to the trees (1229-1255 kg ha^{-1}) than *L. leucocephala* (820-977 kg ha^{-1}).The positive effects of these two leguminous tree species on pasture production may be attributed to their nitrogen (N) fixing ability. In addition, Houlton *et al.* (2008) reported that many N fixing plants, through their enzyme activity, are also able to increase the availability of P in soil. In the nutrient poor soils in this study it is likely that the pastures closest to the N fixing trees will benefit more from these nutrients than pastures further away. The higher production in the *Acacia* plots implies that this species may have a higher N fixation rate than *L. Leucocephala.* This is in contrast to reports by Adams *et al.* (2010) who showed that although N fixation rates are very variable, faster rates (and greater amounts over any given time period) of fixed N were recorded for mesic tropical species such as *Leucaena,* than *Acacia* species that come from drier parts of the tropics or from temperate regions of Africa where drought and fire are common.

Tree growth in the experiment was not significant during the 2005 growing season (Figure 3.5). Growth of tree species planted in combination with pasture grasses were suppressed due to interspecific competition compared to sole trees. The growth of *L. leucocephala* was lower than that of *A. karroo.* This low growth may be attributed to preferential defoliation of this species by cattle that entered the experimental area. The higher growth (>100 cm) observed in *A. karroo* during 2005 (Figure 3.5) indicates that it grows well after the initial slow establishment.

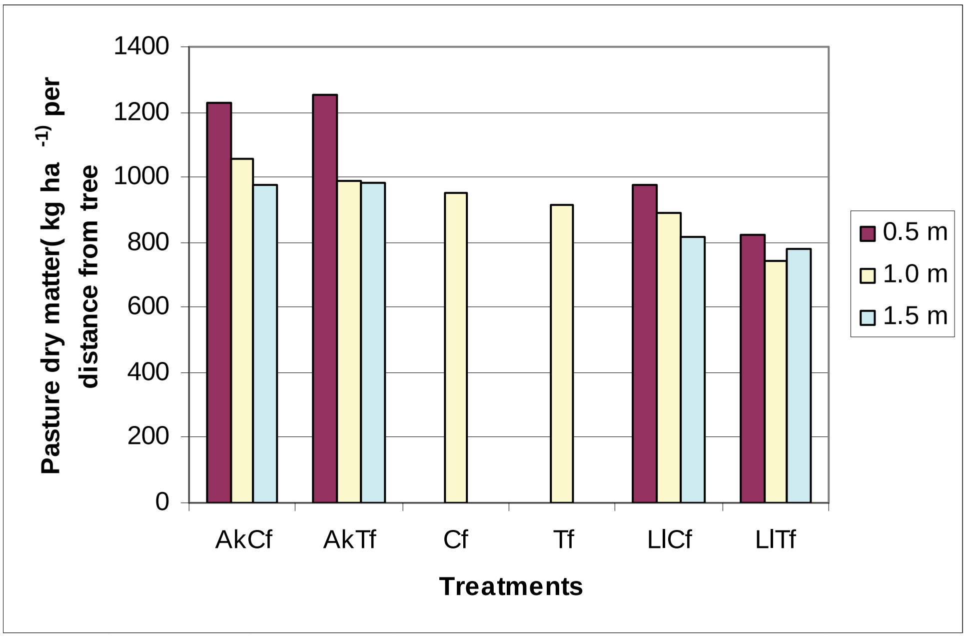


Figure 3.4 **Pasture yield (kg ha^{-1}) per distance away from the tree**

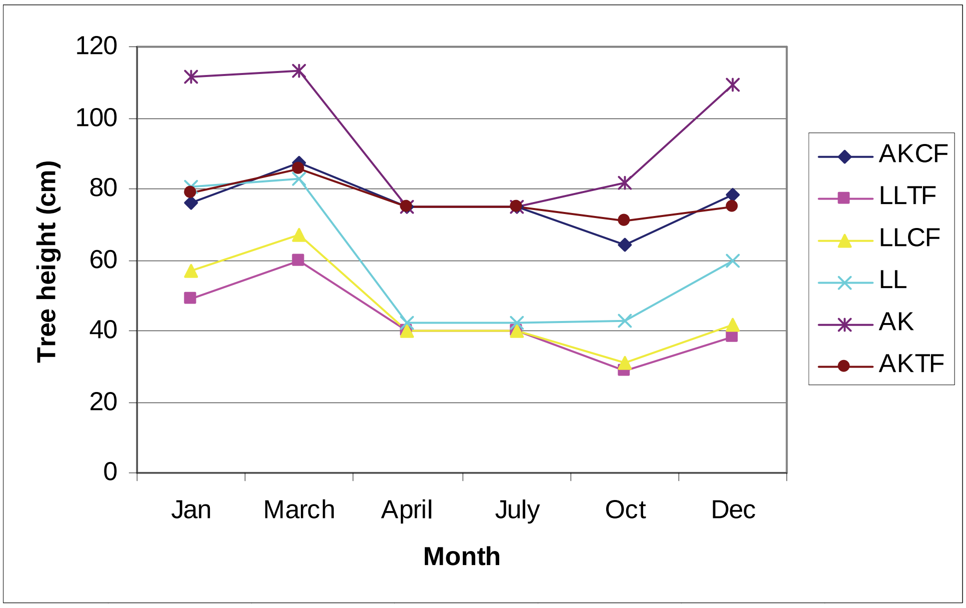


Figure 3.5 **Tree height in 2005**

2006 – Total fodder yield (pasture plus trees)

The total pasture dry matter (DM) yield of Cocksfoot was higher in alley plots (> 5318 kg ha^{-1}) compared to sole pasture plots (3704 kg ha^{-1}) (Table 3.6). Similarly, the Tall Fescue alley plots had a higher yield (>7193 kg ha^{-1}) than in the sole plots (4212 kg ha^{-1}). This high pasture dry matter yield indicates that the N fixing ability of the leguminous trees had positive effects on pasture production in all alley crops with the higher values obtained at distances close to the trees, i.e. 0.5 m to 1 m (Figure 3.6). The higher yields in the

Acacia alley plots imply that this species has a higher N fixing potential than *L. leaucocephala.* The lower dry matter yield recorded during November and December is attributed to defoliation of pasture grasses by unintended cattle grazing of pastures during this period (Figure 3.7). The dry matter yield was the lowest (1518 kg ha^{-1}) in natural veld especially during the winter season (Figure 3.7). The low dry matter yield from the natural veld is the major constraint faced by the small-scale dairy farmers in rural areas. The values from pasture grasses indicate a marked improvement in fodder production which is an increase of 5368 kg ha^{-1} from that of natural veld production which is 1195 kg ha^{-1}. The marked increase in pasture production compared to natural veld is an indication of the potential benefits of a silvopastoral agroforestry system to small-scale dairy farmers in the Upper Thukela region.

Table 3.6 Total dry matter fodder yield (kg ha^{-1}) in 2006

Treatment	Pasture biomass	Tree biomass	Total
Acacia karroo + Cocksfoot	6322	214	6536
Acacia karroo + Tall fescue	8716	212	8928
Tall fescue	4212		4212
Leucaena leucocephala + Cocksfoot	5318	245	5563
Leucaena leucocephala + Tall fescue	7193	224	7417
Cocksfoot	3704		3704
Acacia karroo		126	126
Leucaena leucocephala		254	254
Natural Veld	1195		1195

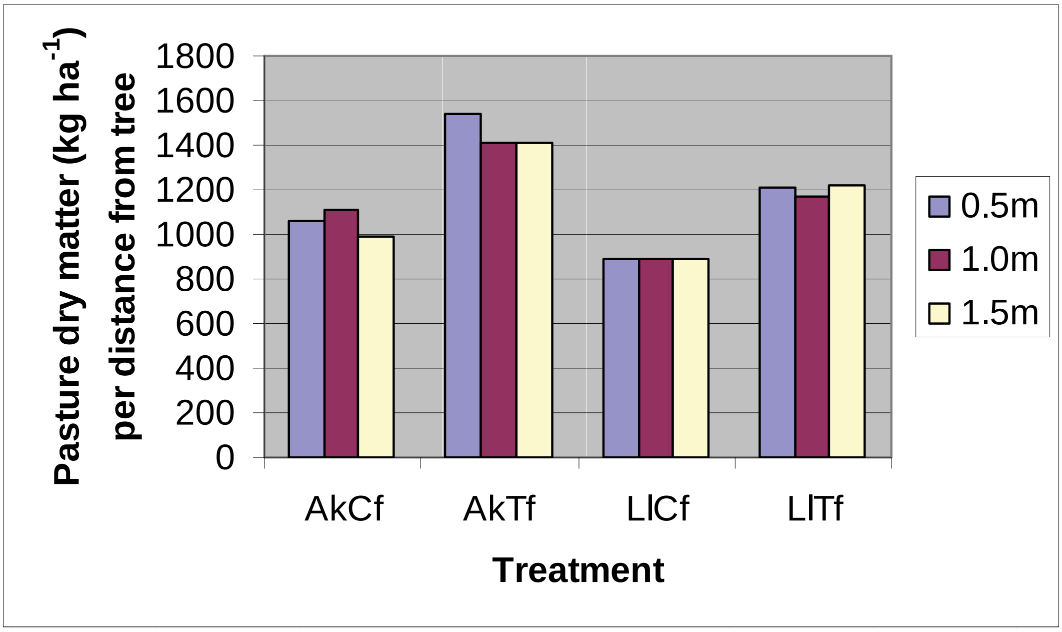


Figure 3.6 Pasture yield (kg ha^{-1}) per distance away from the tree in 2006

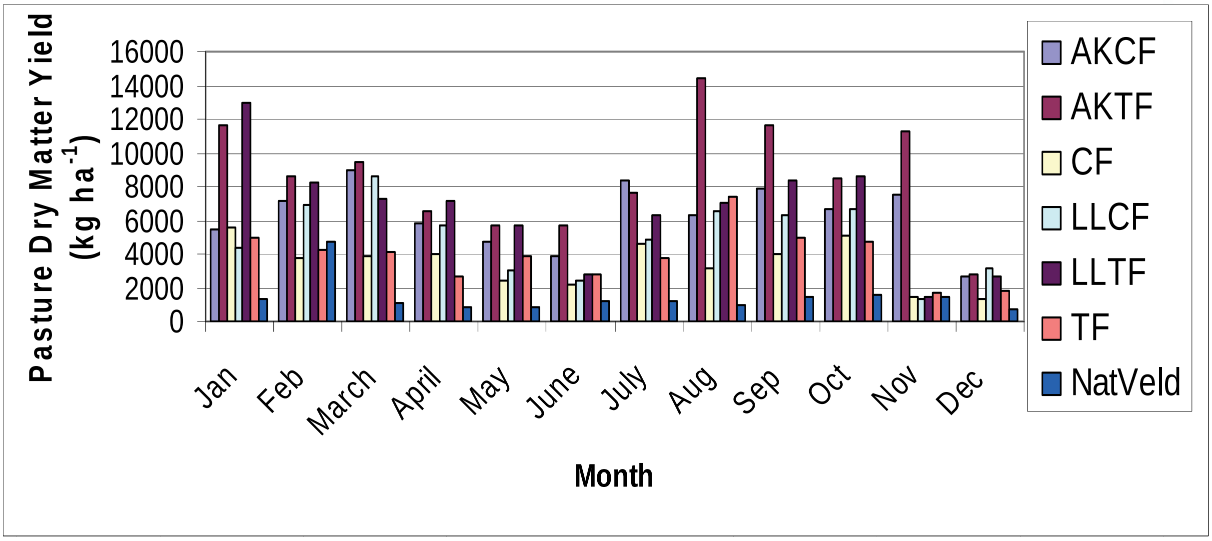


Figure 3.7 **Monthly dry matter yield from various treatments in 2006**

The low tree height during 2006 was due to browsing by cattle (Table 3.7). *Leucaena leucocephala* was more severely browsed than *A. karroo*, particularly in December when some of the *L. leucocephala* trees were completely defoliated. Tree height was reduced by 0.14 m and 0.69 m in September and December respectively. The tree height reduction during October to December period reached a peak of 80% indicating the severe defoliation of the *L. leucocephala* trees.

Table 3.7 **Mean tree height (m) ± std deviation from December 2005 to December 2006**

Treatment	Month				
	December	March	June	September	December
AkCf	0.79 ±0.16	1.08±0.17	0.74±0.09	0.80±0.16	0.51±0.38
LlTf	0.38±0.04	0.92±0.02	0.80±0.06	0.65±0.10	0.15±0.05
LlCf	0.42±0.03	0.89±0.02	0.80±0.00	0.63±0.02	0.15±0.00
Ll	0.60±0.13	1.13±0.15	1.01±0.17	0.89±0.29	0.21±0.07
Ak	1.09±0.09	1.31±0.11	0.74±0.11	0.82±0.11	1.01±0.14
AkTf	0.75±0.11	1.06±0.26	0.73±0.07	0.72±0.06	0.84±0.30

2007 – Total fodder yield (pasture plus trees)

The pasture dry matter fodder yield showed a reduction in pasture dry matter by 33% compared to natural veld in all treatments (Table 3.8). The reduction is attributed to grazing of pastures in the trial by livestock particularly during winter and early spring. At this time the farmers were letting the cattle graze in the trial because it was the only area with green grasses as Zwelisha area was experiencing severe drought. This is an indication of the importance of having silvopastoral trial in rural farming systems. Pasture grasses were severely defoliated to the extent that it was not possible to do harvesting until December 2007 as the pasture grasses were grazed below 5 cm height. Although, the inclusion of dry matter from tree fodder increased the total fodder yield by 8% it was still below the yield of the natural veld.

Table 3.8 Total DM yield in 2007 (kg ha^{-1})

Treatment	Pasture biomass	Tree biomass	Total
Acacia karroo + Cocksfoot	1533	564	2097
Acacia karroo + Tall fescue	1439	207	1646
Leucaena leucocephala + Cocksfoot	1227	18	1245
Leucaena leucocephala + Tall fescue	1588	18	1606
Cocksfoot	1597		1597
Tall fescue	2130		2130
Acacia karroo		23	23
Leucaena leucocephala		247	247
Natural Veld	2114		2114

The tree dry matter fodder yield of *Acacia karroo* was higher with values ranging from 207 kg ha^{-1} to 564 kg ha^{-1} compared to the yield of *Leucaena leucocephala* which ranged from 18 to 23 kg ha^{-1} (Table 3.8). The reduced yield of *Leucaeana leucocephala* from December 2006 to September 2007 (Table 3.9) was due to browsing by livestock. Efforts to protect individual trees with fencing exclosures were evident in December 2007 when tree height increased in *L. leucocephala*. However, it was noted that there was higher dry matter yield from intercropped *Acacia karroo* with a maximum value of 564 compared to sole tree plots of *Acacia karroo* 247 kg ha^{-1}) (Table 3.8). The lower dry matter yield from sole plots of *Acacia karroo* may be attributed to the damage of the *A. karroo* leaves by insects which was more common in sole plots of *A. karroo*.

Table 3.9 Tree height (m) from December 2006 to December 2007

Treatment	December 2006		March 2007		June 2007		September 2007		December 2007	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AkCf	0.51	0.13	1.38	0.14	0.58	0.05	1.06	0.50	0.75	0.45
LlTf	0.15	0.02	0.29	0.11	0.32	0.04	0.36	0.11	0.53	0.18
LlCf	0.15	0.01	0.28	0.03	0.29	0.04	0.40	0.17	0.75	0.17
Ll	0.21	0.02	0.37	0.09	0.44	0.03	0.60	0.25	0.98	0.15
Ak	1.01	0.056	1.17	0.12	0.57	0.05	0.86	0.05	0.89	0.1
AkTf	0.84	0.1	1.06	0.40	0.59	0.12	0.81	0.25	0.87	0.41

SD = Standard Deviation

2008 – Total fodder yield (pasture plus trees)

In 2008, total dry matter yield of the pasture species intercrops in the *Acacia karroo* alley crop system (534.6 kg ha^{-1}) was 115% higher than the dry matter yield of natural veld (248.0 kg ha^{-1}, Table 3.10). The *L. leucocephala* intercrops (613.4 kg ha^{-1}) contributed an even higher dry matter fodder yield, resulting in a 147% increase when compared to the natural veld (248.0 kg ha^{-1}). This significant increase of dry matter fodder yield from intercrops is an indication of the importance of having a silvopastoral fodder production system in rural areas where shortages of fodder are experienced as had been observed in the Zwelisha area.

Table 3.10 Total DM yield in 2008 (kg ha^{-1}).

Treatments	Total yield per year	Mean yield
A. karroo + Cocksfoot	5014.6.0	455.9
A. karroo + Tall fescue	6746.5	613.2
L. leucocephala + Cocksfoot	5791.1	526.5
L. leucocephala + Tall fescue	7702.1	700.2
Cocksfoot	6941.8	631.1
Tall fescue	6133.1	557.6
Natural Veld	2728.4	248.0

The seasonal variation in fodder production (Table 3.11) indicates that the critical period for fodder shortage in 2008 were winter and spring. Biomass values obtained from natural veld in August, September and October were 0 kg ha^{-1} as grasses were below the 5 cm harvesting height. These low values may be related to the exceptionally low rainfall during this period (see section 8.3.1.1 – climatic data). This observation further emphasizes the importance of having alternative sources of fodder in rural farming systems for sustainable small-scale dairy enterprises. The critical shortage of fodder for livestock in the surrounding areas during this period resulted in fence theft and illegal grazing in the trial. This is reflected in the low mean pasture dry matter yield in winter (990 kg ha^{-1}) in the different treatments (Table 3.11). There was a 21.4% and 34.1% decrease in pasture DM yield during the autumn and winter seasons respectively compared to the summer season. However, forage production from the temperate pastures was still 43.3% higher during winter than natural veld despite the grazing of pastures by livestock in July and August. This is an indication that temperate pastures can provide valuable fodder during winter and are therefore alternative fodder sources to supplement natural grazing for sustainable small-scale dairy farming.

Table 3.11 Forage DM (kg ha^{-1}) during various seasons in 2008

Treatment	Summer Dec-Feb	Autumn Mar-May	Winter Jun-Aug	Spring Sept-Nov
A. karroo + Cocksfoot	1328	963	518	2666
A. karroo + Tall fescue	1759	1381	849	3211
L. leucocephala + Cocksfoot	669	1227	770	3362
L. leucocephala + Tall fescue	1448	1339	1436	3947
Cocksfoot	1495	845	1154	3911
Tall fescue	1045	969	1212	3247
A. karroo	1484	1100	691	140
Mean pasture DM	**1291**	**1121**	**990**	**3391**

The total forage DM of 691 kg ha^{-1} and 140 kg ha^{-1} recorded in natural veld during winter and spring was significantly lower when compared to the mean pasture yield for the same seasons (990 kg ha^{-1} and 3391 kg ha^{-1} respectively) (Table 3.11). This may be related to higher soil moisture in the irrigated pasture treatments (section 8.3.7). The climatic results confirm that during winter and early spring the study area was characterized by dry climatic conditions.

By December 2008 tree growth of *A. karroo* was significantly higher for trees with no intercrops (1.42 m ±014) than trees of *Leucaena leucocephala* with no intercrops (1.20 m ±032) (Table 3.12). Nevertheless, the significant increase in height of *Leucaena leucocephala* trees following the provision of tree protective measures 2006 indicates that tree protection is beneficial where the planted fodder trees are vulnerable to livestock damage as is the case in communal grazing systems.

Table 3.12 Tree height (m) from December 2007 to December 2008

Treat-ment	December 2007		March 2008		June 2008		September 2008		December 2008	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AkCf	0.75	0.45	1.24	0.34	0.75	0.02	0.97	0.16	1.37	0.28
LITf	0.53	0.18	1.15	0.24	0.74	0.01	0.75	0.06	1.03	0.05
LICf	0.75	0.17	1.25	0.42	0.75	0.01	0.80	0.08	0.93	0.11
LI	0.98	0.15	1.65	0.43	0.75	0.00	0.83	0.07	1.20	0.32
Ak	0.89	0.1	1.53	0.33	0.75	0.00	1.02	0.12	1.42	0.14
AkTf	0.87	0.41	1.31	0.28	0.73	0.03	1.06	0.11	1.31	0.09

SD = Standard Deviation

Key:

AkCf: *Acacia karroo* X Cocksfoot
LITf: *Leucaena leucocephala* X Tall fescue
LICf: *Leucaena leucocephala* X Cocksfoot
Cf: Cocksfoot
Tf: Tall fescue
LI: *Leucaena leucocephala*
Ak: *Acacia karroo*
NatVeld: Natural veld

3.6.4 Fodder quantity

3.6.4.1 Effect of alley cropping pasture with leguminous trees on chemical composition of fodder

The results showed that in 2008 pasture/tree legume mixtures had a higher nutritive value compared with pure pasture (Table 3.13). The seasonal differences were also significant. In summer, the *A. karroo/*cocksfoot intercrop had 3.2% crude protein more (12.2% CP) than sole cocksfoot (11.8% CP). Similarly, Tall Fescue growing with *A. karroo* had 10.8% more crude protein (9.9% CP) than the Tall Fescue grown without *A. karroo* (8.9% CP) while Tall Fescue/*A. karroo* had 4.4% more crude protein (9.3% CP) than pure Tall Fescue (8.9% CP). During summer, all pasture grasses (intercropped and sole pasture) had higher crude protein than natural veld (6.2%) with CP values ranging from 8.9% to 12.2%. In autumn there was an increase of 2.7% and 4.0% crude protein from *L. leucocephala/*Tall Fescue and *A. karroo* intercrops respectively compared to sole Tall Fescue. During the same period, *A. karroo* and *L. leucocephala* increased the crude protein content of companion Cocksfoot grasses by 8.6% and 14.8% more than the same Cocksfoot planted as sole pasture. The protein content of natural veld was very low (3.5%), an indication that curing had commenced and nutrients in this sourveld grassland were being translocated to the roots.

In winter, the crude protein content was relatively low in all pasture grasses (intercropped and sole pasture) with mean values of 5.2-6.0% CP in intercropped pasture and 4.8-5.7% in sole Tall fescue and Cocksfoot treatments (Table 3.13). The protein content of natural veld dropped to 3.2%, supporting the farmer's statement that winter veld is unable to support milk production from dairy cows.

In addition to crude protein, the fibre content of the fodder is an indication of its quality with high fibre contents decreasing digestibility. Neutral detergent fibre (NDF), which is a measure of the cell wall content of the plant, was lower in alley cropped plots compared to sole plots (Table 3.13). During the summer season the mean NDF values ranged from 61.2-61.5 % in Tall fescue alley crop plots compared to sole Tall fescue plots (62.9%) and sole Cocksfoot (60.3%). During the autumn season the NDF values were 61.7% to 67.1% in alley cropped plots compared to Tall fescue (67.7%) and Cocksfoot (63.7%). The NDF composition was relatively high during winter but was still lower in Tall fescue alley crops with mean values ranging from 67.5 to 68.4% compared to sole Tall fescue (68.5%) and Cocksfoot (67.0%). The NDF composition in natural veld was higher than pasture grasses and differed according to season. The values were 68.7% (summer), 74.3% (autumn) and 73.4% (winter) (Table 3.13). The ADF values are an indication of the percentage of indigestible parts of the forage. The higher the ADF value, the less digestible the fodder is and the lower its feed value. The ADF values showed a similar trend to the NDF values but the differences between alley cropping and sole pastures were not as high. The neutral detergent fibre (NDF) content in legumes were significantly lower (39.79%;p>0.001) compared to grasses which had values ranging from 59.72-75.21% (Table 3.14).

Table 3.13 Chemical composition of pasture in alley cropping and sole cropping treatments

	Chemical Composition (%)		
Treatment	**CP**	**NDF**	**ADF**
SUMMER			
Ak+Cf	12.2	57.9	32.6
Ll+Cf	11.8	57.9	33.0
Cf (control)	11.8	60.3	33.4
Ak+Tf	9.9	61.2	33.7
Ll+Tf	9.3	61.5	34.6
Tf (control)	8.9	62.9	34.8
Natural veld	6.2	68.7	41.7
AUTUMN			
Ak+Cf	8.8	63.7	41.3
Ll+Cf	9.3	61.7	39.7
Cf (control)	8.1	63.1	39.9
Ak+Tf	7.8	66.5	41.4
Ll+Tf	7.7	67.1	40.3
Tf (control)	7.5	67.7	41.5
Natural veld	3.5	74.3	44.2
WINTER			
Ak+Cf	5.5	68.4	41.9
Ll+Cf	6.0	67.5	40.8
Cf (control)	5.7	67.0	40.5
Ak+Tf	5.4	67.9	41.7
Ll+Tf	5.2	67.8	41.5
Tf (control)	4.8	68.5	43.3
Natural veld	3.2	73.4	46.2

Table 3.14 Chemical composition of *Acacia karroo* and *Leucaena leucocephala* grown in mixture with Cocksfoot and Tall fescue and in sole stands

Treatment	Chemical Composition (%)±standard error		
	2008		
	CP	ADF	NDF
Acacia karroo + Cocksfoot	14.16±1.52	33.57±2.75	41.41±2.10
Acacia karroo	14.65±0.48	32.93±1.81	42.18±1.80
P-value	0.721	0.836	0.760
Acacia karroo + Tall fescue	13.57±0.78	33.98±1.83	44.35±1.81
Acacia karroo	14.65±0.48	32.93±1.81	42.18±1.80
P-value	0.435	0.734	0.396
L. leucocephala+Cocksfoot	22.49±0.69	26.96±3.11	33.91±2.17
L. leucocephala	18.60±0.70	32.31±1.26	38.50±1.14
P-value	0.13	0.101	0.087
L. leucocephala+Tall fescue	17.25±1.10	30.1±1.32	38.37±1.13
L. leucocephala	18.60±0.70	32.31±1.26	38.50±1.14
P-value	0.333	0.490	0.959
Acacia karroo + Cocksfoot	14.16±1.52	33.57±2.75	41.41±2.10
L. leucocephala+Cocksfoot	22.49±0.69	26.96±3.11	33.91±2.1
P-value	0.000	0.049	0.010
Acacia karro + Tall fescue	13.57±0.78	33.98±1.83	44.35±1.81
L. leucocephala+Tall fescue	17.25±1.10	30.16±1.32	38.37±1.13
P-value	0.018	0.229	0.032
Acacia karroo	14.65±0.48	32.93±1.81	42.18±1.80
L. leucocephala	18.60±0.70	32.31±1.26	38.50±1.14
P-value	0.012	0.840	0.161

3.7 Conclusion

The alley crop field trial demonstrated the high potential of the use of temperate grass species and tree legumes for small-scale dairy systems in the Upper Thukela region. The study showed that fodder shortage is a major constraint for dairy farming in this area. Total dry matter yield of natural veld was low, ranging from 1195-2728 kg ha^{-1}. The acute seasonal fodder shortages recorded in the trial from natural veld (e.g. 140 kg ha^{-1} in spring 2008) indicate the severity of the problem faced by rural dairy farmers. The dry matter production from the tree and pasture species in spring 2008 (3391 kg ha^{-1}) indicated a 96% increase in fodder. This highlights the role that agroforestry can play in addressing the problem of fodder shortage.

One of the negative factors in alley cropping agroforestry systems is the competition between trees and crops. However, in this trial alley plots produced a higher pasture dry matter yield than sole pasture plots. Throughout the trial trees had a positive effect on pasture production with highest values generally recorded 0.5 m from the trees. This may be attributed to the N fixing ability of the two legume tree species used in this trial. Since many N fixing trees have the ability to increase uptake of phosphorus, it is likely that the increased nutrients had a significant effect on growth in these nutrient poor soils. For example, in 2006 the total pasture dry matter yield of Cocksfoot was higher in alley plots (> 5318 kg ha^{-1}) compared to sole pasture plots (3703 kg ha^{-1}). Similarly, the Tall Fescue alley plots had a higher yield (>7193 kg ha^{-1}) than in the sole plots (<4212 kg ha^{-1}). The study therefore demonstrated that legumes such as *A. karroo* and *L. leucocephala* have potential to increase dry matter fodder yields of temperate pastures (Cocksfoot and Tall fescue) when grown in combination with these tree legumes.

The field trial demonstrated that the advantage of leguminous fodder trees (*A. karroo* and *L. leucocephala*) is that they contained high amount of crude proteins with mean values of 14.65% and 18.6% respectively. Tree legumes can therefore be used to supplement expensive concentrates. In addition, the temperate pasture species were able to provide quality fodder during the dry winter season as their crude protein content was higher in winter compared to the summer season. For example, a mean crude protein content of 15.26% and 16.09% were recorded for Tall fescue and Cocksfoot respectively during winter compared to 8.14% and 9.07% recorded for Tall fescue and Cocksfoot respectively during summer. These findings followed a similar trend to those made by Fulkerson *et al*. (2008) who reported an increase of crude protein content in Cocksfoot and Tall fescue pasture grasses with values of 31.90% and 25.3% respectively during the winter season compared with 22.80% and 21.60% CP during the summer season.
As shortage of quality fodder in winter is the main constraint for dairy farmers in the region, it is recommended that these winter pasture species be planted to increase the quality of fodder for communal dairy systems.

CHAPTER 4: REINFORCEMENT OF PLANTED PASTURES INVADED BY UNWANTED GRASS SPECIES

4.1 Introduction

In 2007 it was observed that less palatable grass species such as *Paspalum notatum* had invaded the two year-old Tall fescue and Cocksfoot treatments in the silvopastoral trial. The resulting decease in dry matter yield (e.g. 5779 kg ha^{-1} in 2006 to 1439 kg ha^{-1} in 2005 in the *L. leucocephala* + Tall fescue alley crop) necessitated an investigation into the extent of the invasion (species and percentage composition) and possible interventions to reverse the deterioration in the temperate pasture quality and yields.

It is generally found that temperate pastures in warm climates lose vigour and are invaded by unwanted local grasses a number of years after establishment. This type of pasture is termed 'depleted pasture' (Samson and Moser, 1982, Nazarko 2008). This may be caused by a combination of factors, including high temperatures, poor fertility, overgrazing and soil water stress. From the climatic data (chapter 8) it was clear that the silvopastoral trial at Zwelisha experienced harsh climatic conditions, including temperature extremes and drought. Moisture stress was exacerbated in 2005 by a failure of the irrigation system due to a breakage in the underground power cable. Low soil moisture is a major stress that limits biomass yields of forage plants (Lascano *et al.* 1996). These unfavourable environmental conditions reduce plant growth and development and eventually the weakened individuals die, leaving open patches, termed "windows" (Wheeler *et al.* 1987). It is through these "windows" that unwanted plant species invade pasture grasses. The indigenous invader grasses species are better adapted to the local conditions and are therefore able to out-compete the weakened cultivated pasture plants.

The situation where planted grass pastures are invaded by unwanted plant species necessitates the reinforcement of the pasture. Reinforcement may be in the form of direct seeding in the existing pasture or cultivated strip seeding of the existing pasture. The major limiting factor for the success of pasture reinforcement is competition by the invading grass species. However, there are procedures that will reduce the competitive ability of the invasive plants until the re-introduced pasture species are well established. These procedures need to be used either alone or in combination and include soil scarification, burning, and chemical herbicides (Tainton *et al.* 2000). However, reinforcement procedures involving tillage (soil scarification) and herbicides are expensive.
The aim of the reinforcement experiment was to investigate the effectiveness of different plant reinforcement techniques in restoring pasture production in the depleted Tall fescue and Cocksfoot pastures.

4.2 Basic techniques for pasture reinforcements

There are various techniques of adding pasture species into existing stands of depleted pastures. According to Nazarko (2008) the basic techniques include the following: Direct-seeding or sod seeding, Renovation and Broadcast seeding.

Direct-seeding

Direct seeding involves the use of low-disturbance equipment such as zero-till drill or sod seeder to seed directly into the existing sward. This technique requires a 20-inch suppression zone of existing vegetation to avoid shading and competition by the existing plants. The advantages of this technique are: reduction of soil erosion and organic matter loss compared to complete ploughing/tillage; conservation of moisture near the soil surface; protection of pasture seedlings from wind erosion and desiccation. In this technique a furrow of existing vegetation is removed and the pasture seed placed in the bottom of the furrow and covered firmly with soil to provide close contact between the seed and soil.

