THE EFFECT OF THE INTRODUCTION OF AGROFORESTRY SPECIES ON THE SOIL MOISTURE REGIME OF TRADITIONAL CROPPING SYSTEMS IN RURAL AREAS

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Prepared for the Water Research Commission by

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EXECUTIVE SUMMARY

1. MOTIVATION

Rural farming systems in the Upper Thukela region of the KwaZulu-Natal Drakensberg operate under communal tenure. The major constraints of these farming systems are the low quality and shortage of fodder during the dry winter season, shortage of land and shortage of water. Fodder trees with a high nutrient content have been used in other parts of Africa to increase animal production. Growing trees together with crops can greatly enhance productivity of rural farming systems, since tree roots can exploit water and nutrients below the shallow roots of crops. Trees can 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; Roothaert 2000), there has been virtually no research on agroforestry systems in the temperate, frost-prone areas of the KwaZulu-Natal Drakensberg.

2. PROJECT OBJECTIVES

Main objective:

To examine agroforestry systems in terms of competition for water between trees and crops.

Secondary objectives:

(a) To monitor soil moisture profiles in agroforestry systems to determine the effects of below ground moisture competition between roots of trees and crops.

(b) To determine the comparative water use of multi-purpose trees in agroforestry systems in the Upper Thukela region for recommendation on appropriate species.

In addition, the project team carried out a study on the economics of the agroforestry system, which was not part of the original objectives.

3. BACKGROUND

In response to a request from a local farmers' association, a project was initiated in 1997 to examine the potential of an agroforestry system to increase fodder production. In 1994 the National Plant Conference was held to address the current wood fuel crisis in South Africa. One recommendation was for the State to incorporate agroforestry into the Reconstruction and Development Programme to increase animal fodder provision and provide fuel wood. In the past, efforts to introduce agroforestry systems to small-scale farmers in the Upper Thukela region have largely been a failure. The main reasons for this are:

(I) There is a general belief that agroforestry species will reduce the water supply and cause low crop yield. Community members have a strong perception that during the recent drought trees were responsible for the drying up of streams.

(ii) There has been a lack of farmer participation in planning research trials and adapting them to people's needs.

In 1994 the CSIR took part in a participatory rural appraisal workshop in the Upper Thukela to give under-serviced communities an opportunity to participate in the planning of their development programmes. One of the main needs identified by the community was to improve the productivity of their cattle. Follow-up workshops have investigated the option of planting fodder trees and addressing the community's needs with respect to trees and water. The current project is part of the implementation phase of these exercises in which farmers are involved in research trials addressing their needs.

The aim of this study was to determine the optimum combination of fodder trees and maize to increase production and minimize soil water competition.

4. METHODS

An on-farm trial was conducted to determine dry matter production of four fodder tree species and their effect on soil water and maize production. The trees were planted in an alley-cropping system and intercropped with maize in a randomised block design. The trees were planted at two row spacings (0.5 and 1 m) with an inter-row spacing of 5.25 m. The four tree species selected were an indigenous fodder tree species (*Acacia karroo*), a nitrogen fixing species *(Leucaena leucocephala)*, a fruit bearing species *(Morus alba)* and a multi-purpose species (*Gleditsia triacanthos)*. The trees were harvested 0.75m above the ground at least twice during the growing season.

In order to increase the chance of adoption of this new technology, the trial was carried out in a participatory way, involving farmers' in all steps (e.g. location of site, management of trees and maize, monitoring biomass production, evaluating tree species etc.). A fodder flow analysis was carried out to determine the farmers' practices and develop an understanding of his farming system and constraints. Regular farmers days were held to provide feedback to the farmers and discuss the benefits and constraints of the agroforestry system.

Volumetric soil moisture was measured in the upper 0.3 m of soil in each row of the trial using the Time Domain Reflectometry technique (Topp, Davis & Annan 1980). One probe was installed in every tree and maize row; a total of one hundred and sixty eight probes throughout the study site. The Neutron probe technique was used for monitoring the water content of the deeper soil in the trial. Twelve aluminium access tubes up to 5 m deep, were placed in each of the plot replicates.

Biomass (fodder and fuelwood) of the trees and maize yield were recorded at regular intervals throughout the study. The effect of shading of the trees on the maize was recorded with a line quantum sensor and seven single quantum sensors. Nutrient analyses were conducted on the four plant species and soil.

5. RESULTS AND DISCUSSION

Fodder yield in all species decreased with the wider intra-row spacing of trees (1 m). It is, therefore, recommended that agroforestry species should be planted 0.5 m apart to maximize fodder production. The most productive tree species throughout the three-year study period was the indigenous species, *Acacia karroo* (1600–3000 kg ha-^{1}). Fodder yield in *L. leucocephala* increased significantly from 1999 (500 kg ha^{-1}) to 2001 (3800 kg ha^{-1}). Although this species was slow in establishing, it is apparent that once established it is a productive species. The *Morus alba* tree had the highest fuel wood production (8300 kg ha^{-1} in 2001) and was favoured by the farmer because of its fruit production.

There were no significant differences in tree height between the wide and narrow intra-row spacing within species. By March 2000 the greatest height was exhibited by *M. alba* (3.8 m) followed by *G. triacanthos* (3.5 m) and *L. leucocephala* (2.8 m). The maize rows next to the *M. alba* trees showed a high percentage of shading (>80%) across all rows. This species should be pruned regularly to minimize the shading effect on adjacent maize rows. By contrast, with the other tree species, the rows furthest from the trees intercepted 50-80% of the available PAR. The least growth in terms of height was exhibited by *A. karroo* (1.5 m). This was due to the relatively slow recovery after the trees were harvested in January 2000. This species should not be pruned severely (>0.75 m) and can be maintained as a hedge.

Shortage of crude protein in diets of cattle has been recognized as a constraint to milk production (CARNET 1996). All four species selected in this trial had high protein contents. *Acacia karroo* and *L. leucocephala* had the highest protein values (23.2 and 25.1 % respectively) of all the tree species. These species can be used as a protein supplement and will increase milk production if they are incorporated into the dairy farming system.

One of the disadvantages of growing fodder trees next to maize is that the trees may compete with the maize for light, nutrients and water. In 1999, the second year of establishment of the trees, the average maize yield in all the plots (5 014 kg ha^{-1}) was higher than the control (4100 kg ha^{-1}). The highest maize yields were recorded in the *A. karroo* and *L. leucocephala* plots (6600 ha^{-1}), and tree spacing did not have a significant effect on maize yield. The maize yield in 2000 was generally lower than the control (3900 kg ha^{-1}) with an average of approximately 3700 kg ha^{-1}. The yield of maize rows closest to the row of each tree species was reduced when compared to the most distant row. This impact was greatest in *G. triacanthos* and *M. alba* where yields decreased from 1190 kg ha^{-1} to 420 kg ha^{-1} and from 1590 kg ha^{-1} to 560 kg ha^{-1}, respectively. The maize yield reduction next to *L. leucocephala* was 100 kg ha^{-1} while that of *A. karroo* was 700 kg ha^{-1}. The results, therefore, show that the trees do impact negatively on maize production of rows closest to the trees, but there are considerable differences between species in this respect.

There was little difference between the soil water content of the tree line and the various maize lines (inner, middle and outer) indicating that competition for water is unlikely to be the reason for lower maize yields. The surface soil water content did not differ significantly between the maize and tree rows. However, at greater soil depths (75-125 cm) the trees in the wide spacing used less water than those in narrow spacing. The high soil water values recorded in this study indicate that in the current cycle of good rainfall the plants in the agroforestry trial were not stressed. Thus the trees did not compete with the crops for soil moisture in good rainfall seasons. Since the trees have access to water at greater soil depths they are likely to be more productive into the dry season than shallow rooted crops.

During dry periods in 2000 the soil water ranged between 19-27%, with no differences recorded between the tree and maize rows. This indicates that the trees exerted no influence on the soil moisture across the trial. The analysis of the wet period showed that values were much higher (28-33%), reflecting the good rainfall over this period. The variability of soil water was much less during the wet periods, and differences due to tree and maize competition would be unlikely during these high moisture conditions.

A comparison of soil water in the profile throughout the study period shows that the trial appeared much drier in 2001 than in 2000, which was in turn drier than 1999. This suggests that there may be drying of the trial profile from year to year as the trees mature.

In order for agroforestry to become widely accepted socially it needs to exhibit clear financial benefits to local communities. Two economic models were applied to the data to determine the financial viability of the agroforestry system compared with a mono-cropped maize system. The results show that agroforestry is economically viable where there is low maize production and high tree production. The relative profitability of agroforestry drops off as maize production increases. Agroforestry systems with a high fodder production by the tree component are, therefore, recommended if agroforestry is to be economically viable.

If the farmer plants one hectare to *A. karroo* intercropped with maize he will save R4500 on dry matter supplements. In addition, the farmer can save costs on fuel wood (R2770) if he intercrops one hectare with *M.alba*. Agroforestry not only benefits the farmer financially but also reduces the pressure on the grassland and indigenous forests.

6. CONCLUSIONS

High soil water values recorded during summer indicated that in the current cycle of good rainfall the plants in the agroforestry trial were not stressed. Thus the trees do not compete with the crops for soil moisture in good rainfall seasons. Light interception was an important factor in reducing maize yields in the row nearest to the trees. Since the trees have access to water at greater depths, they are likely to be more productive into the dry season than shallow rooted crops.

The most productive tree species throughout the three-year study period was the indigenous species, *Acacia karroo* (1600 – 3000 kg ha^{-1}). In spite of decreased maize yields in the trial, this study showed that increased fodder and fuel wood production could result in considerable savings to the farmer. Intercropping trees and maize could result in savings of up to R4 500 on dry maize supplements and R2 700 on fuel wood.

7. EXTENT TO WHICH THE CONTRACT OBJECTIVES HAVE BEEN MET

Main objective:

To examine agroforestry systems in terms of competition for water between trees and crops.

The study indicated that all four fodder trees did not compete with the maize crop for water. However, competition for light had a negative impact on yield of maize rows adjacent to the trees.

Secondary objectives:

(a) *To monitor soil moisture profiles in agroforestry systems to determine the effects of moisture competition between roots of trees and crops.*

The TDR and neutron probe techniques showed that there was little difference in water content between treatments in the surface from 25 to 75 cm where values ranged between 0.16 and 0.18. At 100 cm the less densely spaced trees in both the *A. karroo* and *M. alba* wide treatments appeared to be using less water than the narrow spacing. From 125 to 175 cm the *Acacia* trees in the narrow treatment appeared to be using more water than any other species. From a depth of 200 cm to 400 cm there was little influence of the trees on the water in the profile.

(b) *To determine the comparative water use of multi-purpose trees in agroforestry systems in the Upper Thukela region for recommendation on appropriate species.*

The results of analysis of variance on the TDR soil water data indicated that there were significant differences at the 5% level between the water use of the different tree species. From neutron probe data, the driest profiles were associated with *A. karroo* and the wettest with *M. alba* wide treatment. At 100 cm soil depth the less densely spaced trees in both the *A. karroo* and *M. alba* wide treatments appeared to be using less water than the narrow spacing. From 125 to 175 cm the *Acacia* trees in the narrow treatment appeared to be using more water than any other species.

8. CAPACITY BUILDING & TECHNOLOGY EXCHANGE

The agroforestry trial is an important demonstration of a quantitative on-farm agroforestry experimental trial in KwaZulu-Natal. The trial plays an essential role as a demonstration of the potential of agroforestry in supplementing fodder shortages in rural farming systems. In order to build the capacity of the community, cross visits to the agroforestry trial were held by members of the neighbouring Okhombe community. They had the opportunity to talk to members of Mr Mahlobo's work team and discuss the use of trees in providing fodder to improve productivity. The trial enabled community members to plan their tree planting programmes.

Visits to the trial by rural resource management students, Landcare facilitators and grassland science students at the University of Natal contributed to the learning experience and capacity building of these groups.

The project forms the core of a PhD study for Mr van Niekerk.

Mr. G. Ramuthivheli, a student from RAU, carried out the economics survey on the value of fodder and supplements for cattle in the Upper Thukela district as part of his MSc study.

The on-farm trial was used as a demonstration in a pilot study for rural resource management students at the University of Natal. This proved to be so successful that it is now included in the Participatory Development Certificate in Education. This will be upgraded to 32 credits in 2003. Fifteen students doing the Land Care course have visited the trial and gained valuable experience on solving problems co-operatively with farmers.

Mahlodi Tau, a student at the University of Natal, is currently using the trial in his Masters study on improving rural livelihoods through natural resource management.

The trial is also a valuable demonstration to local and overseas students as it shows the importance of on-farm trials in rural areas. Numerous students have been taken to the trial including students from other countries such as Zimbabwe, Eritrea, and Kenya.

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.

9. RECOMMENDATIONS

This study indicated that the introduction of fodder trees as an alley cropping system into maize fields increased fodder production. However, one of the problems of alley cropping is that it is difficult for the farmer to harvest the fodder and weed the cropland. Two systems suggested by the farmer are the planting of trees within the fence along the farm boundary, or along contour bunds in the maize fields. Further research is required to examine alternative agroforestry systems that will optimize management of crops and fodder trees in temperate, frost-prone areas of KwaZulu-Natal.

In recent years there has been a move by farmers away from the accepted annual ploughing and cropping system to "no till" systems. The impact of these techniques on agroforestry systems requires further investigation.

The broader dissemination of the results of this study to other communities, extension officers, students and researchers, can be achieved through producing a popular article in the form of a leaflet.

10. DATA

All processed data have been catalogued and stored at Environmentek, CSIR, c/o Department of Agrometeorology, UNP, P/Bag X01, Scottsville, 3209.

Contact person: Dr. C.S. Everson.

These data are held on non-flexible diskette. All data can be supplied to researchers and managers on CD-R diskettes.

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Dr Gerhard Backeberg	Water Research Commission (past chairman)
Mr Hugo Maaren	Water Research Commission
Mrs CM Smit	Water Research Commission (committee secretary)
Ms K Chetty	Water Research Commission (committee secretary)
Mr Jan Bosch	CSIR Environmentek
Mr Graham Von Maltitz	CSIR Environmentek
Mr Raymond Auerbach	Rainman Landcare Foundation
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Prof. Norman Rethman	University of Pretoria
Mr Brian Mappeldoram	ARC Range and Forage Institute

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CHAPTER 1: INTRODUCTION

1.1 Background

Fodder shortages, especially during the dry winter season, are one of the main problems facing cattle owners in the Upper Thukela region of KwaZulu-Natal. One option to increase production is to grow fodder trees that supply palatable, nutritious material during winter when natural grassland is not available. Agroforestry could, therefore, provide dry season forage and at the same time diversify the range of products from the cropland. The ability of trees to continue growing into the dry season after crops are harvested, and to commence growth before annual and perennial forages, is important in areas where dry-season fodder shortages are acute (Ong, *et al.* 1991).

In response to a request from a local farmers' association, a project was initiated in 1997 to examine the potential of an agroforestry system to increase fodder production. In many parts of the tropics, fodder trees and shrubs are actively harvested by farmers and fed to livestock (Huxley 1999). Growing trees together with crops can greatly enhance productivity of rural farming systems, since tree roots can exploit water and nutrients below the relatively shallow roots of crops. Trees can 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; Roothaert 2000), there has been virtually no research on agroforestry systems in the temperate summer rainfall region of South Africa. This may be partly due to the paucity of trees in this landscape, lack of farmer knowledge on the potential of agroforestry species, poor soils and the harsh climate.

In 1994 the National Plant Conference was held to address the current wood fuel crisis is South Africa. One recommendation was for the state to incorporate agroforestry into the Reconstruction and Development Programme to increase animal fodder provision and provide fuel wood. Efforts to introduce agroforestry systems to small-scale farmers in the Upper Thukela region have largely been a failure in the past. The main reasons for this are:

(I) There is a general belief that agroforestry species will reduce the water supply and cause low crop yields. Community members have a strong perception that during the recent drought trees were responsible for the drying up of streams.

(ii) There has been a lack of farmer participation in planning research trials and adapting them to people's needs.

In 1994 the CSIR took part in a participatory rural appraisal workshop in the Upper Thukela to give under-serviced communities an opportunity to participate in the planning of their development programmes. One of the main needs identified by the community was to improve the productivity of their cattle. Follow -up workshops have investigated the option of planting fodder trees and addressing the communities' needs with respect to trees and water. The current project is part of the implementation phase of these exercises, in which farmers are involved in research trials addressing their needs.

An on-farm trial was planned and initiated with a local farmer, Mr Mahlobo, who operates a small-scale dairy enterprise. Mr Mahlobo is a member of the Khulani Farmers' Union, and through this involvement had his farm selected for the trial. Although the farm is situated in the foothills of the Drakensberg mountains, the main catchment area for KwaZulu-Natal, there is a shortage of water in the 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.

1.2. Objectives

Main objective:

To examine agroforestry systems in terms of competition for water between trees and crops.

Secondary objectives:

(a) To monitor soil moisture profiles in agroforestry systems to determine the effects of below ground moisture competition between roots of trees and crops.

(b) To determine the comparative water use of multi-purpose trees in agroforestry systems in the Upper Thukela region for recommendation on appropriate species.

CHAPTER 2: THE STUDY SITE

2.1. Study Area

The study site (Fig 2.1) is located approximately 25 km northwest of Bergville (28°30'27"S; 29°00'23"E). The farm where the study was carried out falls within a communal rangeland area previously known as the "Upper Thukela Location". The total area of the region is approximately 1 000 km^2. The area is bordered to the southwest by Lesotho and to the north and north-east by the Thukela River and Woodstock dam. The farm is situated approximately 1000 m from the Woodstock dam.

The vegetation of the area falls into Bioresource Group 12, Moist Tall Grassveld (Camp 1997). The characteristic feature of this bioresource group is the abundance of *Hyparrhenia hirta* (thatch grass) 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

Well managed grassland is dominated by *Themeda triandra*. However, increased grazing pressure by livestock has resulted in changes to the plant community composition. Overgrazed areas of veld are dominated by "mtshiki" species (*Eragrostis curvula, E. plana, Sporobolus africanus* and *S. pyrimidalis*). These areas have a reduced grazing capacity and the grazing value deteriorates early in the season.

The area falls into the summer rainfall region. The mean annual rainfall range of this bioresource group is 712-805 mm and the mean annual temperature is 17.1°C. Temperatures vary substantially from summer to winter. The warmest month is January and the coolest June. Frosts are moderate with the occasional severe frost. Representative temperatures for Bergville are shown in Table 1.1.

The mean annual potential evaporation (A-pan) is 1834 mm. The daily minimum relative humidity is 51 and 30% for January and June respectively.

Table 1.1. Mean temperature data for Bergville. Altitude, 1058 m.

January			June		
Ave Max	Ave Min	Ave Daily	Ave Max	Ave Min	Ave Daily
26.2	14.2	20.2	18.3	3.7	11.1

The soils of the study area are arable and deep with a well developed microstructure and good permeability. However, they are strongly leached, very acid and have a poor inherent fertility (HKS report 1988). Liming and fertilization are therefore essential for good crop growth. Maize is the most important crop in the area. Maize yield estimation based on the ACRU maize yield model is 4-5 $t.ha^{-1}.season^{-1}$ (Schulze *et al.* 1997). The soil in the trial was classified as Hutton.

The traditional farming system is based on the two main enterprises of keeping cattle and growing maize. The grazing rotation is related to the cropping cycle. 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, however, kept in the vicinity of the homesteads.

Figure 2.1 The locality of the agroforestry trial in the foothills of the Drakensberg in KwaZulu-Natal.

CHAPTER 3: METHODS AND MATERIALS

3.1 Experimental design

3.1.1 Plot layout

An on-farm trial was planned and initiated with a local farmer who operates a small-scale dairy enterprise. The trial was conducted in a fenced field close to the homestead.

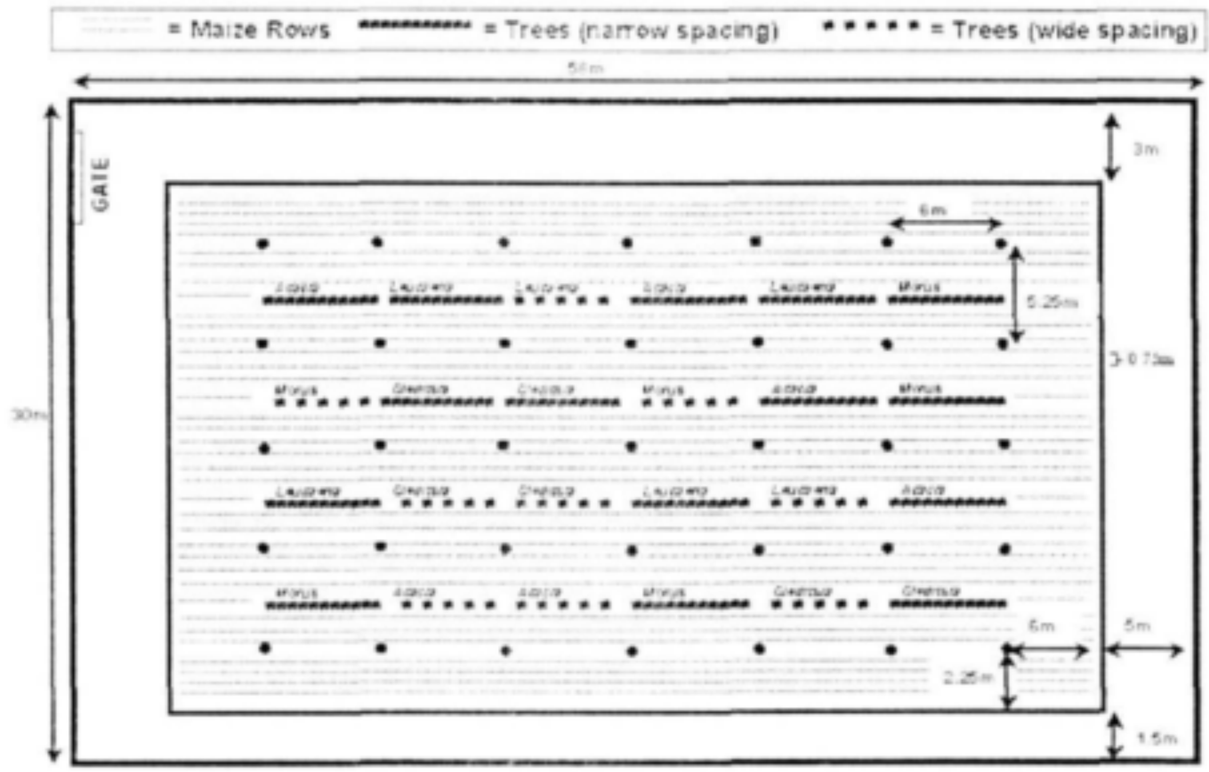


Figure 3.1. The experimental design of the agroforestry trial.

The size of the plot and inclusion of a control were discussed with the farmer. The control (maize with no trees) was planted in two 6m strips on either side of the experimental plot. Also included in the fenced area was a five-metre buffer zone to enable the tractor to turn. The experimental design is shown in Figure 3.1. The size of the fenced area is 58 X 30 metres. A gate was located on the southern side of the plot.

The long axis (north/south) of the plot was:
Buffer: 2 x 5 m = 10m
Control: 2 x 6 m = 12m

Expt. Plot:6 x 6 m = 36m
TOTAL 58m

The short axis (west/east) of the plot was:
Buffer: 1.5m
3 rows maize: 3 x 0.75 = 2.25
Expt. Plot: 4 x 5.25 (7 rows x 0.75m) = 21 m
3 rows maize: 3 x 0.75 = 2.25
buffer: 3.0m
TOTAL 30M

3.1.2 *Agroforestry system*

An alley cropping system was established in which four tree species were planted at two spacings (0.5 m and 1.0 m) between six rows of maize plants (Fig. 3.1). Each treatment was replicated three times ina randomised block design consisting of 24 plots (6m X 3.5m) representing eight treatments (four tree species at two spacing intervals). A total of 216 trees were planted for the whole trial.

The rows of maize and trees were planted in a north/south direction to minimize shading of the crop by the trees. The rows of maize plants were 0.75 m apart while individual plants were 0.3 m apart.

Locating suitable agroforestry species that would meet the farmer's need for fodder was a problem since few registered nurseries stock suitable species.

Plate 3.1. The alley-cropping experiment

One of the factors that will affect recommendations of suitable agroforestry species is the classification of alien species in terms of the 2001 amendments to the Conservation of Agricultural Resources Act No. 43 of 1983. Alien species have been divided under three categories (Henderson 2001) based on their potential invasiveness: Category 1 plants are prohibited and must be controlled; Category 2 plants (commercially used plants) may be grown in demarcated areas provided that there is a permit and that steps are taken to prevent their spread; and Category 3 plants (ornamentally used plants) may only be planted with special permission. Existing plants may remain but must be prevented from spreading.

In KwaZulu-Natal *Leucaena leucocephala* and *Gleditsia triacanthos* are classified as category 2 species, while *Morus alba* is classified as a category 3 species. Permits will be required to plant these trees for agricultural purposes. The species selected in this study were an indigenous species, *Acacia karroo* (sweet thorn), a nitrogen fixing species, *Leucaena leucocephala* (Leucaena), a fruit tree, *Morus alba* (mulberry), and a palatable multi-purpose tree, *Gleditsia triacanthos* (honey locust).

3.1.3. TDR *layout*

Volumetric soil moisture was measured in the upper 0.3 m of soil in each row of the trial using the Time Domain Reflectometry technique (Topp, Davis & Annan 1980). This technique enabled the automatic collection of soil water data at six-hourly intervals. One probe was installed in every tree and maize row; a total of one hundred and sixty eight probes throughout the study site.

3.2 TDR technique

3.2.1 Introduction

Measuring the water uptake by trees is notoriously difficult (Ong, Singh, Khan & Osman 1990). Time domain reflectometry (TDR) is a non-destructive technique for simultaneous measurement of soil water content and soil electrical conductivity. The time domain reflectometry system propagates a balanced waveform, which travels down a coaxial cable and waveguide and is influenced by the type of material surrounding the conductors. If the dielectric constant of the material is high, the signal propagates slower. Because the dielectric constant of water is much higher than most materials, a signal within a moist medium propagates slower than the same medium when dry. Thus the moisture content can be determined by measuring the propagation time over a fixed length probe embedded in the soil. Time domain reflectometry has the advantage that it does not require calibration, is easily automated and can be used to collect hourly or daily data. The principles of TDR, instrumentation and probe design are presented in Appendix A.

In this study the volumetric soil moisture was measured in the upper 0.3m of soil in each row of the trial using the TDR technique (Topp, Davis & Annan 1980). This enabled the automatic collection of soil water data at six-hourly intervals. One probe was installed in every tree and maize row; a total of 168 probes throughout the study site. The addresses, probe configuration and plot and row identification for the 23 multiplexers and 168 probes is shown in Appendix B.

3.2.2 *Geo-Statistical analysis*

Geostatistical methods were used to develop a model and fitting technique to predict water content in the trial for the 1999, 2000 and 2001 TDR data. The spatial prediction was carried out by the Geostatistical technique of kriging (Cressie, 1993), which in turn depends on parameter estimation by use of variograms (Loague 1992, Cressie 1993) or cross validation (Clarke & Dane 1991). In essence, the variogram expresses the change in semi variance ($\gamma(h)$), between two points as a function of their distance apart (h), where the semi-variance is defined to be the variance of the difference of the variate in question (here, water content) measured at points a given distance, h, apart. The critical parameters in this geostatistical model are the range, defined as the distance beyond which there is no spatial correlation and the sill which is the asymtopic value of $\gamma(h)$, for values of h greater the range, and the nugget which is the value of $\gamma(h)$ when h=0.

Data organization and programming

- The TDR records were organized into data files suitable for access by statistical packages. Initially the data were organised into excel files and the data examined graphically to test if there were underlying problems or trends in the data.

From the rainfall data a wet and dry weather period were selected. For each of these periods the data were averaged and then arranged into various Geo-EAS data files.

- 16 different Geo-EAS data files (for the individual treatments) were produced. From these variograms were drawn for each of the treatments, and saved as monochrome bitmap files. The details of the models fitted were also recorded.
- Four other Geo-EAS data files were also produced, of the entire data set (for both groups) and of the entire data set excluding the data from the tree lines. Variograms for these were also drawn, modelled and printed out.

Using the models developed without the tree data, the entire data range was then kriged and the values predicted for the tree lines and the actual tree line values were compared.

3.3 Neutron Probe

The Neutron probe technique was used for monitoring the soil water content in the trial. The count rate was translated into the gravimetric soil moisture content using a calibration curve developed from gravimetric samples collected during the installation of the access tubes.

Water content was converted to volumetric water content from previously determined values of the soil bulk density. Measurements were made at approximately monthly intervals between December 1999 and April 2001.

3.3.1 *Basic principles and theory*

The Neutron probe technique is a nondestructive method for measuring the water content of soil (Reginato & Nakayama 1987). This method is based on the fact that the hydrogen nucleus has the same mass as a neutron. When the two collide there is a transfer of energy, which slows down the neutron. This change in energy is measured with a neutron probe.

The neutron probe contains a fast neutron source and a slow neutron detector, a pulse counter, a cable connecting the two, and a transport shield. The shield is fitted to the protruding upper end of an aluminium access tube that is positioned vertically in the soil. The probe is lowered directly into the access tube to successive measurement depths by means of a cable. A depth indicator and moderator, which acts as a field standard, are incorporated on the shield. The counter unit remains at the surface; this incorporates the electronic controls, the readout display, the battery that powers the system and the circuits that count the pulses from the probe.

The probe contains a radioactive source that emits fast neutrons into the surrounding soil. Collisions with the nuclei of the soil atoms, predominantly those of hydrogen in the soil water, cause the neutrons to scatter, to slow and to lose energy. When they have slowed to a 'thermal' energy level they are absorbed by other nuclear reactions. Thus a 'cloud' of slow neutrons is generated within the soil around the source. A slow neutron detector in the probe samples the density of this cloud, which is largely a function of the soil water content. The electrical pulses from the detector are amplified and shaped before passing up the cable to the counter unit where their mean count rate is displayed. The count rate is translated into the soil moisture content (by volume) using an appropriate calibration curve.

In this study the technique was chosen as it was considered the most suitable for obtaining soil moisture data from deep in the profile.

3.3.2 *Methods*

Twelve aluminium access tubes, were placed approximately 5 m deep in one of each of the plot replicates. The access tubes were installed in October 2000 while moisture contents were still high. During installation gravimetric samples and corresponding count ratios were collected. Count ratios were routinely taken from these sites at 0.25 m intervals whenever the trial was visited during the growing season.

Bulk densities were only determined to a depth of 1 m for feasibility reasons. Soil samples were oven-dried at 105 °C and the percentage soil water content (on a mass basis) determined. A similar procedure was followed at monthly intervals between May and August, except that the soil samples were collected from cores taken approximately 1 m from the access tubes. The samples therefore represented a moisture gradient from saturated (March) to dry (August), the complete range of possible conditions represented at the site.

At the end of August there were 5 pairs of readings (gravimetric and corresponding count ratio) for each depth (8) for every tube (14). However, not all tubes were 2 m deep and eventually 353 pairs of readings were used in the calibration of the instrument (Appendix A). The mean bulk density was 1.10. Soil water content was converted to volumetric water content from the previously determined values of the soil bulk density.

3.4 Plant Production

3.4.1 *Tree Biomass*

The biomass of fodder and fuelwood from the trees was separated into:

(a) The *fodder component* - the total plant material that is potentially edible by cows. All leaves and twigs < 4mm (including thorns) were stripped from the tree, dried and weighed. The samples were milled and incorporated into the winter cattle feed.

(b) The *fuelwood component* - all remaining woody material above a height of 0.75 m was harvested. The wood was dried and weighed and returned to the farmer for firewood.

The biomass of the trees was recorded when the trees were pruned annually in May throughout the study period.

3.4.2 *Tree Growth*

Tree height and diameter were measured at regular intervals throughout the study period. Tree diameter was measured 100 mm above the ground. In the multi-stemmed species, which coppiced after pruning, the largest trunk was selected for diameter measures.

3.4.3 *Maize Yield*

The biomass of the maize was recorded annually in June when the farmer harvested the crop. The biomass was separated into grain, cobs, and stem and leaf material at each harvest.

3.4.4 *Nutrient Analysis*

Fodder

To assess the potential value of the trees as fodder, the nutrient content (N, K, P, Ca and Mg) and acid digestible fibre of the four tree species was determined according to the techniques used by the Cedara Agricultural College (Manson, Milborrow, Miles, Farina & Johnston, 1993).

3.5 **Soil analysis**

Soil analyses (Cedara Agricultural College; Manson, Milborrow, Miles, Farina & Johnston, 1993) were conducted on three of the lands on Mr Mahlobo's farm. Samples reflected the two broad land types on the farm, namely those on alluvial soils close to the river (land 1), and those on upland soils (land 2 and 3).

3.6 The influence of trees on the distribution of light within the maize rows of the agroforestry trial.

3.6.1 Radiation measurement

Details of instruments available for radiation measurement are well described elsewhere (Bainbridge et al. 1966; Rosenburg 1974; Fritschen & Gay 1979; Unwin 1980). This section briefly considers some important considerations that influence the choice of radiation instruments. The commonest techniques involve either (a) photoelectric detectors (e.g. silicon cells, cadmium sulphide photo-resistive cells, or selenium cells) or (b) thermal detectors that measure temperature differences between surfaces that differentially absorb the incident radiation (usually a matt black surface that is a good absorber at all wavelengths). Photoelectric devices generally have a faster response than thermal detectors, are cheaper and were therefore selected for use in this study. Because the spectral responses of various physiological processes differ, the instrument must have an appropriate spectral sensitivity. This is particularly important when the spectral distribution is changed (filtered) by plant canopies. For this reason a sensor that was sensitive to photon irradiance in the photsynthetically active region (PAR) of the light spectrum (400-700µm) was selected. These sensors are termed quantum sensors, and quantum sensors manufactured by Li-cor. Inc. were used in this study. This sensor was chosen as it has a good cosine response, in that the irradiance measured for a beam at an angle θ to the normal is proportional to the cos θ as expected from Lambert's Law.

In studying radiation in plant canopies, spatial heterogeneity can lead to large sampling errors. A useful solution is to use large radiation sensors such as long tube solarimeters that average over a large area. The line quantum senor used in this study is one such instrument. Alternatively one can use many sensors, or one can move the sensors through the crop. A combination of these two approaches was used in this study.

3.6.1.1 *Line Quantum Data*

The line Quantum sensor was used to obtain an integrated PAR value in an east-west direction i.e. across the maize rows.

For DOY 109 four consecutive morning and afternoon reading sets were taken per plot for the eight plots representing the eight treatments used in the trial (A1-D1&A2-D2). Readings were taken on the westerly side of trees in the morning and easterly side in the afternoon since the effect of tree shading on maize was the objective and the trees cast shadows accordingly. The same process was repeated for the morning of DOY 110. Data (LineQ109) was first converted to PAR values for the individual sets and graphs compiled to see what the shading effect per set was. These data were then summed over the whole day to obtain a complete integrated data value per plot/treatment over time for DOY 109 and a graph compiled.

3.6.1.2 *Single Quantum Data*

For each of the eight plots/treatments seven quantum sensors were placed and consecutively moved to the next plot as quickly as possible for DOY 109. i.e. one sensor for each row of maize and one for the tree row = seven sensors. Readings were then logged at one second intervals. This was done to try and establish a shading distribution on either side of tree rows at a given time, and so compare these between treatments. Representative point readings from these data were then selected and multiplied to a PAR value and % shading values graphed for individual row distribution and combined opposite row distributions in order to quantify the shading distribution.

Combined opposite row distributions simply combined pairs of maize rows equidistant from the tree row. An integrated total PAR graph was also compiled to obtain an integrated single PAR value across rows per plot/treatment, in order to see what total radiation each plot received at a point in time.

3.6.1.3 Daily Acacia Narrow - Single Quantum Data

Sensors were again set up exactly as for the Single Quantum Data description above, but only for the *Acacia* Narrow (AN) treatment for the whole day of DOY 110. Unfortunately the number of sensors was limited and so this could not be repeated for each treatment at that given time to enable daily comparisons between treatments to be performed. These data were again plotted for single and combined rows and finally as an integrated daily value.

3.6.1.4 General

Details of the naming convention used to label the data were:

-Row 1 = First row of maize per plot closest to homestead i.e. Most westerly row.

-Row 6 = Last row of maize per plot furthest from the homestead i.e., Most easterly row.

-Plot A1 = First plot as enter the trial from the gate i.e. Most south-westerly plot = *Acacia* Narrow = AN

-Plot B1 (MW), C1 (LN), D1 (MN) are consecutive plots in an easterly direction (A-D represent the four tree rows running in a North-South direction)

-Plot A2 (LW), B2 (GN), C2 (GW), D2 (AW) is simply adjacent rows of plots (1 row north).

-The control sensor was situated near the trial on a raised surface (level) where no shading effects would come into play i.e. full sun

-Control readings were taken at one-second intervals and averaged for each minute except where more detail was necessary.

CHAPTER 4: RESULTS

4.1 Rainfall during study period

Figure 4.1 illustrates daily rainfall amounts during selected periods of the maize growing season, for four successive years of the trial. It is important to note that the rainfall data are in support of the TDR data and do not span the full growing season. The periods selected were from Day of Year (DOY) 27 (27 January) to 88 (28/29 March) for years 1999, 2000 and 2001, and from DOY 57 (26 February) to 88 for year 1998. The first two years were drier during this period than the last two years, with total rainfall amounts of 133.8 mm and 146.2 mm for the experimental periods monitored in each season1998 and 1999 respectively, compared with 215.6 mm and 234.0 mm for 2000 and 2001. The highest daily rainfall total was of 54.6 mm (DOY 49 / 18 February 2001). The mean annual rainfall for Bergville during the years 1996 to 1999 was 1351, 1060, 882 and 776 mm respectively. Thus none of the study years fell below the long term average of about 750 mm.

4.2 Soil Water

4.2.1 Soil Water (1998)

4.2.1.1 Time-Domain Reflectometry

The TDR equipment was installed in February 1998 after the maize was planted. The installation of the probes was randomised within each row by generating random numbers corresponding to the number of maize plants in each row.

After the initial installation the system was struck by lightning damaging the transient suppressor, power supply and a number of the multiplexers. These were repaired at the University and only a few days of data were lost. The failure of a number of the multiplexers also resulted in data loss from certain of the plots early in the experiment.

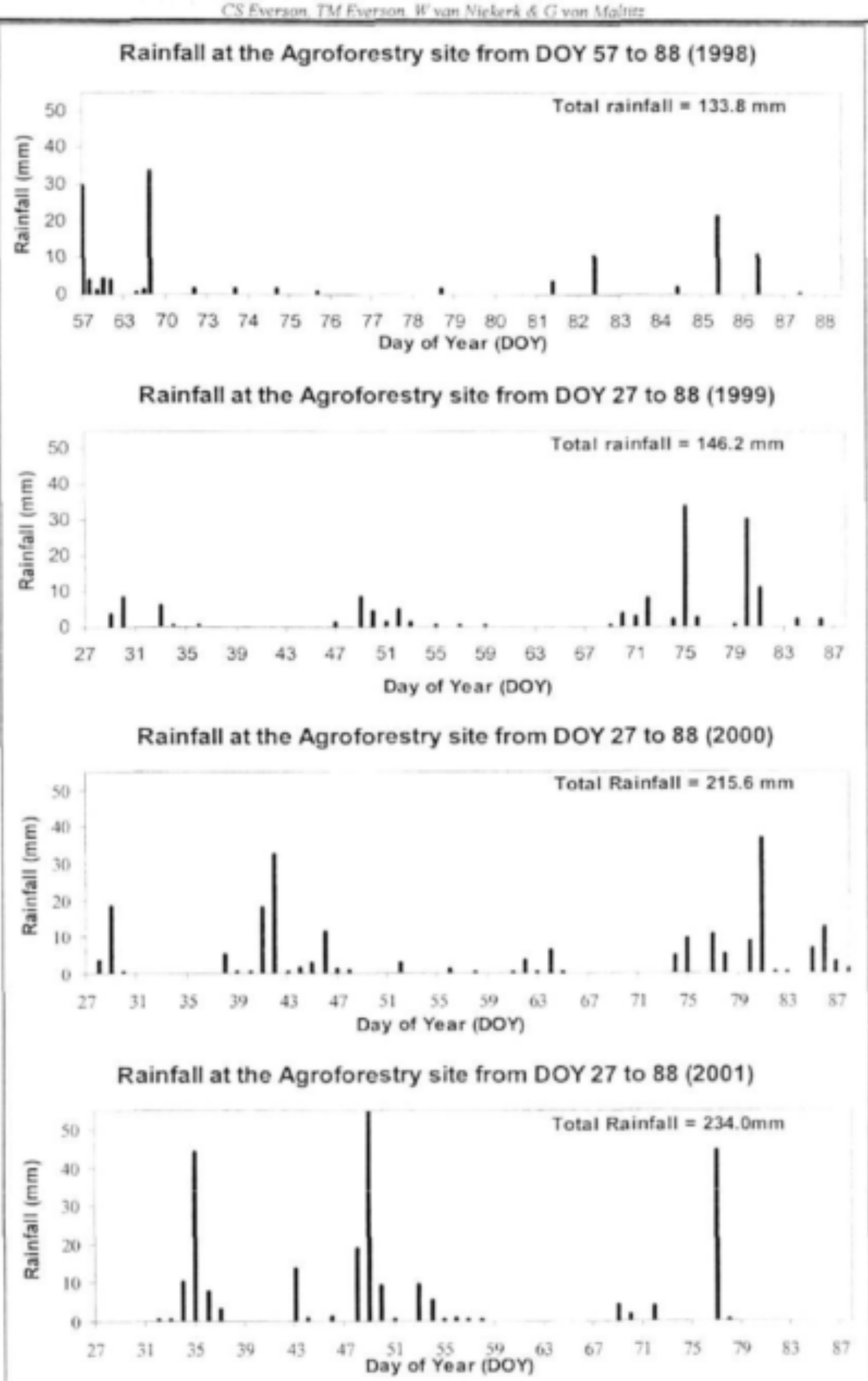
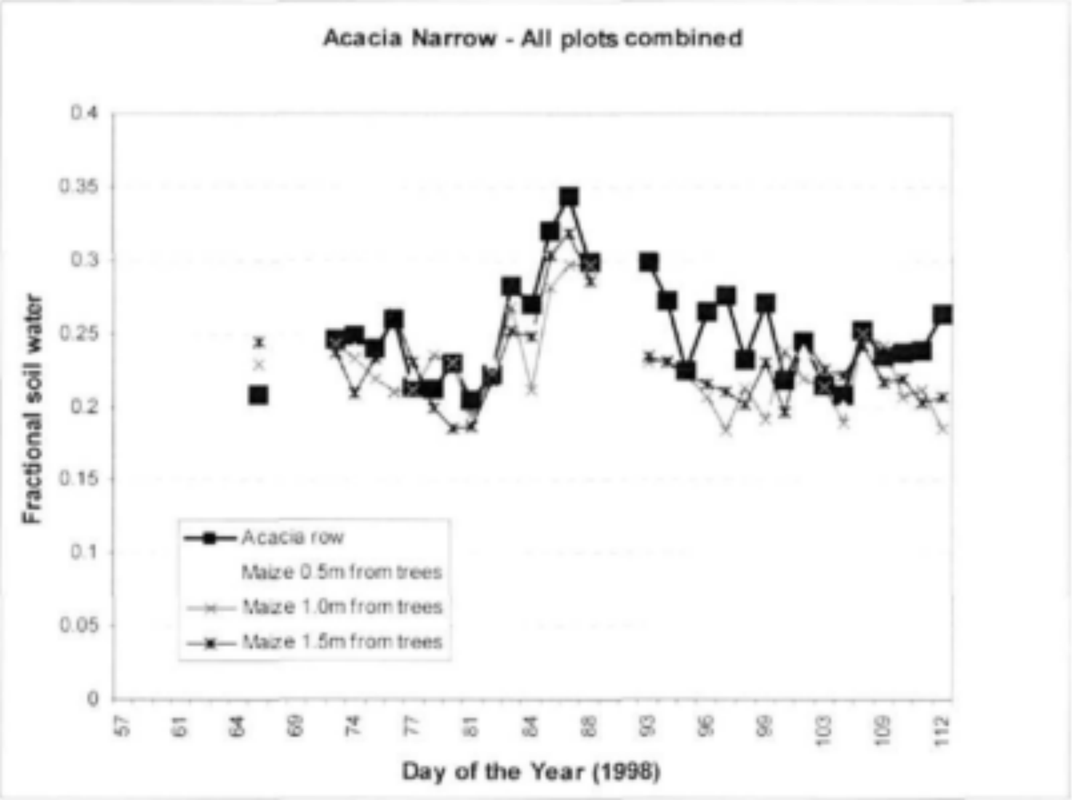


Figure 4.1 Daily rainfall patterns experienced during selected periods of the maize growing season for four successive years of the trial (1998 to 2001).

4.2.1.2 Soil water content 1998

Daily fractional soil moisture data (12h00) was measured in each row of the trial from DOY 57 to DOY 112 (Fig. 4.2). Since distance of the maize plants from the trees is likely to be a key factor in competition for water, the soil water content for the rows of maize plants at specific distances from the trees are presented in Figure 4.2. Replicates of rows 1 and 6 were combined to represent 1.5 m from the trees; rows 2 and 5 represent 1.0 m from the trees and rows 3 and 4 represent 0.5 m from the trees.

High values of fractional soil water (± 0.30) were recorded in all treatments following the two main rainfall events on DOY 56-71 and DOY 84-87 (Fig. 4.2 a-d). Once rainfall ceased there was generally a rapid decline in soil water to ± 0.20 and then a more gradual decline to ± 0.15. Differences between the rows were not easily discernable from the data. However, the maize planted 0.5 m from trees tended to have the lowest soil moisture in most treatments. In the first year of tree establishment the treatment using the most water was the mulberry with the wide spacing (Fig. 4.2 d). This corresponds with the high growth rates recorded for this species (see section 4.5.1). The narrow spacing treatment reduced soil moisture in all the treatments when compared to the wider spacing. For example, in *Gleditsia* plots the soil moisture in the widely spaced treatment was consistently higher than the maize rows, whereas in the narrow treatment the trees tended to have lower soil moisture than the maize (Fig. 4.2 b). The trees using the least water were the *A. karroo* species (Fig. 4.2a) where soil water content was between 0.2 and 0.35 for most of the growing season.



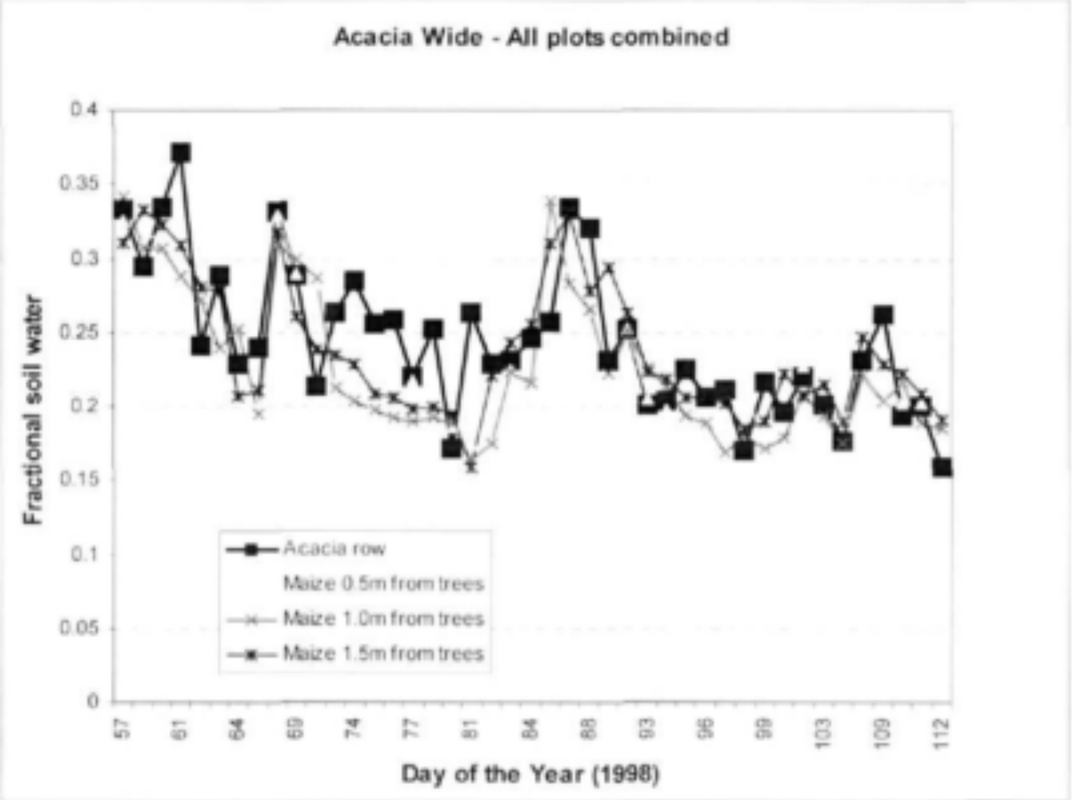


Figure 4.2 a. Daily fractional soil water in the *Acacia* wide and narrow treatments in 1998.

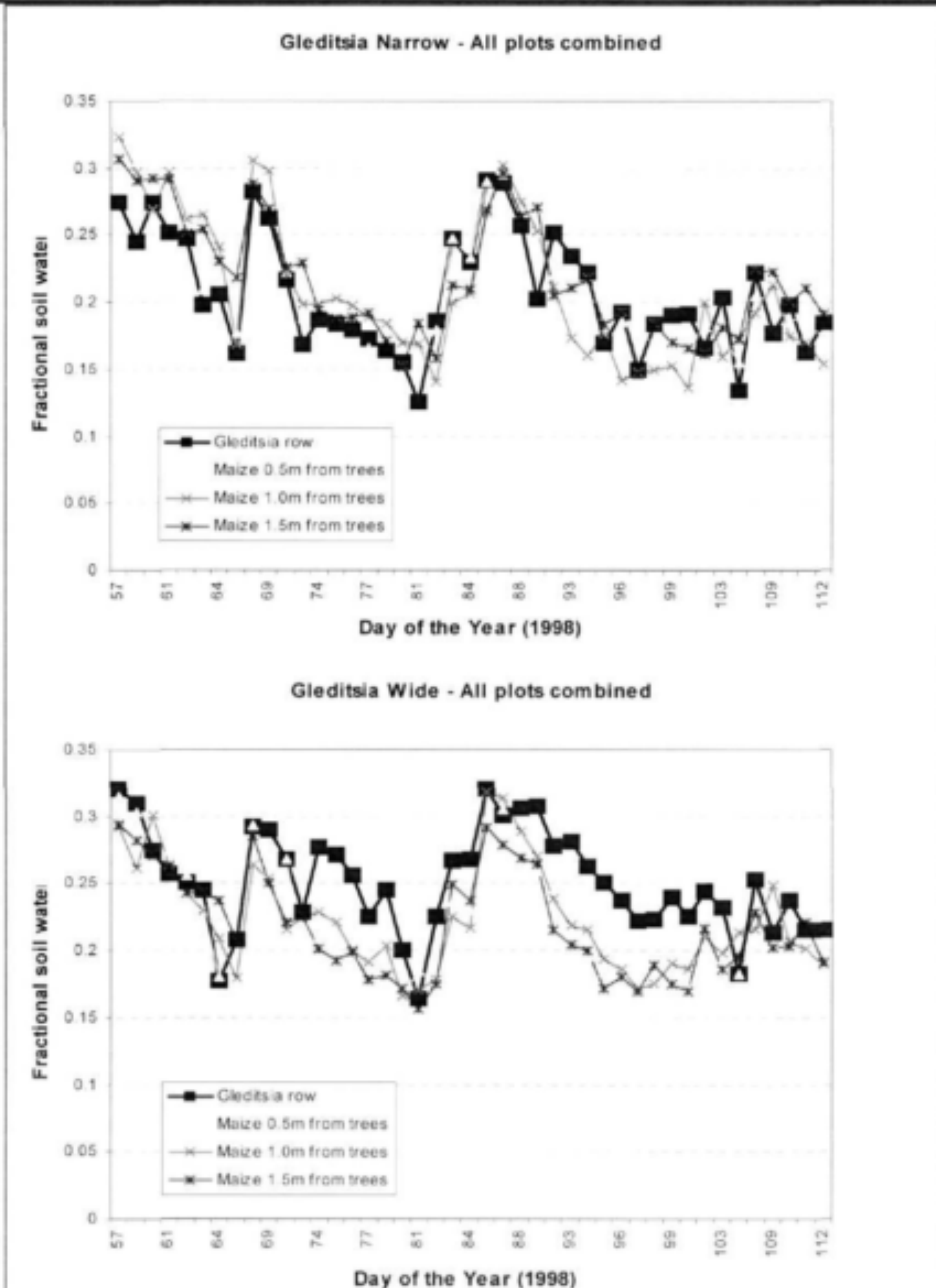
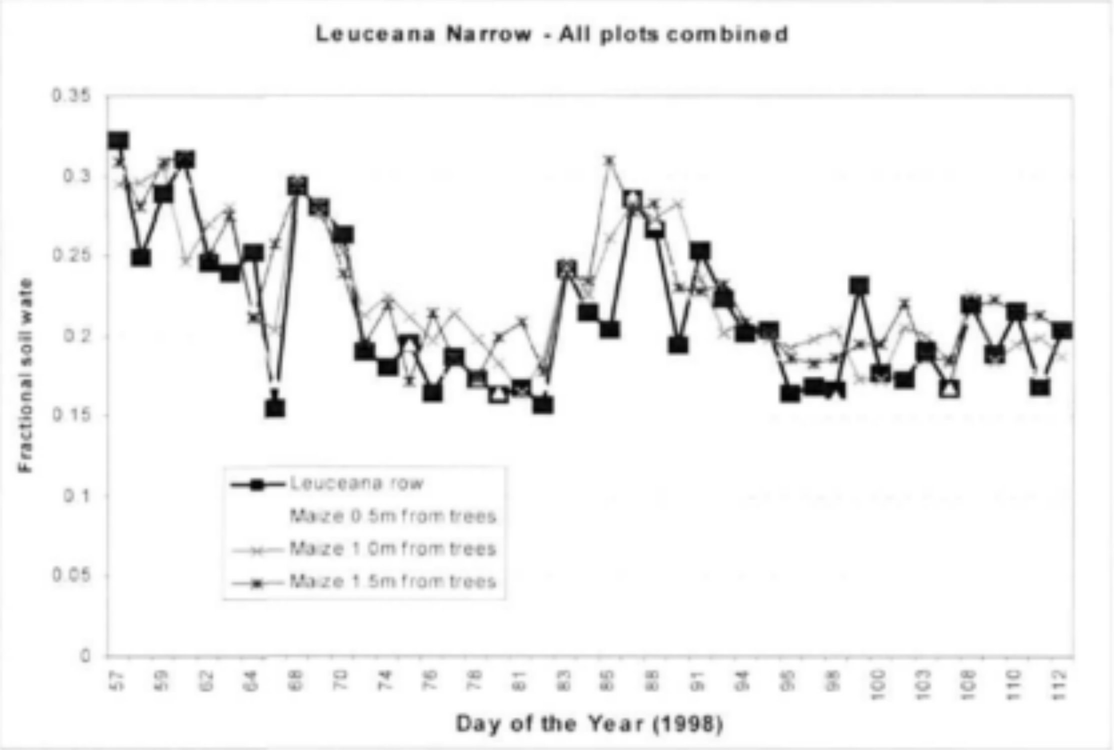


Figure 4.2 b. Daily fractional soil water in the *Gleditsia* wide and narrow treatments 1998.