Broadcast seeding

This method involves broadcasting seed directly into the existing grass sward. The invasive plants must be suppressed to reduce competition to emerging pasture seedlings. Mechanical soil disturbance in the form of spiking or harrowing is necessary. Soil disturbance improves seed-soil contact and ensures successful pasture seed germination and emergence.

Renovation

This method involves planting seed in tilled strips of about 100 cm or in furrows of about two centimetres. In the strip technique the vegetation is killed mechanically by tilling and then planted with the pasture. This technique results in more competition reduction by the invasive grasses and weeds and also creates good seed-soil contact for improving seed germination and establishment. The second approach using the two cm furrows involves undercutting the sod by about two centimetres as a form of soil disturbance and the planting of the seeds at the bottom of the furrow. The seeds are then well-covered by the soil creating a favourable environment for successful germination and pasture seed emergence.

4.3 Materials and methods

4.3.1 Analysis of pasture invasion by weeds

A dry weight rank yield analysis was carried out to determine the species composition and their relative biomass in the silvopasture agroforestry trial before implementing the pasture reinforcement experiments.

The aboveground species composition was assessed in the 9 Cocksfoot and 9 Tall fescue plots of the main silvopastoral experiment in November 2005. The species composition assessment was made in three randomly located quadrats (0.25 m x 0.25 m) in each plot. The different plant species present in each quadrat were identified and the top three ranked from 1 to 3 according to their biomass contribution. Ranks of 1, 2, and 3 and their respective empirically derived percentage multipliers of 70, 21, and 9 were used to determine the species percentage contribution to biomass in each plot. The data were tabulated to give the proportion of quadrats in which the species were ranked first, second or third. Where a rank was allocated equally to two or more species, the quadrat value of unit for the rank was allocated before summation of the number of quadrats by rank and species (t'Mannetje and Haydock 1963). Finally the products for each rank were added to give percentage dry matter for each species (Kirkman 1999).

4.3.2 Reinforcement methods and procedures

The invaded pasture had to be reinforced with Tall Fescue and Cocksfoot pasture grasses to enhance their recovery in July 2007 following the dry weight rank analysis.

The key to the successful pasture reinforcement is to avoid having the seed unfavourably placed for germination and establishment. Reduction of competition by existing plant species with the introduced species and a well prepared seedbed to receive seeds are necessary (Tainton *et al.* 2000). The reinforcement methods used were strip planting i.e. planting on the cultivated strip, and direct seeding by drilling. Seed to soil contact is of extreme importance when planting pasture and the drilling method is most effective as it allows for a better control of seed placement (Rinehart 2008).

4.3.2.1 Cultivated strip method

Strips ranging from 1 to 2 m width and 5 m length were tilled in each plot to create a strip that was free from competition with the existing invasive grass species (Figure 4.1). Planting in selected strips provided protection to the soil against erosion and reduced water loss (Lodge 2010).

The strips in each plot where the pasture grasses were planted were tilled by hand using garden forks, spades and hand-hoes in July 2007 to achieve a fine seedbed for good seed germination and quick establishment. Bartholomew (2000) pointed out that a properly prepared seedbed is essential for obtaining a good stand of the planted pasture species. The fertilizers, super phosphate and potassium chloride, were broadcast at a rate of 350 kg ha^{-1} and 187.5 kg ha^{-1} respectively in the whole plot including uncultivated strips before planting.

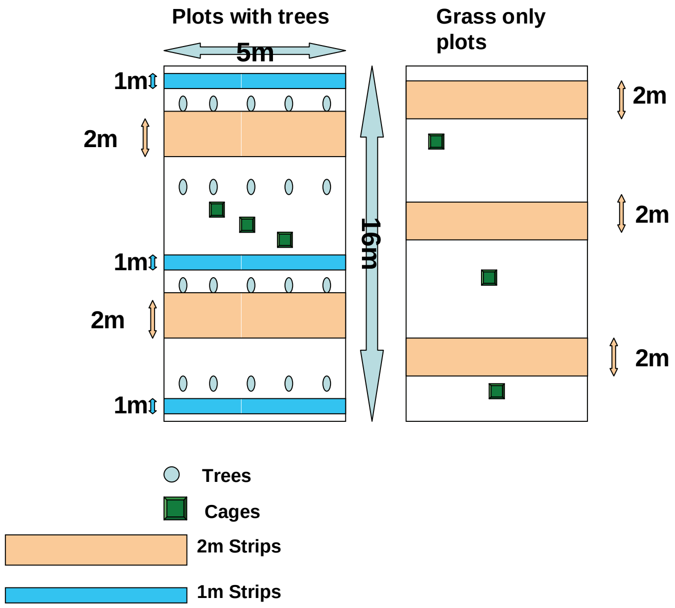


Figure 4.1 Pasture reinforcement in cultivated strips of 1 to 2 m width by 5 m length

In the tilled strips the rows were drawn in each strip using garden forks before broadcasting the seed. This was done to increase the rate of seed germination and emergence because 1) most of the seeds would be placed in the opened rows, 2) be well covered by soil and 3) seed-soil contact is improved. Cocksfoot and Tall fescue pasture grasses were then planted by broadcasting the seed to replace the invading species. A second planting was carried out in plots with poor establishment in January 2008. These plots had to be replanted due to poor establishment attributed to birds eating the germinating seedlings.

4.3.2.2 *Direct seeding method*

The uncultivated strips between the planted strips in the Cocksfoot plots were planted in mid January 2008 after the Cocksfoot seedlings were showing signs of better establishment compared to the Tall fescue. This was done to accelerate the rate of spread of pastures from the sown strips to the non-sown strips. The direct-seeding method was used (Plate 4.1 and Plate 4.2). The furrow was opened by cutting a sod of about 2 cm using a hoe-axe tool. These furrows were 0.2 m apart. The axe side was used to scarify the soil (to open a furrow) to enable the seed to be favourably placed for good germination, promote good establishment and to reduce competition by existing vegetation. To further reduce competition the plots were uniformly mowed to 5 cm immediately after seed planting. The advantage of using the axe side of the hoe in opening the furrow was that it allowed band placement of fertilizer. In addition the seeds were not placed on the soil where they are prone to insects and birds consumption but favourably placed in the soil. Good contact between seed and soil was easily achieved by pressing the furrows either by using the back of the hand-hoe or by foot through trampling.

Plate 4.1 Direct seeding method to reinforce pastures

Plate 4.2 Effects of direct seeding and strips in reinforcement of the pastures.

4.3.3 Statistical analysis

The mean dry matter yield of the reinforced Tall Fescue pastures was compared with the mean dry matter yield of invaded pasture using a one way Analysis of Variance (ANOVA). The mean nutrient contents of the reinforced Cocksfoot strips and the intervening invaded Cocksfoot pasture were compared using one way ANOVA to test the effectiveness of using the strip method of reinforcement. The reason for using nutrient content to determine the effectiveness of reinforcing pasture in Cocksfoot was because the uncultivated strips in Cocksfoot plots were later used in reinforcing Cocksfoot using the direct seeding method. This meant that there was no area of invaded Cocksfoot within the Cocksfoot plot that was not reinforced.

The means of dry matter yield between Cocksfoot reinforced by cultivated strips and those replanted using the direct seeding method were compared using one way ANOVA enabling the strip planting method to be judged against the drawn-furrow scarification method of reinforcement.

The Statistical Package for Social Scientist (2008) was used to perform the ANOVA using the fixed effect model to determine the difference between the means of dry matter yields of the invaded pasture and those of reinforced pasture. Leven's test was used for testing the homogeneity of variance and the means were considered significantly different at $p<0.05$.

4.4 Results

4.4.1 Effects of weed invasion on pasture dry matter yield

Percentage of species in the pasture plots

The dry weight rank yield analysis carried out in the plots showed that Cocksfoot contributed 66% of the species dry weight in the Cocksfoot plots and the remaining 34% was accounted for by *Paspalum notatum*, *Sporobolus africanus*, *Eragrostis plana* and *Paspalum dilatatum* (Table 4.1). Tall fescue contributed only 28% of the dry weight of the species in the Tall Fescue treatments while *Paspalum notatum*, *Paspalum dilatatum*, *Eragrostis plana*, and *Sporobolus africanus* contributed to the remaining 72% (Table 4.1).

Table 4.1 Percentage dry weight rank of species in the pasture plots

Species	Species % dry matter in Cocksfoot plots	Species % dry matter in Tall Fescue plots
Cocksfoot	66	
Paspalum notatum	24	25
Sporobolus africanus	4	7
Eragrostis plana	4	15
Paspalum dilatatum	2	16
Tall fescue		28
Eragrostis curvula		9
Total	100	100

The dry matter yield of reinforced Tall Fescue pasture (290.33 kg ha^{-1}) was significantly higher ($P < 0.017$) than the invaded Tall Fescue pasture plots (191.11 kg ha^{-1}) (Figure 4.2). The cultivated strip reinforcement technique was therefore successful in increasing the fodder production of the invaded pastures by approximately 99 kg ha^{-1} or 34%.

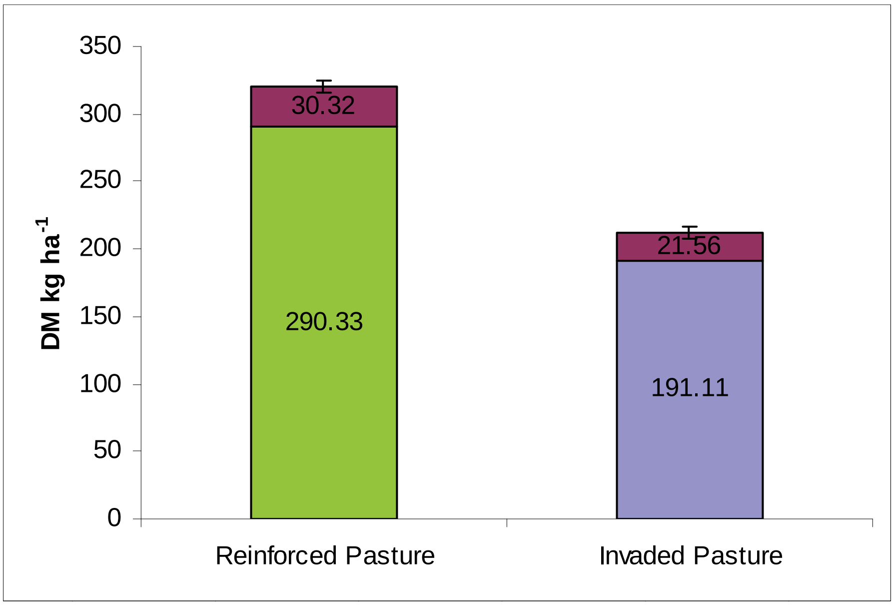


Figure 4.2 Means of dry matter yield of reinforced Tall Fescue pasture and invaded Tall fescue pasture

The dry matter yield of the reinforced Cocksfoot pasture (270.03 kg ha^{-1}) on the cultivated strip was not statistically different ($p = 0.628$) to Cocksfoot established by scarifying soil in the form of drawing furrows (246.35 kg ha^{-1}) (Fig 4.3).

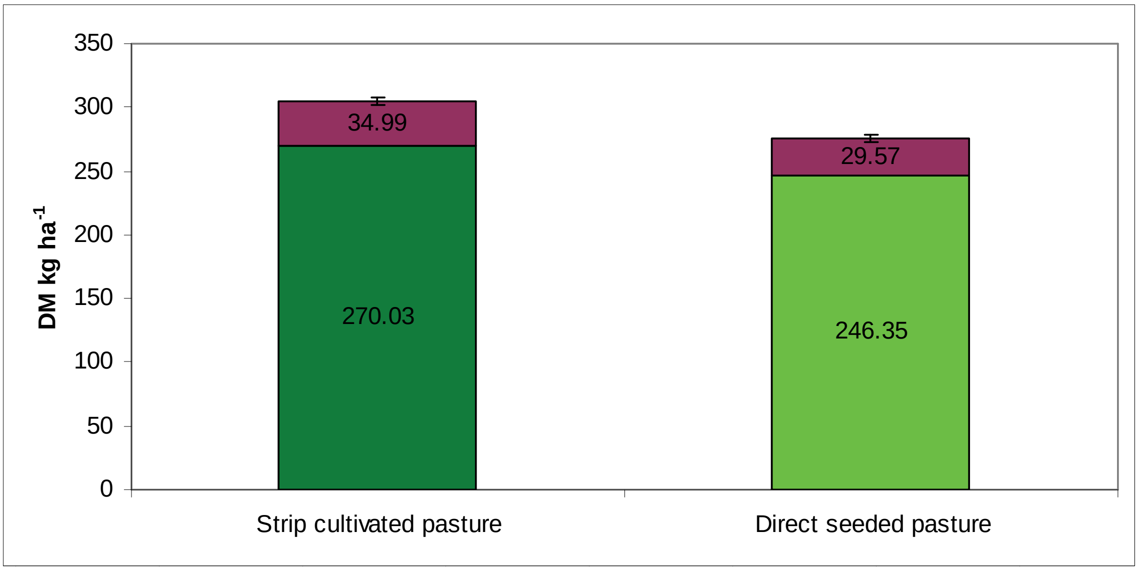


Figure 4.3 Means of dry matter yield of Cocksfoot pasture in cultivated strips (reinforced Cocksfoot) and drawn-furrow reinforced Cocksfoot

The crude protein content of reinforced Cocksfoot pasture (16.09%) was significantly higher (P= <0.001) compared to the invaded Cocksfoot (Table 4.2). The fibre content (ADF) of invaded pasture was 18.5% higher than reinforced Cocksfoot and the difference was statistically significant (P=0.008).

Table 4.2 Chemical composition of invaded Cocksfoot and strip planted Cocksfoot

	Chemical Composition (%)		
	CP	ADF	NDF
Invaded Cocksfoot (Means ±SE)	5.71±0.14	41.08±0.82	67.65±0.83
Reinforced Cocksfoot (Means ±SE)	16.09±1.41	34.67±1.97	64.67±2.14
P-value	0.0001	0.008	0.214

4.5 Discussion and Conclusion

The dry matter yield measurement using the t' Mannetje and Haydock (1963) technique indicated that the Tall fescue pasture was more severely invaded (72%) than the Cocksfoot pasture (34%). The marked decrease in pasture yield in both temperate pastures in 2005 and 2006 (Tables 3.5 and 3.6, section 3.6.3) was associated with this invasion of the pastures by local grasses. The invasion was attributed to harsh climatic conditions which were made worse by increased moisture stress due to the malfunction of the irrigation system.

South Africa has a high seasonal variation of rainfall with annual potential evapotranspiration exceeding annual precipitation and drought is common particularly in winter (Palmer and Ainslie 2005). Supplemental irrigation of winter pastures is practised in summer rainfall areas such as KwaZulu-Natal as rainfall becomes very low in winter. Irrigated winter pasture is important in the summer rainfall areas in order to extend fodder availability as natural veld grasses become fibrous and less palatable during the dry winter season. A study in Texas on cool season perennial grasses also found that drought resulted in high mortality of cool-season perennial grasses such as Tall Fescue (Butler *et al.* 2008). Similarly dry conditions due to low rainfall were found to decrease the biomass of perennial pasture grasses without supplementary irrigation (Badgery and Millar 2009). Local grass species that are better adapted to survive low moisture conditions are able to invade and out compete the moisture stressed temperate pastures. The increase in percentage species composition of *Paspalum notatum* (25%), *Paspalum dilatatum* (16%), *Eragrostis plana* (15%), *Eragrostis curvula* (9%) and *Sporobolus africanus* (7%) in the pure pastures indicated their adaptability to low soil moisture conditions.

There was higher DM yield reduction in Tall fescue compared to Cocksfoot species, indicating that Cocksfoot is more competitive under moisture stress compared to Tall fescue and Cocksfoot is therefore a better choice for small holder farmers.

The significantly higher DM yield in the reinforced Tall fescue pasture (290.33 kg ha^{-1}) when compared to the invaded pasture (191.11 kg ha^{-1}) showed that strip cultivation is an effective pasture reinforcement method. Bartholomew (2005) reported that suppression from existing vegetation generally improves the establishment and productivity of new seedlings. Similarly, Lodge (2010) reported that cultivated seedbeds give reliable establishment of reseeded pasture which contributes to higher yields. This is because this method results in complete reduction of competition by the existing unwanted plant species to the introduced species. The significant difference between reinforced pasture and invaded pasture suggest that the seeds in the reinforced treatments were well placed in the soil and had good germination. The removal of existing vegetation through well prepared seedbeds reduced the competitive ability of the *Paspalum notatum*, *Paspalum dilatatum*, *Eragrostis plana*, and *Sporobolus africanus* species allowing good pasture regrowth.

The significant ($p<0.001$) increase in crude protein content of the reinforced Cocksfoot pasture (16%) compared to the invaded pasture (CP=5.7%, NDF=67.65%) showed the success of reinforcing the pasture to improve fodder quality. The results showed that the dry matter yield of reinforced cocksfoot by strip cultivation (270.03 kg ha^{-1}) did not differ significantly ($P=0.628$) to the direct seeding reinforcement technique (246.35 kg ha^{-1}). Therefore, both techniques are recommended as effective pasture reinforcement methods.

CHAPTER 5: FODDER TREE PREFERENCE IN AGROFORESTRY SYSTEMS

5.1 Introduction

Natural veld is the major source of the cheapest feed for ruminant livestock in communal areas. Ruminant livestock particularly dairy cattle are an important means of accumulating capital assets for emergency cash needs through milk sales. They also provide manure for crop production (Bebe *et al.* 2003; Mapiye *et al.* 2009; Stur *et al.* 2002). Potillo *et al.* (1990) indicated that a great portion of rural people would not be able to survive without livestock. However, one of the major constraints in rural farming systems of the Upper Thukela region is the shortage of adequate and good quality forage during the dry winter season. Supplementation of feed using commercial supplements is expensive for resource-poor farmers and supplements are not easily available in remote areas.

Provision of alternative sources of fodder such as tree leaves and pods can increase production. The introduction of tree species particularly leguminous fodder trees through agroforestry systems (silvopasture, fodder banks) may improve the supply of forage during the dry season (Nyaata *et al.* 2000). Fodder trees can also be used as alternative sources of high quality forage for livestock (Gutteridge 1994; Roshetko and Gutteridge 1996; Shelton *et al.*1998) and can substitute for expensive dairy concentrates (Dzowela *et al.* 1997) as they are rich in protein. Generally, some leguminous trees are not readily consumed by livestock due to plant defence mechanisms notably tannins (Degen *et al.* 2010) and thorns. The intake by ruminant livestock of fodder trees with these defence mechanisms may be reduced with the consequence of poor animal performance. Tannins could reduce fibre digestion by complexing with lignocellulose and preventing microbial digestion or by directly inhibiting cellulolytic microorganisms or both (McSweeny *et al.* 2001). Tannins also have a profound inhibitory effect on digestion of carbohydrates and proteins in particular (McSweeny *et al.* 2005).

Information on the preference of leguminous tree species by ruminant livestock is generally lacking in communal areas of South Africa because of very limited or no preference trials conducted in these areas.

The aim of this study was to determine the relative preference of two tree fodder species (*Acacia. karroo* and *Leucaena. leucocephala*) by dairy cows. The objective of the study was to assess the tree fodder selectivity and intake by dairy cows in a cafeteria experiment and *in situ* grazing. The results of the trial would be used to make informed decisions on whether to allow the dairy cows to browse the trees in the experimental agroforestry trial, or to feed them with the tree forage through the cut and carry technique. It was hypothesized that there is no difference in the tree fodder preference and proportionate intake of *L. leucocephala* and *A. karroo* tree fodder by dairy cows.

5.2 Materials and methods

5.2.1 First Trial "Cafeteria" experiment

Three dairy cows were used in the study which was conducted in May 2006. The study was in the form of a "cafeteria" experiment whereby each cow had a free choice of two tree fodders without disturbance from other cows. The dairy cows were allowed to have free grazing in natural rangeland in the morning prior to the preference trial. Each cow was allocated to an individual pen with two containers each containing 0.75 kg fresh leaves of *L. leucocephala* and *A. karroo.* The cows had access to the fodder for a one-hour period after which the remaining fodder (refusals) was weighed to determine the intake.

The tree leaves of *Acacia karroo* and *Leucaena leucocephala* tree species used in the preference trial were from the silvopastoral agroforestry experiment. The leaves for the experiment were harvested from the border rows of each tree species. The *A. karroo* tree branches were lopped and the leaves were cut from these branches using small shears. *Leucaena leucocephala* tree branches were also lopped but the leaves were hand removed from the branches.

It is important to note that the dairy cows had no previous experience of *L. leucocephala* and *A. karroo* species as these species did not exist in the study site and were introduced for the first time. The freshly cut leaves of each tree species were weighed and put in two feeding containers (one for *L. leucocephala* and the other for *A. karroo*). The two feeding containers were placed in each of the three pens. Each of the feeding containers contained 0.75 kg of fodder leaves. Each dairy cow was allowed to have free access to the fodder in the individual pens. The dairy cows were allowed to feed on the fresh tree fodder leaves for 30 minutes. After this feeding period, the refusals were weighed and recorded. The difference (total feed offered minus refusal) indicated the amount consumed by each dairy cow. The amount consumed represented the feed intake by the dairy cows of each fodder species. The information was used to calculate the dietary preference index whereby the feed intake (amount of feed consumed) was divided by the total amount of feed offered. Omokanye *et al.* (2001) and Degen *et al.* (2010) used similar dietary index techniques to determine fodder preference by ruminant livestock during the studies on the preference of *L. leucocephala*, *Cajanus cajan*, *Gmelina arborea*, *Gliricidia sepuim*, *Adenodolichos paniculatus*, *Cratylia argentea*, *Khaya senegalensis*, *Sphenostylis schweinfurthii*, and *Desmodium velutinum* and preference of *Acacia salicina*, *Acacia saligna*, *Cassia sturtii*, *Atriplex canescens*, *Atriplex halimus* and *Atriplex nummularia* by goats and sheep respectively. The following five preference classes used by Omokanye *et al.* (2001) were adopted: high preference (0.76-1.00); moderate preference (0.56-0.75); fair preference (0.45-0.55); poor preference (0.26-0.44) and no preference (<0.26). The preference of each tree fodder by dairy cows was rated according to these preference classes.

5.2.2 Second Trial: Grazing

The cows had grazed in the natural rangeland before this experiment. The three dairy cows were then allowed to graze directly on the experimental pastures in the silvopastoral trial. During this study the time spent by each cow on browsing the *Leucaena leucocephala* and *Acacia karroo* species and grazing the pasture species was recorded. The behaviour of the cows during the study was observed and noted. The duration of the study was 90 minutes.

The dairy cows were put in sole *Acacia karroo* and sole *Leucaena leucocephala* plots for 15 minutes each and 30 minutes in each of the alley plots of *Leucaena leucocephala* and A*cacia karroo.* The increased duration in alley plots was to allow dairy cows to have the same amount of time for grazing and browsing (15 minutes for grazing and 15 minutes for browsing) similar to the time they had for browsing (which was 15 minutes) in the sole tree plot.

5.2.3 Statistical analysis

The forage intake was analyzed in for a Randomized Complete Block Design (RCB) with three replications (dairy cows); treatments were two tree fodder species and forage intake as yield. The Analysis of Variance (ANOVA) was carried out to test for differences between treatment means using the Statistical Package for Social Scientist (2008). The fixed effect model was used to detect the difference between the intake of the two tree fodder species (*A. karroo* and *L. leucocephala).* Leven's test was used for testing the homogeneity of variance and the means were considered significantly different at $p<0.05$.

5.3 Results

5.3.1 First trial (Cafeteria)

Dietary preference index was higher for *L. leucocephala* with an index of 0.97 compared to *A. karroo* with lower index of 0.52 (Table 5.1). The forage intake also differ significantly ($p=0.019$) between the two species with the *L. leucocephala* having the highest and *A. karroo* the lowest during the cafeteria study (Table 5.2). Dairy cows spent less time consuming *A. karroo*. *L. leucocephala* was the most readily consumed browse compared to *A. karroo*. When they have the first bite on *L. leucocephala*, they virtually ignored the *A. karroo* showing that *L. leucocephala* was their first choice.

Table 5.1 Preference index of *A. karroo* and *L. leucocephala* tree species

Fodder Type	Total fodder (kg)	Feed intake (kg)	Tree preference index
A. karroo	0.75	0.39^{b} (±0.087)	0.52 (fp)
L. leucocephala	0.75	0.73^{a} (±0.020)	0.97 (hp)

Values in parenthesis indicate standard error of means (SE). Means followed by different superscripts are significantly different (p<0.05).

hp = high preference 0.76-1.00) mp = moderate preference (0.56-0.75) fp = fair preference (0.45-0.55)

5.3.2 Second Trial: Grazing

In spite of *Leucaena leucocephala* being the preferred species in the cafeteria trial, this species was not preferred when the dairy cows were put in the silvopastoral trial. Here they spent only 6% of the allocated time on browsing *Leucaena leucocephala* tree leaves. The cows did not browse *Acacia karroo* which contrasted with the cafeteria trial where the same cows consumed 52% of the *Acacia karroo* forage. It was noted during this study that the dairy cows spent most of the time (99.93%) grazing the pasture grasses as opposed to browsing the tree leaves. In the sole *Acacia karroo* plots the dairy cows did not consume a single leaf but instead they spent about 0.13% of their time smelling the tree and then waited to move to another plot with pasture grass (Table 5.2).

Table 5.2 Preference trial (Grazing) of *A. karroo* and *L. leucocephala* by dairy cows

Forage Type	Allocated time (minutes)	Time spent smelling tree	Time spent browsing (minutes)	Time spent grazing (minutes)	Percentage time spent		
					Smelling	Brows-ing	Grazing
Sole *A. karroo*	15	0.02	0.00	0	0.13	0.00	0.00
Alley *A. karroo*	30	0.02	0.00	29.98	0.13	0.00	99.93
Sole *L. leucocephala*	15	0.00	2.00	0.00	0.00	13.33	0.00

5.4 Discussion

The highest dietary preference index for *L. leucocephala* (0.97) showed that it is the most preferred species by dairy cows. In a tree species preference study with sheep in Nigeria, Omokanye *et al.* (2001) found that *L. leucocephala* was the most preferred species when offered as fresh forage in comparison to others (*Gmelina arborea*, *Cajanus cajan* and *Adenodolichos paniculatas*). The higher intake rate of *L. leucocephala* (97%) compared to *A. karroo* (52%) may be attributed to its higher crude protein content (Chapter 3, Table 3.14). It is generally known that ruminants on pasture tend to selectively graze plants that contain a high level of crude protein (Karbo *et al.* 1993). Offering *L. leucocephala* as fresh material and its high crude protein content may partly have contributed to it becoming the most selected tree species compared to *A. karroo* during this study.

The low consumption of *A. karroo* may be attributed to the presence of tannins. The content of total tannins may be the best predictor of tree fodder preference by ruminants (Alonso-Diaz *et al.* 2010). *Acacia* species are known to have high concentrations of condensed tannins which generally deters intake (Degen *et al.* 2010; McSweeney *et al.* 2005; Silanikove *et al.* 2001). For example, in a study on forage quality at Ukulinga Research Farm, Tau (2005) found that *A. karroo* contained a significant amount of condensed tannins (5.69%) compared to *L. leucocephala* (1.19%). Condensed tannins above 3% may act as a feeding deterrence and may reduce animal productivity in terms of weight gain, wool growth and milk production (Silanikove *et al.* 2001). Tannins have the ability to bind proteins and tannin-protein complexes reduce the availability and digestibility of proteins in the ruminant (Wina *et al.* 2005). Condensed tannin--protein complexes thus reduce nitrogen availability to rumen microorganisms (McSweeney *et al.* 2001)

The complete rejection of *A. karroo* by the same dairy cows during the grazing trial under sole plots of *A. karroo* or alley plots of *A. karroo* was a clear indication that the presence of thorns, as a plant defence mechanism limit, the consumption of *A. karroo* by dairy cows. The existence of thorns in *A. karroo* tree restricts its utilization by cattle (Mapiye *et al.* 2009). The thorns render *A. karroo* tree leaves not to be readily browsable by cattle. According to Mapiye *et al.* (2010) cattle are unable to access leaves and pods of *A. karroo* during browsing due to restriction by thorns. Paterson (1994) pointed out that the presence of thorns and their distribution in plants are of great importance in determining the usefulness of the plant as a browse. However, *A. karroo* can still be a useful browse despite the presence of thorns if the harvesting and processing techniques are used. In this trial, it was demonstrated that the problems of thorns from *A. karroo* can be solved by sun-drying branches with leaves after harvesting, placing them into bags and then shaking or beating the bags by sticks to separate the leaves from thorns. The beating technique is well known to the farmers as they also use it to separate dry bean seeds from pods after harvesting. Mapiye *et al.* (2010) pointed out that the effects of thorns can be minimised by sun-drying and then shaking the leaves off from branches in order to separate them from thorns. Dairy cows spent only 0.13% of their time in both sole and alley plots smelling *A. karroo* trees and 99.93% of the time was spent on grazing pasture in the *A. karroo* alley plots (Table 5.3). The contrasting results of 52% *A. karroo* intake in a cafeteria study compared to complete rejection of *A. karroo* in a grazing trial demonstrate that the way tree fodders are fed may influence preference and intake of these tree fodders by dairy cows. It was evident from the results that cut and carry systems whereby the fodder is harvested and fed to livestock may result in more effective and better utilization of *A. karroo*.

5.5 Conclusion

Dairy cows preferred *L. leucocephala* tree fodder (97% intake) compared to A. karroo tree fodder (52% intake). However, when winter pasture species were also available browsing was minimal. There was a complete rejection of *A. karroo* during the grazing trial which may be attributed to thorns and tannins as plant defence mechanisms. The problem of thorns from *A. karroo* can be solved by sun drying branches with leaves after harvesting, placing them into bags and then shaking or beating the bags by sticks to separate the leaves from thorns. Therefore shaking after harvesting and drying is an effective technique for separating of thorns from *A. karroo* tree leaves. This has the potential to enhance effective utilization of this tree species by ruminants.

It was evident from the cafeteria trial that the cows will consume more *L. leucocephala* fodder under cafeteria conditions and that the cut and carry system will be an option for the farmer to use for the dairy cows.

The study showed that *A. karroo* tree fodder may be utilized by the dairy cows if post-harvest treatments such as separation of thorns from tree leaves are conducted before offering them to dairy cows.

CHAPTER 6: INTERCROPPING MAIZE AND *DOLICHOS LABLAB*

6.1 Introduction

Since maize stover is of poor quality due to its low protein content (Undi *et al.* 2001; Tau 2005) there is a need to improve the quality and quantity of fodder for smallholder dairy farmers in communal areas. One option to improve fodder production that was examined in this study was the implementation of intercropping. Intercropping, which is the practice of growing two or more crops on the same land during the growing season (Carlson 2008; Eskandari *et al.* 2009), may give several benefits to smallholder livestock farmers. The benefits include the following: an increase in crop yield per unit area of land; improvement in soil fertility by leguminous crop; reduced soil surface evaporation through increased leaf cover once the intercrop is well established; reduction in soil erosion; weed reduction due to increased leaf cover once the intercrop is well established; less land needed for crop production as two crops are produced in the same field (Carlson 2008; Eskandari *et al.* 2009; Sullivan 2003).

Intercropping cereals with forage legumes has been shown to improve both the quantity and quality of fodder (Mpairwe *et al.* 2003; Dahmardeh *et al.* 2009 Reddy *et al.* 2009). In Turkey, Geren *et al.* (2008) found that maize intercropped with legumes was more effective than sole crop maize in the production of dry matter and quality silage. The total fresh mass yield ranged from 24216-24664 kg ha^{-1} for intercropped maize compared to 23778 kg ha^{-1} for the sole crop. In a cereal-legume intercropping study conducted in Denmark, Prins and De Wit (2006) reported higher CP content (13%) in the wheat intercropped with faba beans compared with the sole wheat crop (11.2 %).

Other grain legume crops such as *Lablab purpureus* can be integrated into agricultural systems and are used as an intercrop with cereals such as maize. According to Ngongoni *et al.* (2007) legumes can improve the productivity of cereal crops and offer a possible lower-cost alternative to nitrogen fertilizers and purchased protein supplements. The leaves and shoots of *Lablab purpureus* form hay which is an important feed resource for livestock and they can therefore replace the conventional supplements which are expensive and in most cases are not readily available to smallholder dairy farmers (Bwire and Wiktorsson 2002). The crude protein content of lablab was three to seven times higher compared to that of maize stover with values ranging from 148 g kg^{-1} to 300 g kg^{-1} DM with high digestibility values of 55 to 67.1% (Murphy and Colucci 1999). The high protein content and digestibility of lablab suggest that it has potential to improve the quantity and quality of maize fodder in a crop-livestock system in rural farming systems such as Zwelisha. However, in intercropping, yield reduction of the cereal crop may occur due to the aggressive competitive ability of the forage legume competing for light, nutrients and water. Simultaneous intercropping and high plant density may result in poor crop performance because of high competition in plants under intercropping. Forage legumes like lablab, velvet bean and scarlet runner bean may also completely entangle the entire cereal plant and may impede physiological development of the plant (Gbaraneh *et al.* 2004; Armstrong *et al.* 2008). The entanglement may be attributed to the climbing ability of these forage legumes. Planting a forage legume such as lablab between two and four weeks after cereal maize planting may reduce competition and entanglement, thus giving a high yield of the cereal maize crop. Maize leaf yield was reduced by 57% in the simultaneous intercrop compared to a sole maize crop (Gbaraneh *et al.* 2004). Any reduction in maize leaf yield is not good because the leaf fraction is mostly preferred to livestock.

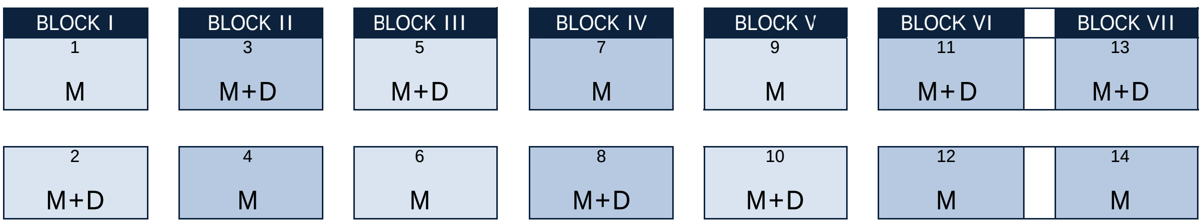
In addition to planting time of crops, a number of other factors need to be taken into account if the farmer is to realize the benefits of intercropping. Sullivan (2003) pointed out that when two or more crops are grown together, each must have adequate space to maximize cooperation and minimize competition between them and to achieve this, spatial arrangements used in intercropping must be considered.

The current study was conducted with the aim of determining the effect of intercropping maize with lablab at different spatial arrangements to increase fodder productivity and quality. The main objective of the study was to conduct an on-farm trial to assess the effect of growing maize and lablab (in the form of row intercropping) on maize fodder and grain yield, total fodder and quality in terms of crude protein and fibre content. It was hypothesized that intercropping maize with lablab would increase maize fodder production, crude protein content and grain yield.

6.2 Material and methods

6.2.1 Experimental design

This trial was laid out in a randomized complete block design with seven replications (blocks). Each block was divided into two experimental plots measuring 5 m x 7 m (Figure 6.1). One experimental plot of each replicate comprised a sole maize crop and the other one comprised maize intercropped with *Lablab purpureus*. The study was carried out for six consecutive seasons, that is, from 2003/2004 to 2008/2009.



A layout of 1 X 1 factorial experiment involving one maize variety, one lablab variety with 2 treatment combinations (M+D = maize + lablab; M = maize) in a randomized complete block design (RCBD) with seven replications.

Figure 6.1 Experimental design of the Maize+Lablab trial

NUMBER OF PLOTS:	14
Plot Sizes:	5 m X 7 m
Block size:	5 m X 15 m
Space between blocks:	1.5 m
Space between plots:	1 m
Net Plot Size (based on plant spacing):	4.6 m X 5.4 m

TREATMENTS

M+D: Maize + Lablab (Maize-Lablab interaction)
M: Maize (Control)

PLANTING

Row spacing: 0.8 m
Plant spacing: 0.2 m

6.2.2 Agronomic practices

A row intercropping system was established and the following agronomic practices were carried out to ensure good establishment of maize and lablab crop: land preparation, soil sampling, liming, fertilization and planting. Agronomic practices for maintenance of the crop included the following: weed control, insect control. Agronomic practices for good crop establishment and for maintenance were conducted in each growing season.

- **Land preparation**

The field experiment was prepared by ploughing the land using a tractor mounted disc plough. Not secondary tillage was carried out to avoid preparing the land into a fine seed-bed as this might result in soil particle detachment and then soil erosion. The farmer assisted in ploughing the land. Land preparation was followed by opening rows of furrows with a spacing of 0.8 m in the whole area of each plot using hand-hoes and garden spades. Ploughing of the land was normally done during the third or fourth week in November or first week of December following the first good spring rains.

- **Soil sampling and fertilizer application**

Soil samples were taken before the establishment of the experiment. Soil samples were sent to Cedara Agricultural Research Institute for nutrient analysis. Composite soil samples were taken in the experimental trial at a depth of 15 cm during the second week in January 2003, first week in October 2004, and third week in October 2007. During soil sampling twenty two soil cores were taken and were thoroughly mixed, air-dried and sent to Cedara Agricultural Development Institute laboratory for soil nutrients analysis. The soil were analysed for phosphorus (P), potassium (K), Magnesium (Mg), calcium (Ca), zinc (Zn), manganese (Mn) nutrients.

Liming

Dolomitic lime was firstly applied in October 2003 during the second maize planting at a rate of 1 t ha^{-1}. The lime was applied in a broadcast form, and incorporated into the soil by thoroughly mixing it with the soil using garden forks. The use of dolomitic lime was based on the results that indicated deficiency of magnesium and low pH (Table 6.1).

Fertilizing

The type and rate of fertilizer application was used based on the soil analysis (Table 6.2). Type of fertilizer and rate: The fertilizer mixture (not straight fertilizers) N:P:K: 2:3:2 (22) +0.5%Zn at a rate of 245 kg ha^{-1} (0.86 kg per 5 m x 7 m plot) was applied in the row during planting of maize. A similar amount and type of fertilizer mixture was applied to lablab.

Method of application
The fertilizer application in the row was done by hand and was covered with 4 cm soil to avoid direct contact between seeds and fertilizer as this may cause a burning effect on seed. No side-dressing with nitrogen was done. This was in accordance with the farmer's practice of not side-dressing his maize crop.

Table 6.1 Soil analytical results for maize-lablab trial during 2003/2004 growing season

P ($mg\ \ell^{-1}$)	K ($mg\ \ell^{-1}$)	Ca ($mg\ \ell^{-1}$)	Mg ($mg\ \ell^{-1}$)	pH
23	260	155	49	3.81

Planting

The maize cultivar used in the trial was PhB3442. Different forms of row intercropping were used during the trial. The first one was alternating row intercropping (2003/2004 to 2004/2005 season) and later the tram line intercropping (from 2005/2006 until the end of the experiment). Alternating row intercropping involves planting one crop in alternate rows with the second crop. Tram line intercropping is when tram lines of maize are intercropped with a row of lablab (Figure 5.2). Changing from alternating row to tram line intercropping was because of the entanglement of maize plants by lablab which resulted in lodging of maize which resulted in yield reduction.

Tram line intercropping: The row spacing between the tram lines was 0.8 m and was 1.8 m between the set of tram lines. Lablab was planted between the sets of maize tram line (0.9 m from the maize row). Tram line intercropping was also used successfully by Smith *et al*. (2004) during the study on intercropping cereal maize with forage legumes lablab, soybean, and cowpea at a Bergville (Emmaus), South Africa.

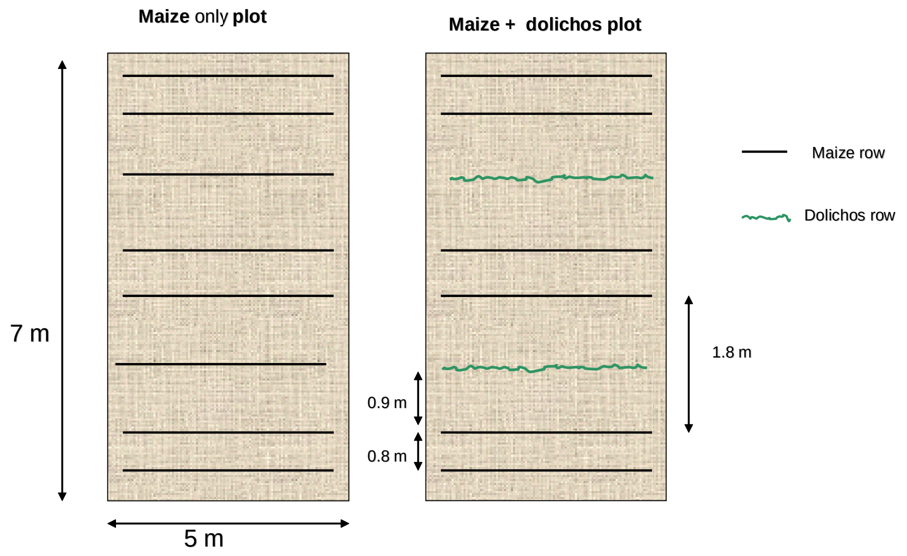


Figure 6.2 Maize-lablab planted in tram lines

Alternating row-intercropping: The lablab was planted midway (0.4 m) between the maize rows which had a row spacing of 0.8 in the 2003/ 2004 season.

The first planting of maize was done during the second week in January 2003 but this was not successful because of poor maize germination due to drought. The second maize planting was done during the fourth week of November 2003.

Planting method: Planting operations were done by hand. Furrows (0.09 m deep) were opened using hand-hoes and garden spades. Fertilizer was placed in the bottom of each furrow and covered with 0.04 m soil. Maize and lablab seeds were planted in furrows which were filled with the remaining soil to cover the crop seed. The 0.2 m in-row spacing was used for both maize and lablab seeds. The same planting method was used throughout the trial including the tram line row intercropping. The difference was the time of planting lablab. In the 2003/2004 growing season, lablab was planted one to two weeks after maize planting. This was changed due to entanglement of maize plants and lablab was then planted three weeks after maize planting. The three weeks delay in planting lablab was started in the 2005/2006 season until completion of the trial in the 2008/2009 season.

Weed control

Weeds were mechanically controlled using hand-hoes. Controlling of weeds was done twice in the intercropping plots but in the sole plots it was done more than twice. This was because lablab had an effect in suppressing weeds in intercropping plots. Herbicides were not used in accordance with the practices of most of the local farmers who normally use hand-hoes to control weeds.

Pest control

The insect which was most problematic was cutworm. Cutworm bait granules were applied by hand within the row (maize and lablab) during the crop emergence.

Harvesting procedures

The first maize grain crop was harvested in the third week of May 2004 on a whole plot basis. The whole plot harvesting was done because some of the maize plants lodged due to entanglement by lablab. However, only two middle rows of maize were harvested when tram line intercropping was used. The early dough (milk dough) stage of harvesting was adopted from 2006/ 2007 to 2008/2009 season following the recommendation by the Reference Group. This was done so that maize and lablab biomass data would be available in the event of the trial being grazed by cattle as occurred in the 2005/2006 season. The early dough stage harvesting was normally done in the last week of March throughout the trial period. Harvesting was done so that grain yields could be determined separately from stalk and leaf yields which were combined. Chemical analyses were done for these two plant fractions.

Alternating row-intercropping: Maize cobs were picked from the standing maize plants of each plot, dehusked and air-dried in the laboratory for one week before shelling. The maize grains were weighed in the laboratory before samples were taken for chemical analysis. Maize stover (stalks and leaves) was chopped and dried at 65ºC for 48 hours for dry matter yield determination and chemical analysis. Lablab was harvested using three quadrats measuring 0.5 m x 0.5 m and weighed immediately for fresh mass determination. The samples were oven-dried at 65ºC for 72 hours for dry matter yield and chemical analysis.

Tramline row-intercropping: Maize harvesting was done on three to five plants randomly selected from two middle rows in March 2007. Maize plants were first cut at ground level before cobs were hand-picked. The cutting prior to picking cobs was to ensure that cobs were from the selected maize plants. Maize stover was later separated into leaf and stem. The leaves were hand-removed from the stem. The stems were chopped and weighed immediately for fresh mass determination. The values of fresh mass were used to determine total dry matter yield. The leaf and stem samples were oven-dried at 65ºC for 48 and 96 hours respectively. Maize cobs were weighed at the farmer's homestead site. The maize cobs were taken to the laboratory and oven-dried at 65ºC for 96 to 120 hours. Lablab was harvested in May 2004 2007, 2008. The harvesting was conducted by taking three quadrats (each measuring 0.5 m x 0.5 m) in each plot. The lablab was weighed at the homestead for fresh mass before it was oven dried at 65ºC for 48 hours. However, harvesting of lablab was not done in 2004/05, 2005/06 and 2008/09 season because of grazing by livestock.

Once the harvesting for yield and sampling for chemical analysis was completed the remaining maize stalks, leaves maize grain and lablab were taken by the farmer for feeding to his dairy cattle to overcome the fodder shortage.

Chemical analysis

Plant fractions such as stem, leaves and grain differ in their digestibility, implying that they have different levels of crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). It was therefore necessary to determine the nutrient content of each plant part.

Maize fractions (leaves, stalk and grain) and lablab samples were analyzed for dry matter (DM). These samples were then ground to pass through a 1 mm screen and analyzed for CP in a LECO FP2000 Nitrogen Analyser using the Dumas Combustion method following standard procedures of AOAC (1990) The NDF and ADF were analysed on a Dosi-Fibre machine according to the method described by Van Soest, Robertson and Lewis (1991). Analysis of maize and lablab samples was conducted at Cedara Agricultural Development Institute and some in the Department of Animal Science at the University of KwaZulu-Natal.

6.2.3 Statistical analysis

The dry matter yields of maize stover, maize grain and total fodder (maize stover + lablab in case of intercropping) for both sole crop and intercrop were statistically analysed using the Statistical Procedures for Social Science (SPSS). The means were compared using one way analysis of variance (ANOVA). The factors sole cropping and intercropping treatments were combined to one factor. The fixed effects model was used to detect the difference between the yield from intercropping and sole cropping treatments. Levene's test was used to test for homogeneity of variance and the means were considered significantly different at $p<0.05$.

6.3 Results and discussion

Since harvesting the whole plot would result in fewer maize rows in the intercropping than sole cropping treatments, which gives sole cropping a maize yield advantage compared to intercropping treatment, it was necessary to standardize the harvesting methods. The results are therefore based on two rows of maize rows harvested in both the intercrop treatment and the mono-crop treatment.

The first maize crop was harvested in May 2004. The results indicated a decrease in maize grain yield from 1288 kg ha^{-1} in the maize only treatment to 1112 kg ha^{-1} in the maize plus lablab treatment (Table 6.2). This decrease in yield was attributed to the simultaneous planting of maize and lablab which caused entanglement of the maize plant by the lablab plants. Any stress during the critical period of maize growth can negatively affect DM accumulation, resulting in poor grain formation and low yield (Gbaraneh *et al.* 2004). In this trial lablab entangled maize and some of the maize plants fell down (lodged) before harvesting stage. To avoid lodging, lablab should be planted 3-4 weeks after maize has been planted.

The highest maize grain yield (4460 kg ha^{-1}) ($p<0.01$) was recorded in the maize plus lablab treatment during the 2006 season (Table 6.2). The yield was significantly higher than the maize only treatment (1490 kg ha^{-1}) ($p<0.01$). The results are in contrast to those obtained in the 2004, 2005 and 2008 seasons where the difference in grain yield between sole maize and intercrop was not significant ($p=0.440$).

Intercropping maize with lablab had a positive impact on maize fodder (stalks and leaves) yields in various seasons (Table 6.2). During the 2006 and 2007 seasons, intercropping maize with lablab significantly increased maize fodder yield by 59% and 43% respectively. Although the impact of intercropping on maize stalk and leaves during the 2004, 2005 and 2008 seasons was not statistically significant, intercropping still increased maize leaves and stalk yields by 2-40%. This was an important increase considering the severe fodder scarcity in smallholder farming areas. A minimal increase of 2% (3030 vs. 3060 kg ha^{-1}) was observed in maize stalks and leaves during the 2008 season and was associated with management problems (late weed control) and livestock grazing in the trial during that season.

The first crop of lablab was harvested in the first week of May 2004 and a yield of 4200 kg ha^{-1} DM was obtained (Table 6.2). The total dry matter yield of lablab decreased from 4200 kg ha^{-1} in 2004 to 2047 kg ha^{-1} in 2005 (Table 6.2). The lablab yield reduction can be attributed to moisture stress due to low rainfall and less favourable temperatures as lablab was planted in late February to avoid entanglement. The results show the importance of planting earlier to avoid yield loss.

Table 6.2 Dry matter yield (kg ha^{-1}) from 2004-2008

Year	Treatment	Maize grain	Maize Fodder (stalks/leaves)	Lablab	Total fodder (excl. grain)
2004	Maize	$1288^b \pm 240$	$1000^b \pm 110$		1000^b
	Maize + Lablab	$1112^b \pm 200$	$1390^a \pm 130$	4200	5590^a
2005	Maize	$124^b \pm 720$	$1050^b \pm 270$		1050^b
	Maize + Lablab	$1260^b \pm 990$	$1470^b \pm 210$	2047	3517^b
2006	Maize	$1490^b \pm 300$	$5810^b \pm 700$		5810^b
	Maize + Lablab	$4460^a \pm 820$	$9240^a \pm 1700$	1443	10683^a
2007	Maize	Grazed	$7360^b \pm 710$		7360^b
	Maize + Lablab	Grazed	$10540^a \pm 680$	1580	12120^a
2008	Maize	$1290^b \pm 580$	3030^b		3030^b
	Maize + Lablab	$1530^b \pm 490$	3060^b		3060^b

In 2007 the total maize fodder yield (grain plus stalks/leaves) was higher in the intercrop plots (12120 kg ha^{-1}) compared to the sole maize plots (7306 kg ha^{-1}) which was a yield increase of 65%. The higher maize fodder yield in the alley plot indicates the positive impact of lablab on maize fodder yield. The fodder from the trial assisted the farmer with his problem of fodder shortage during the June and July winter months of 2007. In 2007 he did not plant any crop for fodder during the growing season as a result of problems he experienced with his implements. He was solely dependent on the fodder from this trial which he fed to his dairy cows for a period of about two months.

The chemical analysis of the fodder showed that intercropping maize with lablab improved the quality of maize leaves significantly ($p<0.05$) compared with sole maize (Table 6.3). The crude protein content of maize leaves that were intercropped was 39% higher ($p<0.001$) than with sole maize (11.72 vs. 8.42%). This is an important finding because leaves in the maize stover fraction are the plant parts that are mostly selected by cattle during grazing (Murphy and Colucci 1999). In contrast to crude protein, there was significant reduction in NDF ($p=0.023$) and ADF ($p=0.019$) of maize leaves which was associated with intercropping compared to sole cropping. The lower fibre values and higher

CP results in a higher feed digestibility and enabled the famer's dairy cows to survive the winter period.

Table 6.3 Chemical composition of maize leaves in intercropping (lablab) and monoculture treatments

Treatment	Chemical Composition (%)		
2006	**CP**	**ADF**	**NDF**
Maize only treatment (Means ±Se)	8.42±0.31	38.17±0.46	68.59±0.67
Maize plus Lablab treatment (Means ±Se)	11.72±0.54	35.26±0.96	65.16±1.13
P-value	0.000	0.019	0.023
2007	**CP**	**ADF**	**NDF**
Maize only treatment (Means ±Se)	7.04^{b} ±0.25	42.78^{b} ±0.72	74.01^{b}±0.57
Maize plus Lablab treatment (Means ±Se)	9.65^{a}±0.57	39.68^{a} ±0.80	69.74^{a} ±0.54
P-value	0.001	0.014	0.000

Means in the column followed by different superscripts are significantly different (p<0.05); se=Standard Error of the Mean

There was no significant (p>0.05) difference between the crude protein content of maize grain in the intercrop treatment and mono crop treatments (9.95 vs. 8.74%) in 2006 and (7.95 vs. 7.07%) in 2007 (Table 6.4). Similarly, the results showed no significant difference in neutral detergent fibre (NDF) and acid detergent fibre (ADF) content between intercrop and sole crop treatment in 2006 and 2007, although these values were low.

Table 6.4 Chemical composition of maize grain in intercropping (lablab) and monoculture treatments

Treatment	Chemical Composition (%)		
2006	**CP**	**ADF**	**NDP**
Maize only treatment (Means ±Se)	8.74^{b} ±0.48	4.87^{b} ± 0.34	15.27^{b} ± 1.36
Maize plus Lablab treatment (Means ±Se)	9.95^{b} ±0.58	5.24^{b} ± 0.61	16.02^{b} ± 1.65
P-value	0.133	0.601	0.731
2007	**CP**	**ADF**	**NDP**
Maize only treatment (Means ±Se)	7.07^{b} ±0.36	5.89^{b} ±0.13	16.23^{b} ±0.44
Maize plus Lablab treatment (Means ±Se)	7.95^{b} ±0.25	6.19^{b} ±0.28	17.44^{b} ±0.73
P-value	0.073	0.365	0.184

Means in the column followed by different superscripts are significantly different (p<0.05); se=Standard Error of the Mean

6.4 Conclusion

The higher total fodder yield observed in the maize plus lablab treatment compared to maize only treatment showed the importance of intercropping maize with lablab for increasing feed quantity. Highest fodder production was obtained in 2007 from intercropping (12120 kg ha^{-1}) compared to sole maize cropping (7360 kg ha^{-1}). The increase in total fodder production in the intercrop treatment compared to sole maize treatment observed in this study is consistent with the findings of Mpairwe *et al*. (2002) who reported an increase of fodder yield in maize-lablab intercrop treatment compared to sole maize cropping (13960 kg ha^{-1} vs. 9710 kg ha^{-1}). A similar effect of maize-lablab intercropping on total fodder yield was observed by Mpairwe *et al*. (2002), Kabirizi *et al*. (2007), Ngongoni *et al*. (2007), Reddy *et al*. (2009) and by Dahmardeh *et al*. (2009) on cereal legume intercrop (maize-lablab and maize-cowpea). Therefore intercropping results in efficient utilization of land (Mukhala *et al*. 1999; Dahmardeh *et al*. 2009) and is beneficial to smallholder farmers who usually have a small area of land (Titterton *et al*. 2002).

The results from this study highlighted the importance of agronomic practices in achieving high yields. Maize grain yield from intercropping systems may be reduced by entanglement and competition between maize and forage legume, damage by insects and foraging by animals (Gbaraneh *et al.* 2004; Ngongoni *et al.* 2007; Armstrong *et al.* 2008). This was the case in this study whereby the maize grain yield was reduced because of the entanglement during the 2004 and 2006 seasons, and livestock grazing during the 2009 season. The complete entanglement of maize plants by lablab and competition for light are associated with planting time of lablab after maize planting (Gbaraneh *et al.* 2004). The yield of maize grain is affected by time of lablab planting with simultaneous or less than two weeks after maize planting reducing grain yield (Gbaraneh *et al.* 2004; Armstrong *et al*. 2008). Simultaneous planting of maize with lablab reduced grain yield by 40 to 63% relative to sole maize crop while higher maize grain yield was obtained when planting of lablab was delayed more than two weeks after planting in Nigeria (Gbaraneh *et al.* 2004). In this study low maize grain yield obtained from the intercrop treatment during the 2004 season was attributed to early planting of lablab which was less than two weeks after maize planting as well as entanglement. The higher ($p=0.007$) maize grain yield (4460 vs. 1490 kg ha^{-1}) from the intercrop treatment obtained in the 2006 season was attributed to both the planting system used, which was tramline, and the three weeks planting interval of lablab after maize planting. Both tramline planting and three weeks after planting resulted in reduced entanglement of maize plants by lablab. Armstrong *et al.* (2008) reported higher fodder yield in late lablab, scarlet and velvet bean planting treatments and in a low maize density treatment which resulted in less competition for light. Poor maize grain yield was also reported by Mpairwe *et al*. (2002) who recorded 20% maize grain yield reduction from the intercrop treatment compared to sole maize. They stated that poor grain yield from the intercrop treatment resulted from complete entanglement of maize plants by lablab and that impeded the physiological development of the maize.

Intercropping lablab with maize resulted in a significant increase in crude protein content of maize leaves. This is an important finding since the leaf component of the maize stover fraction is the plant part that is mostly selected by cattle during grazing (Murphy and Colucci 1999). Intercropping also reduced the fibre content of the maize leaves significantly, an indication that the inclusion of lablab in traditional maize cropping system can improve digestibility and quality of maize leaves. This should result in an increase in the intake of maize stover by livestock.

The higher fibre content of both maize leaves and maize stalks in the maize only treatment compared to the intercropped treatment obtained in this study is an indication that ruminant livestock (cattle) in communal areas graze on low quality fodder during the dry season. High fibre content not only affects the nutritive value of fodder but it also reduces its intake implying that ruminant livestock will consume a lower amount of fodder during the winter season. In communal areas part of the maize stalks remain in the field at the start of the growing season although the cattle have free access to the fields from the end of May to October. This is an indication that maize stalks have lower intake than leaves due to their low digestibility.

Low feed intake may result in poor animal performance in terms of milk production and animal reproductive efficiency. It has been shown that voluntary intake of feed by the animal is the major factor limiting animal performance. It was shown in a trial conducted at Glen that approximately 80% of the difference in quality between roughages could be ascribed to voluntary intake and 20% to digestibility. With very poor quality roughages (such as mature grasses with a high lignin content, and fibrous maize stalks and leaves) cattle cannot ingest enough feed for maintenance requirements (Dugmore 2005). The inclusion of high quality lablab in the diet of dairy cows will therefore enable the farmer to meet the maintenance requirements for his dairy cows.

CHAPTER 7: NITROGEN FIXATION IN INTERCROPPING AND ALLEY CROPPING AGROFORESTRY SYSTEMS

7.1 Introduction

Generally, nitrogen is the most important nutrient that affects growth and yield of cereal crops and pastures. Low and declining soil fertility and inadequate livestock feeds are the major constraints limiting dairy productivity in smallholder farming systems (Nyambati *et al.* 2011). Alexander (1991) reported that the soil nutrient that the plants require in greatest quantity is nitrogen. However, in southern Africa most soils are severely deficient in nitrogen (Ikerra *et al.* 1999) and N deficiency is a major cause of declining soil fertility and poor quality forage (Nnadi and Haque 1986) and is a major constraint to food production in the tropics Nyambati *et al.* 2009). Despite nitrogen deficiency of soils, there is limited use of nitrogen fertilizers by small holder farmers to increase crop production. This may be attributed to inorganic fertilizers being unaffordable for most small holder farmers (Ikerra *et al.* 1999; Ramos *et al.* 2001). Nitrogen is the most expensive nutrient to manufacture since it is tied to escalating energy costs (Nnadi and Haque 1986).

In order to maintain soil fertility under present agricultural production systems, the soil nitrogen content will need to be increased and this may involve modification of the cropping system so that it still satisfies the economic need of the farmer while at the same time improving the nutrient status of the soil (Nnadi and Haque 1986). Soil fertility may be improved by introduction of forage legumes as an intercrop in the cropping system (Tothill 1986, Kang 1997, Masutha *et al.* 1997, Hauggaard-Nielsen *et al.* 2009).

The fixation of atmospheric nitrogen by legumes contributes to the nitrogen economy of the pasture, including the increase in the nitrogen content of the associated grass species (Thomas and Sumberg 1995, Dahlin and Stenberg 2010). The results of the study on the contribution of biological nitrogen fixation and residual benefit to subsequent crop suggested that total below-ground nitrogen could constitute as much as 39 to 49% of the total nitrogen accumulated by the legume crops (Ramos *et al.* 2001). A study on nitrogen fixation and its transfer from *Leucaena* to grass showed that nitrogen accumulation of grass growing along with *Leucaena leucocephala* was enhanced compared with monoculture plants (Rao and Giller 1993). In other studies conducted in Denmark, United Kingdom, France, Germany and Italy it was revealed that pea-barley intercrops had higher accumulation of soil nitrogen than sole crops (Hauggaard-Nielsen *et al.* 2009). Forage legume (faba bean) may contribute to soil mineral nitrogen through rhizodeposits, N mineralized from above-ground organic residues and the nodulated roots following crop harvest (Jensen *et al* 2010). A study conducted in Nigeria on the direct and residual contributions of nitrogen fixation by legumes to the yield and nitrogen uptake of maize revealed that direct transfer of nitrogen from the nodulating soybean, lablab, green gram and black gram to the intercropped maize was 24.9-28.1, 23.8-29.2, 19.7-22.1 and 18.4-18.6 kg N ha^{-1} respectively. The transfer of residual N from these legumes to the succeeding maize crop was 18.4-20.0,19.5-29.9,12.0-13.7 and 9.3-10.3 kg N ha^{-1} respectively (Pal and Shehu 2001).

Nitrogen in the soil may be in the form of organic N, inorganic N which is ammonium (NH_4^+N) and nitrate (NO_3^-N). Organic N mineralizes to ammonium (NH_4^+N) which is rapidly nitrified into (NO_3^-N) and as a result, NO_3^- accumulates in the soil (George *et al.* 1992) and this N transformation may explain the reasons for lower NH_4^+N in the soil than NO_3^-N under some alley cropping systems of legume tree and pasture/ crops.

The study was conducted to evaluate the contribution of intercropping (maize-lablab) and alley cropping agroforestry (pasture-leguminous trees) systems on the accumulation of inorganic nitrogen in the soil. The main objective of the study was: to conduct an on-farm trial to assess the effect of intercropping maize with lablab and alley cropping pasture with tree legume on inorganic nitrogen accumulation in the soil and soil fertility improvement.

It was hypothesized that alley cropping pasture (Cocksfoot and Tall fescue) with tree legume (*L. leucocephala* and *A. karroo*) (silvopastoral agroforestry) and intercropping maize with lablab would increase inorganic soil nitrogen.

7.2 Materials and methods

The field experiments on soil nitrogen accumulation were conducted in the maize-lablab trial at the homestead and in the main silvopastoral trial.

7.2.1 Preparation of the Resin Bags

Resin bags were constructed with nylon knee-high stockings (not dyed). The toe and elastic cuff of the stockings were cut and one end was tied off, placed in a beaker and then filled with 10.0 g anion exchange resins (Cl-form) [Dowex 1X8-50] and 10.0 g cation exchange resin beads (H+ form) [Dowex HCR–W2]. The stocking was twisted in order for the resins to be fairly tight. This was then folded onto itself and its end was tied off.

The resin bags were charged with H^+ by soaking them in 0.6 N HCl (59.51 ml of concentrated HCl diluted with deionized water to a final volume of 1 ℓ) for 30 minutes and then rinsed three times with deionized water. Each resin bag was tied to a stick using monofilament fishing line. The resin bags were placed in plastic bags for protection during transportation before incubating them in the field.

7.2.2 Incubation procedure

The bags were incubated by burying them to a10 cm depth in the soil for a 3 months and 6 months period in the maize-lablab trial and silvopastoral trial respectively.

The resin bags were incubated at 0.5 m, 1.0 m and 1.5 m alley positions away from the tree in alley plots. Three resin bags were incubated in each sole pasture plot in the silvopastoral trial. The marking flags were placed next to each incubated resin bag to aid relocation and easy identification of the bags.

Similarly three resin bags were incubated in each plot in the maize-lablab trial. The marking flags were also placed next to the incubated resin bags for identification purposes.