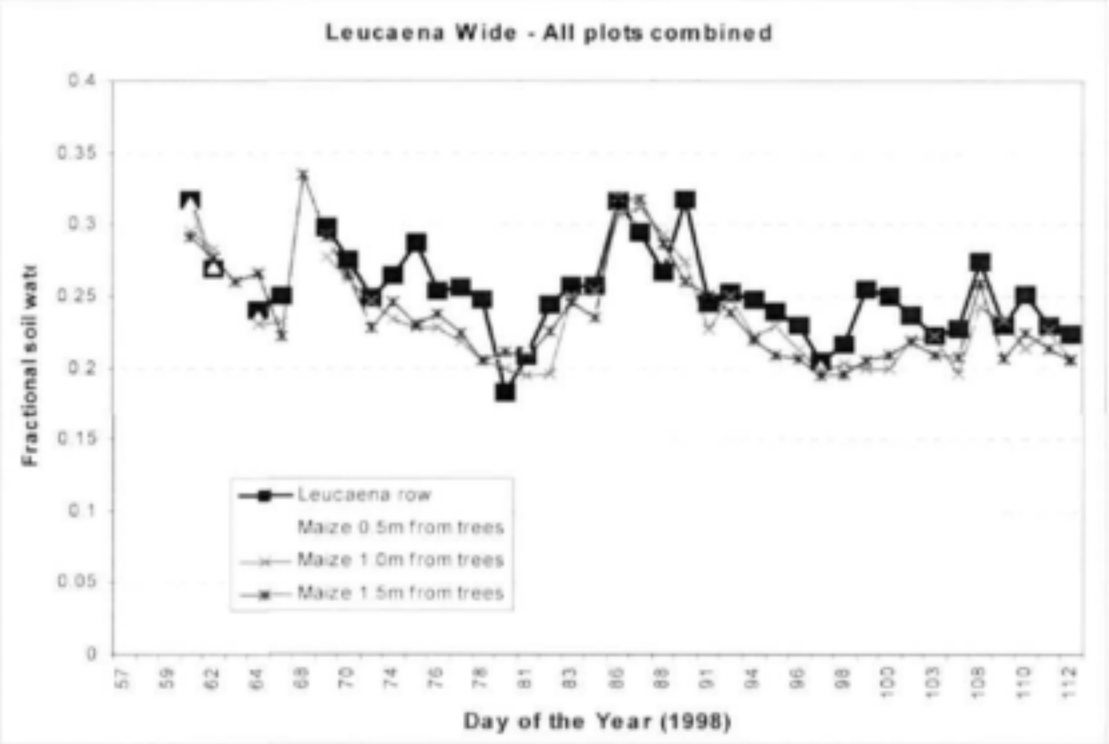


Figure 4.2 c. Daily fractional soil water in the *Leucaena* wide and narrow treatments 1998.

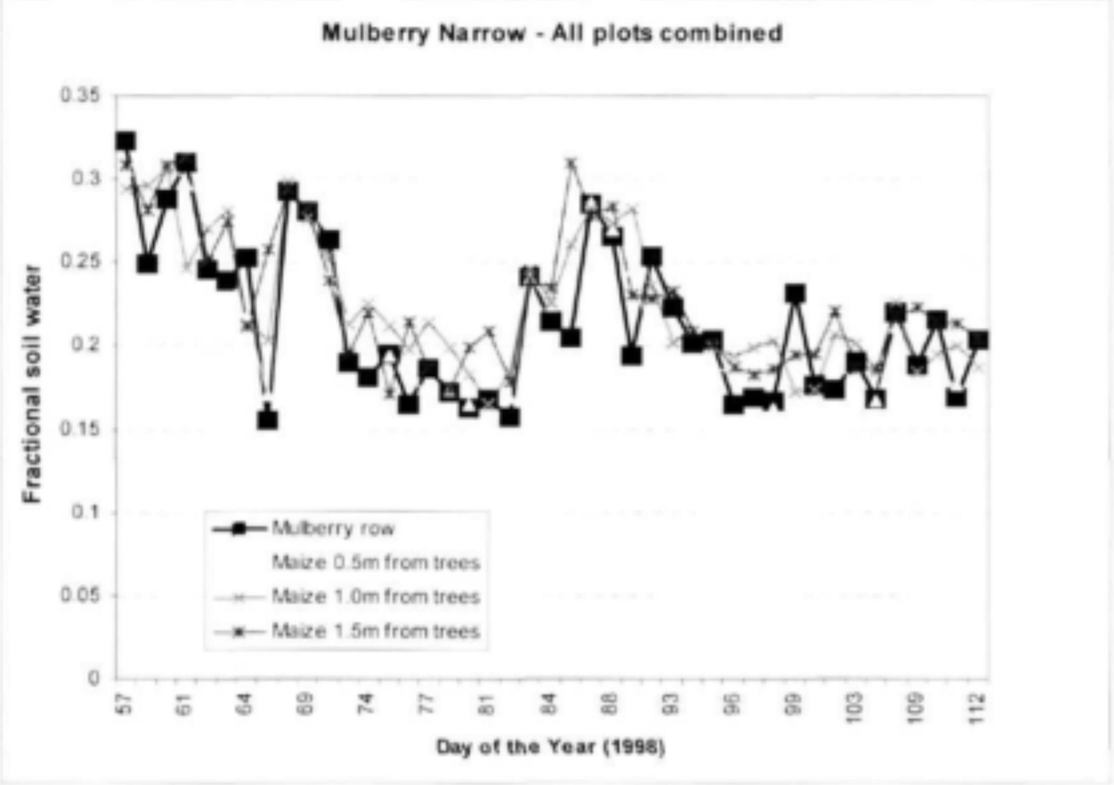


Figure 4.2 d. Daily fractional soil water in the Mulberry wide and narrow treatments 1998.

4.2.2 Soil Water (1999)

4.2.2.1 Time-Domain Reflectometry

The TDR equipment was removed from the experimental site in June 1998 to enable the maize to be harvested. The equipment was serviced and then re-installed in January 1999.

4.2.2.2 Soil water content 1999

A good data set was collected during the 1999 season with most of the 168 probes functioning well. The only data loss occurred from DOY 41 to DOY 64 when a loose wire prevented data capture.

The rainfall for the period mid-January to April 1999 was 255 mm (Fig. 4.1). The high rainfall recorded between DOY 26 and 34 resulted in high fractional soil water content of 0.35 (Fig. 4.3 a-d). This was followed by a very dry period. The rainfall recorded in February (31.6 mm) was 120 mm less than the long-term mean. During this period (DOY 34 to 70) the soil water content decreased by more than 20 % in all treatments. In spite of the high soil water stress during this period, no mortalities of trees or maize plants were recorded at this time. It is likely that the high moisture reserves of January and early February carried the plants through this critical period. Rainfall increased again in mid-March resulting in the rapid increase of soil water content from 0.17 to 0.36. The soil water content remained relatively high (0.2-0.3) for the remainder of the study period.

4.2.2.2.1 Graphic comparison between the narrow and wide tree spacing

The soil water content under the different tree spacings indicated that the driest values were recorded under the narrow tree spacings (Fig. 4.4). Trees in the wide row spacing (1 m apart) were therefore under less stress than those in the narrow row spacing (0.5 m). However, this trend was reversed in the dry period. It is possible that with the high intraspecific competition between trees in the narrow row spacing, trees developed a deeper rooting system to avoid competition for soil water. Thus, during the drought these roots were well established and enabled the tress to access the deeper soil moisture reserves. During the dry period, the trees in the narrow row spacing were, therefore, less stressed than those in the wider spacing.

4.2.2.2.2 Between species comparison

The results (Fig. 4.4d) indicate that *L. leucocephala* and *A. karroo* had the least impact on soil water content. By contrast, the soil water content under *G. triacanthos* was consistently 5-10 % lower than the other species (Fig. 4.5).

4.2.2.2.3 Tree/maize competition for water

The soil moisture under the *L. leucocephala* trees was consistently higher than in the maize rows for both tree spacings (Fig. 4.3d). There was no indication of soil water competition with the maize rows. Possible reasons for this are:

i) *L. leucocephala* has a deep tap root and obtains water from deeper in the profile.
ii) The shading effect of *L. leucocephala* on the soil surface results in a higher soil water content under the trees.
iii) *L. leucocephala* was much slower in establishing than the other trees and in this season was by far the smallest of the trees.

There were no significant differences in soil water under the wide spaced mulberry trees and maize (Figure 4.3c). In the narrow treatment, however, the soil under the trees was drier. This situation was reversed during the dry period (DOY 65-71) when the trees appeared to be obtaining moisture deeper in the profile. Mulberry trees therefore did not appear to be competing with the maize for water.

No competition was apparent between the wide spaced *Acacia* trees and maize (Fig. 4.3a). In the narrow row spacing the tree row was consistently drier than the maize rows (Fig. 4.3a). In this treatment the maize row closest to the trees had the highest soil moisture. Soil water content under *Gleditsia* for both wide and narrow row spacing was always drier than under the maize rows (Fig. 4.3b). This indicates that the trees are using more water than the maize plants.

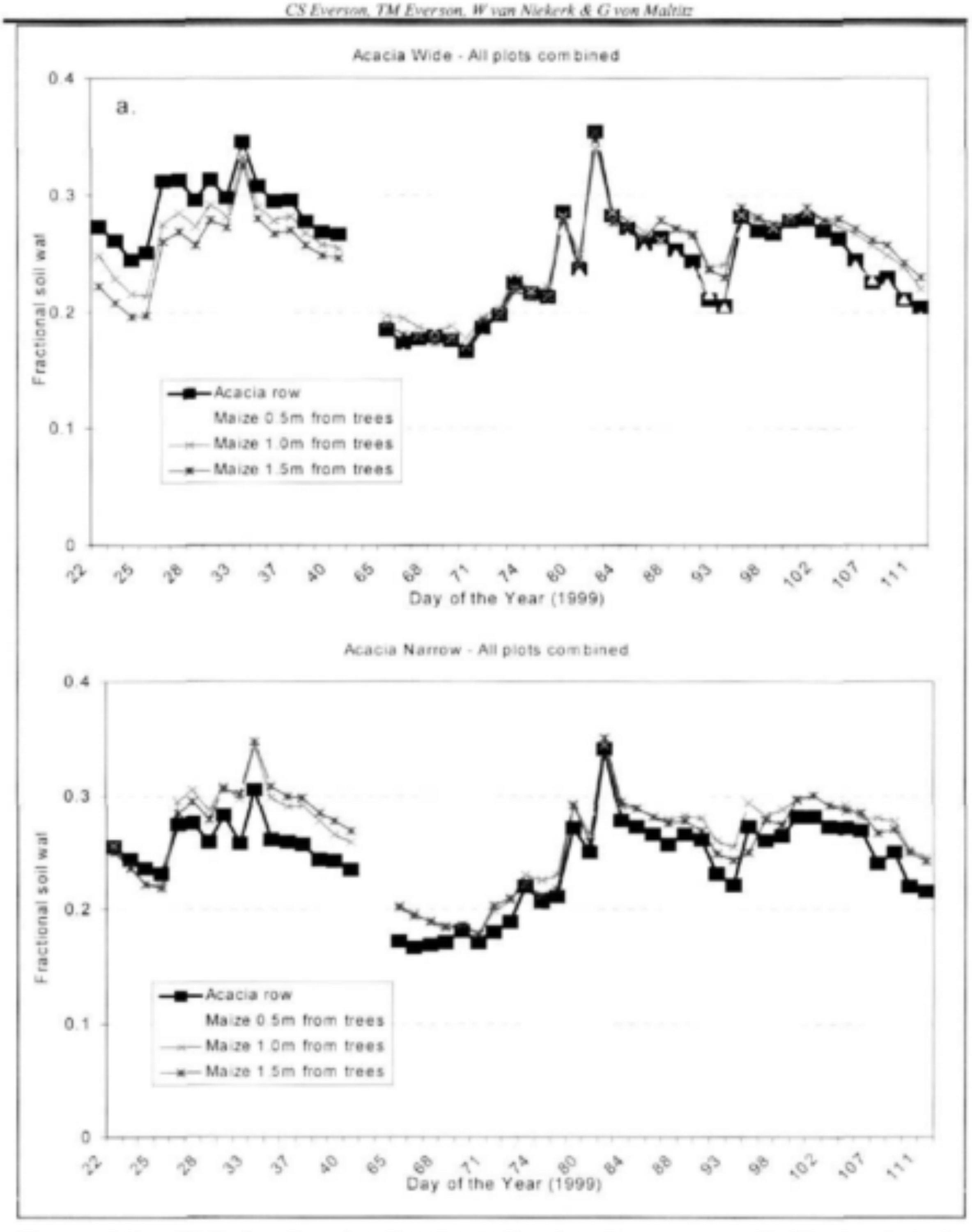


Figure 4.3a. Daily fractional soil water in the *Acacia* narrow and wide treatments 1999.

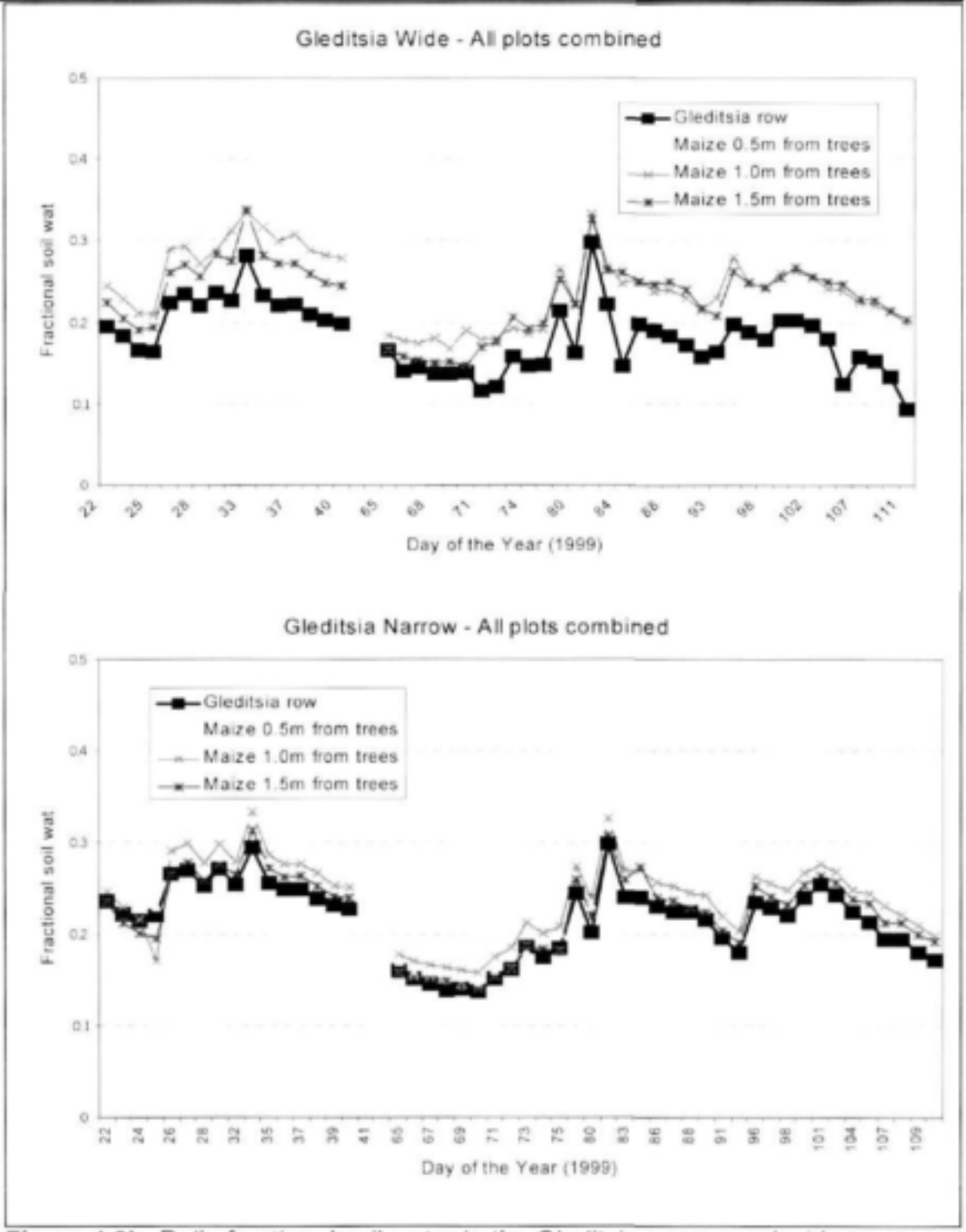


Figure 4.3b. Daily fractional soil water in the *Gleditsia* narrow and wide treatments 1999.

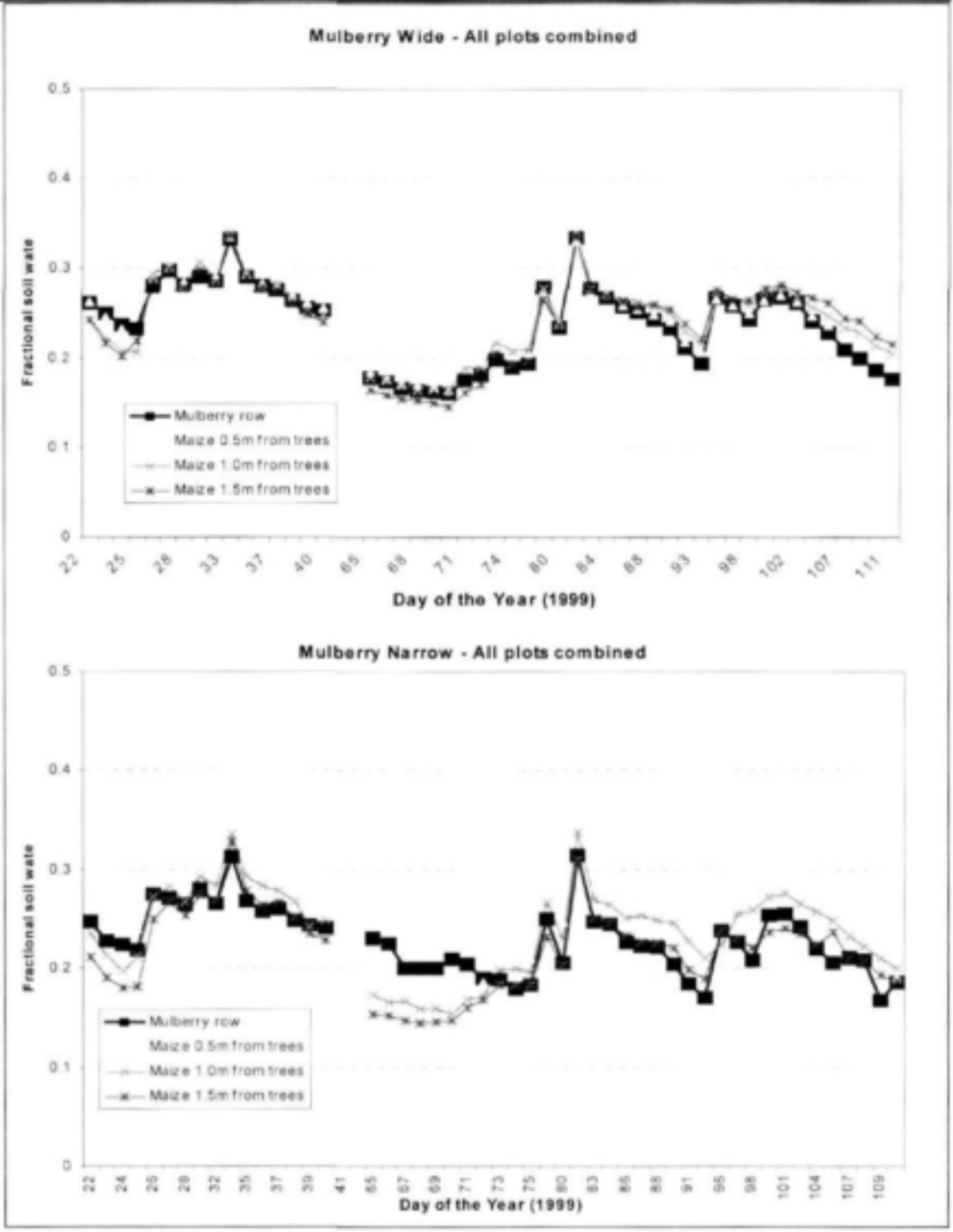


Figure 4.3 c. Daily fractional soil water in the *M alba* narrow and wide treatments 1999.

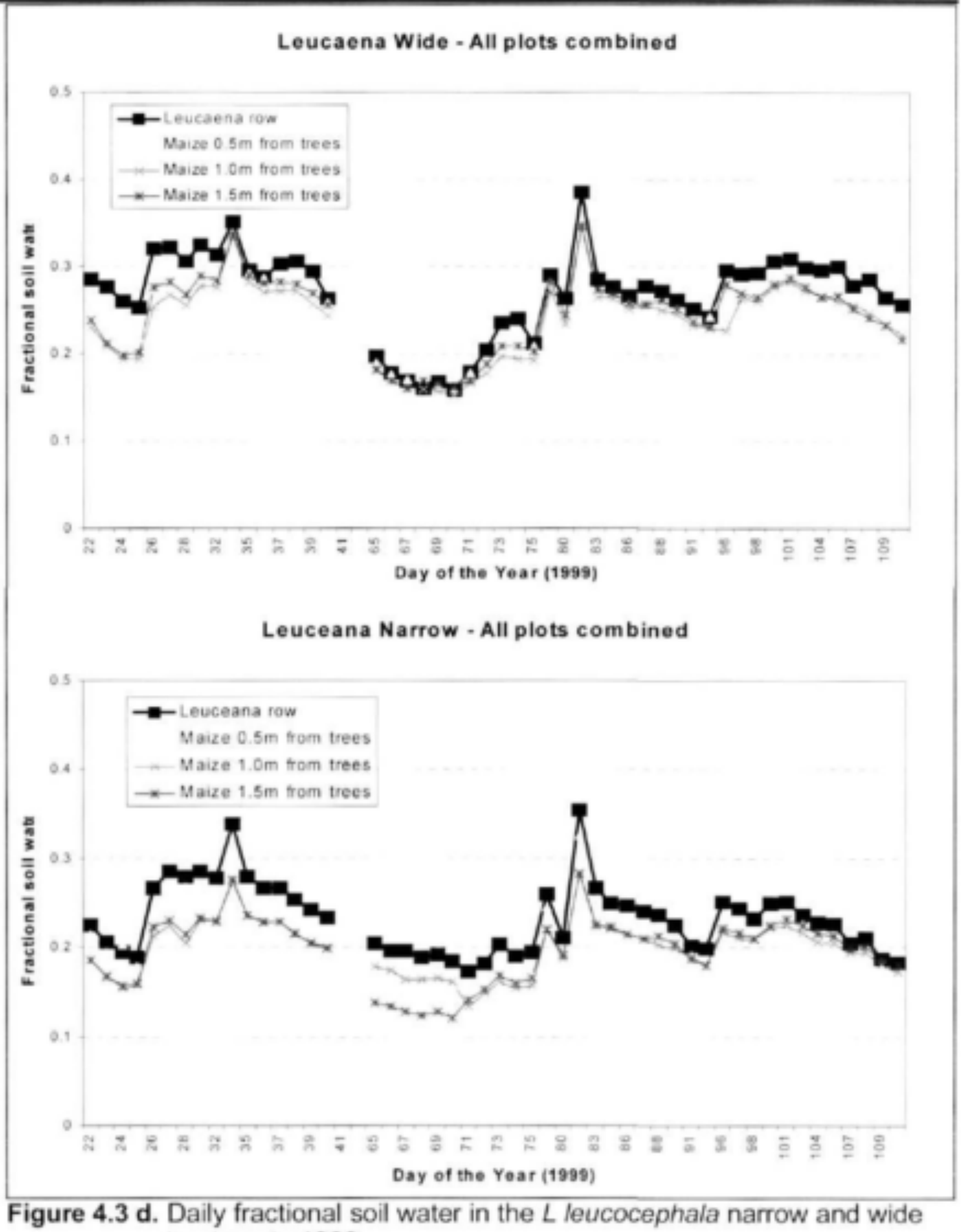


Figure 4.3 d. Daily fractional soil water in the *L leucocephala* narrow and wide treatments 1999.