7.2.3 Resin Bag Extraction

The resin bags were removed from the maize/lablab trial in June 2006 and placed in individual bags and stored in a refrigerator before extraction. The adhered soil and roots from the outside bag were gently removed, rinsed with de-ionized water to remove excess soil in the bag. The bags with holes were wrapped in an additional layer of nylon to prevent loss of beads.

The resin bags were extracted with 100 ml 2N KCl on a standard shaker for 2 hours. The bags were extracted in 250 ml bottles. The extracts were then filtered into medium volumetric flasks. These were then put in 100 ml beakers.

The *0,1M* NH_4Cl standard solution was prepared and this solution was serially diluted to the following:
1×10^{-2} *M*
1×10^{-3} *M*
1×10^{-4} *M*
1×10^{-5} *M*
The above standard was used as measures against the quantities of inorganic nitrogen in the samples.

The samples were diluted using sodium hydroxide (NaOH) solution and analyzed using an Ion Electrode instrument.

7.2.4 Soil sampling

Soil samples were collected with an auger in the silvopastoral trial. Composite soil samples were taken in the experimental trial at a depth of 15 cm in May 2009 before harvesting of trees and pasture grasses. Soil sampling was conducted at the 0.5 m, 1.0 m and 1.5 m alley positions from the tree. The soil samples were thoroughly mixed, air-dried and sent to Cedara Agricultural Development Institute laboratory for soil nitrogen analysis. The soil samples were analyzed for ammonium nitrogen (NH_4^+N) and nitrate nitrogen (NO_3^-N) nutrients. Soil samples were taken because some resin bags were accidentally damaged in the silvopastoral trial.

7.2.5 Statistical analysis

The total inorganic nitrogen, ammonium nitrogen and nitrate nitrogen for both sole crop and intercrop were statistically analysed using the Statistical Procedures for Social Science (SPSS). The means were compared using one way analysis of variance (ANOVA). The inorganic nitrogen means of the silvopastoral trial were separated using a post hoc LSD ANOVA. The factors sole cropping and intercropping treatments were combined into one factor. The fixed effects model was used to detect the difference between the yield from intercropping and sole cropping treatments. Levene's test was used to test homogeneity of variance and the means were considered significantly different at $p<0.05$.

7.3 Results

7.3.1 Total inorganic nitrogen

The total soil inorganic nitrogen was significantly ($p<0.000$) influenced by the cropping system. Alley cropping consistently accumulated high amounts of inorganic nitrogen. Both *L. leucocephala*/cocksfoot and *A. karroo*/cocksfoot alley cropping treatments accumulated the highest ($p<0.000$ and $p<0.001$) soil nitrogen (181.45 and 166.63 ppm) respectively compared to sole cropping treatments (77.69 ppm). Similar trends were observed in the *L. leucocephala*/Tall fescue and *A. karroo*/Tall fescue alley cropping treatments where significant ($p<0.003$ and $p<0.007$) accumulation of soil mineral nitrogen of 153.54 and 145.78 ppm were recorded respectively compared to sole cropping of Tall fescue (77.56 ppm) (Table. 7.1).

Sole cropping treatments of *L. leucocephala* and *A. karroo* resulted in significantly low soil mineral nitrogen compared to alley cropping treatments. Total soil nitrogen was significantly ($p<0.001$) low in sole *L. leucocephala* compared to *L. leucocephala*/cocksfoot and *L. leucocephala*/Tall fescue ($p<0.003$) alley cropping treatments. Similarly, total soil nitrogen was significantly lower in sole treatments of *A. karroo* compared to *A. karroo*/cocksfoot ($p<0.001$) and A. karroo/Tall fescue ($p<0.012$) treatments (Table 7.1). However, the differences in soil inorganic N between sole forage legume (tree only treatment) and sole pasture grass treatments were non-significant (Table 7.1).

Table 7.1 Total inorganic nitrogen in alley cropping and sole cropping treatments

Soil inorganic nitrogen (ppm)			
Parameter	**Sole treatment**	**Alley treatment**	**P-value**
Cf vs. Ak + Cf	$77.69^{b}\pm4.47$	$166.63^{a}\pm15.66$	0.001
Cf vs. Ll + Cf	$77.69^{b}\pm4.47$	$181.45^{b}\pm23.58$	0.000
Tf vs. Ak + Tf	$77.56^{b}\pm6.46$	$145.78^{a}\pm10.45$	0.007
Tf vs. Ll + Tf	$77.59^{b}\pm6.46$	$153.54^{a}\pm16.21$	0.003
Ak vs. Ak + Cf	$89.68^{b}\pm12.79$	$166.63^{a}\pm15.66$	0.001
Ak vs. Ak + Tf	$89.68^{b}\pm12.79$	$145.78^{a}\pm10.45$	0.012
Ll vs. Ll + Cf	$87.46^{b}\pm18.40$	$181.45^{b}\pm23.58$	0.000
Ll vs. Ll + Tf	$87.46^{b}\pm18.40$	$153.54^{a}\pm16.21$	0.003
Cf vs. Ak	$77.69^{b}\pm4.47$	$89.68^{b}\pm12.79$	0.623
Cf vs. Ll	$77.69^{b}\pm4.47$	$87.46^{b}\pm18.40$	0.688
Tf vs. Ak	$77.56^{b}\pm6.46$	$89.68^{b}\pm12.79$	0.619
Tf vs. Ll	$77.56^{b}\pm6.46$	$87.46^{b}\pm18.40$	0.684

Means in the row followed by different superscripts are significantly different ($p<0.05$); se=Standard Error of the Mean

7.3.2 Ammonium (NH_4^+N and Nitrates (NO_3^-N) concentration

The ammonium and nitrates concentrations in the soil were significantly ($p<0.000$) different across treatments and the values are shown in Table 7.2. The nitrate nitrogen (NO_3^-N) concentrations were significantly ($p<0.001$) higher than the corresponding ammonium nitrogen (NH_4^+N) concentration irrespective of cropping treatments. Both ammonium and nitrate values increased under alley cropping treatments compared to sole cropping treatments (Table 7.2).

The nitrate nitrogen values in the tree legume/grass mixture ranged from 129.19 ppm to 158.55 ppm. In contrast, nitrate nitrogen values ranged from 67.46 to 71.28 ppm and 79.90 to 81.41 ppm in sole grass treatments and in sole tree legume treatments respectively. Similar trends were observed in ammonium nitrogen values where 12.05 to 22.90 ppm was recorded in the tree legume/grass mixture compared to a range of 7.70 to 10.09 ppm recorded in the corresponding sole pasture treatments. Ammonium values ranging from 7.56 to 8.27 ppm were recorded in the two sole leguminous tree treatments (Table 7.2).

Table 7.2 Ammonium (NH_4^+N) and Nitrate (NO_3^-N) concentrations

Ammonium (NH_4^+N) and Nitrate (NO_3 N) concentrations (ppm)			
Parameter	NH_4^+N Means ±se	NO_3^-N Means ±se	P-value
Ak + Cf	$12.05^{c}\pm3.04$	$154.58^{b}\pm16.05$	0.00
Cf	$7.70^{c}\pm0.72$	$71.28^{b}\pm4.20$	0.001
Ll + Cf	$22.90^{c}\pm9.15$	$158.55^{b}\pm15.36$	0.000
Ak + Tf	$16.59^{c}\pm5.92$	$129.19^{b}\pm7.81$	0.000
Tf	10.09 ± 0.80	$67.46^{b}\pm6.27$	0.001
Ll + Tf	$12.10^{c}\pm2.64$	$141.43^{b}\pm14.17$	0.000
Ak	$8.27^{c}\pm1.36$	$81.41^{b}\pm12.85$	0.000
Ll	$7.56^{c}\pm1.03$	$79.90^{b}\pm17.60$	0.000

Means in the row followed by different superscripts are significantly different ($p<0.05$); se=Standard Error of the Mean

7.3.3 Alley position effect on total inorganic nitrogen

The concentration of inorganic nitrogen at different alley positions (0.5, 1.0 m and 1.5 m) was not significantly different in all tree legume/pasture mixture and sole tree legume treatments (Table 7.3). The ammonium nitrogen (NH_4^+N) and nitrate nitrogen (NO_3^-N) increased with increasing distance relative to the tree base, but the observed increase was not statistically significant ($p>0.391$).

Table 7.3 Inorganic nitrogen concentrations at different alley position

Soil inorganic nitrogen (ppm)		
Alley position (m)	NH_4^+N Means ±se	NO_3^-N Means ±se
0.5	$10.38^{b}\pm1.68$	$111.31^{b}\pm11.36$
1.0	$12.63^{b}\pm2.79$	$126.01^{b}\pm10.98$
1.5	$16.73^{b}\pm5.04$	$135.21^{b}\pm14.34$
P-value	0.429	0.391

Means in the column followed by different superscripts are significantly different ($p<0.05$); se=Standard Error of the Mean

A similar increase in total inorganic nitrogen content was observed in both sole tree treatments and in tree/grass mixture treatments. The concentration of nitrogen in the sole tree legume treatment was 82.96, 88.36, 94.39 ppm at 0.5 m, 1.0 m and 1.5 m alley positions relative to the tree base. In the tree legume/grass mixtures the nitrogen values were 121.69, 138.64 and 151.93 ppm at 0.5 m, 1.0 m, 1.5 m alley positions respectively. The observed increase in nitrogen values was also not statistically significant for both sole tree legume treatments ($p=0.921$) and tree legume/grass mixture treatments ($p=0.325$) (Table 7.4).

Table 7.4 Total inorganic nitrogen concentrations at different alley positions

Alley position (m)	Soil inorganic nitrogen (ppm) Sole tree treatment Means ±se	Tree/grass mixture Means ±se
0.5	82.96^{b}±21.42	121.69^{b}±11.56
1.0	88.36^{b}±16.58	138.64^{b}±11.96
1.5	94.39^{b}±21.43	151.93^{b}±17.96
P-value	0.921	0.325

Means in the column followed by different superscripts are significantly different (p<0.05); se=Standard Error of the Mean

7.3.4 The effect of intercropping on total inorganic nitrogen in the soil

The total inorganic nitrogen concentration differed significantly between the sole maize only treatment and maize-lablab intercrop. The maize-lablab intercrop had significantly (p=0.013) higher soil nitrogen concentrations (1.84 mgℓ$^{-1}$) than maize only treatment (1.17 mgℓ$^{-1}$). There was also a strong (r=0.398) correlation between cropping system and nitrogen concentration in the soil (Table 7.5).

Table 7.5 Total inorganic nitrogen concentration in intercropping (lablab) and monoculture treatments

	Nitrogen (mgℓ$^{-1}$) Maize only treatment Means ±se	Maize + Lablab treatment Means ±se	P-value
Inorganic N (mgℓ)	1.17^{b}±0.08	1.84^{a}±0.23	0.013
Pearson Correlation	0.398*		0.013

Means in the row followed by different superscripts are significantly different (p<0.05); se=Standard Error of the Mean
**Correlation is significant at the 0.05 level*

7.4 Discussion

The highest concentration of inorganic nitrogen observed in the tree legume/pasture treatments compared to sole pasture or sole tree treatments demonstrated the importance of alley cropping pasture grasses with leguminous fodder trees for improving the soil nitrogen fertility status. The tree legume/pasture treatments had the greatest (p=<0.001) total inorganic nitrogen, with nitrogen values ranging from 145.78 ppm to 181.45 ppm compared to sole treatments (77.56 to 89.68 ppm). Similar results were obtained by Ikkera *et al.* (1999) who reported high accumulation of total inorganic nitrogen in *Gliricidia*/maize (133 kg N ha^{-1}) compared to sole maize treatments (26 kg N ha^{-1}). High concentrations of total inorganic nitrogen obtained in alley cropping treatments may be attributed to the stimulation of legumes to symbiotically fix more nitrogen when grown in mixtures as compared to pure stands. There is also an increase in the nitrogen transfer of symbiotically fixed nitrogen from the legumes to the grasses (Nyfeler *et al.* 2011).

The concentration of nitrate nitrogen (NO_3^-N) was higher (67.46 to 158.55 ppm) across the treatments than the corresponding ammonium nitrogen (NH_4^+N) concentration (7.56 to 22.90 ppm). The accumulation of soil nitrogen was significantly (p=<0.001) high for nitrate and non-significant for ammonium (p=0.243). The alley cropping treatments had the greatest concentration of nitrate nitrogen (129.19 to 158.55 ppm). In contrast, Ikerra *et al.* (1999) reported a significant (p<0.001) accumulation of ammonium and non-significant accumulation of nitrate nitrogen during the dry season in a study conducted in Malawi on soil nitrogen dynamics in *Gliricidia*-maize intercrops. He attributed the ammonium accumulation to ammonification as this process is not limited by soil water deficit and the less accumulation of nitrate was related to a lack of nitrification as this process is more sensitive to water deficit. The significant ($p<0.001$) high concentration of nitrate nitrogen (NO_3^-N) observed in the study may be attributed to improved soil moisture status due to irrigation. Improving soil moisture status stimulates mineralization in the form of nitrification in which ammonium is oxidized to nitrate (Alexander 1991). Much of the ammonium nitrogen NH_4^+N might have been converted to NO_3^-N by nitrifying bacteria in a process called nitrification (Tisdale *et al.* 1993). The observed low ammonium concentration is in agreement with the findings of Bahmani *et al.* (2009) who reported low concentrations of ammonium (NH_4^+N) from the surface to 120 cm depth during a study conducted in Khuzestan, in Iran. They attributed the low concentration of ammonium to nitrification process and conversion of ammonium to nitrate in the upper soil layers.

The trend of low accumulation of inorganic N at 0.5 m alley position to trees in both tree/pasture mixtures and sole tree stand may be attributed to competitive demand for nitrogen between microorganisms and the tree legume for assimilation and protein manufacturing respectively. The low N accumulation may be attributed to very limited tree legume leaf fall as the leaves were all removed during harvesting while only the twigs were left and available for decomposition. Twigs are known to contain high amounts of lignin compared with leaves. This might have induced immobilization of nitrogen. Dahlin and Stenberg (2010) found high N where leaf litter fall was allowed and mulch was left on the soil surface compared to where leaf litter fall was prevented due to shoot harvesting.

There was low accumulation of inorganic nitrogen under sole tree legume compared with mixtures. The findings of the study are in agreement with those of Hauggaard-Nielsen *et al.* (2009) who reported a higher concentration of nitrogen when forage pea legume was intercropped with barley than when grown as a sole crop.

Intercropping increased the concentration of soil inorganic nitrogen. This higher inorganic nitrogen (1.84 $mg\ell^{-1}$) in the intercrop treatment indicates the positive effect of lablab on soil nitrogen fertility improvement.

7.5 Conclusion

The trial showed that the lablab forage legume improved nitrogen content in the soil as indicated by a significant ($p=0.013$) accumulation of inorganic nitrogen in the intercrop plots (1.84 $mg\ell^{-1}$) compared with the maize only treatment plots (1.17 $mg\ell^{-1}$). This demonstrated the positive benefits of using lablab in improving the fertility status of the soil and increasing the yield of the maize crop (Chapter 6).

Silvopastoral agroforestry resulted in a significant accumulation of total inorganic nitrogen in the soil, indicating that the alley cropping improved soil nitrogen nutrient status. There was also a strong correlation between the alley cropping system and nitrogen concentration. Nitrate nitrogen accumulation was higher than the corresponding ammonium nitrogen indicating that the nitrification process was superior to ammonification during the study. Intercropping (maize-lablab) and silvopastoral agroforestry

(*L. leucocephala* and *A. karroo*-Cocksfoot/Tall fescue pastures) are relevant cropping strategies to use in order to improve nitrogen soil fertility status in small holder farming systems.

CHAPTER 8: WATER USE OF SELECTED AGROFORESTRY SPECIES

8.1 Introduction

Mr Mbhele's farm (the site for this study) is situated in the foothills of the Drakensberg mountains, the main catchment area for KwaZulu-Natal. Rainfall declines sharply from over 1200 mm on the main escarpment to < 800 mm annum^{-1} towards Winterton and Bergville. This creates a relative shortage of water in the study area, especially during the dry winter season (April to October). An understanding of the water use of agroforestry species is, therefore, important in recommending sustainable agroforestry systems in this region.

This study has demonstrated that growing trees in combination with pastures can enhance the productivity of small holder farms in rural farming systems (Chapter 3). This is generally accepted to be through niche differentiation, since tree roots can exploit water and nutrients below the relatively shallow roots of pastures and crops. The leguminous trees in this study were shown to also increase productivity through soil nitrogen fixation and the provision of fodder. While the benefits of the intensive use of fodder trees to supplement forage production have been well documented (Jabbar, Reynolds, Larbi & Smith 1997), there has been little research on agroforestry systems in the temperate summer rainfall region of South Africa. This was ascribed to the paucity of trees in this landscape, lack of farmer knowledge on the potential of agroforestry species, poor soils and the harsh climate (Everson *et al* 2009). In addition there have been no measurements of the water-use of the fodder trees in silvopastoral systems in South Africa.

This agroforestry research project was concerned with the value of trees as a means of providing increased fodder in small-scale dairy systems. In a broader context, the project needed to provide a future basis for predicting the hydrological impacts of trees in the landscape, including windbreaks, trees used in alley-cropping, trees in silvopastoral systems and individual or scattered trees in farming systems. In addition the water-use of trees used in rehabilitating degraded areas is becoming increasingly important. Trees scattered across the landscape, in whatever arrangements, will have significant effects on the flow of water over and through the soil.

It is important to provide as much information as possible about the prevailing weather and soil water conditions when tree water-use measurements are made. To this end an automatic weather station recording hourly temperature, relative humidity, solar radiation and wind speed was installed at the trial site to provide detailed climatic information. Soil moisture measurements were obtained to provide additional water balance information. As the trial was situated on a cold south facing slope and frosts were frequent, micro-climate measurements of the spatial and temporal distribution of temperature across the trial were made in 2005 and 2006.

An important objective of this study was to estimate the water use of the various trees species in the trial. In this study the term "water use" applies to transpirational or green water use. In the Zwelisha trial only the *Acacia* trees were large enough for sap flow measurements using the Heat Pulse Velocity technique. However, large trees of *Morus alba, Gleditsia triacanthos* and *Acacia karroo* were available at the initial agroforestry trial situated on Mr Mahlobo's farm and were therefore included in the measurements of water use.

8.2 Methods

8.2.1 Climate

8.2.1.1 Automatic weather station measurements

Measurements of wind speed, wind direction, precipitation, air temperature, relative humidity and incoming solar radiation were recorded at a height of 2 m above the ground surface.

The weather station instruments, linked to the CR1000 data logger, recorded the following measurements:

1. Rain using a Rimco tipping bucket rain gauge (0.2 mm tip).
2. Solar radiation measured with a Kipp solarimeter.
3. Wind speed measured at a height of 2.0 m above the canopy with a Met-One cup anemometer.
4. Wind direction using a Met-One wind direction sensor.
5. Temperature and relative humidity were measured with a CS500 probe.

All sensors were averaged or totalled at 60-minute intervals.

8.2.1.2 Microclimate measurements across the trial

Four Hobo loggers, measuring ambient temperature and relative humidity were installed at the trial to determine the temperature gradient from the bottom of the trial (near the stream) to the top of the slope. This experiment was started in 2005 and repeated in 2006 because of the frost damage to the *Acacia karroo* trees at the bottom of the trial.

8.2.2 Soil Water

Seventeen access tubes for the measurement of soil water content, using the Diviner 2000 system of measurement (Plate 8.1) were installed in each of the treatments (Figure 8.1 and Table 8.1). In some plots five or three access tubes were installed to measure the tree effect, while in the grass only plots only one tube was deemed necessary. Volumetric water content was measured at approximately monthly intervals during the 2007-2009 seasons. The Diviner 2000 probe (Plate 8.1), which uses the dielectric properties of the soil (dependent upon water content) is lowered into the access tube and measurements are taken at 10 cm depth intervals by simply swiping the sensor in and out of the access tube.

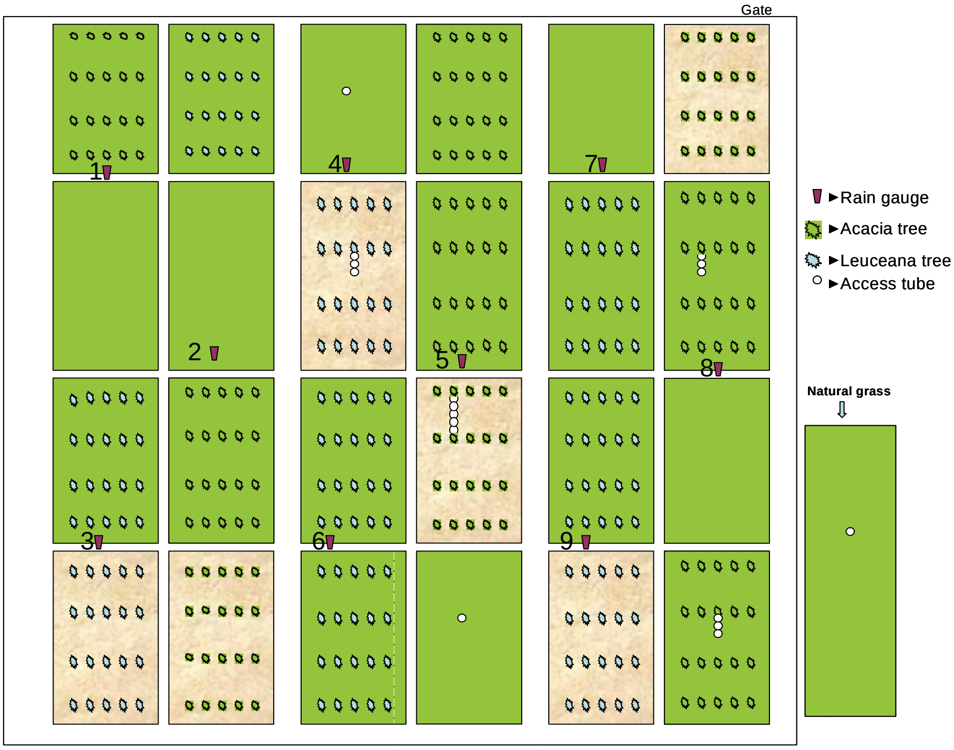


Figure 8.1 The position of the treatment plots in relation to the Diviner access tubes

Table 8.1 Details of the Diviner access tubes at the Zwelisha agroforestry site

Access tube Number	Diviner Probe Number	Plot number
1	Probe 31	9
2	Probe 32	10
3	Probe 33	10
4	Probe 34	10
5	Probe 35	16
6	Probe 36	22
7	Probe 37	22
8	Probe 38	22
9	Probe 39	24
10	Probe 40	24
11	Probe 41	24
12	Probe 42	Natural veld
13	Probe 81	15
14	Probe 82	15
15	Probe 83	15
16	Probe 84	15
17	Probe 85	15

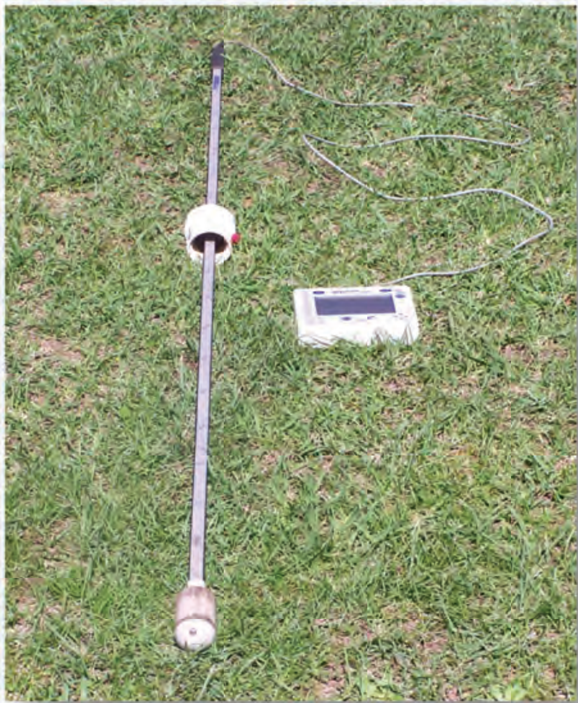


Plate 8.1 The Diviner 20000 soil moisture meter

8.2.3 Heat Pulse Velocity Technique

The heat pulse velocity (HPV) technique is an appropriate technique for the measurement of sap flow / transpiration rates in trees, and consequently facilitates the quantification of water use in species to which it is applied. The heat ratio method (HRM) of operation applied in the HPV technique allows the measurement of very slow sap flow rates, which is beneficial in drier environments such as those generally experienced in South Africa. The Heat Ratio Method is fully described in Burgess *et al.*, 2001, and the description below is largely drawn from that reference.

The Heat Ratio Method measures the ratio of the increase in temperature, following the release of a pulse of heat, at points equidistant below and above a heater probe. In order to achieve this, three parallel holes are accurately drilled (with the help of a drill guide strapped to the tree) into the sapwood (xylem) portion of tree trunks. The upper and lower holes are both situated 5 mm from the central hole (above and below, respectively). Copper-constantan thermocouples, wired to a multiplexer or logger, are inserted into the upper and lower holes to a specific depth below the cambium (below-bark insertion depth). A heater probe, wired to a relay control module, is inserted into the central hole. The sap flux sensors are locally constructed from Type T Copper-Constantine thermocouples embedded in 2 mm outside-diameter PTFE tubing, while the 60 mm long line-heaters are made from 1.8 mm outside-diameter stainless steel tubing, with a constantan filament.

At a pre-determined time interval (usually hourly), the temperatures in the upper and lower thermocouples are measured and the ratio (upper over lower) is logged. Directly thereafter, the central (heater) probe releases a short (0.5 second) pulse of heat, which diffuses through the adjacent wood and is taken up by the sap moving upwards through the xylem of the tree. As the heat pulse is carried up the tree by the sap, the upper thermocouple begins to warm. Logging of the changing heat ratio commences 60 seconds after the initiation of the heat pulse and is measured continuously (approximately every second, depending on the processing speed of the logger) until 100 seconds after the heat pulse. The average of these ratios is calculated and utilised in subsequent formulae to derive the sap velocity. These formulae are described in Burgess *et al.*, 2001. Data loggers are programmed to initiate the heat pulses and record the heat ratio changes in each of the thermocouple pairs. Further measurements of sapwood area, moisture content and density, as well as the width of wounded (non-functional) xylem around the thermocouples, are used to convert sap velocity to a total sap flow rate for the entire sample tree. These measurements are taken at the termination of the experiment due to the destructive sampling required to obtain them and therefore only sap velocity data are presented in this report.

The conversion of sap velocity to sap flow is readily derived as the product of sap velocity and cross-sectional area of conducting sapwood. Gross wood cross-sectional area is calculated from its under-bark radius. Heartwood is discounted by staining the sapwood or by observing the dark colour often associated with heartwood. Where sap velocity is estimated at several radial depths (probe insertion depths), total sapwood area is divided into concentric annuli delimited by midpoints between measurement depths. In this way, point estimates of sap velocity are weighted according to the amount of conducting sapwood in the annulus they sample. The number of probe sets (2 thermocouples and one heater) utilised per tree is determined by the diameter of the tree, and range from 4 to 12. The thermocouples are typically inserted to four different depths, since flow rates differ relative to sapwood depth (Figure 8.2). Sap flow rates are usually fastest in the younger xylem near the cambium and slower in the older, deeper xylem.

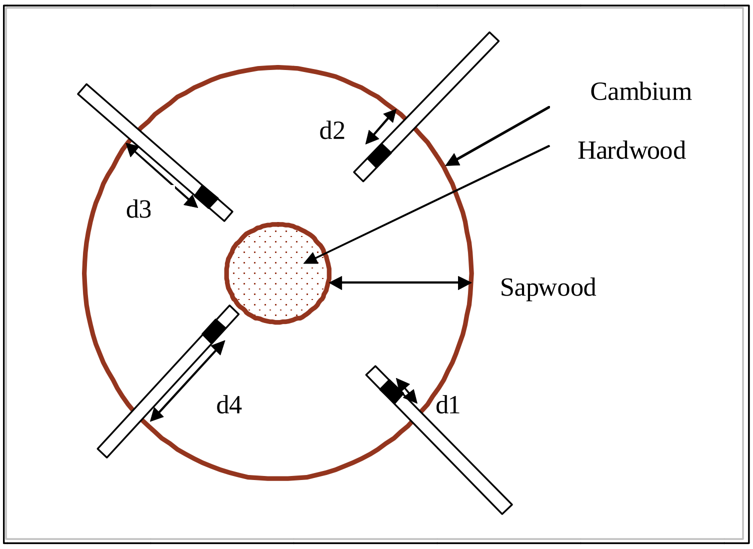


Figure 8.2 Illustration of different probe set insertion depths applied in the Heat Pulse Velocity technique (heat ratio method)

Occasionally it was necessary to reposition sapflow monitoring probes to compensate for increased diameter growth in the trees. This is necessary due to the fact that the final sap flow calculations using this technique are significantly influenced by the insertion depth associated with a particular probe set. These depths are measured extremely accurately at the time of installation; however while the sample tree stem diameter expands with growth the probes tend to remain at their original position (relative to the centre of the stem), so the insertion depths gradually become deeper over time. It was therefore necessary to periodically remove, re-measure and re-insert the probes to the desired depths.

The sites were instrumented in February 2007 and the first data were collected in early February 2007 and the measurements were stopped in June 2009 providing water-use data from the three species from the two sites. A list of the instrumentation used for the purposes of conducting measurements of transpiration (sap-flow) and the climatic variation at the Zwelisha and Mr Mahlobo agroforestry sites are listed in Table 8.2.

Table 8.2 List of instrumentation used for the project

Item	No
Cell-phone modem + Cable + Antenna	2
CR1000 Data Logger	2
Reference Temperature Thermistor	2
CS500 Vaisala Probe (Temp & Humidity)	2
Radiation Shield for CS500	2
Enclosure for Logger / Multiplexer / Modem	2
Multiplexer	2
Rain gauge & Cable	1
Pyranometer & Levelling Base (Solar Rad.)	1
Wind Sentry (speed and direction)	1
Tripod Kit (full) for AWS	1
RR1 Battery	1
RR2 Battery	2
HPV Thermocouples (pairs)	28
HPV Heater Units	9
HPV Relay Module	3
Strongbox (for battery & relay module)	2

The instrumentation was connected to the loggers and multiplexers prior to installation to test that everything was working, and to configure the programs required by the loggers to monitor the sensors and output the data (Plates 8.2-8.5).Specific details of the site installation are presented in Table 8.3.

Table 8.3 Details of the Zwelisha and Mahlobo HPV installation.

Location	Tree / Branch	Diam (mm)	Bark (mm)	Over bark Probe Insertion Depths (# = TC pair number)			
				1	2	3	4
Mahlobo farm (multiplexer 1)	*A. karroo* 1	100	5	10 (#1)	20 (#2)	30 (#3)	40 (#4)
	A. karroo 2	84	5	10 (#5)	20 (#6)	30 (#7)	40 (#8)
Mahlobo farm (multiplexer 2)	*Gleditsia*	68	2	7 (#1)	14 (#2)	21 (#3)	28 (#4)
	Mulberry Branch 1 (tag)	76	2	7 (#5)	14 (#6)	21 (#7)	28 (#8)
	Mulberry Branch 2	72	2	7 (#9)	12 (#10)	17 (#11)	22 (#12)
Mbhele Farm	*A. karroo* 1	90	3	8 (#1)	15 (#2)	23 (#3)	33 (#4)
	A. karroo 2 (main stem)	78	3	10 (#5)	28 (#6)		
	A. karroo 2 (branch 1)	42	3			10 (#7)	
	A. karroo 2 (branch 1)	42	3				10 (#8)

Plate 8.2 The HPV installation in two young *Acacia karroo* trees at Zwelisha. Note the Diviner 2000 access tubes for soil water monitoring in the background

Plate 8.3 Drilling the guide holes for the HPV installation in two mature *Acacia karroo* trees at the Mahlobo agroforestry site.

Plate 8.4 The HPV installation in the mature *Gleditsia* and Mulberry trees at the Mahlobo agroforestry site.

Plate 8.5 Down loading data from the HPV installation at the Mahlobo agroforestry site. The RR1 battery, CR 1000 data logger, Campbell AM 32A multiplexer and HPV relay control module can be seen in the security box.

8.3 Results

8.3.1 Climate during 2004

8.3.1.1 Rainfall

Rainfall for the period July to December 2004 totalled 522 mm (Figure 8.3). Since the average annual rainfall for the site is 700-800 mm, it is clear that the 2004 growing season was characterized by above normal rainfall. The extreme event (100 mm in a single day) on the 14 December is clearly noticeable. This rainfall event resulted in the destruction of the small weir used for irrigating the silvopastoral trial. Good rains were also received in mid to late September (DOY 268-270), while regular rain fell during November and December (DOY 310-366).

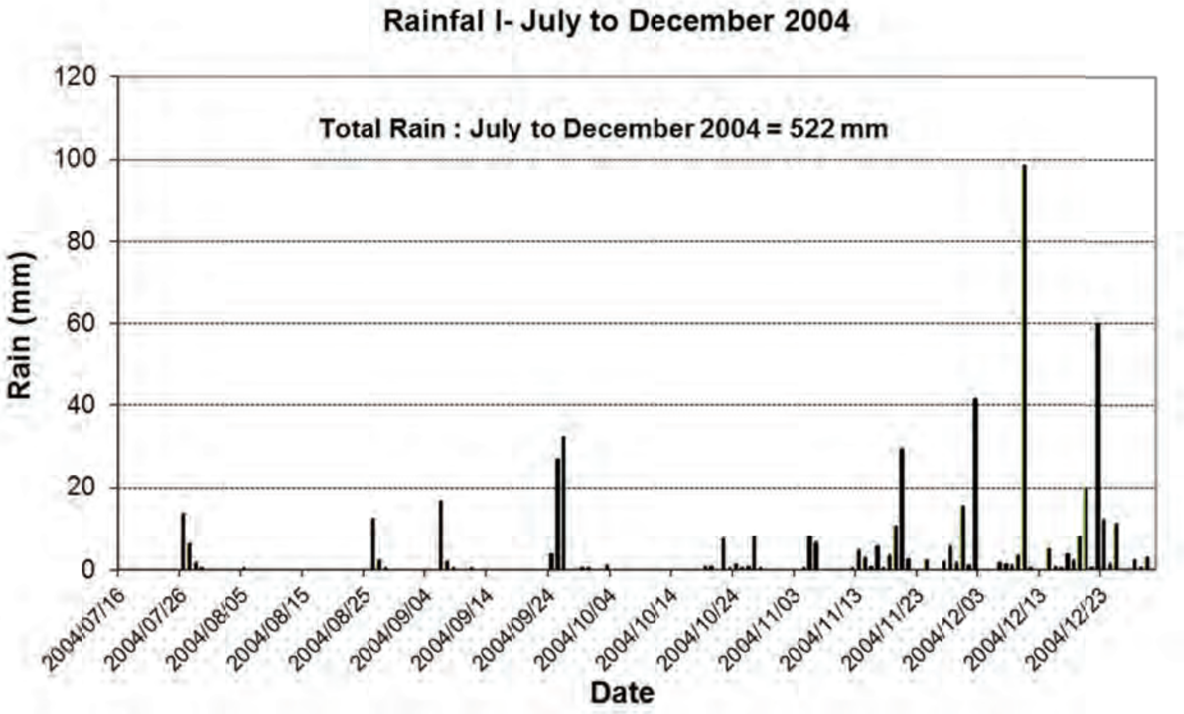


Figure 8.3 Daily rainfall at the Zwelisha study site (July to December 2004).

8.3.1.2 Relative Humidity and Temperature

Temperature and relative humidity data are presented in Figs. 8.4 & 8.5. The July 2004 data illustrate quite clearly the occurrence of regular frosts at the silvopastoral trial from DOY 197-205 (Figure 8.4). During this period the ambient temperature dropped to -4°C. Although this site was chosen for its potentially cold position to favour the temperate grass pastures, it has had the negative effect of limiting the growth of the *A. karroo* trees. Many trees had to be replaced in the various trials following the severe frosts experienced in the winter of 2004. In spite of the cold nights the day time winter temperatures generally exceeded 20°C at midday in winter while summer maxima were generally above 30 °C (Figure 8.5).

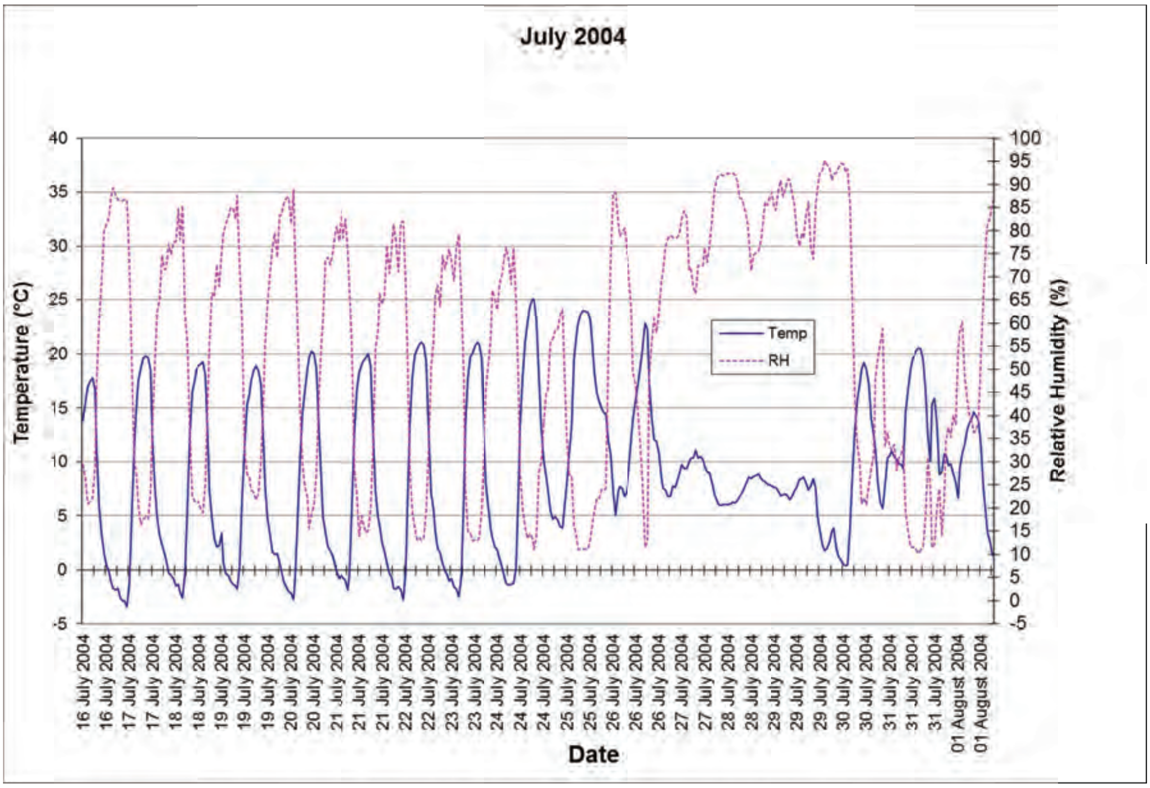


Figure 8.4 Hourly temperatures and relative humidity at the Zwelisha study site (July 2004)

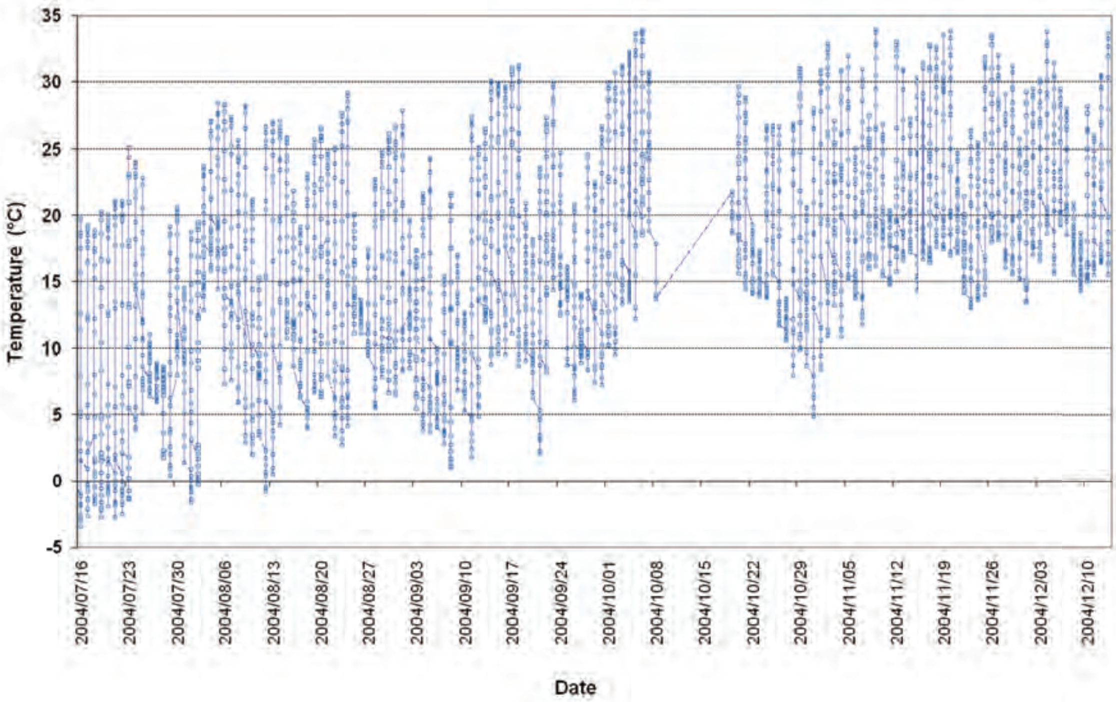


Figure 8.5 Hourly temperatures at the Zwelisha study site (July to December 2004).

8.3.1.3 Solar Radiation

The hourly trends in solar radiation showed that during winter (July and August) the conditions were characterized by clear cloudless skies. Maximum values at midday were only 550 Wm^{-2} day^{-1} (Figure 8.6). The incidence of cloudy days steadily increased as summer approached (midday values below 300 Wm^{-2}). At this time (November to December) maximum values exceed 800 WM^{-2}.

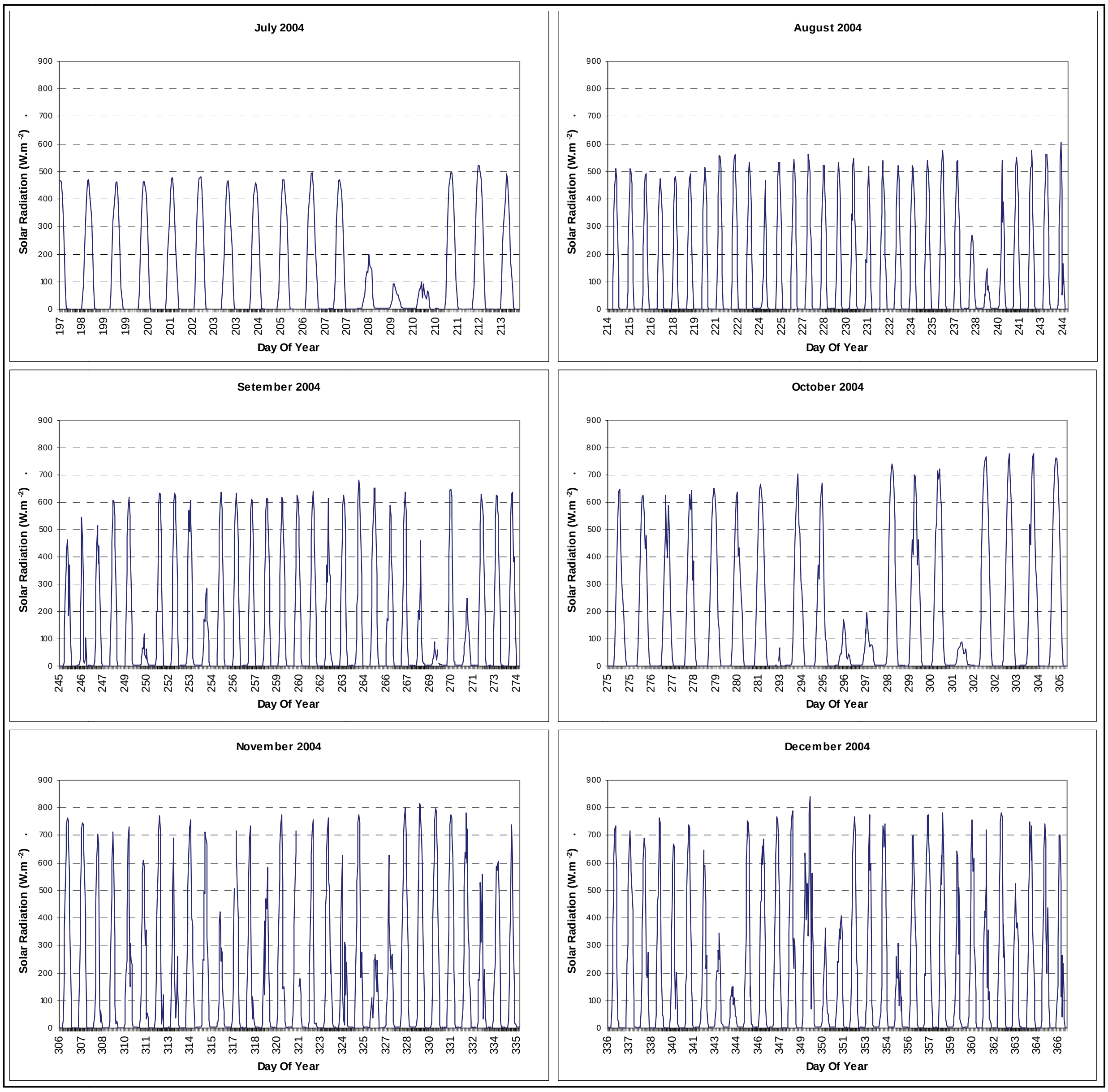


Figure 8.6 The diurnal course of hourly radiation at Zwelisha (July to December 2004). Refer to Appendix 1 for DOY calendar.

8.3.1.4 Vapour Pressure Deficit (VPD)

Vapour pressure deficit (VPD) is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated. VPD functions as a convenient indicator of the evaporation potential or degree of stress experienced, because it quantifies how close the air is to saturation. The size of the VPD gives an indication of the atmospheric evaporative demand (potential water stress).

Daily means of vapour pressure deficit calculated between 06h00 and 18h00 from the hourly temperature and relative humidity data are shown in Figure 8.7. The daily trend shows a steady increase from about 1.5 to 3.50 kPa from winter to early October (DOY 196-275). With the onset of spring and summer the VPD decreases to summer levels which are generally below 2 kPa. Clearly the maximum stress for plants in the study area is early spring when temperatures and radiation levels are rising rapidly, but there is little moisture (low relative humidity and rain) in the atmosphere. October is therefore the period when young establishing plants would experience maximum stress.

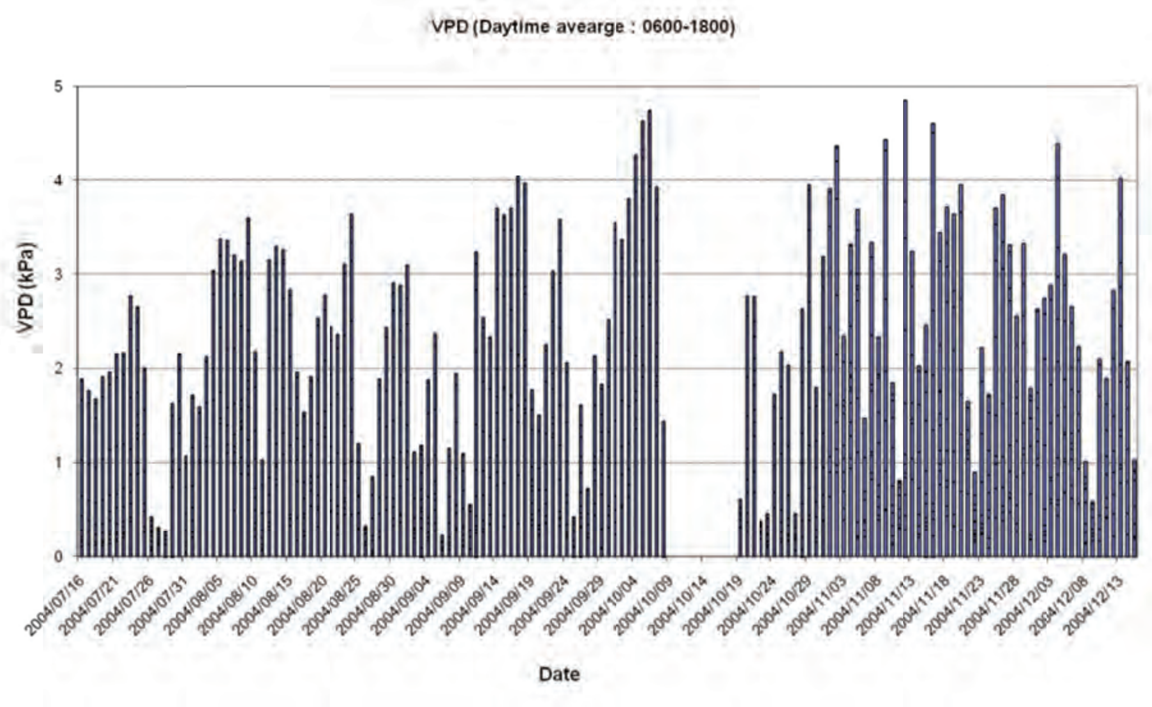


Figure 8.7 Daily trends in VPD at the study site during the 2004 growing season

8.3.2 Climate during 2005

Rainfall for the 2005 year was high with a total annual rainfall of 1194 mm (Figure 8.8). January to March was wet (DOY 1-90), while the winter and early spring (May to September were dry – DOY 121-273). The dry period ended with a major rainfall event on DOY 289 (16th October), when over 100 mm of rainfall was recorded (58.8 mm in a one hour period was recorded on this day). Clearly this was a very high intensity storm. It is these high intensity storms which wreak havoc in the newly planted maize fields in the area. Rainfall for November and December was frequent and good planting conditions were experienced. Solar radiation showed a typical trend of high maximum values in summer (>800 W m-2) decreasing to seasonal lows in July, when maximum daily values of approximately 400 W m-2 were recorded at the agroforestry trial (Figure 8.9).

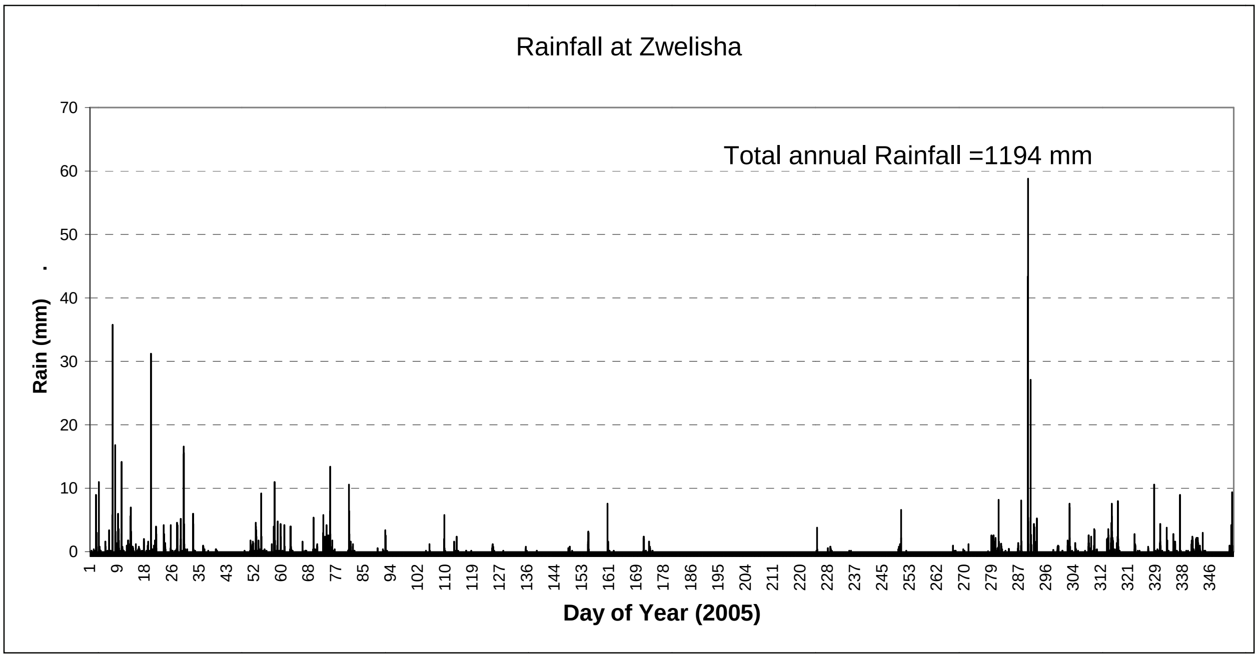


Figure 8.8 **Daily rainfall during the 2005 year at the agroforestry trial at Zwelisha (see appendix 1 for DOY calendar)**

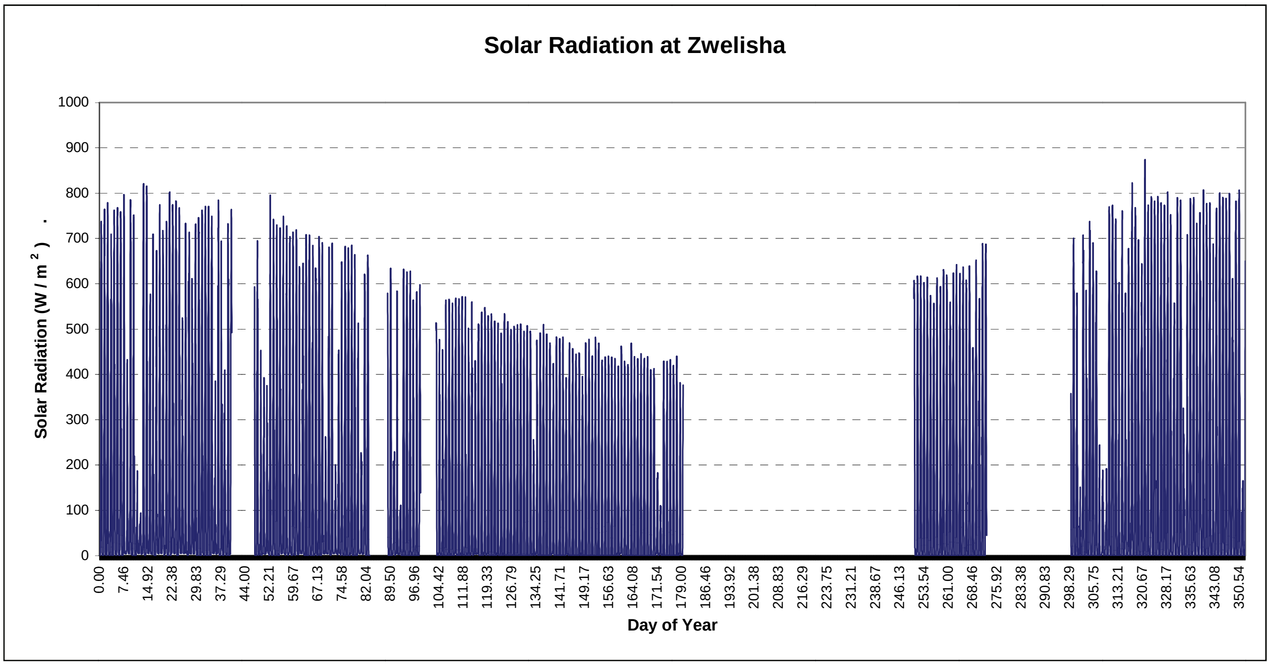


Figure 8.9 **Solar radiation during the 2005 year at the agroforestry trial at Zwelisha**

8.3.3 Climate during 2006

Solar radiation showed typical trends of high maximum values in summer (>20 MJ day^{-1}) decreasing to seasonal lows in July, when maximum daily values of approximately 10 MJ day^{-1} were recorded at the agroforestry trial (Figure 8.10).

Vapour pressure deficit (a showed no clear seasonal trends, with high VPDs of > 3 being regularly recorded throughout the year (Figure 8.11). These data indicate that plants at the Zwelisha site experience high water stress if soil moisture is limiting (as is the case in the dry winter period). This shows the importance of irrigation in limiting plant water stress in the planted pastures and young trees at this site.

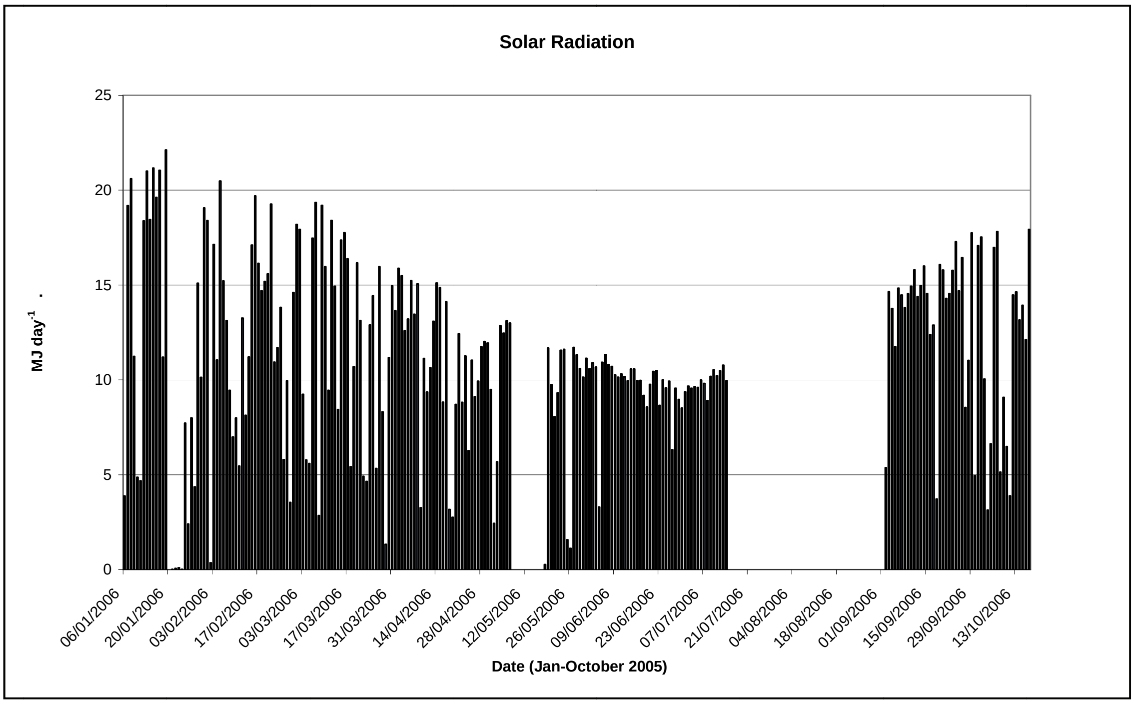


Figure 8.10 Solar radiation (MJ day^{-1}) at Zwelisha from January to October 2006

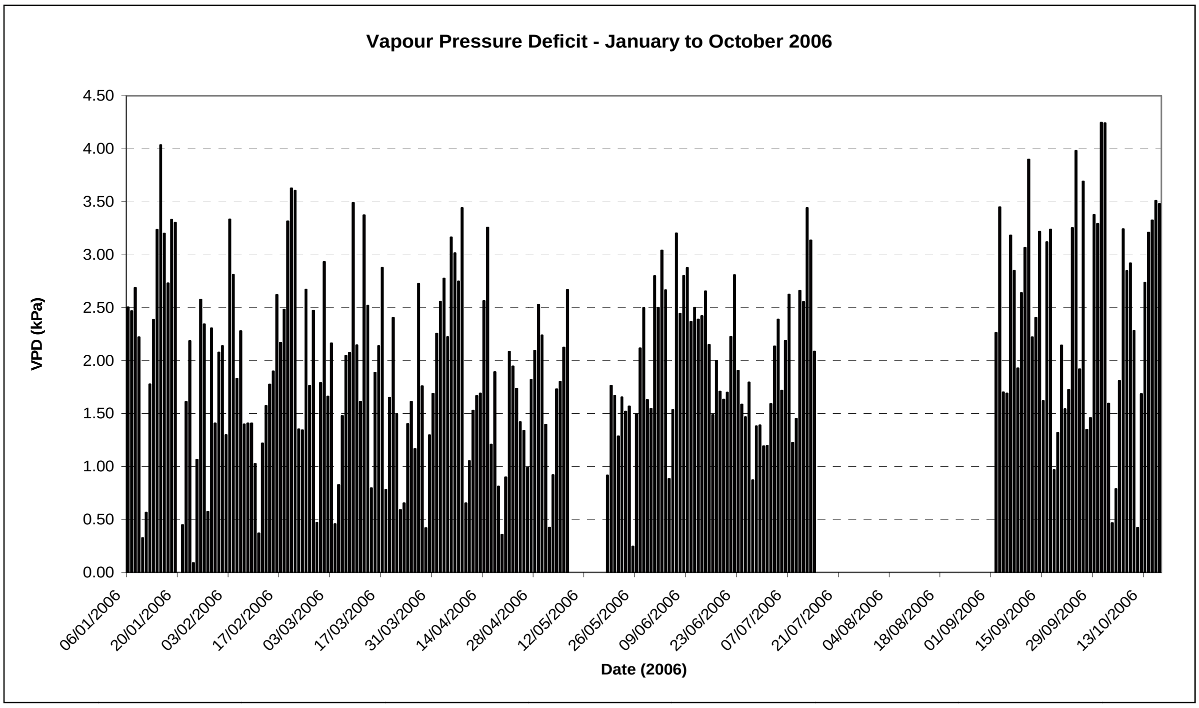


Figure 8.11 Vapour pressure deficit at the Zwelisha study site from January to October 2006

The minimum relative humidity (Figure 8.12) followed a regular (5 day) cyclical trend, dropping below 40% in dry spells to average values greater than 60% in the wet spells. There was a clear seasonal trend in the data with the summer highs (>60) dropping to <10% in June to September. Low milk production also coincides with these very dry conditions.

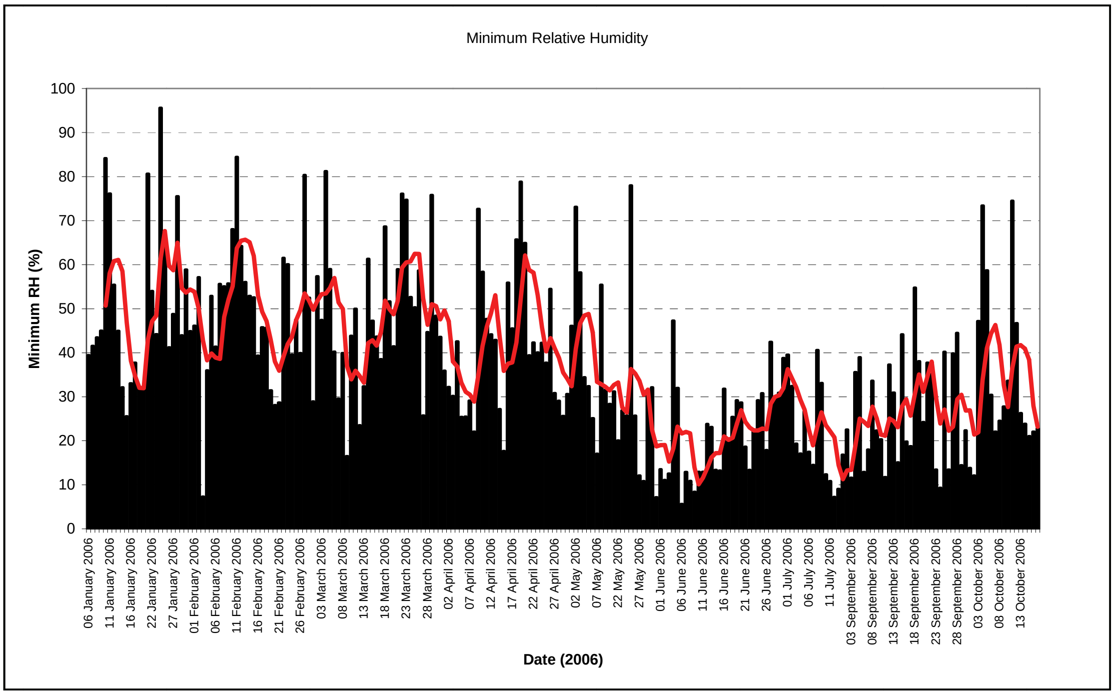


Figure 8.12 Minimum relative humidity (vertical bars) measured at Zwelisha from January to October 2006. The solid line represents a five day moving average

8.3.4 Climate January 2007 to November 2008

Solar radiation showed a typical seasonal trend of high maximum values in the three recorded summer seasons, when values exceeded 20 MJ day^{-1} (Figure 8.13). Winter lows were recorded in July 2007 and 2008, when maximum daily values of approximately 10 MJ day^{-1} were recorded.