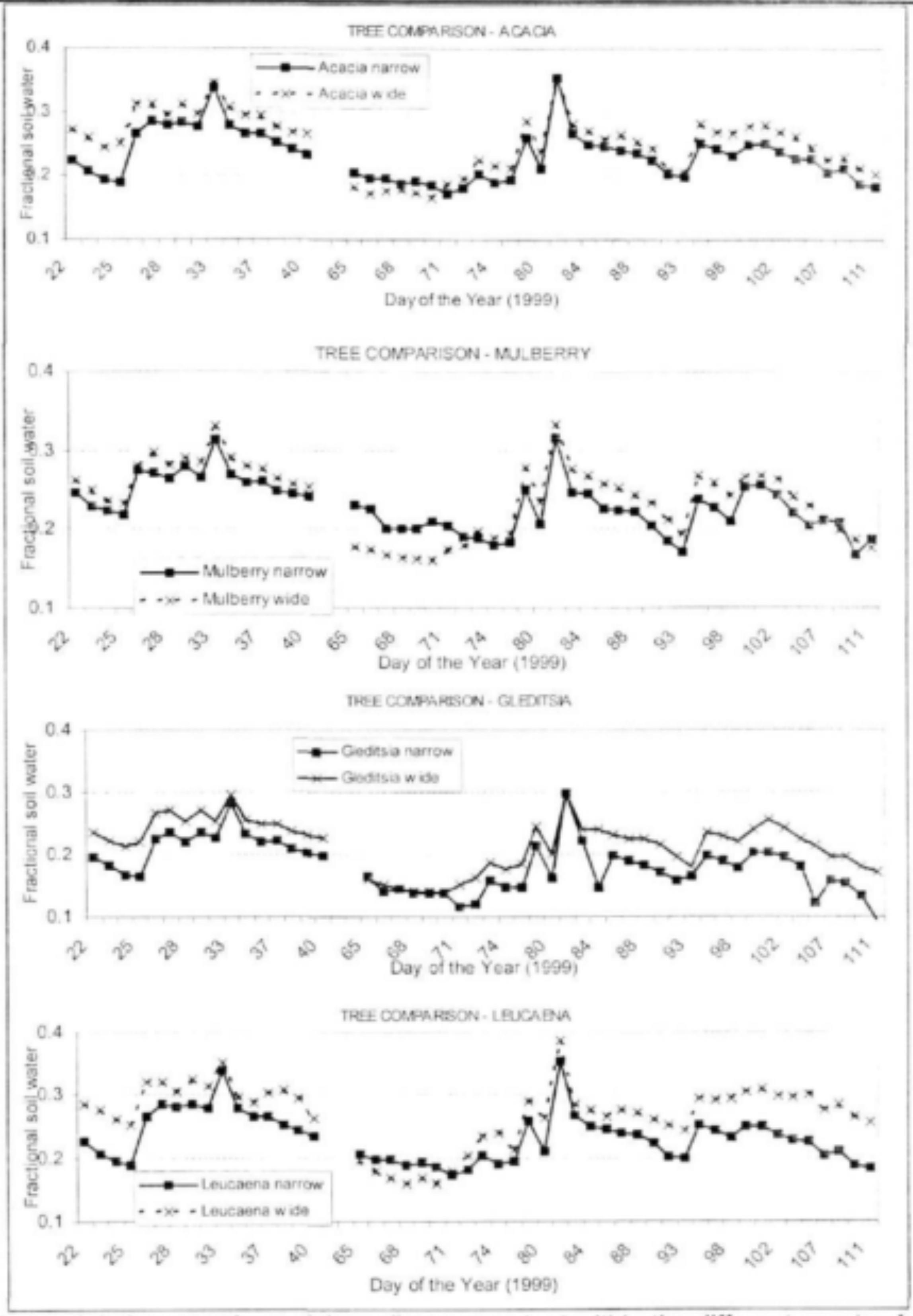


Figure 4.4. A comparison of the soil water content within the different species for different row spacings in 1999.

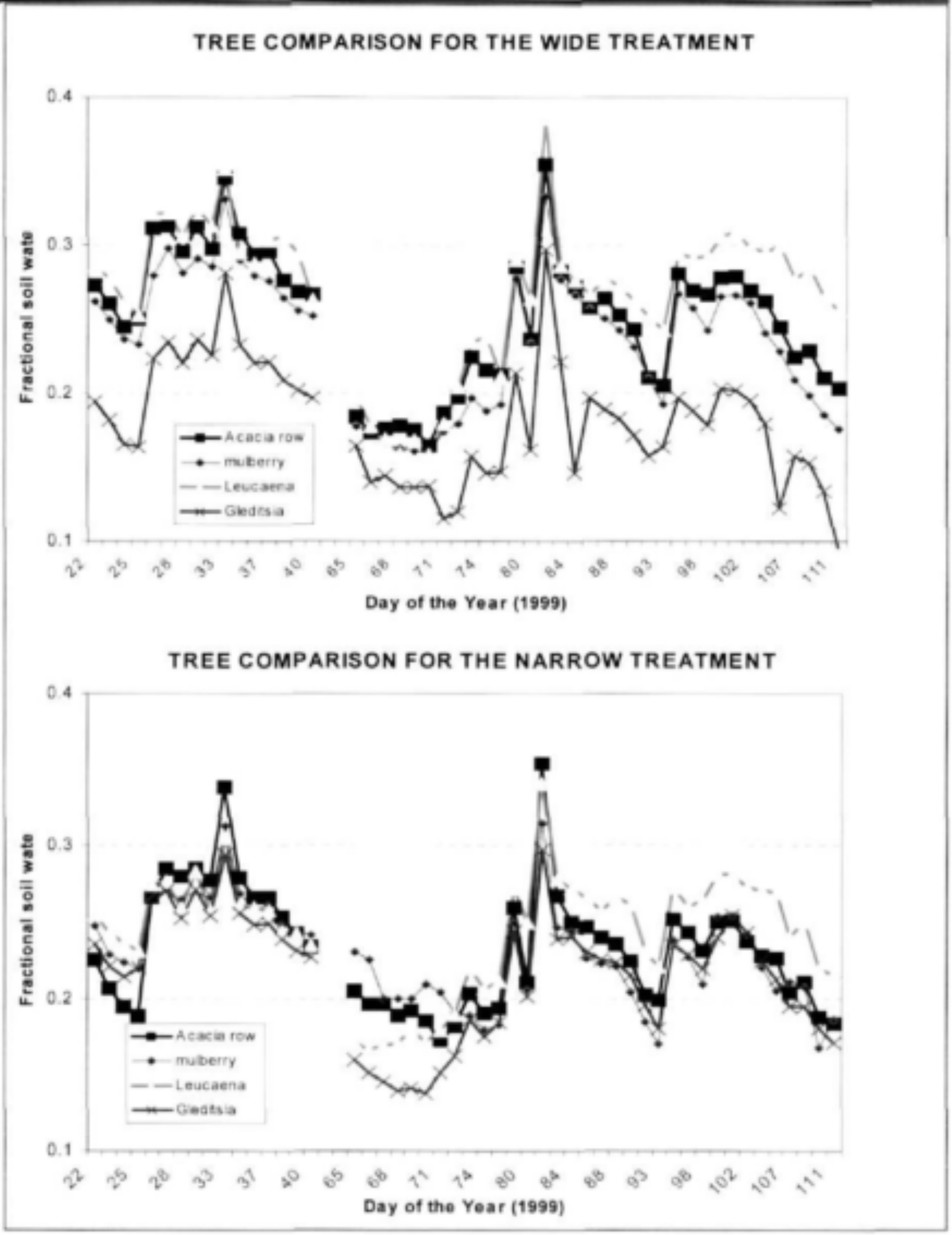


Figure 4.5. A comparison of the soil water content of the different species with narrow and wide row spacings in 1999.

4.2.2.3 Geo-Statistical analysis-1999

From the rainfall data a wet and dry weather period were selected: wet group-days 44-47 (February) and dry 57 – 60 (March). For each of these periods the data were averaged and then arranged into various Geo-EAS data files.

- 16 different Geo-EAS data files (for the individual treatments) were produced. Variograms were drawn from these data for each of the treatments, and saved as monochrome bitmap files. The details of the models fitted were also recorded.
- Four other Geo-EAS data files were also produced of the entire data set (for both groups) and of the entire data set excluding the data from the tree lines. Variograms for these were also drawn, modelled and printed out (Figures 4.6 a-d are examples of the variograms for 1999).

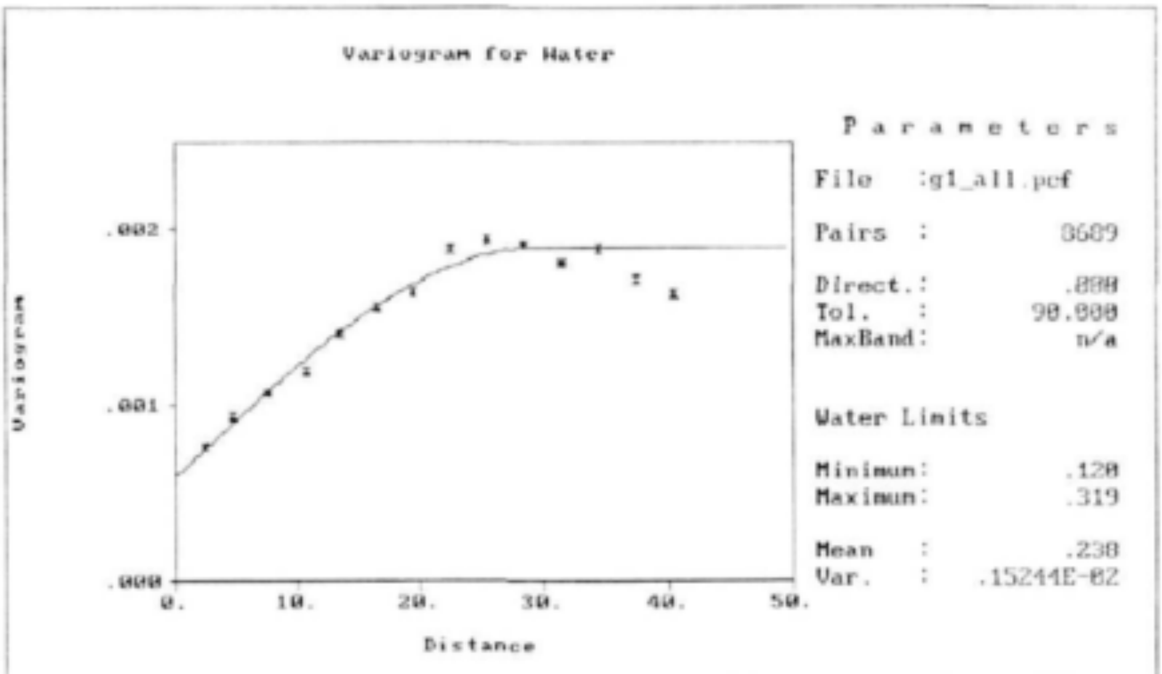


Figure 4.6 (a) **Variogram used for estimating the nugget, sill and range for producing the kriged values for the spatial plotting of the data for the wet and dry periods.**

Variogram model:

Spherical
Nugget = 0.0006
Sill= 0.0013
Range = 30

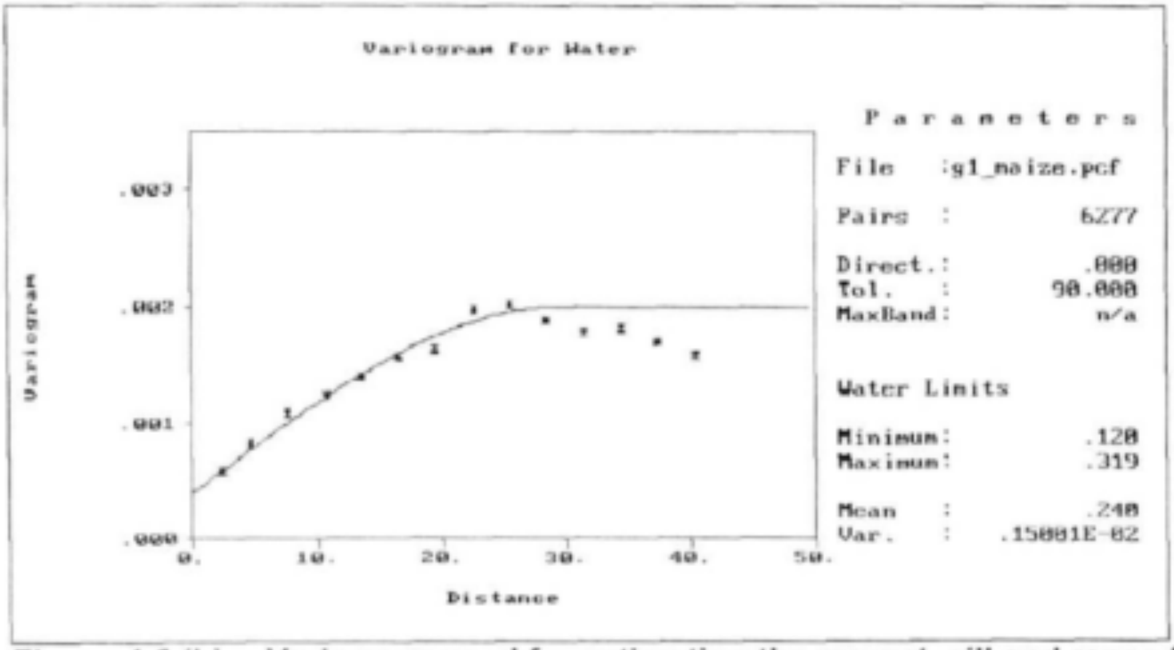


Figure 4.6 (b) Variogram used for estimating the nugget, sill and range for producing the kriged values for the spatial plotting of the data for the wet and dry periods.

Variogram Model:

Spherical
Nugget = 0.0004
Sill = 0.0016
Range = 30

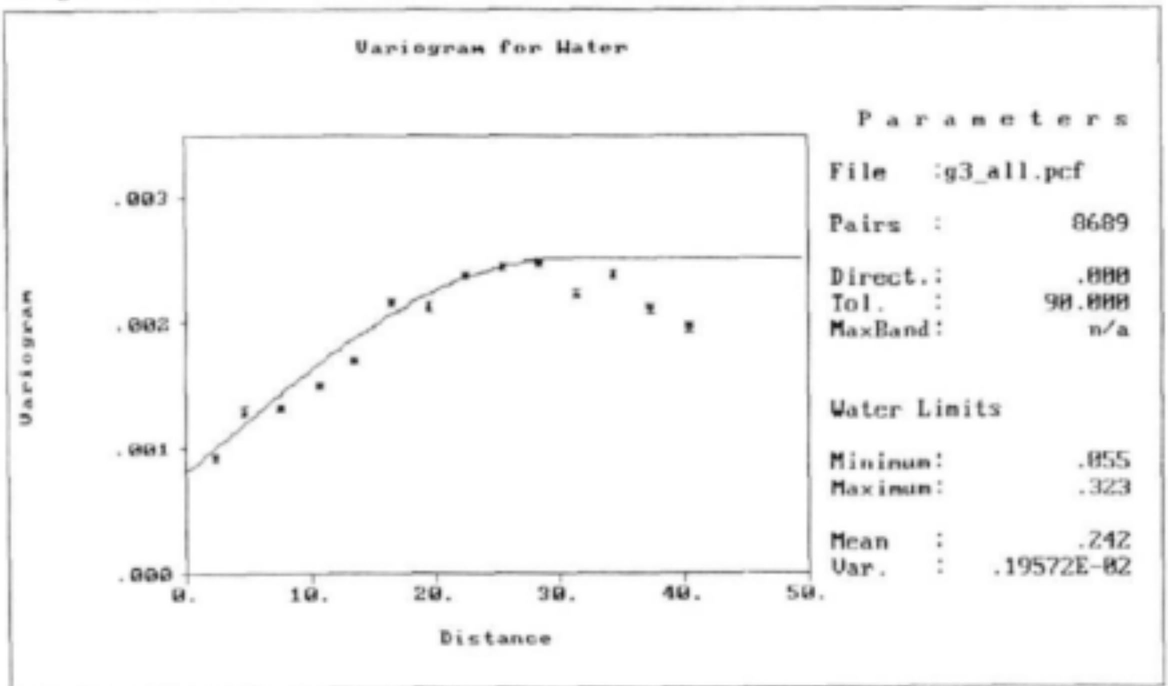


Figure 4.6 (c) Variogram used for estimating the nugget, sill and range for producing the kriged values for the spatial plotting of the data for the wet and dry periods.

Variogram Model:

Spherical
Nugget = 0.0008
Sill = 0.0017
Range = 30

Figure 4.6 (d) **Variogram used for estimating the nugget, sill and range for producing the kriged values for the spatial plotting of the data for the wet and dry periods.**

Variogram Model:

Spherical
Nugget = 0.0008
Sill = 0.0017
Range = 30

Using the models developed without the tree data, the entire data range was then kriged and the values predicted for the tree lines and the actual tree line values were compared for dry and wet periods (Figure 4.7). The range of values measured varied from 18% in the centre of the trial to 27% on the outside. There was no difference between the data with tree lines included or excluded, showing the trees were having little or no effect on the overall moisture distribution across the trial in either the wet or dry period during 1999.

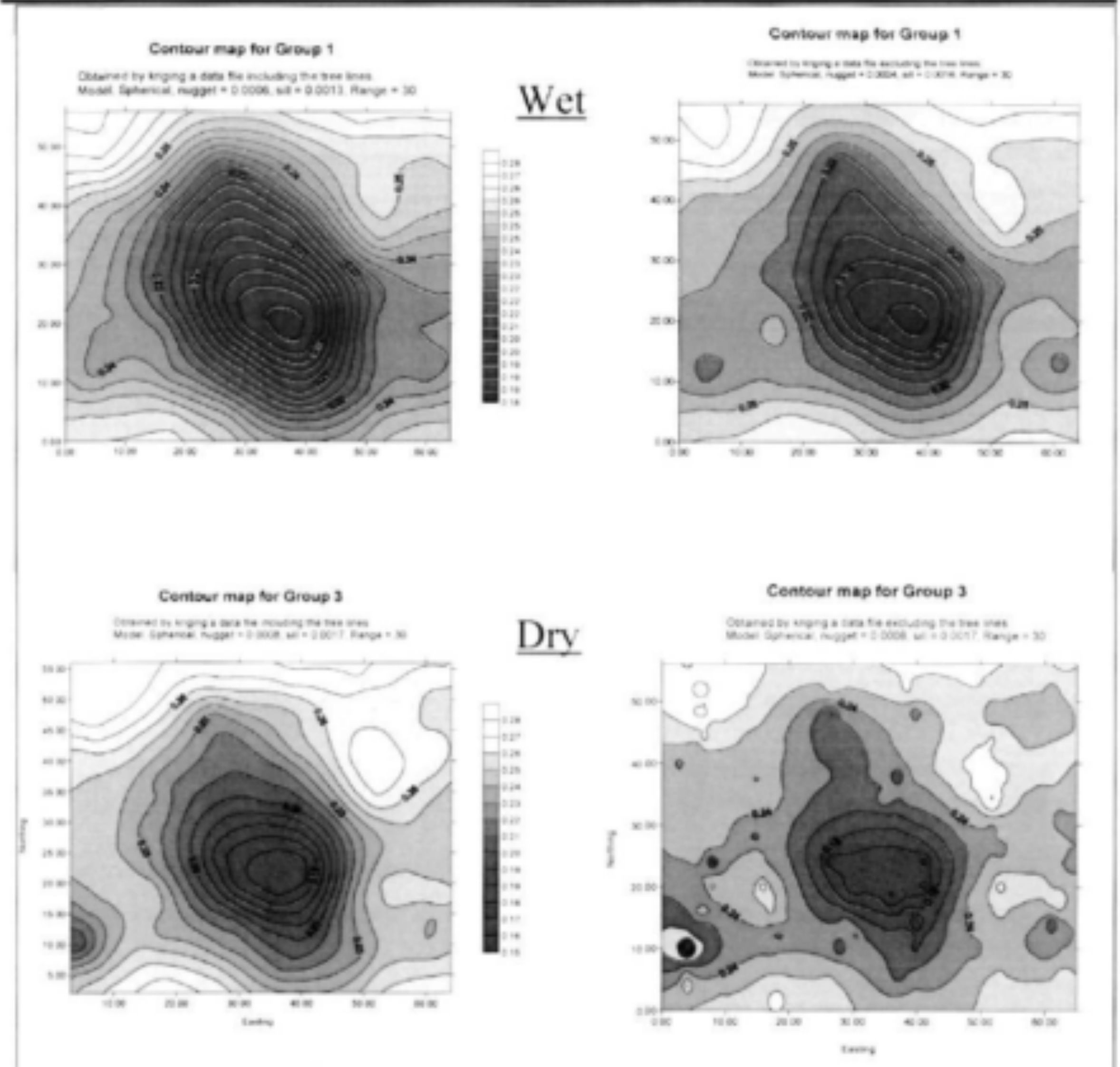


Figure 4.7 Spatial representation of the kriged 1999 data for values obtained by including tree lines (left) and excluding tree lines (right).

Genstat (Version 4.1 4th edition) was used to perform ANOVA's on the group data, using both the observed tree line values, the average of the observed maize lines (averaged over each plot), as well as the kriged predicted tree values, and the predicted maize lines (also averaged over each plot). The predicted values were obtained when kriging over the entire data range, but excluding the tree line data. The results of the ANOVA's are presented in Appendix C.

4.2.3 *Soil Water Analysis (2000)*

The trend in soil water during the 2000 monitoring period showed that February was wet, with high moisture contents (0.26) between DOY 39 and 50), while early March was much drier, with values generally below 0.25. From late March (DOY 76), soil moisture values returned to above 0.25 again (Fig. 4.8).

From the rainfall data (Fig. 4.1) and the TDR data (Fig. 4.8) a wet and dry weather periods were selected: wet group- days 44-47 (February) and dry 57 – 60 (March). The same approach to data analysis was followed as for the 1999 season.

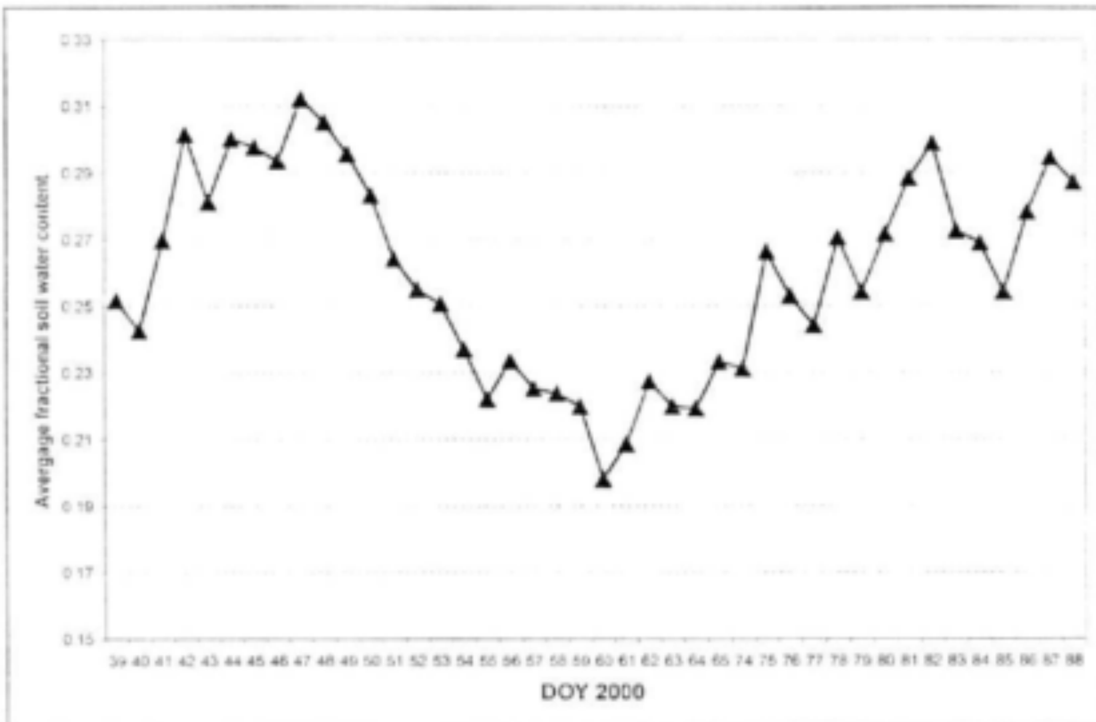


Figure 4.8 Average daily trends in the soil water content of the trial during 2000.

4.2.3.1 Spatial distribution of the soil water content

For the dry group in the year 2000 (including tree lines) the soil water ranged between 19-27% (Fig. 4.9). This was similar to 1999 (Fig. 4.7), although the proportion of dry soil in the trial was greater in 2000, showing a pattern of drying from the center outwards across the trial. This may be due to the greater impact

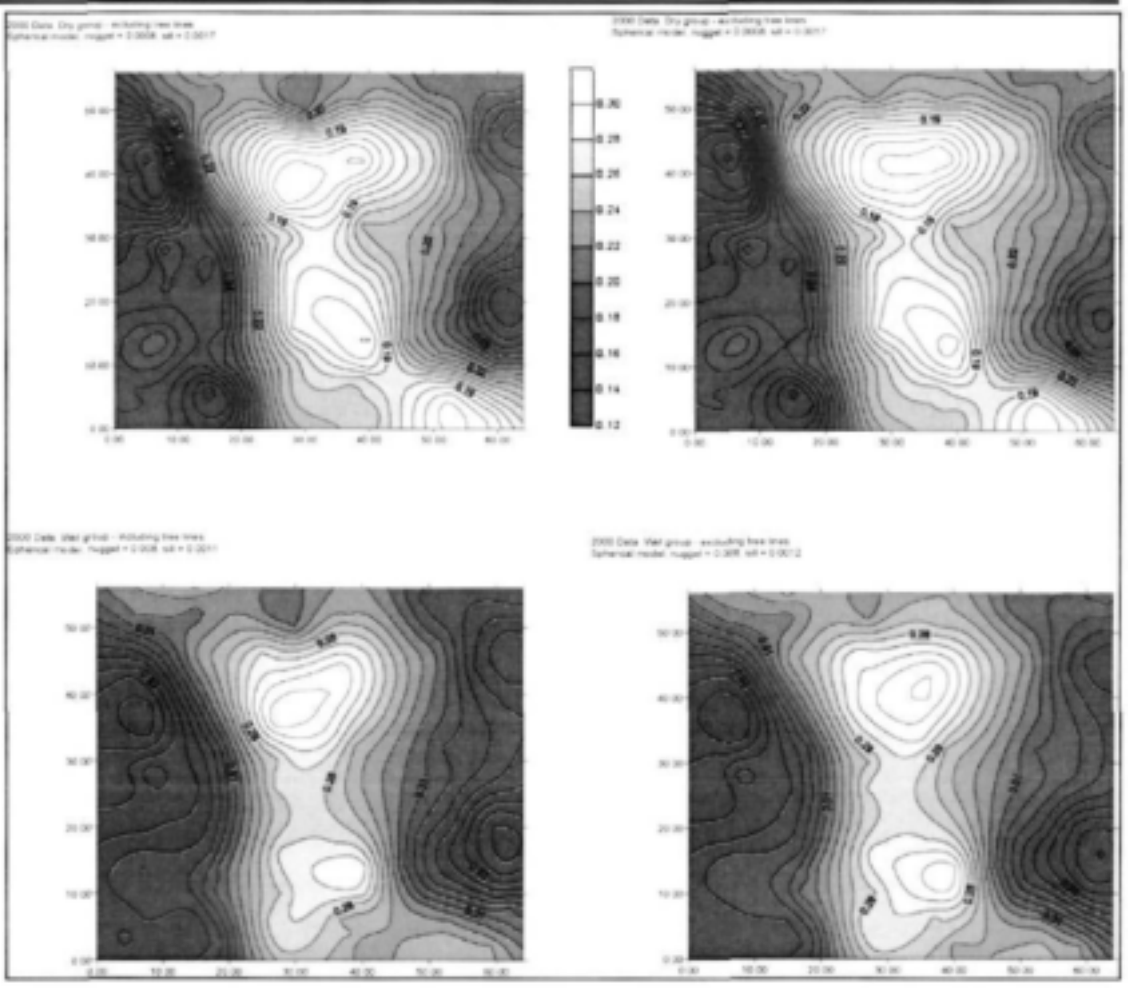


Figure 4.9 Spatial representation of the kriged 2000 data for values obtained by including tree lines (left) and excluding tree lines (right).

of the trees in their second year of establishment. A comparison of the trends in the dry and wet groups (including and excluding the tree rows) showed that the general patterns were similar, indicating no influence of the trees across the trial. The analysis of the wet period showed that values were much higher (28-33%), reflecting the good rainfall over this period. The variability of soil water was much less during the wet periods since tree and maize competition would be unlikely during these high moisture conditions.

Genstat (Version 4.1 4th edition) was again used to perform ANOVA's on the group data, using both the observed tree line values, the average of the observed maize lines (averaged over each plot), as well as the kriged predicted tree values, and the predicted maize lines (also averaged over each plot). The predicted values were obtained when kriging over the entire data range, but excluding the tree line data.

4.2.4 Soil Water Analysis (2001)

4.2.4.1 Time-Domain Reflectometry

The TDR system was re-established in the trial in January, but due to a major malfunction with the Tektronix 1502B, measurements were delayed until February 2001.

From February to April a good set of surface soil water data were obtained. A plot of the average soil moisture from selected probes showed two distinct dry periods at DOY 28-30 and again between DOY 65 and 90, when values dropped below 0.15 (Fig. 4.10).

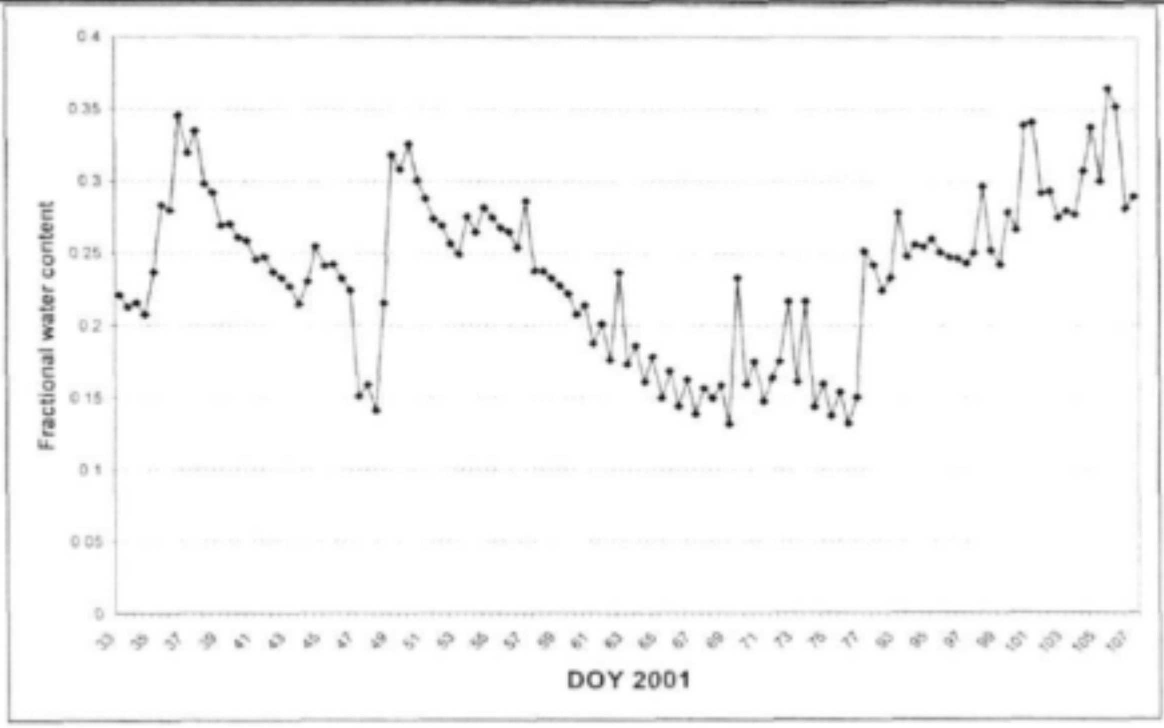


Figure 4.10 Time series of surface layer soil moisture content (%) as measured using the TDR System.

4.2.4.2 Spatial distribution of the soil water content

A similar approach to the spatial analysis was followed as for 1999 and 2000. The results of the spatial analysis in Fig. 4.11) show (as previously) that there were no visible changes in either the wet or dry period between the spatial distribution of soil water with or without the tree lines in the top soil. This indicates that the trees were not having a significant effect on the spatial distribution of soil water in the top soil across the trial. However, a comparison with the 2000 picture of soil water during the dry period shows that the trial appeared much drier in 2001 than in 2000, which was in turn drier than 1999. This suggests that there may be drying of the trial from year to year as the trees are maturing.

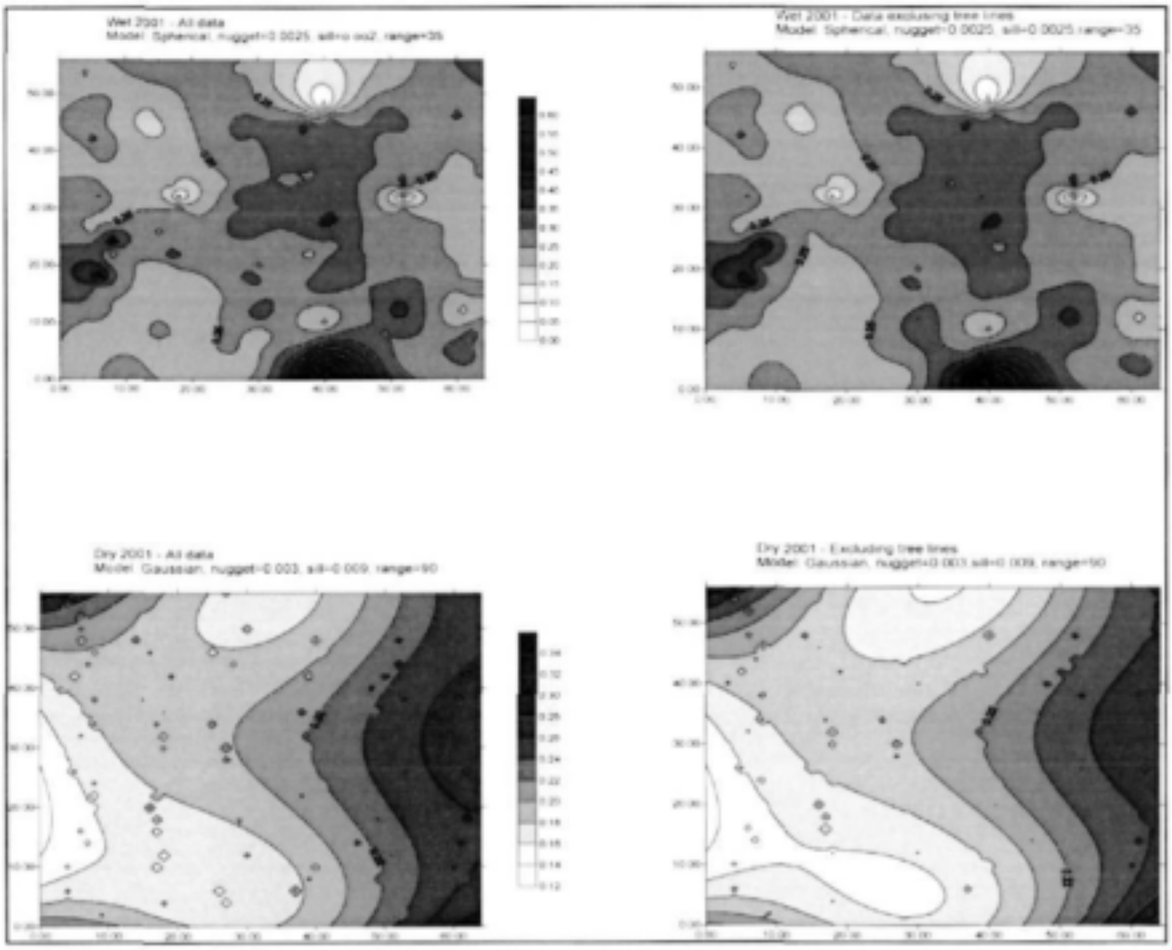


Figure 4.11 Spatial representation of the volumetric soil water content across the trial for both included and excluded tree rows.

4.2.5 *Soil Water Measurements Using the Neutron Probe*

Neutron probe measurements were made at approximately monthly intervals between December 1999 and April 2001 (Fig. 4.12). Total profile water contents representing the upper 2.5 m of the soil profile for the entire study period of measurement showed that the soil profile in the 2000 growing season was generally wetter than the 2001 season. For example, values in January 2000 for selected tree lines (only the narrow treatments), were approximately 100 mm higher than in January 2001 (Fig. 4.12). Only the narrow treatments are illustrated, as maximum soil drying is most likely to occur in these treatments. The poor performance of the maize in 2001 is probably a result of these drier soil conditions. Both the *M. alba* and *A. karroo* narrow treatments generally had drier profiles than the *L. leucocephala* and *G. triacanthos* treatments. These data also showed that October and November would be poor planting dates as the soil is driest at these times.

Total profile water contents, representing the upper 2.5 m of the soil profile, are shown for January and February 2001 for all treatments (Fig. 4.13). These data showed that there were large differences in the profile water content between species and treatments, the *M. alba* narrow, both *A. karroo* treatments and one of the *L. leucocephala* wide sites having values of less than 600 mm. The treatment, which consistently showed the driest profile, was the narrow spaced *M. alba* trees, which were about 550 mm, compared with 650 mm for the wider spaced trees (Fig. 4.13). These data show that sylvicultural practices (in this case planting space) may result in significant savings in water use by some trees.

The soil water content ranged widely between treatments in the top 25 cm of soil (Fig.4.14). Values varied from as low as 43 mm in some species to 74 mm for the *L. leucocephala* wide treatment. This suggests that some species are utilizing the surface water more actively than others. This trend continued to the 50 and 75 cm depths although the variation was not as great. This implies that all the trees are actively removing water at these depths. From 1 m onwards there is a steep increase in the available water, and by 2 m the soil is close to field capacity (FC). Field capacity can be roughly estimated as approximately 88 mm, as the maximum soil water measured is 35% (e.g. for a 250 mm depth, the FC is 0.35 X 250 =88 mm). A notable exception to this trend is the narrow *M. alba* treatment, where the tress appeared to be extracting water to depths of 3.0 m.

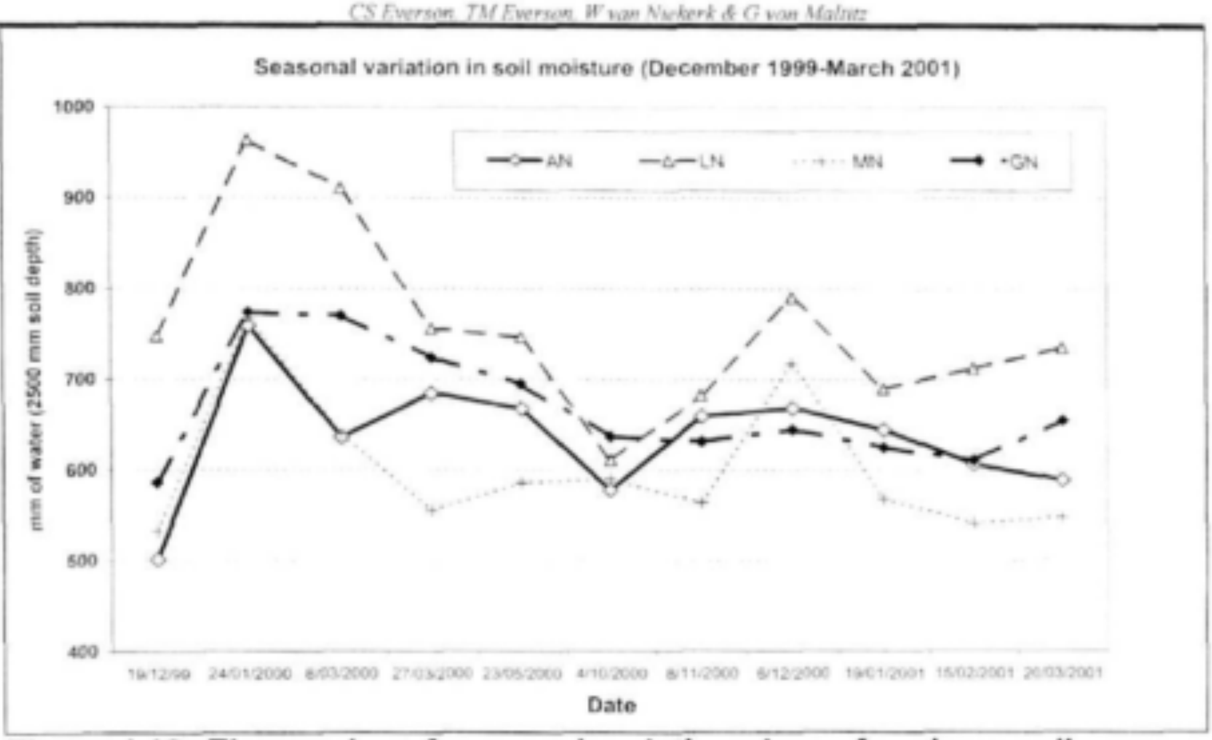


Figure 4.12 Time series of seasonal variations in surface layer soil moisture levels as measured using the Neutron Probe.

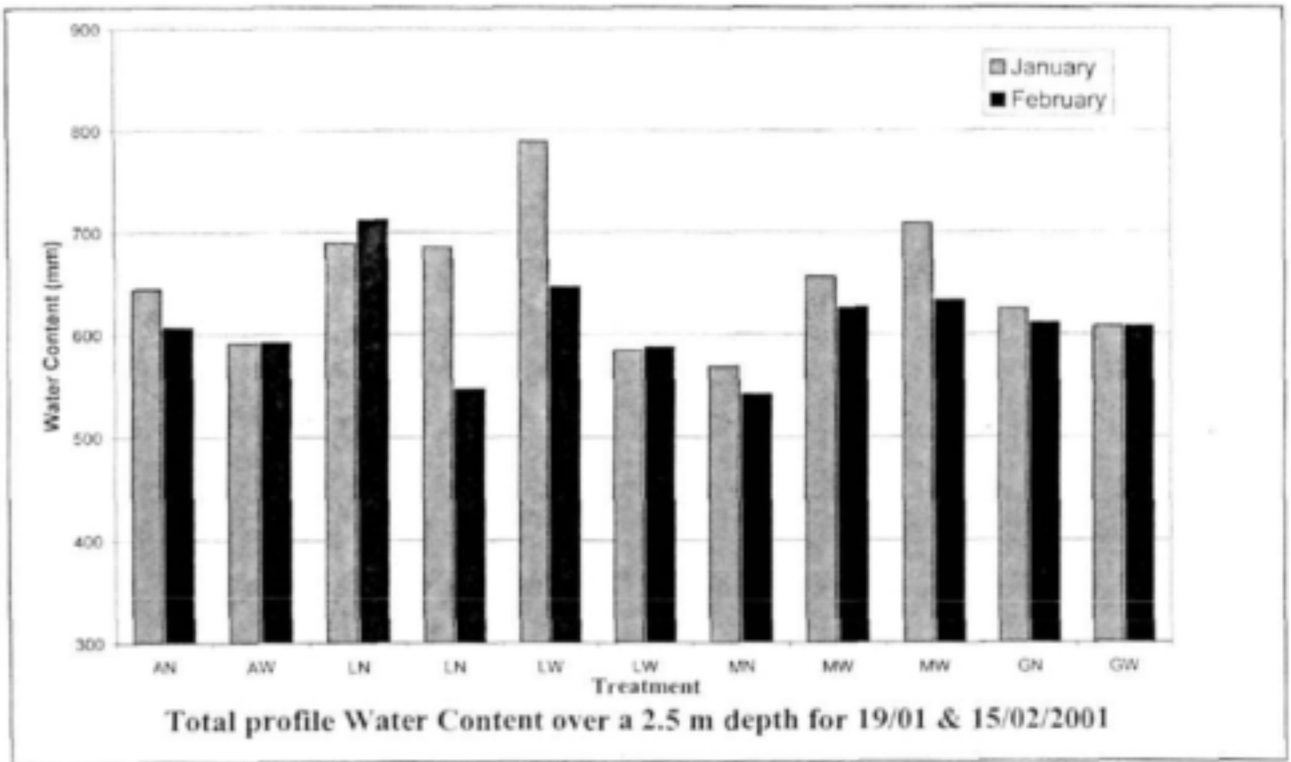


Figure 4.13 Total profile soil moisture contents for selected treatments as measured using the Neutron Probe.

The data presented here show that the TDR technique can record continuous moisture measurements over long periods. The high precision of the data is reflected in the consistency of the results. The ability of the TDR technique to record daily soil moisture will provide a unique data set for determining the impact of trees on soil moisture availability for crops. Extension of the project to include collection of data when the trees are fully established is essential to provide insight into the mechanisms governing soil water competition.

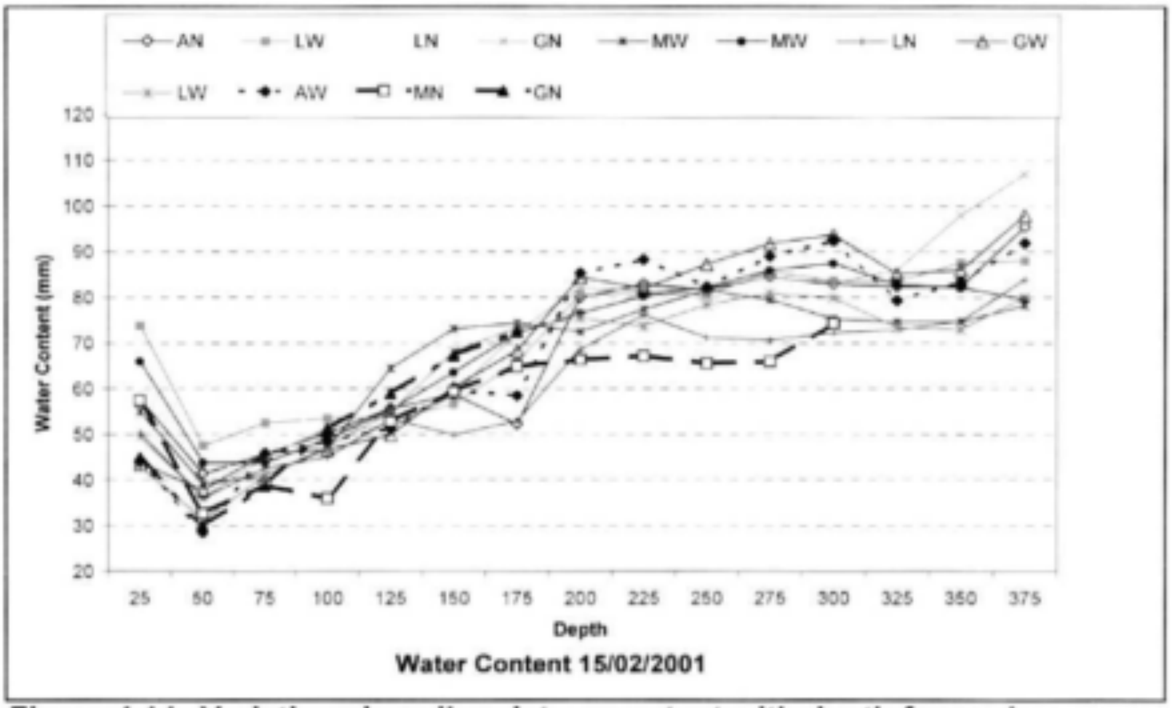


Figure 4.14 Variations in soil moisture content with depth for each treatment on a specific day (15/02/2001).

4.3 Radiation Experiments

4.3.1 The effect of shading on maize rows

The integrated value of PAR for the line quantum sensor for the different treatments showed that the penetration of light across the maize rows varied with the different treatments (Fig. 4.15). The lowest PAR values (<1000 μ moles s^{-1} m^{2}) were found in the *A karroo* wide, *G. triacanthos* wide, *L. leucocephala* narrow and *M. alba* narrow treatments. Treatments which received the most light were AN, MW, LW and GN. The data show that over 90% of the intercepted light was absorbed in the former species and about 70% on the latter. Clearly light penetration into the maize canopy is significantly reduced across all treatments.

The effect of the trees on the adjacent maize rows (paired data corresponding to the two closest, mid and furthest rows) for a selected period showed that in treatments where there was vigorous growth, the tree row intercepted over 90% of the PAR (Fig. 4.16). The exceptions were AW, LW and GW. The rows next to the trees (row 3+ row4), were generally more shaded than either of the other row

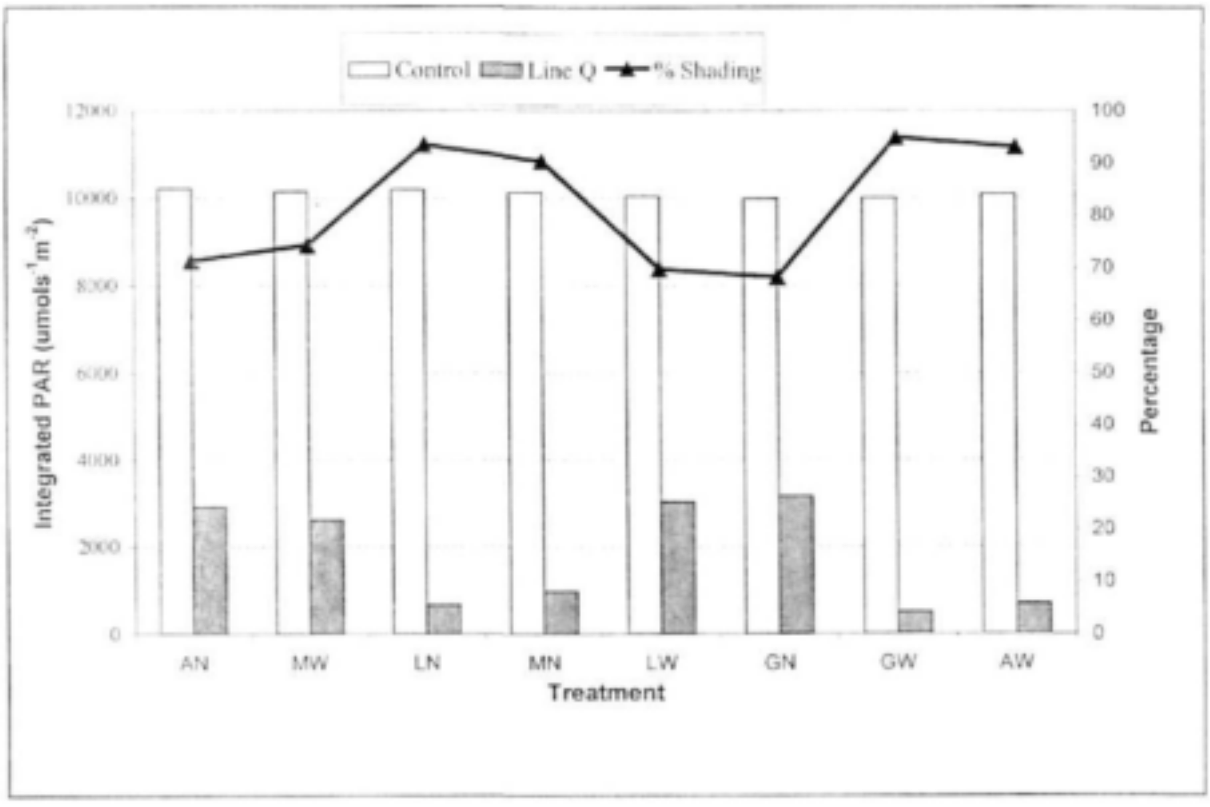


Figure 4.15 Integrated line quantum data for Day Of Year 109.

distances, with the rows furthest from the trees intercepting as much as 50-80% of the available PAR (i.e. only 20-50 % shaded). The maize rows next to the MW, LN, and MN treatments showed a high percentage (>80%) of shading across all rows. The vigorous growth and concomitant shading in these treatments will result in a competitive interaction (reduced yield) in these treatments. The sylvicultural practices (pruning height and season) are important factors, which need to be considered when maize is grown in close association with trees with tall canopies.