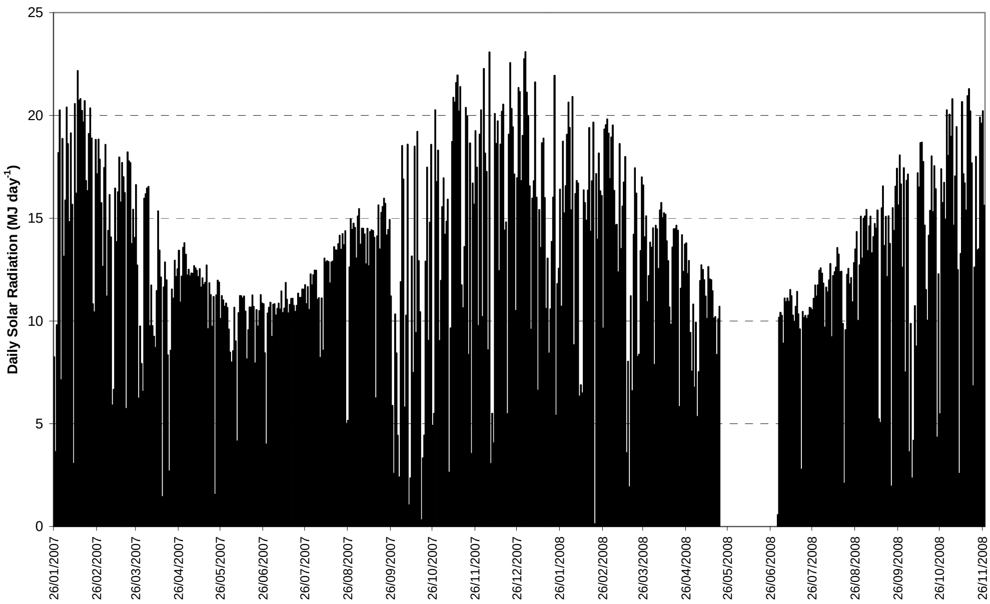


Figure 8.13 Solar radiation from January 2007 to November 2008 at the agroforestry trial at Zwelisha

Rainfall for the period 1 October 2007 to 30 September 2008 (hydrological year) was only 418 mm, clearly showing the dry conditions experienced in the 2007/08 growing season (Figure 8.14).

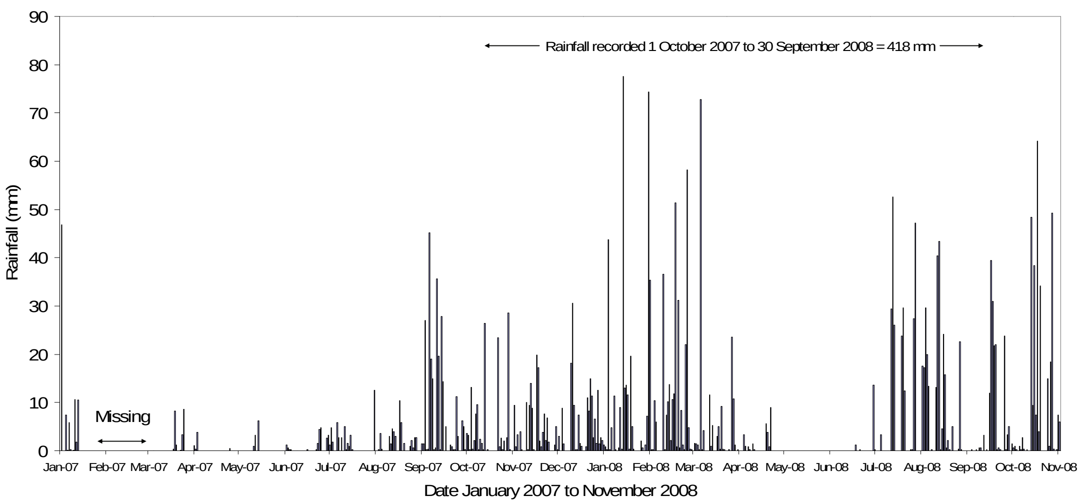


Figure 8.14 Daily rainfall from January 2007 to November 2008 at the study site

Winter and early spring (June to August 2007) were typically dry while the first good rains were only received in February 2008, when 77 and 74 mm of rainfall was recorded on the 8th and 25th of February respectively (Figure 8.14). Rainfall for December was characterised with frequent but small rain events, with a total of 128 mm being recorded.

The trend in the vapour pressure deficit (VPD), which gives a good indication of the atmospheric evaporative demand, showed that the most extreme conditions occurred in August to September at the end of dry winter period in both 2007 and 2008. During these periods VPDs of over 2 kPa were recorded (Figure 8.15). These periods coincided with very low humidity (Figure 8.16), high temperatures (Figure 8.17), and high average and maximum wind speeds measured at the site during the late winter (Figs. 8.18 & 8.19). The seasonal trend in the hourly temperatures also revealed the cold nature of the winter nights with values consistently below zero from May to July in both 2007 and 2008 (Figure 8.17), while the spring and summer maxima regularly approached 35°C. These data clearly illustrate the harsh climatic conditions of the study site.

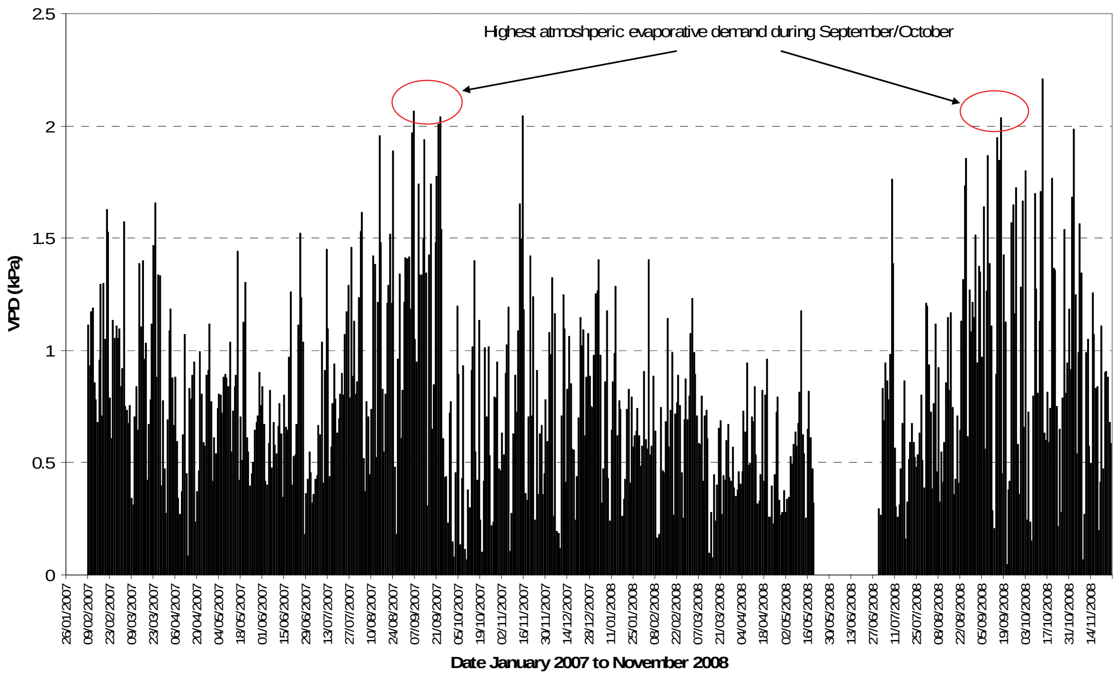


Figure 8.15 Daily vapour pressure deficit from January 2007 to November 2008 at the Zwelisha study site

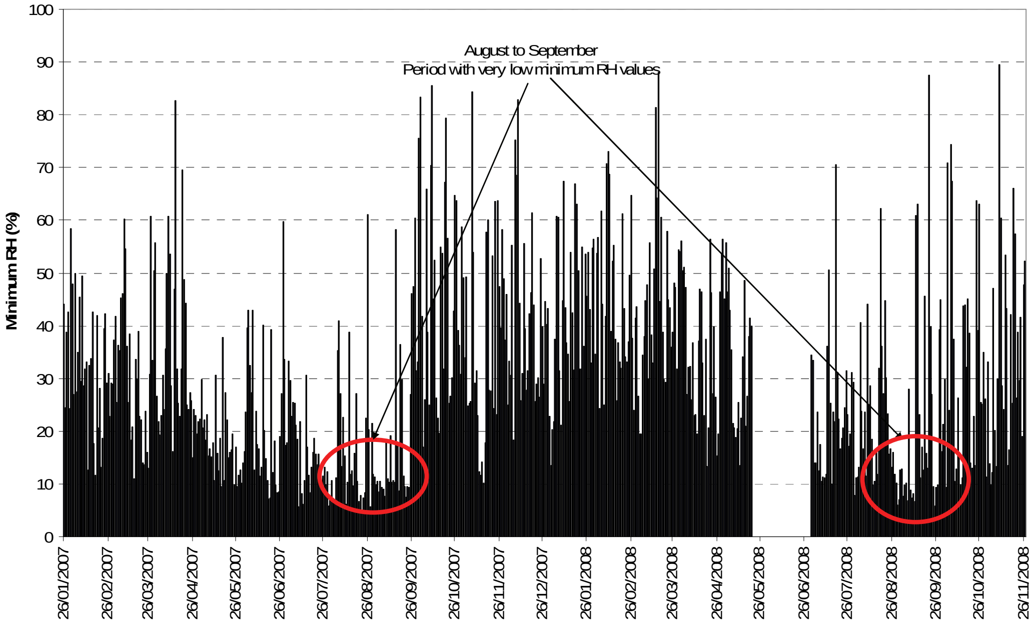


Figure 8.16 Daily minimum relative humidity values from January 2007 to November 2008 at the Zwelisha study site

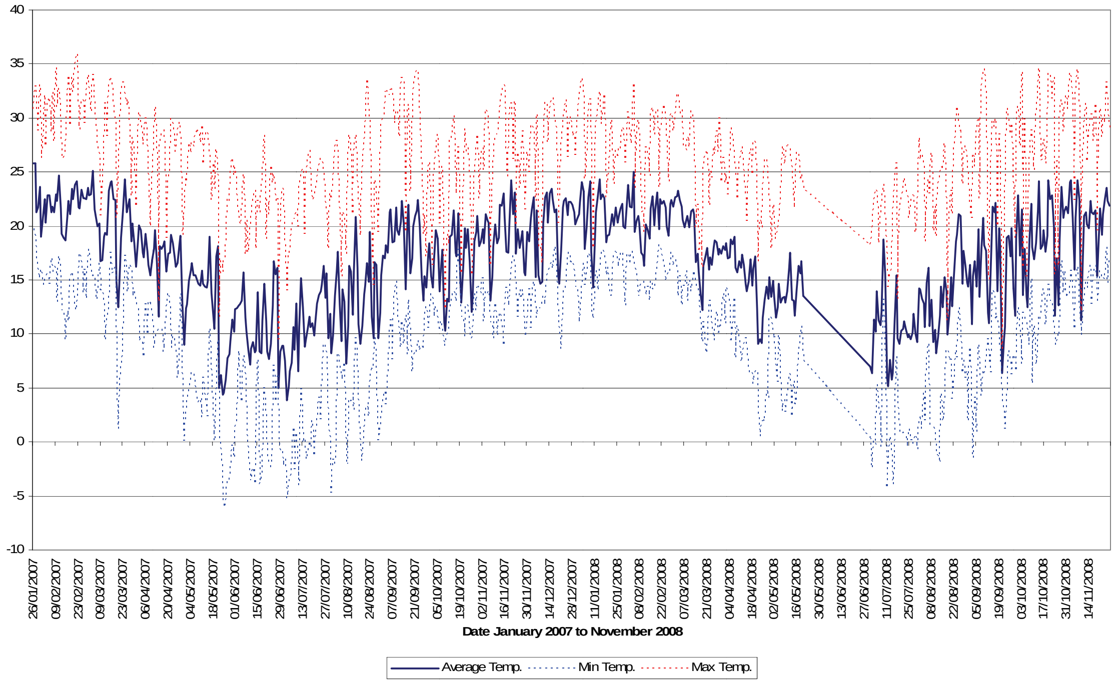


Figure 8.17 Daily average, maximum and minimum temperature from January 2007 to November 2008 at the study site

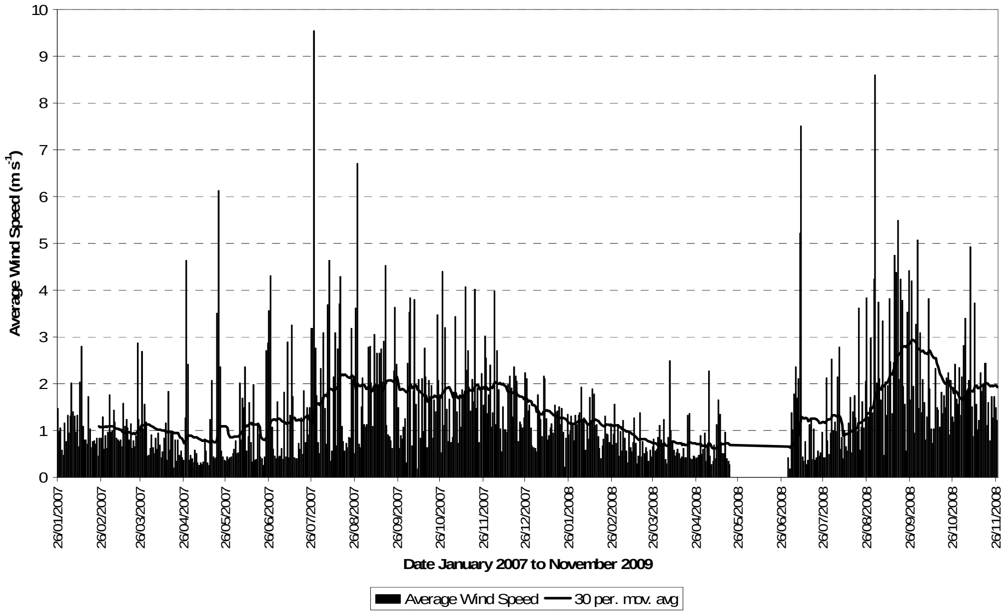


Figure 8.18 Daily average wind speed from January 2007 to November 2008 at the study site

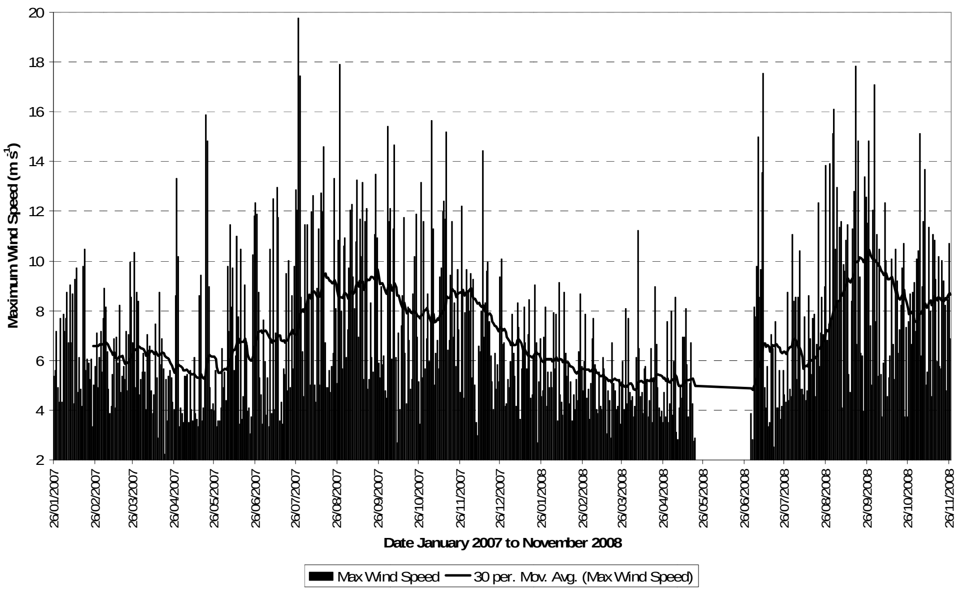


Figure 8.19 Daily maximum wind speed from January 2007 to November 2008 at the study site

8.3.5 Temperature trends across the trial – August 2005 to January 2006.

Hourly temperatures at the four sites were monitored from August 2005 to January 2006. Since measuring frost events was the main objective of these measurements only data from August 2005 are presented (Figure 8.20). Higher than expected day time values are a result of inadequate ventilation of the Hobo sensors as proper radiation shields were not available. However night time data are acceptable as there is no direct radiation at night. From the data it is clear that on the 6 and 25 August (DOY 218 & 237 respectively), minimum temperatures at 1.5 m height were < 1°C. It is likely therefore that the ground level temperature was at zero and that frost occurred on these days. On other nights minimum temperatures seldom dropped below 5°C and there was little difference between the four hillslope positions.

On both frost nights a consistent trend of the hilltop being warmer than the valley bottom was measured. Although these differences were only 1 or 2 degrees centigrade different, they clearly have a very important effect on the formation of frost, due to cold adiabatic air collecting in the valley. Since no serious dieback of plants was noted after frost it is concluded they were not as severe as those experienced it the 2004 winter period when major frost damage was recorded.

8.3.6 Temperature trends across the trial – May 2006 to September 2006

Monitoring of hourly temperatures at the four sites was repeated from May 2006 to September 2006. Since measuring frost events was the main objective of these measurements only data from 01h30 to 06h00 are presented (Figure 8.20). From the data it is clear that during the winter period regular frosts were again recorded at the study site as evidenced by the minimum night time temperatures regularly dropping below zero. Between 1 June and 15 July 2006, minima of -5°C were frequently recorded at the study site (Figure 8.21). The differences between the top and bottom sites were generally about 1°C, but due to the severity of the frosts, hillslope position probably had little influence on plant growth. These data contrast with those of 2005 when only a few frost events were measured, but are probably similar to 2004 winter period when major frost damage was recorded at the study site.

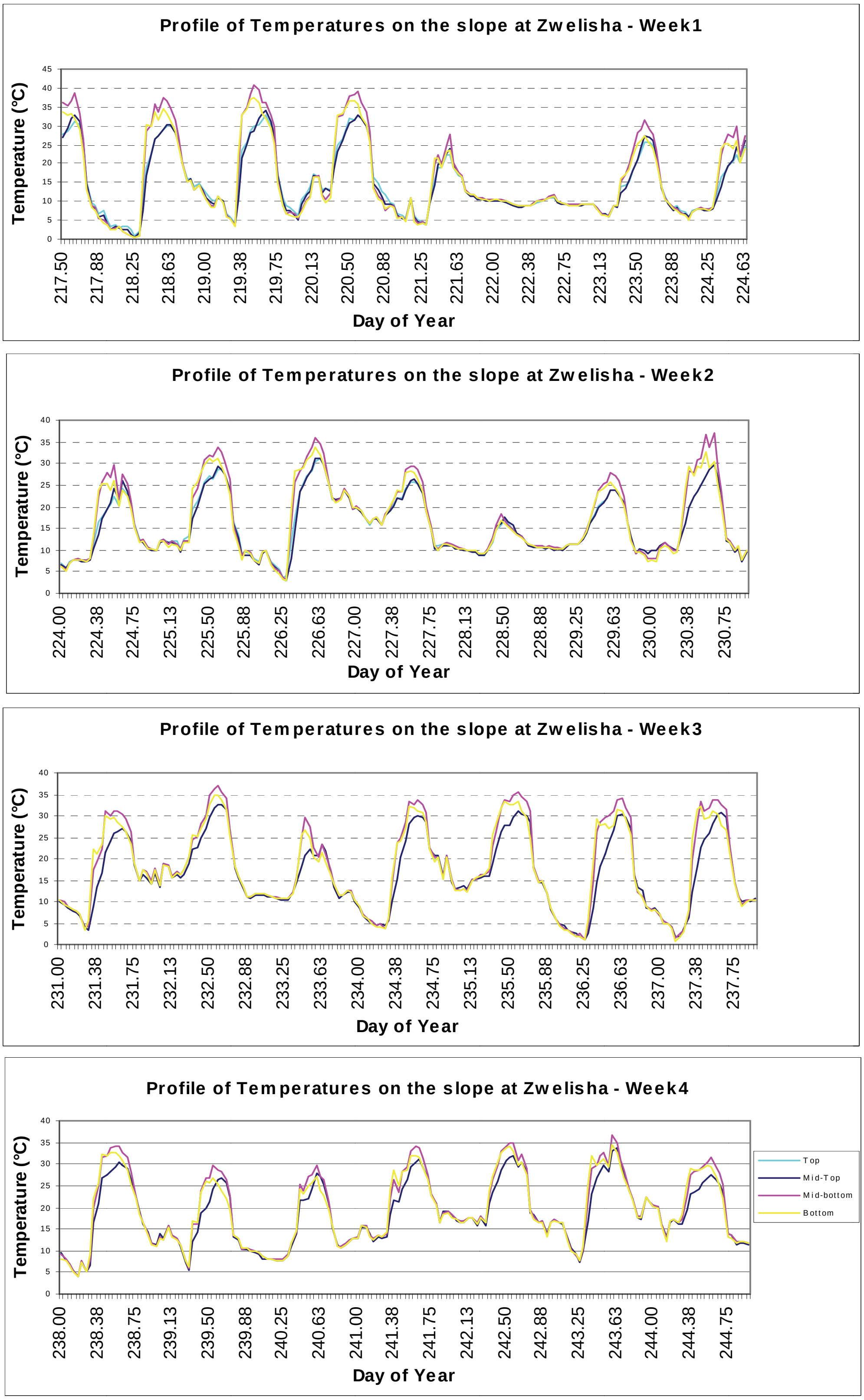
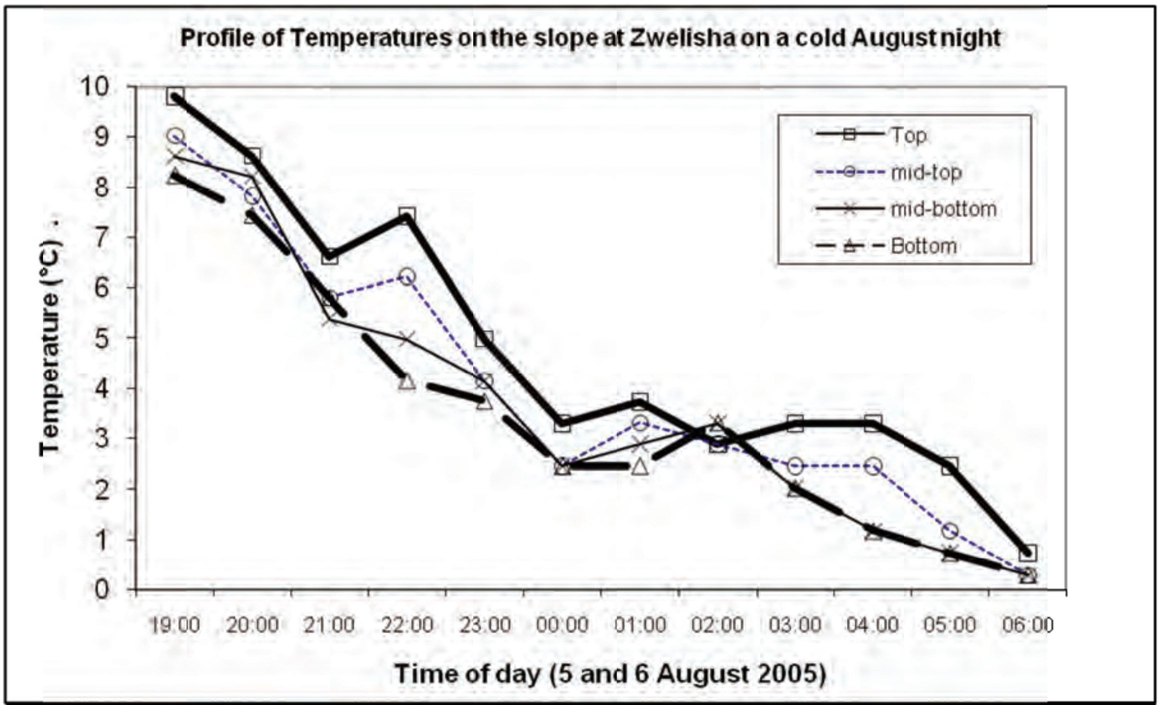


Figure 8.20 Temperature variation across the hillslope of the agroforestry trial. Note: High day time values are a result of inadequate radiation shields. Week 1 – DOY 271 = 28 September, Week 2 – DOY 224 = 12 August, Week 3 – DOY 231 = 19 August, Week 4 – DOY 238 = 26 August (see Appendix 1 for DOY calendar)



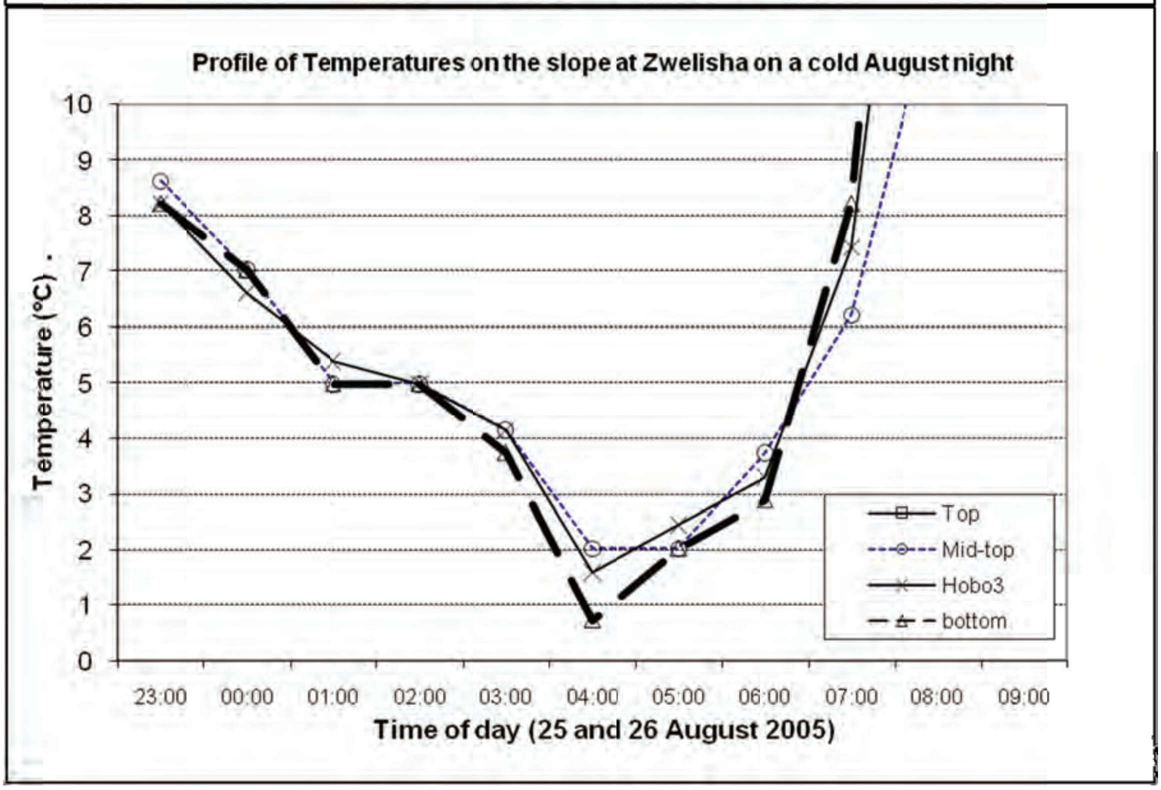


Figure 8.21 Hourly night time temperatures across the agroforestry trial on two cold nights in August 2005

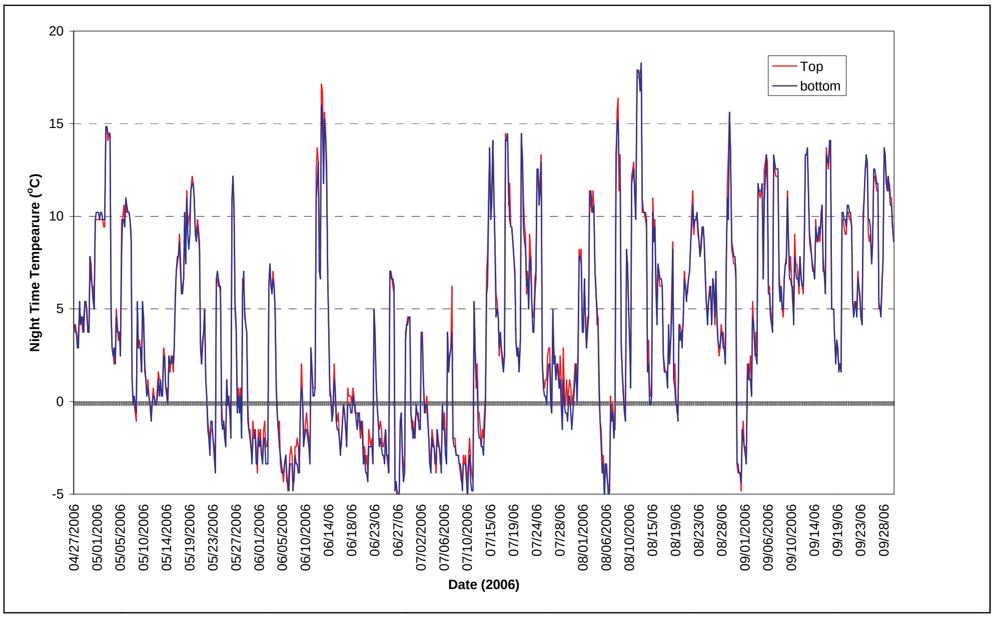


Figure 8.22 Night time trends in air temperature at two hillslope positions (top and bottom) from April to September 2006 in the silvopastoral trial at Zwelisha

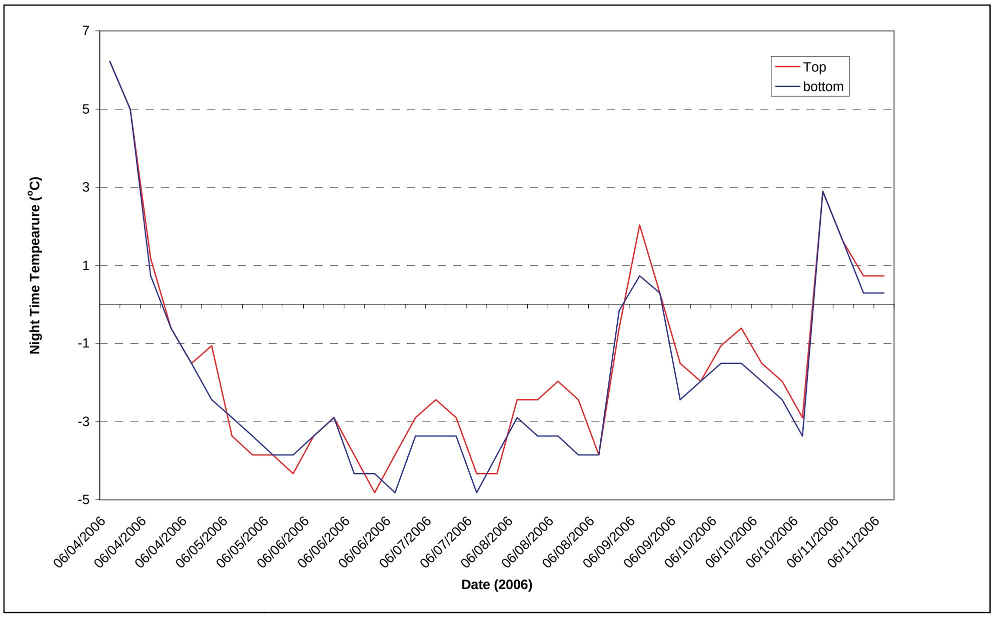


Figure 8.23 Night time trends in air temperature at two hillslope positions (top and bottom) from June 04 to June 11 2006 in the silvopastoral trial at Zwelisha

8.3.7 Soil Water

Seasonal trends in the total profile water content for a 1 m soil profile for the five access tubes in the *Acacia* only treatment (plot 15) for January/February 2007 to January 2009 are presented in Figures 8.24-8.28. These data integrate the ten depth readings taken at each sampling date. Access tubes 81 and 85 are in the first and second tree rows respectively. Access tube 83 is equidistant from the first and second tree row and in the centre of the bare area (Figure 8.1). Clear seasonal trends were found in plot 15 in the 2007 year, with the lowest water contents (±130 mm) being recorded in the winter (June and July) while the highest water contents (±260 mm) were recorded during the rainy season from November to February. These values represent volumetric water contents of 13 and 26% respectively. The trend in the water content across the plot showed interesting trends with the highest total profile water contents being recorded in November in the two tree rows (tubes 81 and 85). The access tubes (e.g. tube 82, Figure 8.25) in the bare soil had water contents that were over 100 mm lower than in the tree rows. This is a surprising result as the soil water in the tree row would be expected to be higher due to the high transpiration in the tree rows, when compared with the bare area. We conclude that this is a result of higher surface evaporation from the bare soil when compared to the tree transpiration. This illustrates the importance of mulching in soil water conservation.