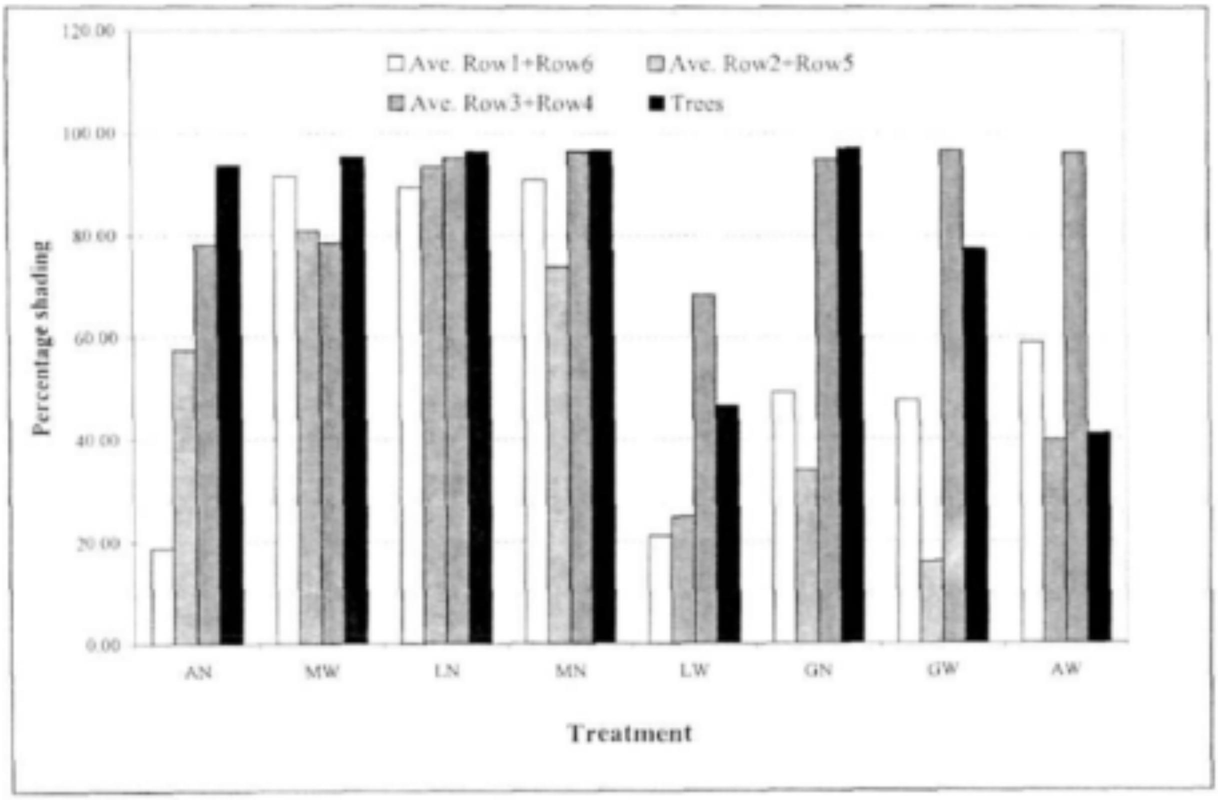


Figure 4.16 Average percentage row shading of opposite rows for 8 treatments plots between 08h26 and 09h59 on day of year 108.

The experiment to investigate the amount of light interception for a whole day for the *Acacia* narrow treatment showed that relative to the control all rows had reduced light interception (Fig. 4.17). For this treatment there was clearly a trend of increased shading (decreasing PAR) across the rows as one moved towards the trees (note row 3 data were considered incorrect due to a possible faulty sensor). The reduction in row 6 was a result of shading from an adjacent mulberry plot. As expected, maximum shading (total PAR only 10 000 μ mol s^{-1} m^{-2}) was found beneath the trees.

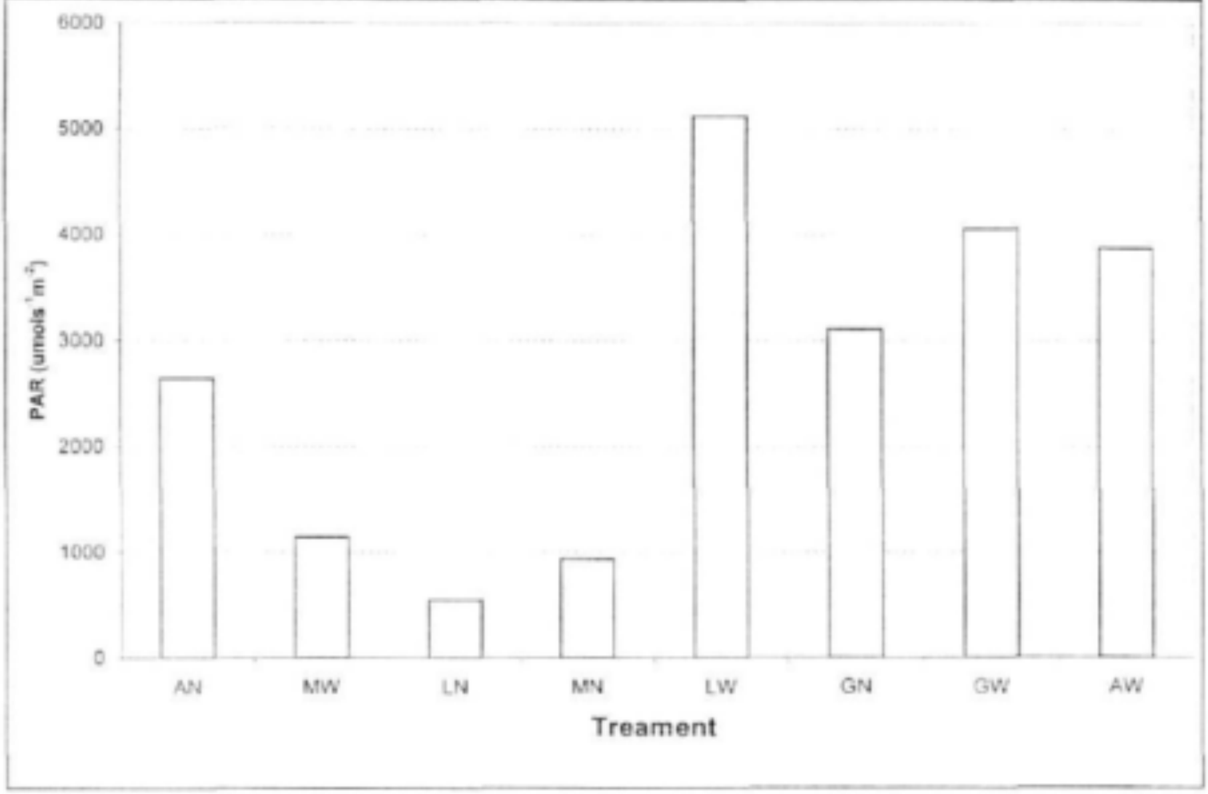


Figure 4.17 Integrated daily PAR (μ mol s^{-1} m^{-2}) in the Acacia narrow treatment on day of year 110.

4.4 Tree Biomass

4.4.1 Tree biomass 1999

Biomass from the trees was first recorded when the trees were harvested at the end of May 1999 after 12 months growth. The trees were well established and had a strong stem base. Thereafter, biomass was harvested in May before the first frosts.

The results (Fig. 4.18) indicate that in all species the biomass of the leaves and twigs decreased with the wider row spacing of trees. In this second year of establishment, the most productive tree in terms of available forage was the indigenous tree *Acacia karroo* ($\bar{x}$ = 1600 kg ha^{-1} [narrow]; $\bar{x}$ = 1200 kg ha^{-1} [wide]). *Morus alba* had the highest wood production ($\bar{x}$ = 5500 kg ha^{-1}) and a high forage production ($\bar{x}$ = 1300 kg ha^{-1}). The low values recorded for *Gleditsia triacanthos* (< 300 kg ha^{-1}) may be attributed to the early loss of leaves of this species before harvesting. The slow establishment of *Leucaena leucocephala* resulted in low biomass production (<500 kg ha^{-1}) in the first two years after planting.

4.4.2 *Tree biomass 2000*

All species had increased fodder yield from 1999 to 2000 (Fig. 4.18). Fodder and fuel wood yield were greater in the narrow row spacing when compared with the wide spacing. The most productive fodder trees were *Morus alba* (2800 kg ha^{-1}) and *Acacia karroo* (2300 kg ha^{-1}). The most productive fuel wood species were *Morus alba* (11800 kg ha^{-1}) and *Gleditsia triacanthos* (7900 kg ha^{-1}). These species put most of their energy into wood growth under the pruning treatments applied, which may be a disadvantage for dairy farmers.

Acacia karroo produced less fuel wood in 2000 than in 1999. It is apparent that the trees responded to the less severe pruning by producing more young coppice shoots than wood production. Fodder yield in *Leucaena leucocephala* (narrow) increased significantly from 1999 (500 kg ha^{-1}) to 2000 (kg ha^{-1}). Although this species was slow in establishing it is apparent that once established it is a productive species. Fodder yield of *Morus alba* doubled from 1300 kg ha^{-1} in 1999 to 2800 kg ha^{-1} while that of *Gleditsia triacanthos* (narrow) increased from 300 kg ha^{-1} to 2200 kg ha^{-1}. Similar trends occurred with the wide spacing, but production was not as high.

4.4.3 *Tree biomass 2001*

In 2001 (the third year of establishment) the fodder and fuel wood yield of all species was again higher in the narrow spacing treatment (Fig. 4.18). Fodder yield of *Acacia karroo* (narrow) increased from 2300 kg ha^{-1} in 2000 to 3000 kg ha^{-1} in 2001.By contrast, yield in the wide spacing increased from 1300 kg ha^{-1} to a maximum of 2300 kg ha^{-1}. In 2001 fodder yield in the narrow spacing of *Leucaena leucocephala* increased by 2000 kg ha^{-1}, compared to an increase of only 1000 kg ha^{-1} in the wide spacing. The greater fodder to fuel wood ratio of *Acacia karroo* and *Leucaena leucocephala* when compared to *Morus alba* and

Gleditsia triacanthos make these species more suitable for fodder production. The decreased fodder yield of *Morus alba* and *G. triacanthos* in 2001 was compensated for by an increase in fuel wood.

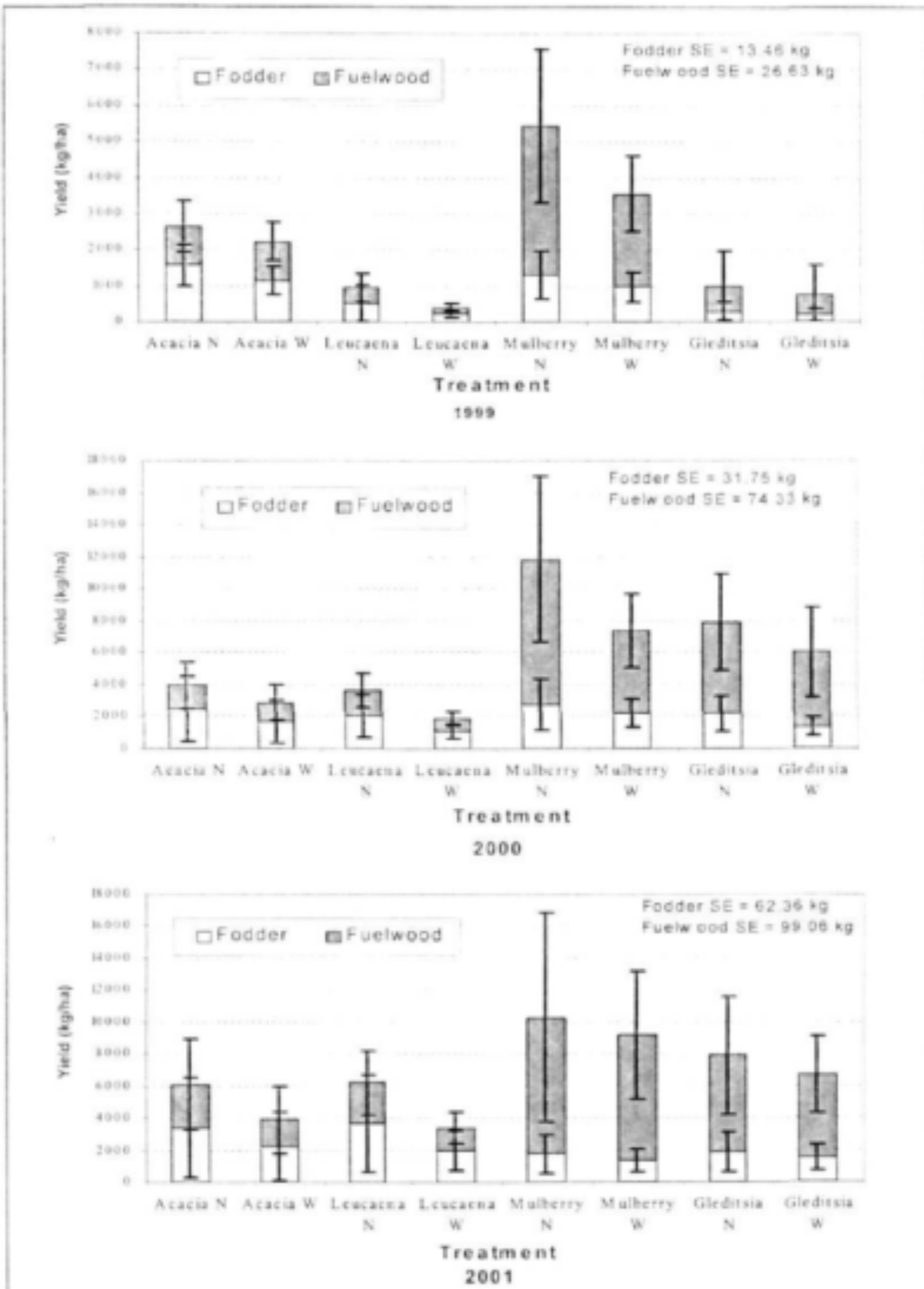


Figure 4.18 Mean tree biomass: 1999-2001.

4.5 Tree Growth

4.5.1 Tree Height

Tree height at the end of the first growing season in May 98 (450 days after planting) varied significantly between species (Fig. 4.19). Height ranged from an average of 1.5 m in *A. karroo, G. triacanthos* and *L. leucocephala* to 3m in *M.alba*. Growth rate of *L. leucocephala* was initially slower than the other species but increased rapidly between 300 and 450 days after planting. The rapid increase in height of *L. leucocephala* indicates that this species recovered well from the pruning in May 1998). Tree spacing had no effect on tree height.

By March 2000 the greatest growth between species was again exhibited by *M. alba* (3.8 m) followed by *G. triacanthos* (3.5 m) and *L. leucocephala* (2.8 m). The least growth in terms of height was exhibited by *A. karroo* (1.5 m). This may be ascribed to the relatively low recovery of *Acacia* after the severe pruning in January. The lower tree height of *Acacia* had a positive affect on maize yield indicating that there was little competition for incoming solar radiation.

It is apparent that *L. leucocephala* has a very slow establishment phase taking approximately two years before it reached the height of the other species. The less severe pruning adopted in January 1999 resulted in a faster recovery in all species. The recommended pruning height is therefore 0.75m.

There were no significant differences in tree height between the wide and narrow spacings within species in 2000 (Fig. 4.23). This indicates that there was no competition between trees at the two spacings.

4.5.2 Tree Diameter

The increase in tree diameter (Fig. 4.24) after planting showed a similar trend to that of tree height, with *M. alba* trees reaching the greatest diameter (42 mm). Growth was initially slow in all species in the first year, followed by a rapid increase in diameter during the second year of establishment. The results indicate that the trees are unlikely to impact on crop production in the first year of establishment.

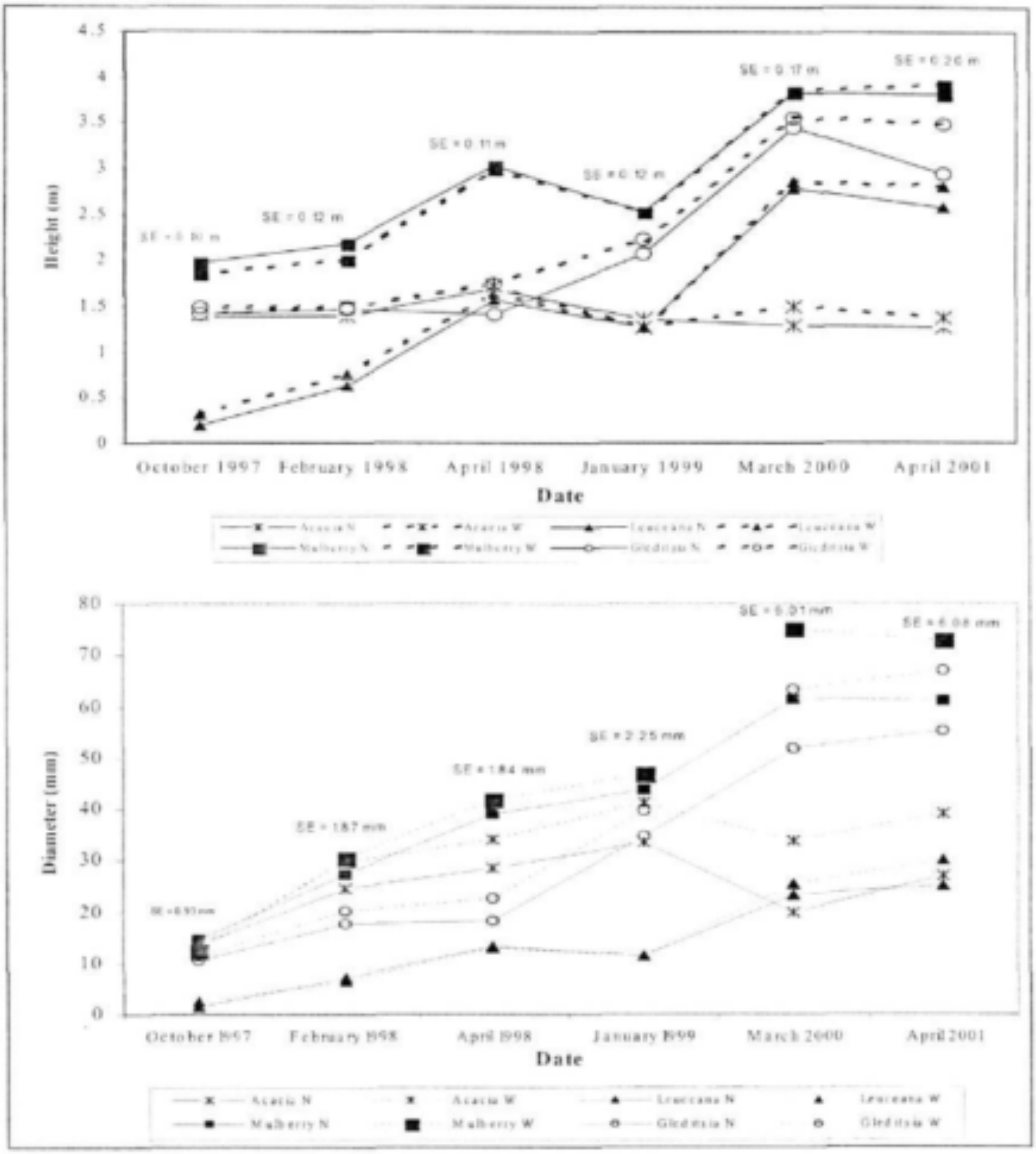


Figure 4.19 Total mean tree heights and diameters from October 1997 to April 2001.

By January 1999 the tree diameter of all species was greater than at the end of the 1998 growing season Fig. 4.19). Values ranged from 11.4 mm in *L. leucocephala* to 47 mm in *M. alba*. The decrease in trunk diameter of *A. karroo* is attributed to the low tolerance this species had to the severe pruning that resulted in the death of the main trunk. With the exception of *Leucaena*, the wide spacing treatment resulted in significantly greater trunk diameters than the narrow spacing.

There was no significant increase in tree diameter (Fig. 4.19) between 2000 and 2001. In general, the trees in the wide spacing treatment had a greater diameter than the narrow spacing treatment for all species.

4.6 Maize Yield

The biomass of the first maize crop was recorded in July 1997 for each interior row of maize separately (total dry mass and grain mass) The maize grain production for each treatment is presented in Table 4.1. Total grain yield for the experimental site was 2460 kg ha^{-1}.

Table 4.1 Maize grain production (kg m^{-2}) in July 1997.

Acacia-narrow	rep1	rep2	rep3	*mean*	**Acacia-wide** rep1	rep2	rep3	*mean*
row 1	13.09	12.24	10.20	**11.86**	5.53	4.68	12.33	**7.52**
row 2	13.18	13.01	11.09	**12.41**	4.25	3.83	12.33	**6.80**
row 3	9.82	14.45	17.89	**14.07**	11.90	20.83	15.73	**16.15**
row 4	11.43	14.45	12.33	**14.15**	8.08	7.65	7.23	**7.65**
row 5	9.82	15.51	12.88	**12.75**	8.50	8.93	6.38	**7.95**
row 6	11.86	15.73	9.69	**12.41**	5.95	8.08	7.23	**7.10**
			Total=	**77.65**			Total=	**53.17**

Leucaena-narrow	rep1	rep2	rep3	*mean*	**Leucaena-wide** rep1	rep2	rep3	*mean*
row 1	15.98	10.12	10.12	12.07	13.47	15.68	13.18	14.11
row 2	13.35	10.37	10.37	11.73	11.60	15.64	13.18	13.47
row 3	12.11	9.44	9.44	10.33	12.92	13.69	12.33	12.96
row 4	10.67	4.51	4.51	6.55	11.65	18.32	14.03	14.66
row 5	8.84	6.50	6.50	7.27	11.65	11.35	7.86	10.29
row 6	9.26	5.39	5.39	6.67	10.32	12.49	6.37	9.73
			Total=	**54.62**			Total=	**75.22**

Gleditsia-narrow	rep1	rep2	rep3	*mean*	**Gleditsia-wide** rep1	rep2	rep3	*mean*
row 1	17.04	15.68	0.00	**10.92**	5.53	11.90	11.90	**9.78**
row 2	21.12	15.64	0.00	**12.24**	7.65	11.90	12.75	**10.75**
row 3	31.75	13.69	0.00	**15.13**	6.38	8.50	11.90	**8.93**
row 4	13.94	18.32	0.00	**10.75**	5.95	5.74	11.05	**7.57**
row 5	11.09	11.35	0.00	**7.48**	10.63	6.59	6.80	**7.99**
row 6	14.28	12.50	0.00	**8.93**	4.25	8.93	8.50	**7.23**
			Total=	**65.45**			Total=	**52.23**

Mulberry-narrow	rep1	rep2	rep3	*mean*	**Mulberry-wide** rep1	rep2	rep3	*mean*
row 1	9.22	6.72	6.38	**7.44**	10.33	10.41	13.22	**11.31**
row 2	17.04	6.80	5.53	**9.78**	16.15	13.77	12.62	**14.20**
row 3	16.62	16.28	12.33	**15.09**	16.19	16.87	16.83	**16.62**
row 4	16.24	7.52	8.50	**10.75**	12.96	14.83	17.85	**15.22**
row 5	18.49	9.48	6.38	**11.43**	11.99	14.79	13.90	**13.56**
row 6	14.75	4.08	4.68	**7.82**	10.88	14.58	13.56	**13.01**
			Total=	**62.31**			Total=	**83.90**

Mr. Mahlobo planted the second maize crop in December 1997. Planting was followed by a severe drought period resulting in death of all the maize plants. This necessitated replanting in January 1998. The biomass yield of the maize was not obtained in July 1998 because of communication problems between the farmer and his supervisor. Instead of only harvesting the maize in the surrounding field the supervisor harvested the maize in the experimental site. Unfortunately no records were kept of this yield

1999

With the exception of *M. alba* narrow treatment, the maize grain yield in all the plots was higher than the control. The highest maize grain yields (Fig. 4.20) were recorded in the *A. karroo* narrow (6500 kg ha^{-1}) and *L. leucocephala* wide plots (6000 kg ha^{-1}). This may be attributed to the nitrogen fixing properties of these two species. Tree spacing did not have a significant effect on maize yield.

2000

The maize yield in 2000 was generally lower than the control (3900 kg ha^{-1}) with an average of approximately 2 500 kg ha^{-1} (Fig. 4.20). The yields in 2000 were less variable between plots than in 1999.

An important factor determining the success of intercropping with trees is the effect of the trees on the yield of the adjacent rows of mielies. The maize yields in 2000 of the different rows are presented in Figure 4.21, where row 3 is the closest row to the trees. In this trial the maize yield of the rows closest to *L. leucocephala* and *A. karroo* were not significantly lower then the rows further away. By contrast, *M. alba and G. triacanthos* had a negative impact on maize yield of the rows closest to the trees. This may be attributed to the greater tree heights of these two species and the consequent negative effect of shading on crop yield.

2001

Maize grain yield decreased in 2001 in all treatments when compared to previous years (Fig. 4.20). For example, maize grain yield of the control decreased from

3900 kg ha^{-1} in 2000 to 3000 kg ha^{-1} in 2001. This may be attributed to the very dry period that occurred just after planting in November to early January (Fig. 4.1 rainfall). Maize yield was, however, less variable between treatments, when compared to previous years. The increased yield of fodder and fuel wood in the narrow spacing treatments did not have a negative impact on total maize yield. In fact, the maize yield of individual rows was higher in the narrow tree spacing treatments than in the wide treatments (Figs. 4.21a-h). As in previous years, the maize grain yield of the rows adjacent to the trees was lower than the other rows. This was most apparent in *G. triacanthos* (narrow spacing) where maize yield of the adjacent row was only 100 kg ha^{-1} compared to 950 kg ha^{-1} in the row furthest from the trees (Fig. 4.21h). By contrast, the difference in yield between the closest and furthest maize rows in the *A. karroo* narrow treatment was only 230 kg ha^{-1} (Fig. 4.21 c&d).

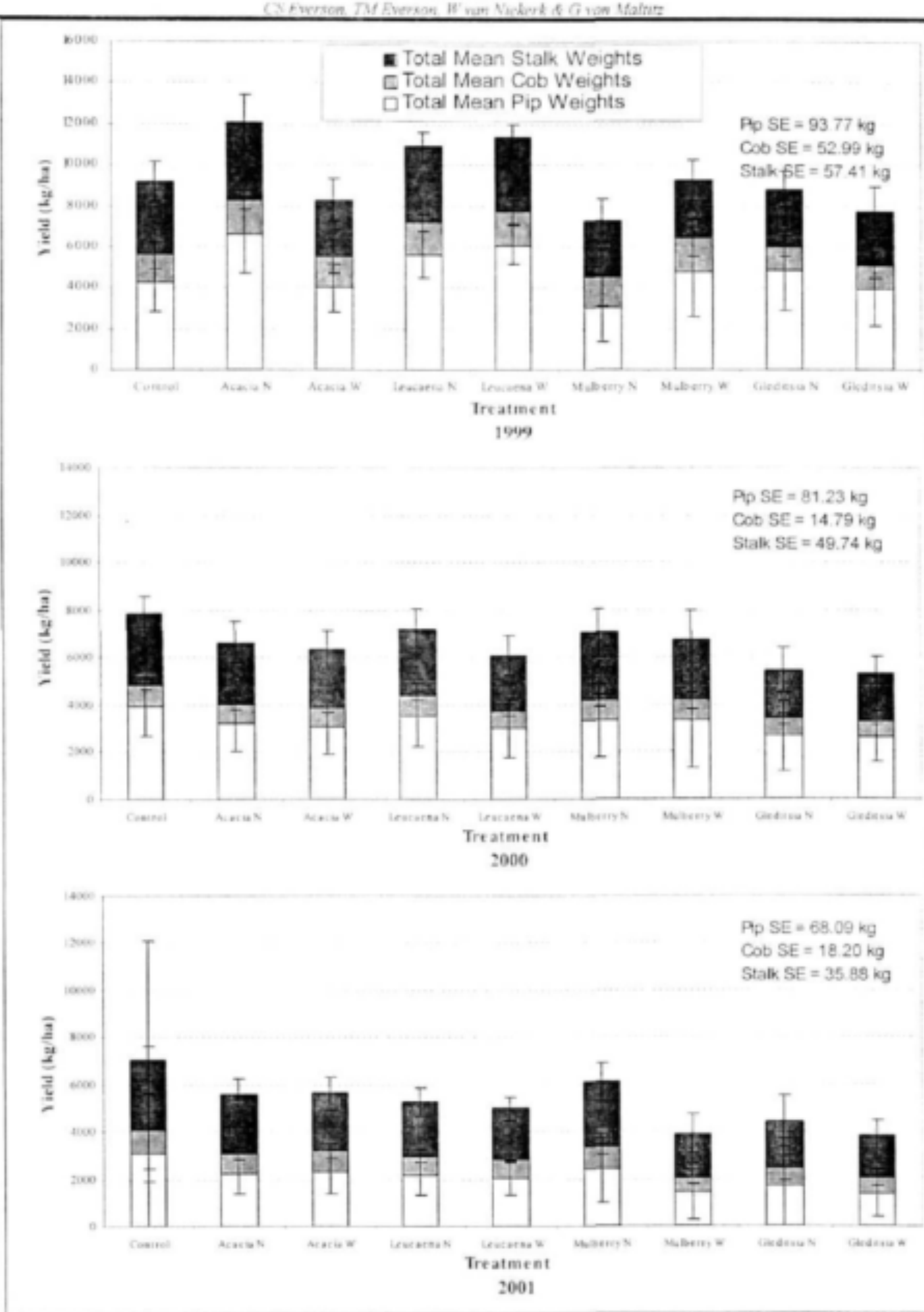


Figure 4.20 Mean total maize yield: 1999-2001.

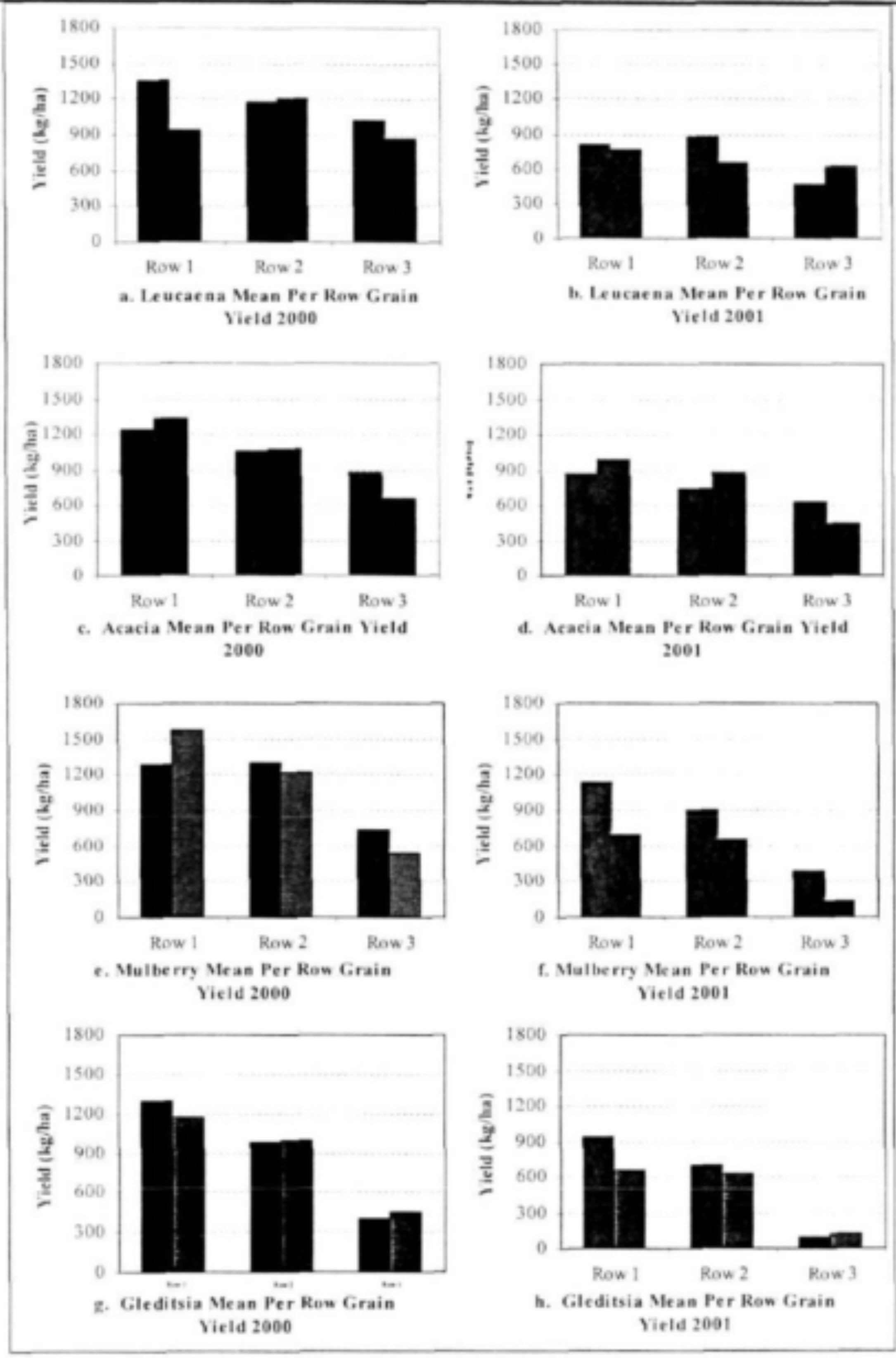


Fig. 4.21 a-h. Mean per row grain yield for 4 species for 2000 and 2001. Note: solid bars = narrow spacing and hatched = wide spacing.

4.7 Nutrient Analysis

4.7.1 *Fodder*

The nutrient content of the four tree species was analysed in both 1999 and 2000 to determine their potential value as fodder (Table 4.2).

Table 4.2: Nutrient analysis of the tree species. ADF= acid detergent fibre.

Tree species		Protein (%)	K (ppm)	P (ppm)	Ca (ppm)	Mg (ppm)	ADF (%)
Acacia narrow	1999 2000	17.1 23.2	1.5 1.3	0.1 0.2	1.1 1.4	0.5 0.5	61.6 33.0
Acacia wide	1999 2000	15.6 19.7	1.4 0.9	0.2 0.2	1.4 1.6	0.5 0.6	59.0 33.2
Leucaena narrow	1999 2000	22.8 25.1	2.1 1.5	0.2 0.2	1.4 1.4	0.7 0.5	47.9 26.8
Leucaena wide	1999 2000	23.2 22.2	1.8 1.3	0.2 0.2	1.6 1.7	0.9 0.5	47.8 21.3
Morus narrow	1999 2000	18.7 21.4	3.5 0.8	0.3 0.2	4.4 2.3	0.9 0.5	36.0 26.7
Morus wide	1999 2000	18.6 21.1	3.2 1.3	0.3 0.2	4.3 2.2	0.8 0.4	34.0 29.9
Gleditsia narrow	1999 2000	10.4 23.1	1.3 0.9	0.1 0.2	1.2 1.3	0.2 0.4	50.2 36.8
Gleditsia wide	1999 2000	10.1 22.0	1.5 1.1	0.1 0.2	1.2 1.4	0.2 0.3	55.2 30.8

Spacing had no significant effect on the nutrient content of edible material. The nutrient content of the trees varied between 1999 and 2000 with the most significant change being the increase in protein and decline in fibre, indicating that physiologically younger material was harvested in 2000. In particular, the low protein values of *G. triacanthos* (<10 ppm) recorded in 1999 had doubled in 2000. Overall, *M. alba* has the highest nutrient content of all the trees on the study site.

4.7.2 Soils

Table 4.3. Summary of analytical results

Land	P *mg/l*	K *mg/l*	Ca *mg/l*	Mg *mg/l*	pH *KCl*
1	5	105	240	784	5.1
2	12	213	440	123	3.8
3	15	206	501	144	3.9
Standard for maize	<10 = poor	<100 =poor	<250 =poor	<50 =poor	<5=too acidic

1 Land under maize, occasionally irrigated, alluvial soil near a river.
2 Land on which agroforestry trial is situated, uplands soil (Hutton).
3 Land under maize inter-cropped with beans, uplands soil (Hutton).

Phosphorous

For beans and maize land 1 is low in phosphorous (beans require 12, maize requires 14 mg/l respectively), while lands 2 and 3 have sufficient phosphorous for beans and maize (currently grown). Approximately 60 kg P/ha is required for maize in land 1, while a starter boost of P in lands 2 and 3 of 20 kg P/ha is advised to promote initial seedling development.

Potassium

Potassium is currently adequate in all lands for both bean and maize production.

Calcium and magnesium

The absolute levels of calcium and magnesium are adequate for bean and maize production, as is the Ca:Mg ratio (never above 7:1).

pH

The pH of land 1 is optimal. Lands 2 and 3 are in need of lime at a rate of 2.5 and 6.5 t/ha for maize and bean production respectively.

Summary

The production of maize or a maize/ bean combination would be improved by fertilizing land 1 with phosphorous, and supplying lands 2 and 3 with lime. The soil is very acidic and well over the recommended value for maize. It is strongly advisable that lime be added to the soil according to the recommendations made by Cedara. This will not only decrease the acidity, but will also increase the Ca and Mg values.

CHAPTER 5: TECHNOLOGY EXCHANGE AND CAPACITY BUILDING

Farmers' involvement in the trial was considered crucial in the development of an agroforestry system for the Upper Thukela region and the adoption of this agroforestry technology by local farmers. The process that was carried out to achieve farmer involvement is therefore outlined in detail. The first step was a survey that explored the farmer's current practices and knowledge on fodder management. An initial workshop was then held with the farmers to discuss needs, plan the trial and determine responsibilities. This was followed by a number of farmers days, farmers feedback meetings and cross visits from neighbouring communities throughout the duration of the project.

5.1 Liaison with farmers

A workshop was held with the farmers to:

a) establish ways of achieving the farmer's' objectives

b) establish responsibilities of different components of the trial

Major constraints to farming in this area are:

(i) ***shortage of land***

Under the current communal grazing tenure there is no access to land other than that allocated to individuals by the chief. They cannot purchase land to expand farming activities. If a neighbour is not utilizing land it may be rented, but this is on an *ad hoc* basis and does not allow long term planning.

(ii) ***shortage of fodder***

The natural grassland of the area is classified as Southern Tall Grassveld, which is characterized by low nutritional value during winter. Therefore cattle feed has to be supplemented during winter. Mr Mahlobo, the co-operating, has planted pastures of oats and rye grass.

(iii) ***shortage of water***

Although the farm is situated adjacent to the Woodstock dam, Mr Mahlobo has no access to this water supply. Only dry land planting of crops is possible on the farm. The building of the dam has caused much unhappiness among the communities living in the area. The communities regard the water as theirs because it is in their area. However, no one is allowed to use the water. Many people were relocated when the dam was built.

5.1.1 *Selection of the field plot*

Mr Mahlobo indicated that the experiment should be carried out in a field close to his homestead to ensure safety of the equipment that would be installed. The size of the plot and inclusion of a control were discussed. Mr Mahlobo requested that a five-metre buffer zone be included in the fenced area to enable the tractor to turn. It was decided that the size of the fenced area would be 58 X 30 metres and that a gate would be located on the southern side of the plot.

5.1.2 *Spacing of plants and trees*

The project team and farmer agreed that the rows of maize and trees should be planted in a north/south direction to minimize shading of the crop by the trees. The rows of maize plants should be planting according to Mr Mahlobo's current practice where rows are planted 0.75 m apart and individual plants are 0.3 m apart. A total of 216 holes had to be prepared for the trees.

5.1.3 *Responsibilities*

i) Mr Mahlobo undertook to plough the field

ii) Holes for trees were prepared by Mr Vilakazi and Mr Mahlobo

iii) Project team supervised marking of plots

iv) Dr T Everson accessed 80 trees of each of the four species

v) Dr T Everson organized payment and transport of trees

vi) Mr Vilakazi transported the water cart to the farm

vii) Mr Mahlobo ensured the trees were watered at planting.

5.1.4 *Fencing*

It was decided to use existing fencing on two sides of the plot.

i) Dr C Everson ordered fencing and organized payment

ii) Mr Vilakazi transported 2 rolls of fencing from Zamimpilo

iii) Mr Vilakazi purchased poles, gate and barbed wire from NLK

iv) Mr Mahlobo put up fencing with Mr Vilakazi's help

5.1.5 *Fertilizer regime*

It was agreed that Mr Mahlobo should continue his normal fertilizer regime for the maize crop. This was MAP (Mono ammonium phosphate) 15 tons ha^{-1} at planting; NPK 3:2:1 - 25 tons ha^{-1} at planting.

Kraal manure was added to the holes for the trees.

5.1.6 *Application for electricity*

Dr C Everson submitted an application to Eskom for electricity for the TDR equipment. It was agreed that the project would pay for the installation costs and that Mr Mahlobo would pay the monthly costs.

5.2 **Farmers' days**

5.2.1 *Khulani farmers day*

Farmers from the Khulani Farmers' Union were invited to attend a farmers' day at the site to view the experiment and discuss the concepts of:

a) agroforestry – potential benefits

b) water use of different tree species

c) tree removal programmes (e.g. "working for water" programme to remove wattle) versus planting water friendly trees

d) water and trees competing for water.

10 local farmers and the project team attended the field day.

The meeting was opened with a prayer. Dr T Everson welcomed everyone and this was followed by introductions.

Background to the project: Dr T Everson gave a brief summery of how the project started. She spoke about the government's tree planting initiative and the reluctance of farmers to plant trees because of their fear that the trees would compete with their crops for water. She explained how funding was obtained from the WRC to examine the effect of different tree species on the growth and water uptake of crops. At a Khulani farmer's union meeting in 1996 she told the local farmers about the proposed WRC project to initiate an on-farm trial. At this meeting Mr. Mahlobo volunteered to have the trial on his farm. He is a dairy farmer and his biggest problem is fodder shortage in winter.

What is agroforestry? Benefits of trees.

Dr T Everson introduced the concept of agroforestry and explained how it is successful in other areas where land is short. She discussed the benefits of trees and explained how the user's objectives would influence the type of trees that are planted. Samples of the four experimental trees were then shown to the farmers and Dr Everson explained their potential benefits for forage and nitrogen fixing. She said that little was known about how much water they used. She pointed out that some trees like wattle were "water greedy" which was why the "Working for Water "programme was initiated to remove wattle from water courses. It was important to find "water friendly" trees that could be grown in the area. She explained that the results from this trial would be used to make recommendations to farmers in the area.

Visit the agroforestry trial

Dr Colin Everson explained how the equipment in the trial was used to measure the effect of the trees on the available water for the maize crop. He demonstrated the concept by placing probes in a bucket of sand and showed the farmers how he could get an instantaneous reading of how wet the soil was. He then poured water on the soil and showed how the reading increased. This demonstration was very successful and initiated a lot of discussion among the farmers. He then explained how the cell phone link enabled him to phone the site and obtain all the data while sitting in his office 200 km away.

One farmer asked whether the trees in the trial were like wattle where nothing grows underneath them. This was a good point to visit the site and show the farmers how well the maize was growing next to the trees. Dr Everson also showed the farmers how the equipment worked. The farmers enjoyed the visit and asked lots of questions.

Questions and discussion

The farmers all agreed that their main constraint in farming was fodder shortage in winter. They requested assistance in obtaining *Leucaena* trees, as they wanted a species that fixed nitrogen. Several farmers indicated that they would like to initiate agroforestry but were concerned that they did not have electricity to measure the water use of trees. It was explained that this was not necessary, especially when the results from the experiment were available.

Report back by Mr Mahlobo

Mr Mahlobo gave a brief background to his involvement in the project. He said that initially he didn't really understand what the project team was doing. Now that things were happening he was very happy with the trial. He could understand how important it was to show farmers which trees they could grow. He also told the farmers of some of the mistakes that had been made. He told of his horror on finding that his supervisor had harvested the experimental maize the day before the project team arrived. He also spoke about the effect of the drought that killed the first planting of maize and how everything had to be replanted. He said he

was very worried when he saw the team pruning all the trees last May because he was convinced that they would never grow again. He was very happy to look around him today and see how well they were doing.
Mr Mahlobo thanked everyone for taking an interest in farmers' problems and persisting even though mistakes were made.

The meeting ended with a request by the farmers to hold the farmers's day as an annual event.

5.2.2 Okhombe farmers day

Fifteen community members from Okhombe (6 women & 9 men) visited the agroforestry trial on 8/02/01. The constraints of farming (little land, available markets, no fences, lack of winter fodder etc) were discussed. The potential of agroforestry species to contribute to winter fodder was debated. People were also interested in the role of agroforestry species as green manure and as an alternative to buying fertilizer.

The trial played an essential role as a demonstration of the potential of agroforestry in supplementing fodder shortage in rural farming systems. People commentated on the excellent condition of the trees and said they hoped to plant similar trees in their Land Care programme.

Mr Mahlobo showed how the leaves and young stalks from the trees were harvested and ground in his small hammer mill. This was then mixed with stover to form high quality fodder, which was stored in bags for winter-feed. He noted that the cut and carry method of harvesting was time consuming. He suggested that if the trees were grown in blocks instead of next to the maize rows, the cattle could feed directly from the trees and this would cut costs on employing people to harvest.

5.3 Cross visits

In order to build the capacity of the community, two cross visits to the agroforestry trial were held on 30/11/99 and 1/8/00.

5.3.1 *Ngubhela community*

Six members from Ngubhela, a neighbouring sub ward, were taken to the site to view the experiment and discuss the concept of agroforestry. They had the opportunity to talk to members of Mr Mahlobo's work team and discuss the use of trees in providing fodder to improve productivity. The Ngubhela community members said the visit was useful to help them plan their tree-planting programme. When they evaluated the day they commented on the following:

- It was the first time they had seen some of the tree species.
- They learnt about water competition and had a better understanding of why some trees were better to plant than others.
- They had a better vision of how a tree-planting program can benefit the livestock and the people.
- They did not know that trees could grow so well next to crops.
- It was helpful to see a project, which had made good progress.
- They learnt how trees could provide food for cattle in winter.
- They had a good understanding of the difference between exotic and indigenous trees.

The cross visit provided an opportunity for sharing experiences and learning. The participants requested that further cross visits be held to enable more people from the community to learn about agroforestry.

5.3.2 *Land Care facilitators*

One of the objectives of the national Landcare programme is to assist rural communities in sustained natural resource management. One of the ways this can be achieved is to provide alternative fodder to the current degraded rangeland through the introduction of agroforestry programmes. The agroforestry trial provided a good on-farm demonstration and training opportunity for Land Care facilitators who are currently employed by the National Department of Agriculture and Forestry to work with communities and implement the Land Care programme. With the exception of the current project, there are no known examples of agroforestry systems in frost prone areas of Kwa-ZuluNatal.

The cross visit was held on 1/8/00 and was attended by 12 community members and 6 for Land Care facilitators from Okhombe, Edenvale, Willowfontein, Taylor's Halt and Marionnhill. Mr Mahlobo gave a presentation to the group and answered questions from the community. He said that the best species was *Acacia*, as this is most preferred by the livestock. However, mulberry is the most productive tree and is good for fodder.

At the end of the day the community said that it was very helpful to see the trees growing with maize, as they had only seen it on a video before. They also said that it was encouraging to see the system working for a black farmer and was an inspiration for them to try it out.

5.4 Students

Visits to the trial by rural resource management students, Landcare facilitators and grassland science students at the University of Natal contributed to the learning experience and capacity building of these groups.

The project forms the core of a PhD study for Mr van Niekerk.

Mr. G. Ramuthivheli, a student from RAU, carried out the economics survey on the value of fodder and supplements for cattle in the Upper Thukela district as part of his MSc study.

The on-farm trial was used as a demonstration in a pilot study for rural resource management students at the University of Natal. This proved to be so successful that it is now included in the Participatory Development Certificate in Education.

This will be upgraded to 32 credits in 2003. Fifteen students doing the Land Care course have visited the trial and gained valuable experience on solving problems co-operatively with farmers.

Mahlodi Tau, a student at the University of Natal, is currently using the trial in his Masters study on improving rural livelihoods through natural resource management.

The trial is also a valuable demonstration to local and overseas students as it shows the importance of of-farm trials in rural areas. Numerous students have been taken to the trial including students from other countries such as Zimbabwe, Eritrea, and Kenya.

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.

5.5 Conclusion

Farmer participation in this trial provided a means of integrating local knowledge and perspective into the process, and also enabled greater understanding of the operation and constraints of traditional farming systems. Farmers' Days were important in improving communication of results between target communities, the farmer and the work team. Facilitating partnerships between the local people and the work team resulted in more effective identification and prioritisation of research objectives that will lead to more appropriate research.

CHAPTER 6

ECONOMIC STUDY OF THE AGROFORESTRY SYSTEM

6.1 Fodder Flow

The objective of this economic study was to examine the fodder flow of a rural farming system to make recommendations of ways to improve fodder production for dairy cows. The farmer participating in this trial is a small-scale dairy farmer who currently has 14 dairy cows. Mr. Mahlobo's animal-production enterprise involves the production and sale of milk from the dairy herd, and the sale of bull calves and cull cows. He also manages a beef-herd that operates in the traditional community-tenure grazing pattern. His markets are located in the surrounding rural communities, with fresh milk being sold on a daily basis in centres as far away as Estcourt (c. 75 km). Milk production per cow ranges from approximately six litres per day in winter to eight litres per day in summer.

Beef animals, and dairy calves and cull-cows are sold according to demand, this often occurring at Christmas or Easter, or other social or religious events. He is also a crop farmer, growing maize, beans and potatoes on most of his land (both owned and rented), with kitchen-produce (onions, egg plants, spinach, etc.) occupying a limited area. He has, over several years, proved to be a good example of how commercial objectives may be met in a rural community structure.

The area in which Mr Mahlobo farms comprises residential, subsistence-farming, and commercial-farming landowners. The area is well known for its involvement in the Lesotho Highland Water Scheme, and is in close proximity to the Woodstock Dam, one of the scheme's large water-holding dams. Arable land may be owned by individuals (on permission from the chief of the region), and is farmed according to the user's wants; the land is in some cases rented out to other landowners. Grazing land operates under a communal tenure, with any residents having equal rights to its use regarding the grazing of animals (mainly cattle). In winter, individual homesteads have the right to graze their animals on crop residues in their fenced fields. However, residues on unfenced fields are available to all livestock owners.

This study assessed the farm's resources in terms of land, water, labour, management, and capital to determine the forage production potential of the farm and produce a fodder flow to identify methods to maximize productivity.

6.1.1 Current grazing practice

The co-operating farmer in this trial keeps his 14 cows that are mainly of Jersey, Simmentaler and Friesland extraction, with some Afrikander or Bonsmara blood. The structure of the herd appears to be dynamic in the short term; in 1996 the herd size was 20 (Everson, Du Toit & Everson 1998).

The grazing practices in the area are strongly influenced by the topographic division of the area into lowlands, hill slopes and the Little Berg plateaux. The grazing system is related to the cropping cycle. In winter following harvest the cattle graze on the maize residues (stover) and grassland in the lowlands. During summer and the cropping season the cattle are moved on to the plateaux. Milk cows and calves are kept in the vicinity of the homesteads.

During the spring and summer the cattle graze on kikuyu and the surrounding grasslands under the supervision of a herder. Salt is given as a supplement to all animals, while those being milked receive a dairy concentrate meal bought from a local co-op. Meal rations increase during autumn and winter to maintain a relatively constant supply of milk. However, large seasonal variations indicate that this may be a recent development (Everson, Du Toit & Everson 1998). During winter the cows graze the kikuyu pasture, and also an oats-ryegrass pasture, and have access to maize stover as an additional source of roughage. The pastures are fertilized with 90 kg LAN per hectare to increase their productivity. Current milk production is as follows: spring 5.3 l cow^{-1}; summer 6.8 l cow^{-1}; autumn 5.0 l cow^{-1}; winter 5.3 l cow^{-1}.

6.1.2 *Dairy herd requirements and supply*

Two features that distinguish this small-scale dairy enterprise from most commercial operations is the dynamic nature of the rental agreements regarding arable land, and the use of communal land for grazing. The variable nature of these aspects raises the question of the applicability of the concept of carrying capacity to rural farming systems. The calculation of fodder flow is determined by the requirements of the current herd structure (Table 6.1). Although the calving schedules may vary during the year, for the purposes of this study a constant monthly herd requirement is assumed throughout the year. Matching this to the current fodder input (veld, pasture, and bought feed) will indicate obvious bottlenecks in quantity and quality, or other problems such as economic feasibility. Once identified, ways of alleviating these problems to improve animal performance and increase productivity are identified.

Table 6.1. Feed requirements of dairy herd*

Animal	Number	Dry matter (kg month $^{-1}$)
Cow (in milk)	12	3 960
Dry cow	2	560
Bull	1	275
TOTAL		4 795

*Lactating cows assumed to be producing 6 litres of milk per day.

The current monthly production of the pastures (Table 6.2) is estimated using published growth curves (Klug & Webster, 1993). The dry matter production is estimated at 5 and 4 tons per hectare per annum for oats/ryegrass and Kikuyu respectively based on the farm's nitrogen application rates and substituting them into published formulas for estimating forage yield (Klug & Webster 1993; Smith 1993).

Table 6. 2. Monthly dry matter requirements sourced from pastures and bought feed (kg)

Forage	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
herd req.	4795	4795	4795	4795	4795	4795	4795	4795	4795	4795	4795	4795
oats/rye	120	180	850	1000	810	0	0	30	210	330	1020	450
kikuyu	0	0	0	240	560	1080	1040	640	280	160	0	0
Bought feed	1440	1440	720	720	720	720	720	720	1440	1440	1440	1440
Deficit	**3235**	**3175**	**3225**	**2835**	**2705**	**2995**	**3035**	**3405**	**2865**	**2865**	**2335**	**2905**

It is obvious that the herd, even in the most productive month (November) is currently only getting a small proportion (<25%) of its dry matter intake from the pastures. Assuming the estimated intakes to be correct, the deficit is made up from bought feed and natural veld. Feed rations to the cattle comprise 2 kg/cow/day during spring and summer and 4 kg/cow/day during autumn and winter.

The fertilization rates used by the farmer (Table 6.3) are low in comparison to norms recommended by extension services. This indicates that there is potential for increasing productivity with additional fertilization. Also of interest is that the only macro-nutrient applied is nitrogen. While this is vital, it will not have its potential impact on production if other macro-nutrients (mainly potassium and phosphorous) are in short supply. Further recommendations included the addition of lime to these acidic soils to improve production. This once again highlights the importance of soil analyses.