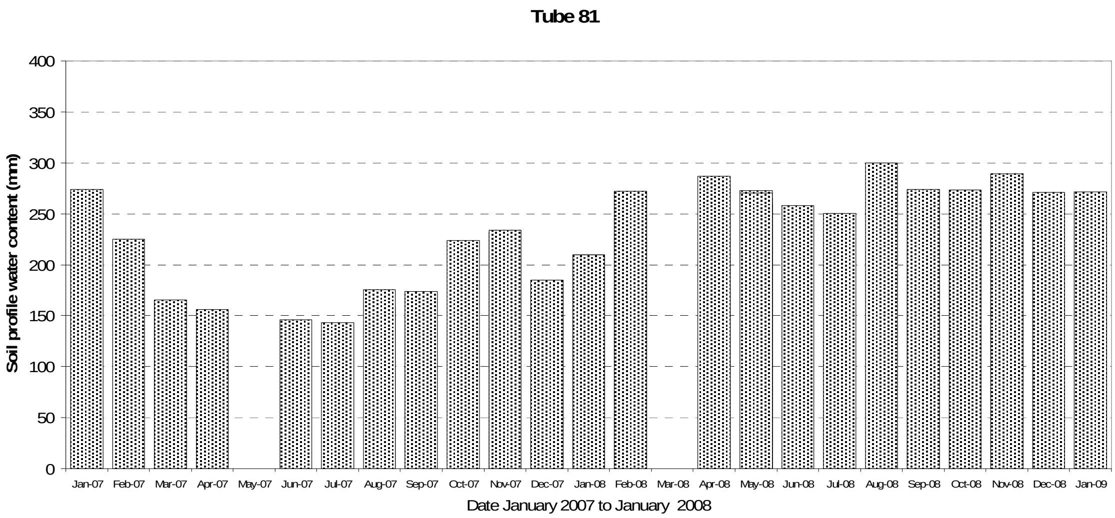


Figure 8.24 Total profile water content (mm) in the 1st tree row (tube 81) in plot 15 from January 2007 to January 2009

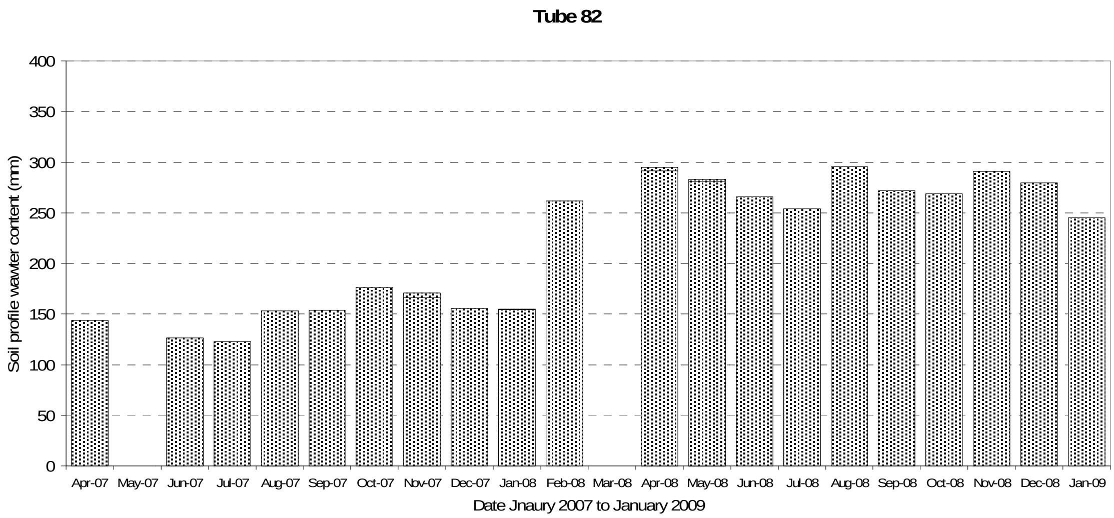


Figure 8.25 Total profile water content (mm) in the intermediate bare soil site (tube 82) in plot 15 from April 2007 to January 2008

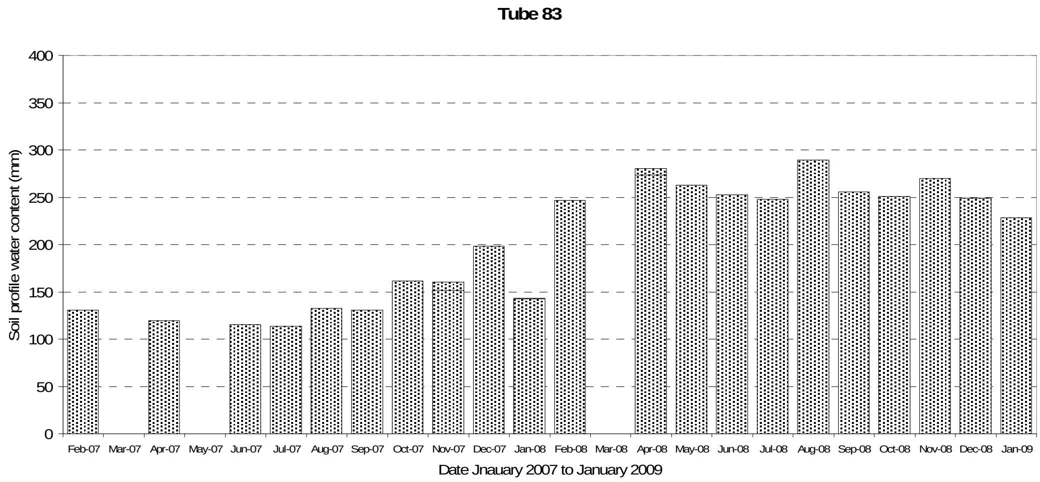


Figure 8.26 Total profile water content (mm) in the central bare soil site (tube 83) in plot 15 from February 2007 to January 2009

What was evident from all the access tubes was the consistently higher total profile water contents (>250 mm) in 2008 when compared with the 2007 data (< 250 mm). In 2008 there were no clear seasonal trends as were found in 2007, with the soil water values remaining consistently high (250-300 mm) in all months. During 2008 there was regular irrigation of the plots and it is most likely this activity which resulted in the higher water contents in 2008 than in the 2007 year. As a result, no differences were noticeable between the tree rows and the intermediate and bare soil plots as seen in 2007.

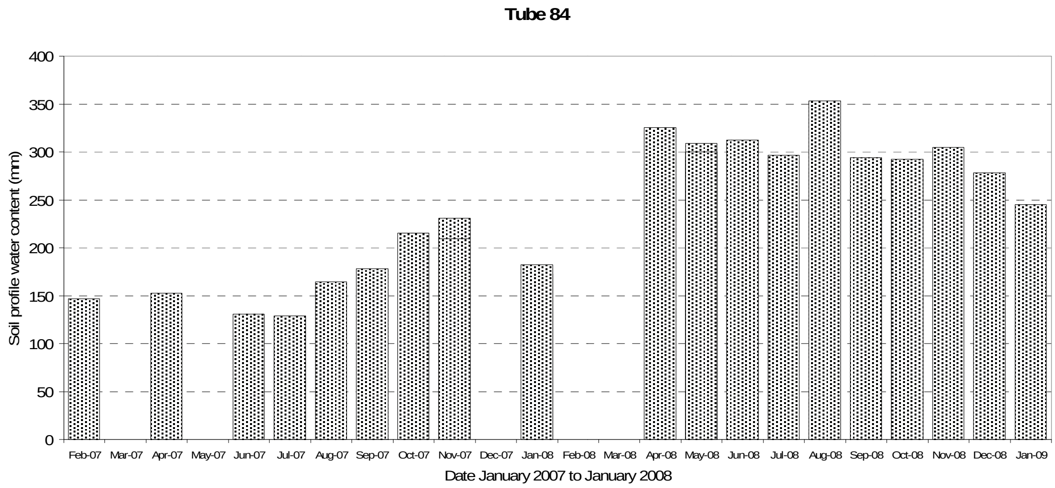


Figure 8.27 Total profile water content (mm) in the intermediate bare soil site (tube 84) in plot 15 from February 2007 to January 2009

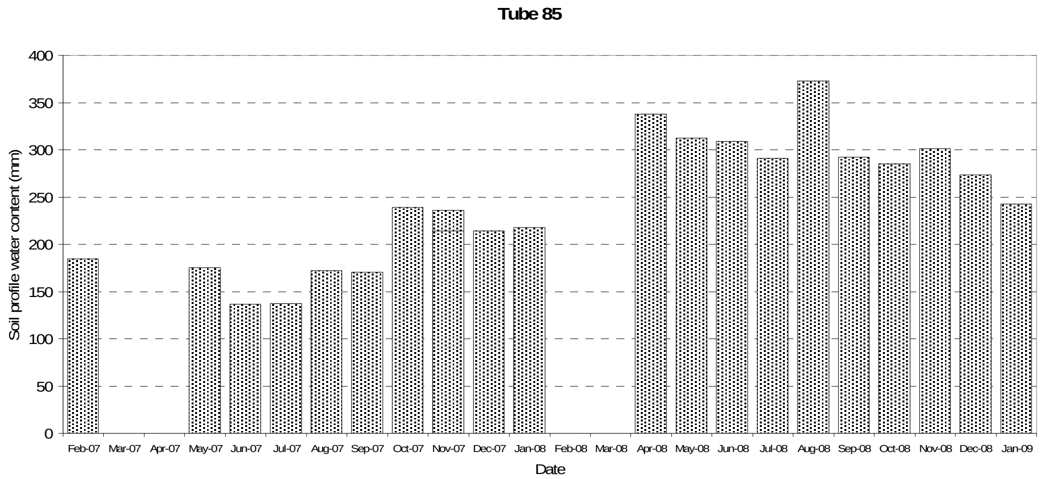


Figure 8.28 Total profile water content (mm) in the 2nd tree row (tube 85) in plot 15 from February 2007 to January 2008

8.3.8 Sap Flow Measurements

The hourly water use (l hr^{-1}) in summer 2007 of the indigenous tree (*Acacia karroo*) and the two introduced agroforestry species, (*Morus alba*, and *Gleditsia triacanthos*) showed marked diurnal differences between species (Figure 8.29). Maximum sap flow rates varied considerably from day to day as a result of fluctuating climatic conditions with maximum solar radiation varying between 500 and 800 W m^{-2} (Figure 8.29). Highest water-use was recorded for the *Gleditsia* tree (stem diam. 68 mm) with maximum summer sap flow rates of 2.5 l hr^{-1} on the 27th of December. The *Acacia karroo* at both Mr Mahlobo's and Zwelisha (tree diameters 90 and 78 mm respectively) were much lower than the Gleditsia tree, varying between 0.5 and 1.5 l hr^{-1}. The lowest water-use was measured in the Mulberry tree, where hourly values seldom exceeded 0.25 l hr^{-1}. The water-use of all three species was generally strongly associated with the diurnal trends in solar radiation (Figure 8.29).

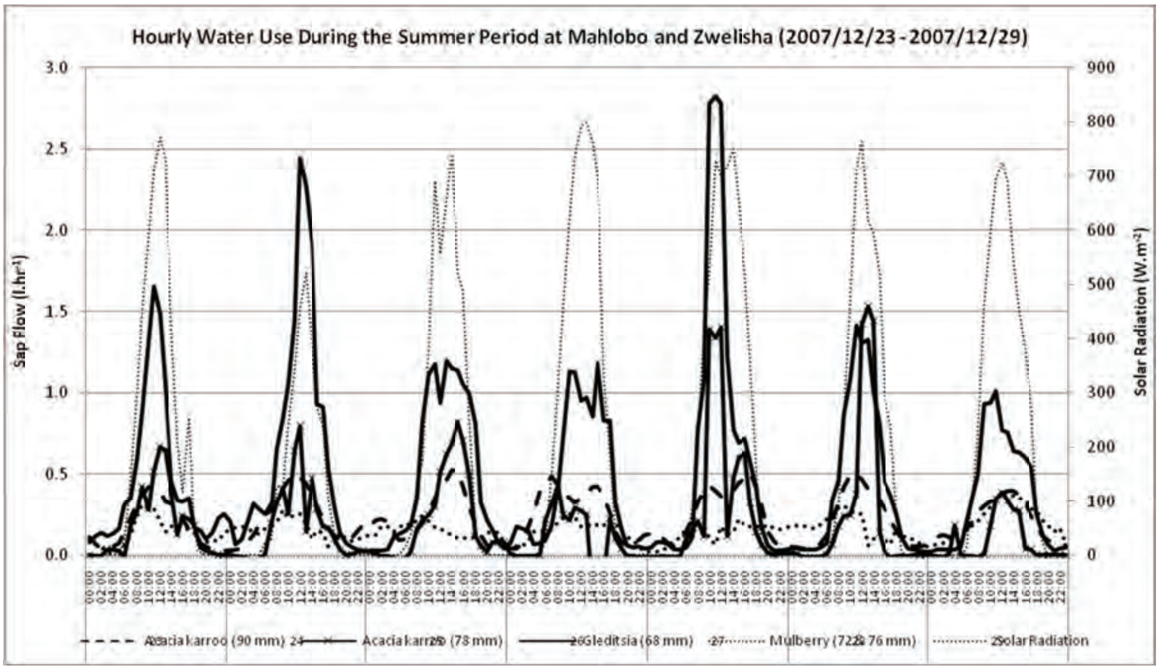


Figure 8.29 **Diurnal trends in the hourly sap flow rates (l hr^{-1}) for *Acacia karroo*, *Gleditsia* and *Morus alba* at the Mahlobo and Zwelisha study sites in summer**

By contrast the diurnal trends in sap flow for the three tree species for 7 typical days in winter (July 1st to 7th 2007) reflected the deciduous nature of the two introduced species, with maximum sap flow rates being essentially zero (< 0.1 mm hr^{-1}) (Figure 8.30). The evergreen Acacia trees although only reaching maximum rates of 0.3 l hr^{-1} did show some transpiration activity during winter. The low winter water-use of all these agroforestry trees makes them suitable for the growing with temperate pastures since they do not compete for water at a time when the pastures are most active

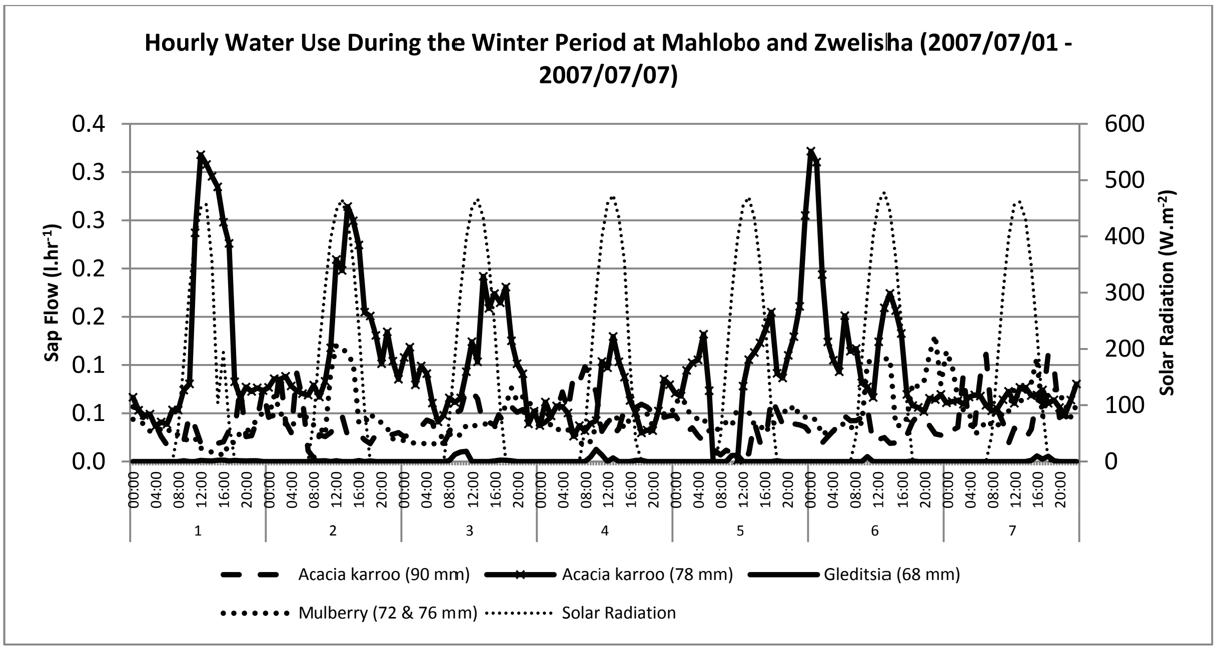


Figure 8.30 **Diurnal trends in the hourly sap flow rates (l hr^{-1}) for *Acacia karroo*, *Gleditsia* and *Morus alba* at the Mahlobo and Zwelisha study sites in winter (July 2007)**

Trends in daily sap flow in the *Gleditsia* tree at the Mahlobo site varied from highs of 25-30 l day^{-1} in summer (November to February) of both the 2007/08 and 2008/09 years, gradually declining to zero in the cold winter months when the plants lost their leaves (Figure 8.31). Large daily variations in sap flow were evident and attributed to the characteristically variable summer weather conditions of the study area (see section 8.3.1.3). Typically on overcast rainy days (low VPD and low solar radiation) sap flow rates were at their lowest and conversely on clear hot sunny days at their highest. The indigenous Acacia tree at Zwelisha showed similar trends to the *Gleditsia* tree although the daily totals were generally between 20-25 l day^{-1}, approximately 5 l day^{-1} less than the Gleditsia tree at the Mahlobo site. During winter sap flow in the Acacia trees averaged less than 5 l day^{-1}, whereas there was no water use in the two deciduous agroforestry trees (Figs. 8.29-8.31). The impact of pruning and heavy frost in June 2008 on the Acacia trees and subsequent recovery in spring is evidenced by the low sap flow rates (< 3 l day^{-1}) during this period (Figure 8.31 and Plate 8.6. In comparison to *Gleditsia* and *Acacia* the *Morus* tree had much lower sap flow rates, averaging only 10 l day^{-1} in summer (Figure 8.29). Although the base of the stem of this tree was 75 mm in diameter (similar to the other trees) the development of new branches was severely retarded by the pruning. This resulted in a reduction in the leaf area of the *Morus* trees (Plate 8.7) and associated low sap flow rates.

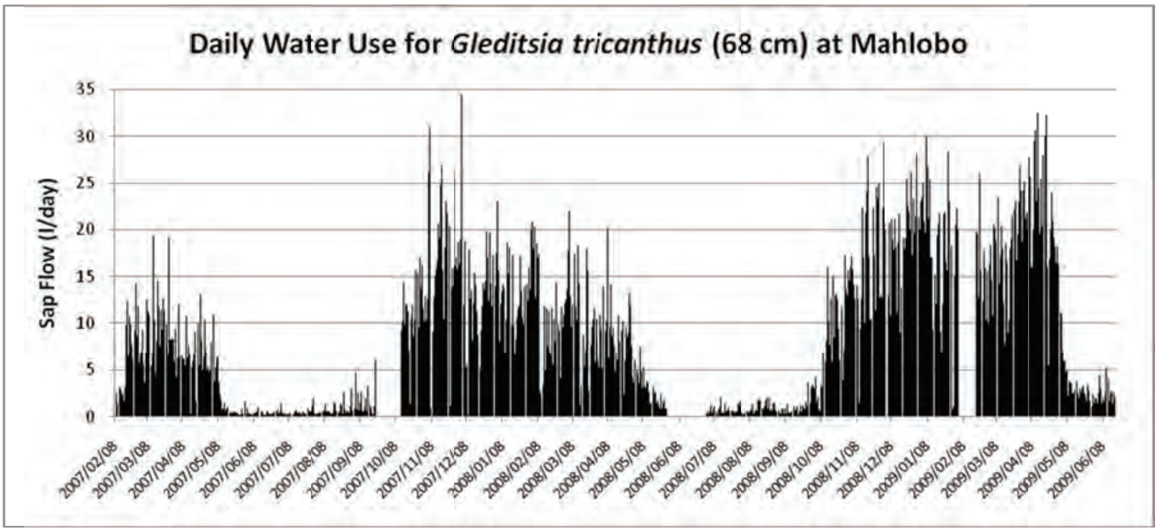


Figure 8.31 Daily sap flow in the *Gleditsia* tree at the Mahlobo site from February 2007 to June 2009

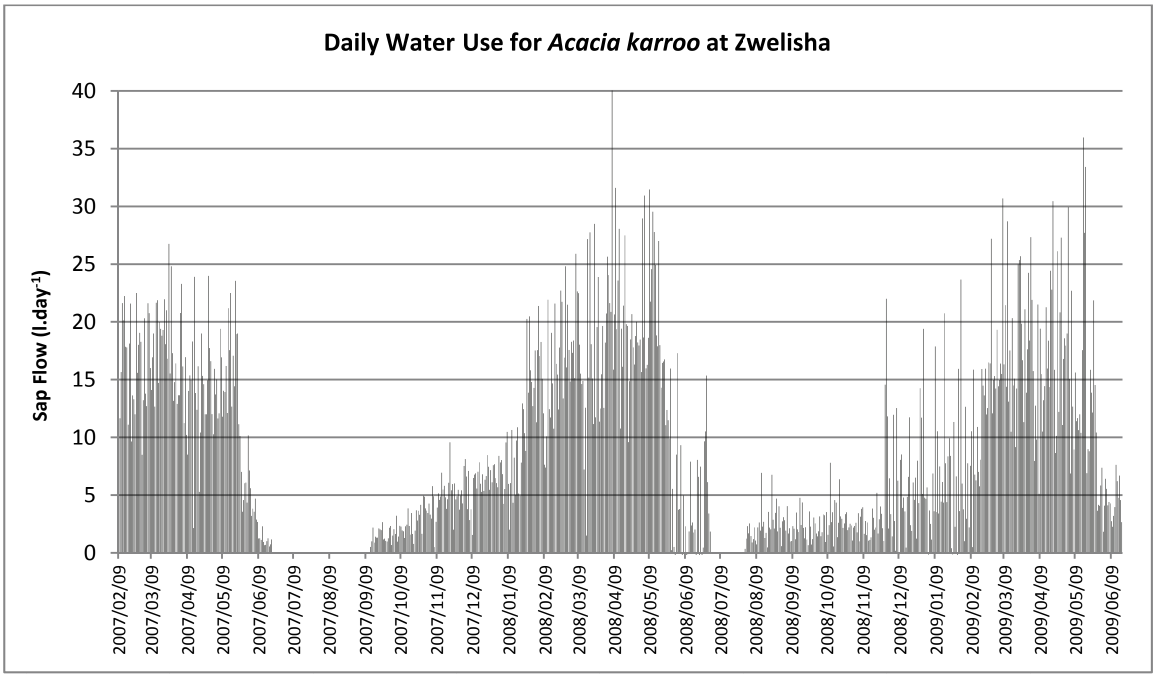


Figure 8.32 Daily sap flow in the *Acacia karroo* trees at the Zwelisha site from February 2007 to June 2009

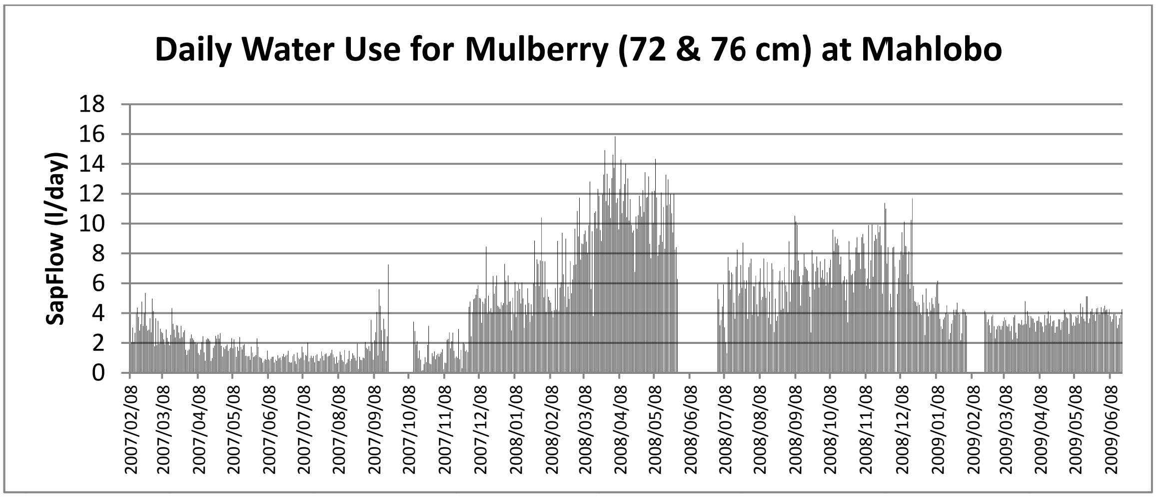


Figure 8.33 Daily sap flow in the *Morus alba* tree at the Mahlobo site from February 2007 to June 2009.

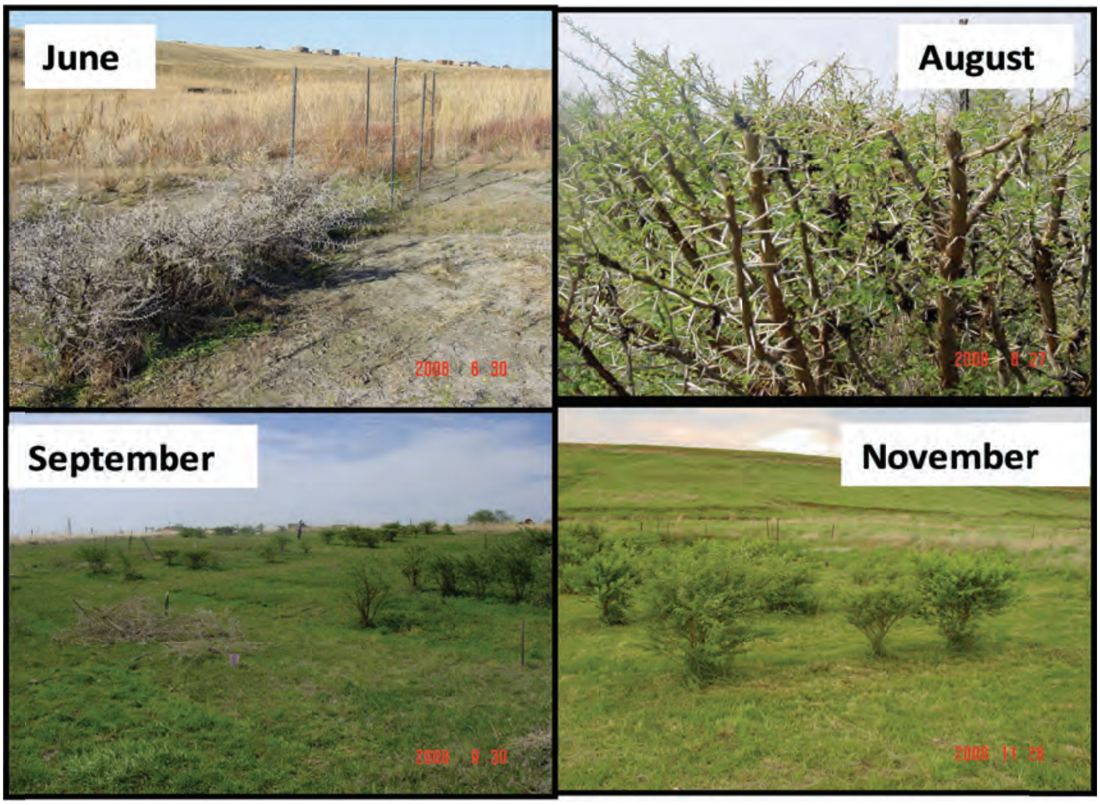


Plate 8.6 **Canopy development of *Acacia karroo* from June to November 2008 showing the impact of pruning and winter frost in June and subsequent recovery in spring**

Plate 8.7 **The effect of regular pruning on *Morus alba* at the Mahlobo site (February 2008)**

8.4 Conclusion

An important objective of this study was to estimate the water use of the various agroforestry tree species in the trial. In the Zwelisha trial only the *A. karroo* trees were large enough for sap flow measurements using the Heat Pulse Velocity technique. Additional trees (*Morus alba, Gleditsia triacanthos* and *Acacia karroo*) from the initial agroforestry trial situated on Mr Mahlobo's farm were chosen for the water-use measurements.

Detailed climatic information and soil moisture measurements were obtained to provide additional water balance information. Because the trial was situated on a cold south facing slope and frosts were frequent, micro-climate measurements of the spatial and temporal distribution of temperature across the trial were made in 2005 and 2006.

The trend in the vapour pressure deficit (VPD), which gives a good indication of the atmospheric evaporative demand, showed that the most extreme climatic conditions occurred in August to September at the end of dry winter period in all years. During these periods VPDs of over 2 kPa were recorded, coinciding with very low humidity, high temperatures and high average and maximum wind speeds. Temperature trends across the trial were measured from May 2006 to September 2006 using Hobo loggers. During the winter period regular frosts were recorded at the study site. Between 1 June and 15 July 2006, minima of -5°C were frequently recorded at the study site. Clear seasonal trends were found in the soil water content in the 2007 year, with the lowest water contents (±130 mm) being recorded in the winter (June and July) while the highest water contents (±260 mm) were recorded during the rainy season from November to February. In the bare soil areas water contents were over 100 mm lower than in the tree rows. It was concluded that this was a result of higher surface evaporation from the bare soil than from tree transpiration. This illustrates the importance of mulching in soil water conservation. In 2008 there were no clear seasonal trends in soil water between treatments. Unlike 2007, soil water values were consistently high (250-300 mm) in all months, probably as a result of regular irrigation of the plots.

The water use for *A. karroo* in this silvopastoral trial indicated that maximum sap-flow rates were between 20-25 l day^{-1} in summer, while the fast growing *G. triacanthos* tree averaged 25-30 l day^{-1}. The semi deciduous nature of the indigenous *A. karroo* trees resulted in water-use later into the winter months, although these values were low. Heavy frost in 2008 resulted in seasonal plant die back and reduced water use. The introduced *M. alba* trees had maximum sap-flow rates of 10 l day^{-1} in summer as a result of pruning and showed reduced transpiration in winter due to the dry conditions and the deciduous nature of the trees. The data showed that *M. alba* had a lower water use than either the *G. triacanthos* or *A. karroo* trees. The impact of pruning was evident in all the tree species and pruning made absolute estimates of undisturbed single tree water use impossible. The results of the water-use estimates of all three species in this trial were conservative when compared to other South African studies, but must be seen against the silvicultural practice of pruning, which clearly had a major impact on leaf area and water use.

Measurements on indigenous tree species in riparian forest in the Kruger National Park have shown that the variation in mean daily transpiration rates recorded for *Ficus* *sycomorus* and *Trichilia emetica* trees, ranged between 40 to 80 l day^{-1} in summer (Birkhead *et al*., 1996). Similar results (maximum sap flow rates of 60-80 l day^{-1}) were reported by Dye *et al*. (2008) in a more recent WRC study on the water-use of the indigenous trees *Trema orientalis* and *Celtis africana* (White Stinkwood) in the KwaZulu-Natal midlands. Even maximum sap flow rates for the slow growing *Podocarpus falcatus* (Yellowwood) of 30-50 l day^{-1} were higher than the trees measured in this study. The results of the water-use estimates of all three species in this trial are therefore conservative, but must be seen against the silvicultutal practice of pruning, which clearly had a major impact on leaf area and water-use.

CHAPTER 9: GENERAL DISCUSSION AND CONCLUSION

The shortage of good quality fodder is one of the major constraints in rural farming systems of the Upper Thukela region during the dry winter season. In particular, the fodder scarcities adversely limited the milk production from a small-scale dairy enterprise run by a rural farmer, Mr Mbhele. The crop residues which provide valuable fodder for livestock during the dry season are poor in nutritive value and do not last long due to uncontrolled livestock grazing in the communal farming system at Zwelisha. Therefore there is a need for an appropriate forage technology that will be simpler, sustainable, acceptable and affordable for smallholder farmers. Improved fodder has great potential to sustain dairy cows' production.

The aim of this on-farm study was to determine the effect of silvopastoral agroforestry and maize-lablab intercropping systems on fodder production and assess their impact on soil fertility and water availability. The specific objectives of the project (outlined in the introduction) were all achieved. However, the effect of trees on soil loss was not measured because of the flat aspect of the experimental site and the high basal cover. To achieve the objectives it was important to build capacity of the farmer by involving him in the planning, implementation, management and evaluation of the trials (see Appendix 2 – Technology transfer and capacity building report).

The research study showed that intercropping (maize with lablab) and alley cropping (*L. leucocephala* and *A. karroo* tree legume with the temperate pasture species, Cocksfoot and Tall fescue, are viable options to fill the fodder gap during the dry season. The alley cropping field trial demonstrated the potential for the use of temperate grass species for small-scale dairy systems in the Upper Thukela region. However, this can only be achieved if the pasture species are irrigated. The project demonstrated that small-scale, inexpensive irrigation is feasible if there is electricity and a small water course in the vicinity.

The introduction of leguminous fodder trees in communal farming systems has the potential to provide highly nutritious fodder for livestock. The field trial demonstrated that the advantage of growing leguminous fodder trees (*A. karroo* and *L. leucocephala*) is that they contained high amount of crude proteins with mean values of 14.7 and 18.6% respectively and therefore can be used to supplement expensive concentrates.

The establishment of the fodder trees was slow and is linked to the severe frosts with *A. karroo* appearing to be more frost sensitive than *L. leucocephala*. It is evident that *A. karroo* was not able to compete well with the pastures. But it is of interest to note that both tree species have a positive effect on pasture productivity, particularly *A. karroo* where grass production in alley plots cocksfoot was high compared to sole cocksfoot plots.

There was a marked improvement in fodder production (P=0.000) which in alley crops ranged from a minimum of 4830 kg ha^{-1} in 2005 in *L. leucocephala* alley cropped with cocksfoot to a maximum of 8928 kg ha^{-1} in 2006 in *A. karroo* alley cropped with Tall fescue. This is in contrast to natural veld production which ranged from 1195-2728 kg ha^{-1}. This is an indication of the importance of having silvopastoral fodder production systems in rural areas where shortages of fodder are usually experienced during winter and spring season as had been observed in the Zwelisha area. It is important to indicate that although annual yield of natural veld ranged from 1195-2728 kg ha^{-1} values of 0 kg ha^{-1} were recorded during some winter (August) and spring (September and October) months as grasses were below 5 cm height. This observation further emphasizes the importance of having alternative sources of fodder in rural farming systems for sustainable small-scale dairy enterprises.

The study demonstrated that legumes such as *A. karroo* and *L. leucocephala* have potential to increase dry matter fodder yields of temperate pastures (Cocksfoot and Tall fescue) when grown in combination with these tree legumes. The higher total fodder production obtained from alley cropping compared to sole pasture in some years (e.g. 2006: *Acacia karroo* + Tall fescue =8716 kg ha^{-1} vs. Tall fescue =4212 kg ha^{-1} was a further demonstration that growing pastures in combination with tree legumes may be an appropriate fodder production technology for smallholder farmers in communal areas.

The study demonstrated that cultivated strip planting is an effective technique as it resulted in significantly higher DM yield in the reinforced Tall fescue pasture (290.33 kg ha^{-1}) when compared to infested pasture (191.11 kg ha^{-1}). The trial clearly showed the effectiveness of strip planting and direct seeding reinforcement techniques suggesting that the two techniques can be combined when reinforcing invaded pasture in rural farming systems.

The higher total fodder yield observed in the maize plus lablab treatment compared to maize only treatment showed the importance of intercropping maize with lablab for increasing feed quantity. Highest fodder production was obtained from intercropping (10 540 kg ha^{-1}) compared to sole maize cropping (7360 kg ha^{-1}) in 2007. This was a demonstration that more land will be required in sole cropping than intercropping to produce the same yield per unit area. This is based on the land equivalent ratio principle which is the total land area required under sole cropping to give the yields obtained in the intercropping mixture (Mukhala *et al.* 1999).

Intercropping lablab with maize resulted in a significant increase in crude protein content of maize leaves. This is an important finding since the leaf component of the maize stover fraction is the plant part that is mostly selected by cattle during grazing (Murphy and Colucci 1999). Intercropping also reduced the fibre content of the maize leaves significantly, an indication that the inclusion of lablab in traditional maize cropping system can improve digestibility and quality of maize leaves. This should result in an increase in the intake of maize stover by livestock.

Highest total fodder production obtained from intercropping (12120 kg ha^{-1}) compared to sole maize cropping (7360t ha^{-1}) was a demonstration that intercropping maize with lablab is an appropriate technology for smallholder farmers who are usually constrained by a small area of land with an average of 1 ha (FAO 2004). These farmers usually experienced low quantity and quality fodder during dry season. Intercropping is therefore a fodder production technology that can fill fodder gaps in rural farming systems during the dry season.

The silvopastoral agroforestry system resulted in a significant accumulation of total inorganic nitrogen in the soil, indicating that alley cropping may improve soil nitrogen nutrient status. There was also a strong correlation between alley cropping system and nitrogen concentration. Nitrate nitrogen accumulation was higher than the corresponding ammonium nitrogen indicating that nitrification process was superior to ammonification during the study.

The trial indicated that the lablab forage legume did improve nitrogen content in the soil as indicated by significant ($p=0.013$) accumulation of inorganic nitrogen (1.84 $mg\ell^{-1}$) in the intercrop plots compared with maize only treatment plots (1.17 $mg\ell^{-1}$). This demonstrated the positive benefits of using lablab in improving the fertility status of the soil which has the potential of increasing yield for the maize crop. There was a strong correlation cropping system and inorganic nitrogen concentrations.

The significant ($p=0.000$) high concentration of nitrate nitrogen (NO_3^-N) observed in the study may be attributed to improved soil moisture status due to irrigation. Improving soil moisture status stimulates mineralization in the form of nitrification in which ammonium is oxidized to nitrate (Alexander 1991). Much of the ammonium nitrogen NH_4^+N might have been converted to NO_3^-N by nitrifying bacteria in a process called nitrification (Tisdale *et al.* 1993). The observed low ammonium concentration is in agreement with the findings of Bahmani *et al.* (2009) who reported low concentration of ammonium (NH_4^+N) from the surface to 120 cm depth during a study conducted in Khuzestan, in Iran. They attributed the low concentration of ammonium to nitrification process and conversion of ammonium to nitrate in the upper soil layers.

It was evident from the cafeteria trial that dairy cows preferred *L. leucocephala* tree fodder (97% intake) compared to *A. karroo* tree fodder (52% intake). The lower preference of *A. karroo* tree fodder may be attributed to its thorns and tannins which are its defence mechanisms against herbivory. It was evident from the cafeteria trial that the cut and carry system will be an option for the farmer to feed his dairy cows. The study showed that *A. karroo* tree fodder may be utilized by the dairy cows if post-harvest treatments such as separation of thorns from tree leaves are conducted before offering them to dairy cows. This has the potential to enhance effective utilization of this tree species by ruminants.

The trial has shown that conducting the field experiment on the farmer's land and facilitating his involvement in all the field experimental activities has been a positive learning experience for both the farmer and the project team. The feedback from the farmers' days was that on-farm trials are beneficial as they observed that the farmer who managed the trial was at their level and benefited from new technologies.

All the farmers (100%) who attended the farmers' day stated that shortage of fodder was the major constraint to their livestock production. The shortage of fodder in terms of quality and quantity as reported by all farmers, justifies the necessity of having agroforestry and intercropping technologies that are adaptable, appropriate and applicable to smallholder farmers to improve the quality and quantity of fodder in the Upper Thukela region.

The farmers' days provided Mr Mbhele with an opportunity to share with the farmers his observations that the leguminous fodder trees have the ability to grow even during the dry season. *Acacia karroo* was able to withstand frost compared to *L. leucocephala* which shed its leaves during severe frost. He reported that having these trials on his land assisted him to acquire knowledge and skills on establishing and managing the trees, pastures, maize and lablab. This was a clear demonstration of the importance of having on-farm trials where the farmer participates in various trials activities.

The on-farm trials and farmers' days also promoted collaboration with the KZN Department of Agriculture and Environmental Affairs extension services, researchers and the private sector e.g. input supplying companies like Pioneer Seed Company. These on-farm trials gave the farmers an opportunity to make a thorough evaluation of the technology in terms of feasibility, adaptability and applicability of the real benefits of the technology. They enabled farmers to acquire knowledge of forage technologies which enhanced adoption and implementation of the forage technologies. This was shown by the willingness of Mr Mbhele towards the developed fodder technologies. He informed other farmers during the farmers' days that he wanted to plant the leguminous trees and cocksfoot pasture in a larger area as he has realized their potential to increase the amount of fodder and its quality.

However, it should be noted that a number of problems were experienced during the on-farm trials which negatively impacted the research trials. It was apparent that access to water for irrigation was essential in the establishment of the pasture species. This involved costs that may not be affordable to many communal farmers. Although the project set up a low cost water pump for the farmer, this could not be run initially because there were problems with outstanding electricity payments owed by the farmer. This had serious consequences to the research with the loss of the first pasture crop.

A major problem throughout the course of the on-farm trials was the grazing of pastures and browsing of fodder trees by livestock, in spite of fencing of the site. This contributed to the low biomass values recorded during various growing seasons. This was a problem that was difficult to control as the farmer prioritized feeding his cattle over quality of research data. In addition, neighbours cut the fence to give their cattle access to the high quality forage in the trial. This highlights the need for providing fodder during winter in sourveld communal areas.

In spite of these problems, the study showed clearly that agroforestry and intercropping technologies should be tested under local farming conditions through on-farm trials with farmer involvement. Further on-farm research on fodder conservation technology is recommended in communal areas to assist smallholder farmers to acquire skills and create an interest in fodder conservation techniques.

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APPENDIX 1: DAY OF YEAR CALENDAR. FOR LEAP YEARS ADD 1 FROM MARCH 1 ONWARDS. 2004 WAS A LEAP YEAR.

Day	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	**1**
2	002	033	061	092	122	153	183	214	245	275	306	336	**2**
3	003	034	062	093	123	154	184	215	246	276	307	337	**3**
4	004	035	063	094	124	155	185	216	247	277	308	338	**4**
5	005	036	064	095	125	156	186	217	248	278	309	339	**5**
6	006	037	065	096	126	157	187	218	249	279	310	340	**6**
7	007	038	066	097	127	158	188	219	250	280	311	341	**7**
8	008	039	067	098	128	159	189	220	251	281	312	342	**8**
9	009	040	068	099	129	160	190	221	252	282	313	343	**9**
10	010	041	069	100	130	161	191	222	253	283	314	344	**10**
11	011	042	070	101	131	162	192	223	254	284	315	345	**11**
12	012	043	071	102	132	163	193	224	255	285	316	346	**12**
13	013	044	072	103	133	164	194	225	256	286	317	347	**13**
14	014	045	073	104	134	165	195	226	257	287	318	348	**14**
15	015	046	074	105	135	166	196	227	258	288	319	349	**15**
16	016	047	075	106	136	167	197	228	259	289	320	350	**16**
17	017	048	076	107	137	168	198	229	260	290	321	351	**17**
18	018	049	077	108	138	169	199	230	261	291	322	352	**18**
19	019	050	078	109	139	170	200	231	262	292	323	353	**19**
20	020	051	079	110	140	171	201	232	263	293	324	354	**20**
21	021	052	080	111	141	172	202	233	264	294	325	355	**21**
22	022	053	081	112	142	173	203	234	265	295	326	356	**22**
23	023	054	082	113	143	174	204	235	266	296	327	357	**23**
24	024	055	083	114	144	175	205	236	267	297	328	358	**24**
25	025	056	084	115	145	176	206	237	268	298	329	359	**25**
26	026	057	085	116	146	177	207	238	269	299	330	360	**26**
27	027	058	086	117	147	178	208	239	270	300	331	361	**27**
28	028	059	087	118	148	179	209	240	271	301	332	362	**28**
29	029	060	088	119	149	180	210	241	272	302	333	363	**29**
30	030		089	120	150	181	211	242	273	303	334	364	**30**
31	031		090		151		212	243		304		365	**31**

APPENDIX 2: TECHNOLOGY TRANSFER AND CAPACITY BUILDING REPORT

1. Introduction

Research strategies for livestock feed improvement and technology transfer that are appropriate to communal farming systems need to be developed to alleviate the problem of feed scarcity and poor quality. Traditionally, research is usually carried out at research stations (on-station trials) and the research results are transferred by the government extension system to farmers using top down dissemination methods (Mubiru *et al.* 2004). In contrast, on-farm trials, where research that is carried out on farmer's field and in a farmer's environment, are increasingly seen as a more appropriate approach to enhancing the understanding and the adoption of new technologies by small holder farmers (Angstreich and Zinnah 2007). They are also valuable for contributing knowledge to researchers, extension officers and farmers. Interacting with farmers allows the researcher to have an appreciation of the farmers' conditions and problems.

On-farm trials involve four key elements: the farmer, farmer's land, farmer's involvement and the farmer' environment (Atta-Krah 1992). In an on-farm trial, farmers are empowered to own the technologies because they are practically involved in the process of developing them. In the dissemination of technologies, it becomes relatively easier for other farmers to adopt the technologies when they see the crop responses in trials managed by their fellow farmers whom they can identify with, other than researches and extension agents who are considered to have immense resources and technical knowledge (Mubiru *et al.* 2004).

Agroforestry is a relatively new technology in the Upper Thukela region which enables smallholder farmers such as Mr Mbhele to evaluate potential low-cost options to improving both crop and livestock production. Agroforestry was considered a suitable option for the rural farmers in the area because it is reputed to reduce the farmer's reliance on external inputs and increase sustainable off-take from the land (Reynolds and Cobbina 1992).

2. On-farm trial at Zwelisha

The aim of this on-farm trial was to examine the potential of alternative fodder systems for small-scale dairy farmers and determine their impact on water availability. Therefore the first step was the involvement of the farmer (Mr Mbhele) through meetings where discussions were held on his fodder shortage problems and possible solutions. This was done to develop an understanding of Mr Mbhele's fodder management plans for his small-scale dairy enterprise. Site visits took place where Mr Mbhele indicated the sites that he preferred to be used for the on-farm trials. Throughout the duration of the project the capacity of rural farmers was built by organizing on-farm farmers' days which involved Mr Mbhele and farmers from the local farmers' associations in the planning, implementation, management and evaluation of the trials.

3. Farmers' days and demonstrations

A number of farmers' days were held throughout the project to disseminate the on-farm trial results to promote the agroforestry technology to the wider farming community. Lessons learnt from these technology transfer days are highlighted below.

(i) Farmers' day and demonstration in 2005

A farmers' day was held on the 6th May 2005 which was broadcast on SABC TV. The farmers' day therefore created national awareness and interest about agroforestry, particularly the silvopastoral system and maize-lablab intercropping system. Community participants said that this was a new system in the Upper Thukela region. Some community members felt that the silvopastoral agroforestry system was practicable under their local conditions and was important in dairy enterprises.

(ii) Farmers' day and demonstration in 2007

The following comments and questions were made by the community members after visiting the maize-lablab trial. The questions and replies highlight the importance of communication in the technology transfer process.

Q1. Why does maize differ in the trial – that is those with lablab and those without lablab?
A1. The difference is due to the nitrogen that is supplied by lablab. Mr Ngcobo from Pioneer Seed Company explained further that lablab presently supplies nitrogen to the companion crop.

Q2.Weeds are problematic in maize production. What are the effective methods of weed control?
A2. Weed control is important and it must be done as early as possible as weeds can result in a significant decrease in maize yield. Herbicides especially the pre-emergence herbicides must be used. Herbicides also effectively kill weeds that are difficult to be controlled with the use of mechanical methods of weed control.

Q3. Mechanical cultivation is used to control weeds but after using it, the maize plants show some moisture stress e.g. wilting. What causes this because we value this method of controlling weeds as the one which is effective and beneficial?
A3. Mechanical cultivation as method of weed control must be done properly in order to avoid injuries of maize crop. The injuries of maize during cultivation are the one that results in wilting of maize crop.

Q4. Maize plants look good in the trial. Was the fertilizer applied and how was it applied? Is it wrong to put the seed in the row and apply fertilizer on top of the seed?
A4. – It is important to apply fertilizer properly when planting maize by ensuring that there is no direct contact with maize seeds and fertilizer as fertilizer has a burning effect and that can result in poor germination of maize seeds and eventually low crop yield. This means that the fertilizer must be applied first and then it must be covered by a thin layer of soil and then the maize seeds can be planted thereafter.

Q5. Is it correct to apply kraal manure in your maize crop? When do you apply kraal manure?
A5. When using the kraal manure it is important to apply it well in advance before planting maize, for example kraal manure can be applied 4 to 6 months before planting. The

importance of kraal manure is that it improves soil fertility. The use of kraal manure also improve soil aggregation particularly in soils with high sand content as well as in those with high clay content. But it is important for the farmer to know that kraal manure do not consists of all the nutrients that are required by the plant.

Q6.Which cultivar is better than the other cultivar?
A6. Both maize cultivars show that they are well adapted in the area. Both are drought tolerant and are resistant to various diseases particularly rust disease.

The community members indicated that they would like to include lablab in their maize crop as they had seen that lablab improved maize growth. They as observed in the trial and also due to other benefits of alley-cropping maize with lablab outlined during the farmers' day. They indicated that they would like to have this type of trial as soon as possible in their area.

Farmers commented that in the silvopastoral agroforestry trial the thorns of *A. karroo* might be problematic to cattle, but in general the silvopastoral system can help in the increase of fodder and ensure that fodder is available even during seasons when there is scarcity of fodder.

Farmers enquired about the availability of pasture seeds and their costs. They showed an interest in the silvopastoral agroforestry system but they stated that they will need more time to learn about the management of this agroforestry system.

Conclusions

The community members indicated that they want these trials particularly the agroforestry and maize lablab trials to be conducted in their areas as soon as possible as they had seen the benefits of using leguminous fodder trees and alley-cropping maize with lablab to increase fodder and its quality during the winter season.

The community members learnt some agronomic practices that result in reduction of costs in maize production. For example, reduction in the use of nitrogenous fertilizers due to the use of lablab, judicious methods of applying fertilizers, benefits of using kraal manure and its application and effective methods of weed control.

(iii) Farmers' day and demonstration in 2010

A farmers' day was held at Zwelisha on the 24th March 2010. The participants included farmers from Okhombe, Zwelisha and Edukuza as well as officials from the KwaZulu-Natal Department of Agriculture in Bergville and project team members. Approximately a total of 26 people attended the farmers' day.

Agroforestry technology for fodder production is a new concept for smallholder farmers and other community members in the Upper Thukela region. The purpose of the farmers' day was to: (i) disseminate information on silvopasture agroforestry technology and intercropping cereals with forage legume to increase quantity and improve quality of fodder, (ii) create interest among farmers on these fodder production technologies, (iii) give the farmers an opportunity to express the problems they experience in livestock production in general and with fodder availability, quantity and quality in particular, (iv) allow farmers to give their views on fodder production technologies and to give Mr Mbhele an opportunity to share with other farmers his experiences with the forage technology that was tested on his farm.

(a) Constraints to livestock production: farmers' views

The farmers were given an opportunity to give their views on constraints they encounter in livestock production. All the farmers (100%) who attended stated that shortage of fodder was the major constraint to their livestock production. This was consistent with studies conducted in the Eastern Cape Province in South Africa and central Kenya (Mapiye *et al*. 2009; Nyaata *et al*. 2000) respectively, where most of the farmers reported fodder shortage as the major livestock production constraint.

Livestock diseases were reported by the farmers as the second most important constraint followed by livestock theft. It is well known that livestock diseases occurrence and parasites are strongly influenced by rangeland condition. Livestock that subsist under poor quality rangeland will have high disease infestation problems (Mapiye *et al.* 2009). Most of the farmers stated the non-practice of rotational grazing, unplanned fires and lack of fences were some of the major factors exacerbating the scarcity of good quality feed. Lack of rotational grazing, incorrect burning of the veld and lack of fences, which are common in communal grazing areas, lead to deterioration of veld condition. These views expressed by the farmers are a clear indication that feed scarcity in communal areas is largely related to poor veld management.

The shortage of fodder in terms of quality and quantity as reported by all farmers, justifies the necessity of having agroforestry and intercropping technologies that are adaptable, appropriate and applicable to smallholder farmers to improve the quality and quantity of fodder in the Upper Thukela region. This also emphasizes the significance of having the on-farm research trials in communal areas not only at Zwelisha but to extend these to wider communities in the Upper Thukela region.

Farmers also reported invasion of rangeland by unwanted plant species as a constraint to livestock production. The example of the invader plant according to farmers is *uhlanzafukwe (Pteridium aquilinum)* which causes a huge reduction of grass species in the rangeland and thus accelerates soil erosion. This is a revelation about the extent of rangeland deterioration in the communal areas where the replacement of grass species is no longer attributed to livestock overgrazing but is caused by other plant communities. The rangeland invasion by unwanted plant species indicates the need to intensify land care projects in communal areas.

The other constraint reported by the farmers was the lack of youth involvement in agriculture. Farmers stated that participation by youth in agriculture can play a major role especially when there is a problem of livestock diseases. Farmers stated that the youth can act quickly in organizing vaccines and the problem will be solved without delay. But with them as old people, organizing takes time.

(b) Role of temperate pastures, leguminous trees and maize-lablab as livestock fodder – Presentation by Mr Mbhele

Mr Mbhele, a small-scale dairy farmer, reported to the farmers that leguminous trees provide quality fodder to livestock. He reported that what he likes about these leguminous trees is their ability to increase grass pasture growth next to them which is in contrast to most of the trees where there is no grasses below them. Mr Mbhele informed the farmers that livestock browse these trees especially *Leucaena leucocephala* and to the lesser extent *Acacia karroo*. According to his observation, livestock browse tender branches of *A. karroo* towards the tip of the branches as there are no thorns in this part of the branches. He shared with the farmers that these trees have the ability to grow even during the dry season especially *A. karroo* which is able to withstand frost compared to *L. leucocephala* which sheds its leaves during severe frost. He reported that having these trials on his land assisted him to acquire knowledge and skills on establishing and managing of the trees, pastures, maize and lablab.

He also reported to the farmers that he had learnt from the trials that lablab improve growth and fodder yield of the maize crop and that mixing lablab with maize stover improve the quality of maize. He told other farmers that a single plant of lablab gives a high amount of fodder, an indication that lablab provides large quantities of good quality fodder. He stated that his dairy cows benefited from the inclusion of lablab in maize stover as he noticed the increase in milk production resulting from the maize stover/lablab mixture.

Mr Mbhele informed other farmers that he now wants to plant the leguminous trees and cocksfoot pasture in a larger area as he has realized their potential to increase the amount of fodder and its quality. The comments by Mr Mbhele highlight the importance of having on-farm research trials in communal areas. They enable farmers to acquire knowledge, become interested in forage technologies, acquire skills from the technologies and enhance adoption and implementation of the forage technologies. On-farm trials give the farmers an opportunity to make a thorough evaluation of the technology in terms of feasibility, adaptability and applicability of the real benefits of the technology. These will then enable the farmer to make informed decisions on whether to adopt the technology or not.

(iv) Oral and poster presentation on silvopastoral trial and maize-lablab trial – Mr Mthembu

Mr Mthembu reported to the farmers that silvopastoral and maize-lablab trials had demonstrated that they have potential to increase quantity and improve quality of fodder during the dry season when natural veld has low quantity and poor quality fodder. *Acacia karroo* and *L. leucocephala* can be mixed with poor quality feeds such as maize stover to improve quality. Mr Mthembu informed farmers that the problems of thorns from *A. karroo* can be solved by sun drying branches with leaves after harvesting, placing them into bags and then shaking or beating the bags by sticks to separate the leaves from thorns. The beating technique is well known to the farmers as they also use it to separate dry bean seeds from pods after harvesting. The advantage of *A. karroo* is that it remains green throughout the dry season and this shows the ability to tolerate frost better than *L. leucocephala*. This had been demonstrated at the dairy fodder bank site where some of the *A. karroo* trees were not pruned and remained green even during the winter season.

The experimental results of the trial were also presented as a scientific paper entitled “Increasing fodder production for small-scale dairy farming in the Upper Thukela Region” by Mr Mthembu at the International Commission on Irrigation and Drainage conference in 2007.

Questions and comments by the farmers

Farmers raised concerns about whether these leguminous trees spread and their potential to become a threat to the environment. Mr Mthembu informed the farmers that although *L. leucocephala* has potential of spreading in warmer regions, this is not the case in the Upper Thukela where the cool temperate climate controls the spreading of this tree. That control by climate was demonstrated at a neighbouring homestead (Mr Mahlobo's land) where *L. leucocephala* trees had been in existent for more than 10 years without spreading.

The other concern of the farmers was the availability of lablab seeds. Mr Mthembu informed them that seeds of lablab can be organized at farming co-operatives in Bergville where farmers normally buy other agricultural inputs like fertilizers, pesticides, fungicides and crop seeds. However, lablab seeds will only be available in the shops if there is demand for them as is the case with other agricultural inputs.

Farmers also requested that these trials (that were conducted at Mr Mbhele's land) be expanded to their respective areas (e.g. Okhombe). The request was an indication that farmers are interested in these forage technologies and that there is a need to expand the fodder technologies to their areas. Farmers from Okhombe also reported that there is another tree species (Lothandu) that they wish to be tested in their area as they have observed that it has potential to be used as livestock fodder and also to reduce soil erosion.

Farmers and DoA Extension Officers visited the silvopastoral trial and had an opportunity to observe and ask questions about the species and results of the trial. During the trial observation, farmers emphasized the need of having similar trials in their areas in order to improve fodder productivity and quality for sustainable livestock production. They also emphasized the need of having maize-lablab trial in their area.

Mr Nkosi who is the Head of District at Bergville Department of Agriculture thanked the farmers for attending the farmers' day. He also thanked the project team members for organizing the farmers' day which made it possible to exchange and disseminate the technologies to DoA staff members and farmers. He stated that such cooperation between them and research institutions are very important in ensuring that developed technologies reach a wider community.

(v) Technology transfer to smallholder farmers, Extension Officers, Agricultural Scientists in other provinces: Presentation in GSSA Congress in July 2008

Mr Mbhele made a presentation to other small-scale farmers, scientists and other officials during the Grassland Society of Southern Africa Congress (GSSA) at a Special Session organized by the National Department of Agriculture. He shared the knowledge, technologies and experiences he had gained from the trials with the farmers and other people attending the session. Other farmers showed interest in the trial that Mr Mbhele was involved in, as it was evident from the presentation and discussion by Mr Mbhele that there is potential that small-scale farmers can benefit from the trial. The presentation by Mr Mbhele at the GSSA Congress aroused the farmers' interest. One farmer commented that it was encouraging to hear a farmer just like them presenting new ideas to increase fodder shortage. Mr Mbhele's presentation was supported by a scientific paper presented by Mr Mthembu at the same congress on the experimental results of the trial.

The government officials present commended the WRC and UKZN for the initiative of having this type of research projects conducted in the farmer's field. They made a request for similar on-farm trials to be expanded to Mpumalanga province and other areas of South Africa. The farmers wanted to visit the trial at Mr Mbhele's place for them to further learn and gain practical experience in the trial. The presentation by Mr Mbhele during GSSA Congress resulted in extensive dissemination of the trial results to wider communities across South Africa.

Capacity Building

- This project increased the viability of rural farming systems in the Upper Thukela through the training of small-scale commercial farmers in the application of agroforestry principles.
- Mr Mbhele received training on the establishment of fodder production systems for dairy farming.
- Mr Mandla Miya a fourth year student from Fort Cox College worked on the project for his experiential learning. He has subsequently found permanent employment in the forestry sector.
- Mr Lelethu Sinuka, a student from Fort Cox College, completed his Experiential Training in social forestry while working on the project.
- The broader community received information on various agroforestry technology systems through farmers' days.
- Mr Bongi Mthembu is currently registered for a PhD.

Conclusion

The questions, requests, comments, and concerns during the farmers' days justify the importance of having these on-farm trials of fodder technologies at Zwelisha. They also clearly indicated the need to extend similar on-farm trials to wider communities of the Upper Thukela region. The comments by Mr Mbhele to other farmers that he now wants to plant the leguminous trees and cocksfoot pasture in a larger area as he has realized their potential to increase the amount of fodder and its quality, highlight the importance of having on-farm research trials in communal areas. His comments clearly indicated that on-farm trials enable farmers to acquire knowledge, become interested in forage technologies, acquire skills from the technologies and enhance adoption and implementation of the forage technologies. The on-farm trials and farmers' days also created a link and promoted collaboration with DoA extension services, researchers and private sector e.g. input supplying companies like Pioneer Seed Company.

The farmers' day resulted in farmers, researchers and DoA staff members acquiring knowledge, and more information about forage technologies and their benefits in terms of increasing fodder quantity and quality. Mr Mbhele ended off the final farmers' day by thanking the project team for giving the farmers an opportunity to learn a lot from the on-farm pasture trial. He stated that if it was up to him, he would like to grow these trees all over the area. He said that the project team had enabled them to learn which give them power. He used the example of the need to be taught how to fish. Learning how to catch the fish himself is better than being given a fish and wondering when he will be given one again. By catching the fish himself he learns that he must go to the deeper water and he can use that knowledge to catch more fish. This example illustrates the benefits of on-farm trials.