Table 6.3. Pasture fertilization schedule

Pasture type	Area (ha)	Fertilizer	Amount (kg N ha^{-1})	Fertilization schedule	Total Fertilizer (kg)
Kikuyu	1.0	LAN (28)	84	1 dressing	300
Oats/ryegrass	2.5	LAN (28)	90	2 dressings	800

From Table 6.2 it appears that approximately 40% of the herd's requirements are supplied by pastures and bought feed, while the remaining 60% comes from natural veld. Bought feed is relatively expensive (R1,50c per kilogram dry matter). If one assumes that a kikuyu pasture, without any fertilization, produces approximately 1.7 tons of dry matter per year, and the application of 85 kg nitrogen increases this to 4.0 tons, it is costing approximately 14c per kilogram of dry matter produced (@ R1.10 per kg LAN). To increase the production of kikuyu to 7.5 tons per hectare (using the formula of Smith, 1993) would require an additional 590 kg LAN per year, or 19c for every additional kilogram dry matter produced (the increased cost is due to the law of diminishing returns). On average, this would allow 12 cows to consume 30 kg (40% wastage) extra per month, for 6 months - with the result that milk production of those cows would increase from 6 l to 8 l per day. Working on a gross margin for milk of R0.50c per litre (local selling price is R2/*l*), this translates into R2160 (2 *l* x 12 cows x 180 days x 50c) in increased income - this far outweighs the extra R650 spent on fertilizer. This indicates that it is not economically viable to produce milk at a low level. One option to improve the profit margin, therefore, is to increase fodder supply.

However, buying in more feed would probably prove to be too expensive, as it costs about five times more on a mass basis. It is, however, a good practice to feed the cows some bought feed as it contains macro- and micro- nutrients and other concentrates that are vital for production, which would not be obtainable from veld or pastures alone. Improving summer production would be possible, and an increase for winter is also possible to a certain extent if the oats/ryegrass pastures were irrigated, although this would still result in definite periods of deficit (Table 6.2)

An important source of fodder available to rural farmers is the maize stover. This is an average quality feed, which provides vital roughage during winter when natural grazing is at a minimum. The farmer utilizes up to three tons of stover after the maize has been harvested. This is effectively free (except for handling and transportation costs). Fresh stover can be consumed with good results, but as it becomes older and less palatable to the animals, a supplement is required. Commercial supplements such as urea, molasses, licks, or energy or protein supplements are readily available but are relatively costly. A cheaper option is to supplement the diet with high protein fodder from trees grown on the farm. Dry matter yields of four tons per hectare have been recorded from fodder trees (Pauw 1994; Cronje & Rethman 1998).

The most feasible way to increase feed production is to grow it on the farm. A relatively low cost option of increasing feed production is to supplement the diet with high protein fodder from trees. Dry matter yields of four tons per hectare have been recorded from fodder trees (Pauw 1994; Cronje & Rethman 1998).

6.1.3 Conclusion

The small-scale farming enterprise in this study provides a good example of how commercial objectives may be met in a rural community structure. The study highlights the importance of three factors that must be considered in the development of sustainable rural farming systems: land tenure, availability of water and fodder shortage. It is apparent that agroforestry species have the potential to provide an affordable fodder supplement for increasing productivity of cattle.

The most feasible way to increase production is to grow fodder trees, which supply palatable, nutritious material during winter when natural grassland is not available. Agroforestry will, therefore, not only provide dry season forage, but will also diversify the range of products from the cropland. Added benefits of agroforestry species may be the provision of organic matter, increased fertility through nitrogen fixation and improved microclimate for the crop.

6.2 Economic model

In order for agroforestry to become widely accepted socially it needs to exhibit clear financial benefits to local communities. The nature of an agroforestry system is such that it produces a diversity of goods and services. Many of these goods and services are used directly on farm by the farmer and are not openly traded. An economic study was conducted to identify the goods and services likely to emanate from an agroforestry system, while investigating whether these goods were traded locally and what their local value was. Using this data a simple model was created to simulate under which circumstances agroforestry was likely to be a better land use option than mono cropping of maize. The study was conducted in the Okhombe valley to ascertain the local values likely to be placed on the products of an agroforestry system. Local market values were used as opposed to commercial market values as it was assumed that most products would either be traded locally or would be used to replace a commodity that would have to be purchased locally. A summary of local values is given in Table 6.4.

Table 6.4 **Summary of products utilized locally with associated purchase and transport costs.**

Product	Unit Mass (kg)	Price per Unit	Price per ton	Transport Costs per ton	Total Cost per ton
Maize (Spaza shops)	80kg	R80	R1000	n/a	R1000
Maize (town)	80kg	R70	R875	R150	R1025
Mieliemeal (Spaza shops)	80kg	R120	R1500	n/a	R1500
Mieliemeal (town)	80kg	R80	R1000	R150	R1150
Wood (Local woodlot)	25kg (headload)	R10	R400	n/a	R400
Wood (external source)	1000kg (truckload)	R280	R280	included	R280
Fodder	150kg (bale)	R60	R400	R79	R479
Molasses supplement	50kg	R33	R660	R200	R860
Calf meal supplement	50kg	R53	R1060	R200	R1260
Complete Beef supplement	50kg	R55	R1100	R200	R1300
Production Lick	50kg	R55	R1100	R200	R1300
Protein Lick	50kg	R55	R1100	R200	R1300

Maize

A price of R1000 per ton was used as the local value of maize as this was the best price for locally obtained maize. Although maize was obtainable for less in towns such as Bergville, a substantial transport cost was involved in bringing it to the community.

Maize stalks

No local market existed for maize stalks, but they still had a high local value, as they were the main fodder source used for cattle during the winter months. Despite their relatively low nutrient value, stalks play a major role in providing bulk to the cattle diet. Stalks are normally seen as communal property as they are simply left on the fields for the cattle to graze. A value of R200 per ton was given to maize stalks as input for the model, which was substantially less than the community paid for hay. Assigning maize stalks a value of zero had a relatively minor impact on the outcome of the model.

Wood

Fuelwood was an important commodity to the community and although many households collected their own fuel, there was an active wood market. Wood was either sold by the headload or bought from wood merchants who sold it by the truckload, which was approximately one ton. A value of R280 per ton (truckload) was used for the model.

Fodder

Fodder is a major problem during the winter months as the area is a 'sourveld' region, which offers poor quality winter grazing. The economic study found that there was an active market for the purchase of hay as many cattle owners saw this as important for their cattle's well being. Nevertheless, farmers tried to minimize this expense as much as possible. It was assumed that the leaf and twig components of trees should be equivalent in value to this fodder. It was therefore given a value of R400 per ton in the model. The assumption of the value of this fodder was possibly the weakest point of the model. Firstly it did not take into account the cost of harvesting and storing the leaves, secondly there was no current market for this type of fodder and thirdly it was assumed to have similar local value to hay, despite having a much higher protein content.

Nitrogen supplements

The community did purchase protein supplements. Although the tree leaves may have reduced the need for this, it was decided, for simplicity sake, to only value the fodder. Clearly if the community bought Lucerne fodder it would have the same nitrogen supplement effect.

Primary production models

The model is loosely based on the data from the *Acacia karroo* component of the alley-cropping experiment on Mr. Mahlobo's farm. Exact production values have not been used for the following reasons.

1) These clearly change on a yearly basis, both as the trial matures and in response to rainfall.
2) The control plot used in the experiment may be biased due to the close proximity of trees
3) The model is designed to investigate trends and the impacts of changing key variables, so absolute values are not that important. In addition absolute production values have only estimated economic values attached to them.

The agroforestry system

The model assumes an ally-cropping agroforestry system where six rows of maize are planted between each row of trees. It was assumed that the rows of maize are impacted in proportion to their distance from the tree row, and that the rows on each side of the trees are impacted to the same extent. It was assumed that the control i.e. maize with no trees, would have the exact same layout except that there would be seven rows of maize and no row of trees.

Maize production

The model allows two ways of considering maize production. Either actual value can be entered for the control and each of the three row spacings from the tree. Alternatively values can be entered as a percentage of maize production of the control per row. If actual values are entered these must be normalized to ton per ha (assuming the entire ha was planted with all producing at the rate of the row one). The same logic has been used for estimating the stalk value.

Wood and leaf production

These values can be directly entered, though a fixed ratio of two wood units to three leaf units was used in the production of the three-dimensional model. These are approximately the values observed in the agroforestry trial for *Acacia karroo* during the 2001 year.

The simple model

The model Agroforestry.xls is a Microsoft excel model that compares the Rand value obtained from an agroforestry system with a mono-cropped maize system. The sheet labelled inputs allows all values to be customized. If actual maize production values are entered this overrules the percentage values. The alternative is to enter the percentage production compared to the control (i.e. 60% would indicate a production of 600kg if the control was one ton per hectare). The model gives gross value and does not take into consideration production costs since these are assumed to be similar for both systems. A partial budget approach is used to allow for possible corrections based on the differing production costs in the two systems. The output page allows for the addition of additional costs (or savings if negative) between the two systems. It must be noted that this model is designed for exploratory investigation of the impact of changing different variables, and that until direct production, control and market values can be confirmed its results must be used with caution.

The 3-D model

This model uses the exact same logic as in the simple model, but investigates the interaction between differences in maize grain and fuelwood production. For simplicity fuelwood and leaves are assumed to be produced in ratio to each other and maize grain and stalk production is also expressed in a simple ratio. This model investigates the profitability of agroforestry as fuelwood and maize grain production varies. To keep it simple it has inbuilt assumptions that must be considered when interpreting the results.

1) The interaction between trees and maize is not modelled. Reduction in maize due to trees stays the same regardless of tree production. This

assumption may have biological faults, but would approximate likely responses to increased fertilization or rainfall. The model must be interpreted as economic feasibility given specific ratios of crop production in the agroforestry trial.

2) No consideration is given to changes in input costs
3) Wood to leaf ratios stay constant for trees
4) Some options, particularly the high wood/high maze production may well be biologically unrealistic.

Results

The results indicate that there are situations where agroforestry may well be economically more viable than mono-cropped maize even in situations where maize production in all rows is suppressed compared to the control (Figs. 6.1 & 6.2. This result is, however, heavily dependent on a market existing for the leaf fodder. Since maize has a higher value than leaves and wood, the relative profitability of agroforestry drops off as maize production increases. In situations where high fertilizer inputs are used to bring maize production up to 3t/ha or more it is clear that farmers will suffer a loss from agroforestry if the wood and leaf production stays the same (Fig. 6.3). However if leaf and wood production increases without causing a greater decrease in maize production then the system may still be viable. The 3D model attempts to investigate the change in profitability as both maize grain and fuelwood production varies. Figures 6.4 and 6.5 show gross profit from the combined system. The x and y axis of this graph have been reversed to show more clearly the maize control (0 trees) and how its value is greater than agroforestry trials where there is low tree production. Figure 6.6 shows the break-even profitability of agroforestry. The value of the control is subtracted from the value achieved in the agroforestry trial. It clearly indicates that, where there is high maize grain and low tree production, agroforestry is non-viable, but where there is high tree production and low maize production (in the control) agroforestry is viable providing input costs remain similar and providing there is a local value for the fodder (other inputs are the same as Fig. 6.1). If fodder and stalks are given zero value and the only value from the agroforestry trial is wood then it is almost never profitable (Fig. 6.7).

Figure 6.1 Sample input screen. All settings stay constant for the sample outputs except control maize.

Figure 6.2 Agroforestry versus maize if the maize control is 1.4 t grain ha^{-1}

	A	B	C	F	G	I
1		Agroforestry		Mono-crop of maize		
2			Value in rand			Value in rand
3	Tree production	Wood17	280	Maize production	Control	3000
4		Fodder	800	Stalk production	7 X control	600
5	Maize production	2 X row 1	429			
6		2 X row 2	600			
7		2 X row 3	686			
8	Stalk production	2 X row 1	86			
9		2 X row 2	120			
10		2 X row 3	137			
11						
12	Total value in R		3137.1	For Agroforestry system	Only maize	3600
13	Additional input costs can be entered below - since the model is for comparative purposes, it is recommend that only additional cost are entered (rather than total costs)					
14	For instance if an additional R50 per ha/year is needed in labour in the agroforestry situation then this can be added					
15	Costs					
16	Lost of water		10			0
17	Extra fertilizer		0			0
18	extra pesticides		0			0
19	extra fencing		0			0
20	extra labour		100			0
21						
22	Total costs		110			0
23						
24	Total value		3027.1			3600
25	with input cost corrections					

Figure 6.3 Agroforestry versus maize if the maize control is 3 t grain ha^{-1}

Sample input screen

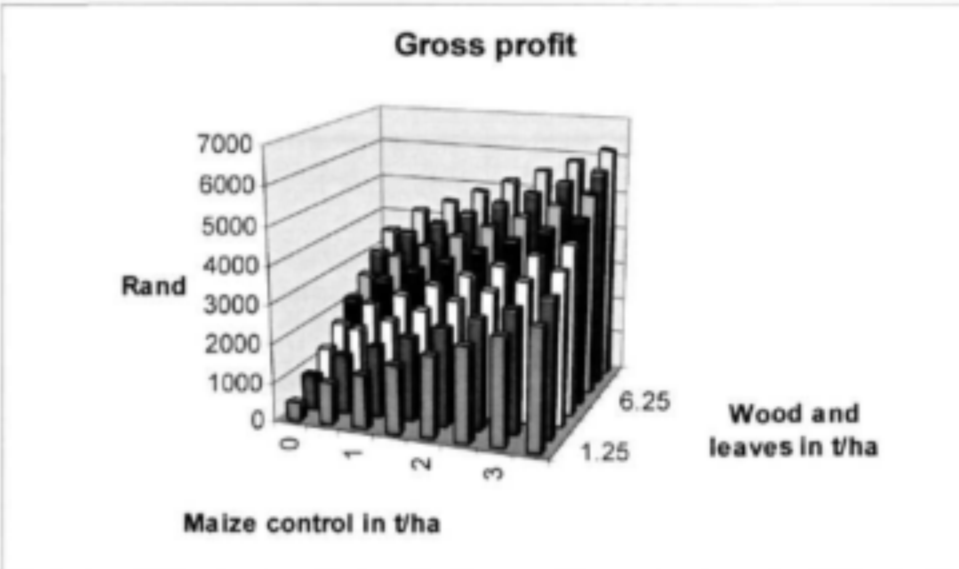


Figure 6.4 Gross profit in an agroforestry system as tree and maize grain production is varied. Note the maize production figure relates to the production of maize in the control, not the production in the agroforestry trial. The control has been excluded since it obscures other values.

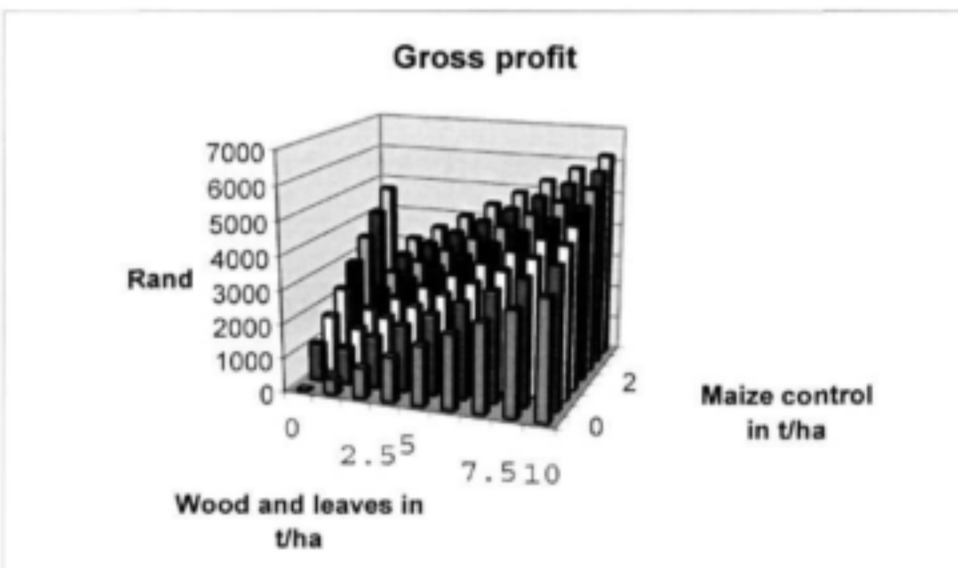


Figure 6.5 Gross profit in an agroforestry system compared to monocropped maize (control) this is the same data as Figure 6.4, but with the rows and columns reversed so that the included mono-copped maize data can be clearly seen.

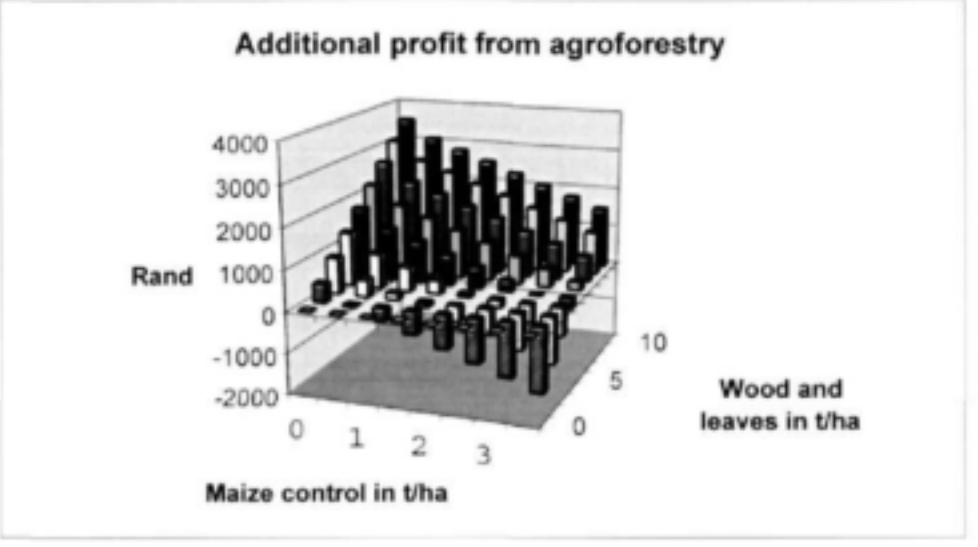


Figure 6.6. The relative profitability of agroforestry compared to monocropped maize. Input values are as in Figure 6.1.

Figure 6.7. The relative profitability of agroforestry compared to mono-cropped maize in a situation where both maize stalks and leaf fodder are given zero financial value.

CHAPTER 7

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Fodder shortages especially during the dry winter season, were identified as a key factor limiting dairy production in the Upper Thukela region of KwaZulu-Natal. An investigation into how farmers are currently managing the fodder shortage was carried out to help focus the project activities at solving the farmer's priorities with appropriate interventions through the introduction of agroforestry technologies. The aim of this study was to determine the optimum combination of fodder trees and maize to increase production and minimize soil water competition. An on-farm trial was conducted to determine dry matter production of four fodder tree species and their effect on soil water and maize production.

Fodder yield in all species decreased with the wider row spacing of trees. It is therefore recommended that agroforestry species should be planted 0.5 m apart to maximize fodder production. The most productive tree in terms of available fodder was the indigenous tree *Acacia karroo* (3000 kg ha^{-1}). The *M. alba* tree had the highest fuel wood production in 2001 (8300 kg ha^{-1}) and was favoured by the farmer because of its fruit production. The fodder production of the exotic species *Gleditsia triacanthos* (<300 kg ha^{-1}) was significantly lower than the other species and is not recommended for fodder production. Fodder yield in *L. leucocephala* increased significantly from 1999 (500 kg ha-1) to 2001 (3800 kg ha-1). Although this species was slow in establishing, it is apparent that once established it is a productive species.

There were no significant differences in tree height between the wide and narrow spacing within species. By March 2000 the greatest height between species was exhibited by *M. alba* (3.8 m) followed by *G. triacanthos* (3.5 m) and *L. leucocephala* (2.8 m). The maize rows next to the *M. alba* trees showed a high percentage of shading (>80%) across all rows. These species should be pruned regularly to minimize their shading effect of adjacent maize rows. By contrast, in the other tree species the rows furthest from the trees intercepted as much as 50-80% of the available PAR (i.e. were only 20-50 % shaded). The least growth in terms of height was exhibited by *A. karroo* (1.5 m). This was due to the relatively slow recovery of

A. karroo after the trees were harvested in January 2000. This species should not be pruned severely (>0.75 m) and can be maintained as a hedge.

Shortage of crude protein in diets of cattle has been recognized as a constraint to milk production (CARNET 1996). All four species selected in this trial had high protein contents. *Acacia karroo* and *L. leucocephala* had the highest protein values (23.2 and 25.1 % respectively) of all the tree species. These species can be classified as a protein supplement and will increase milk production if they are incorporated into the dairy farming system.

One of the disadvantages of growing fodder trees next to maize is that the trees may compete with the maize for light, nutrients and water. In 1999, the second year of establishment of the trees, the average maize yield in all the plots (5 014 kg ha^{-1}) was higher than the control (4100 kg ha^{-1}). One exception to this was the *M. alba* narrow treatment. The highest maize yields were recorded in the *A. karroo* and *L. leucocephala* plots (6 600 ha^{-1}), and tree spacing did not have a significant effect on maize yield. The maize yield in 2000 was generally lower than the control (3900 kg ha^{-1}) with an average of approximately 3700 kg ha^{-1}. The yield of maize rows closest to the row of each tree species was reduced when compared to the most distant row. This impact was greatest in *G. triacanthos* and *M. alba* where yields decreased from 1190 kg ha^{-1} to 420 kg ha^{-1} and from 1590 kg ha^{-1} to 560 kg ha^{-1}, respectively. The maize yield reduction next to *L. leucocephala* was 100 kg ha^{-1} while that of *A. karroo* was 700 kg ha^{-1}. The results therefore show that the trees do impact negatively on maize production of rows closest to the trees.

There was little difference between the soil water content of the tree line and the various maize lines (inner, middle and outer) indicating that competition for water is unlikely to be the reason for lower maize yields. The surface soil water content did not differ significantly between the maize and tree rows. However, at greater soil depths (75-125 cm) the trees in the wide spacing used less water than those in narrow spacing. The high soil water values recorded in this study indicate that in the current cycle of good rainfall the plants in the agroforestry trial were not stressed. Thus, in good rainfall seasons the trees do not compete with the crop for soil moisture. Since the trees have access to water at greater soil depths they are likely to be more productive into the dry season than shallow rooted crops.

Total profile water contents, representing the upper 2.5 m of the soil profile, showed that in 2000 the soil profile was dry in December (500-600 mm), increased markedly (600-1000 mm) following the good rains in February (associated with the floods in Mozambique), and then dried out by the end of May. Therefore during the growing period moisture was not a limiting factor. No clear trends were evident between the different treatments, although the driest profiles were associated with *A. karroo* and the wettest with *M. alba* wide treatment (1000 mm). The relationship of the fractional water content with depth for *A. karroo* and *M. alba* showed that there was little difference in water content between treatments in the surface from 25 to 75 cm where values ranged between 0.16 and 0.18. At 100 cm the less densely spaced trees in both the *A. karroo* and *M. alba* wide treatments appeared to be using less water than the narrow spacing. From 125 to 175 cm the *A. karroo* trees in the narrow treatment appeared to be using more water than any other species. From a depth of 200 cm to 400 cm there was little influence of the trees on the water in the profile. The ability of these trees to access deeper soil water without competing with the maize is an important factor contributing to the provision of green fodder well into the dry winter season.

During dry periods in the year 2000 the soil water ranged between 19-27% with no differences recorded between the tree and maize rows. This indicates that the trees exerted no influence on the soil moisture across the trial. The analysis of the wet period showed that values were much higher (28-33%), reflecting the good rainfall over this period. The variability of soil water was much less during the wet periods, and differences due to tree and maize competition would be unlikely during these high moisture conditions.

A comparison of soil water throughout the study period shows that the trial appeared much drier in 2001 than in 2000, which was in turn drier than 1999. This suggests that there may be drying of the trial from year to year as the trees matured.

The soil water content under the different tree spacings indicated that the driest values were recorded under the narrow tree spacings. Trees in the wide row spacing (1 m apart) were, therefore, under less stress than those in the narrow row spacing (0.5 m). However, this trend was reversed in the dry period. It is possible that with the high intraspecific competition between trees in the narrow row spacing, trees developed a deeper rooting system to avoid competition for soil water. Thus, during the drought these roots were well established and enabled the trees to access the deeper soil moisture reserves.

In terms of both fodder and fuel wood production the most promising species are *A.karroo* and *M. alba*. These species produced significantly greater biomass than *G. triacanthos* and *L. leucocephala*. In *A. karroo* the reduced maize yield in the row closest to the trees was compensated for by the high fodder yield (approximately 1500 kg ha^{-1}) and in *M. alba* by the high fuel wood production (4000 kg ha^{-1}). The high fodder to fuel wood ratio of *A. karroo* indicates that it has a high potential to supplement low quality winter diets. *Acacia karroo* has the advantage that it is well adapted to the climate and soil and it is known by farmers. The multi-purpose nature of *M. alba* (fruit, fodder and fuel wood production) made this species a popular choice with the co-operating farmer.

This trial has proved to be a valuable demonstration of the use of agroforestry species for alternative fodder for livestock in rural communities in similar bioresource units throughout KwaZulu-Natal. In particular, the indigenous species *A. karroo* has potential through its high protein content (23.2%), high digestibility (acid detergent fibre = 26.7%) and its capacity to produce fodder well into the dry season. The provision of alternative fodder sources through the establishment of agroforestry species will take the grazing pressure off the grassland, and will also result in considerable savings to the farmer. The daily dry matter (DM) requirements of his dairy herd (12 cows, 2 dry cows and one bull) are 10.65 kg $head^{-1}$ day^{-1}. On an annual basis, approximately 40% of the herd's requirements are supplied through pastures and bought feed, while the remaining 60% comes from natural grassland and maize residues (stover). Bought feed rations to the cattle comprise 2kg $head^{-1}$ day^{-1} during spring and summer and 4 kg $head^{-1}$ day^{-1} during autumn and winter. This feed is relatively expensive (R1.50 kg $^{-1}$ DM containing 14% protein). If the farmer plants one hectare of *A. karroo* alley-cropped with maize, he will save R2 400 to R4 500 per annum on dry matter supplements. This hectare will carry his herd through 50 days of the winter season. In addition, the farmer can save costs on fuel wood and reduce the pressure on wood collection from indigenous resources. Current fuel wood costs are R10 per head load (20-30 kg) or R280 ton^{-1}. In comparison, if the farmer plants one hectare to *M. alba* he will save R1 120-2770 per annum.

In order for agroforestry to become widely accepted socially it needs to exhibit clear financial benefits to local communities. Two economic models were applied to the data to determine the financial viability of the agroforestry system compared with a mono-cropped maize system. The results show that agroforestry is economically viable where there is low maize production and high tree production. The relative profitability of agroforestry drops off as maize production increases. Agroforestry systems with a high fodder production by the tree component are, therefore, recommended if agroforestry is to be economically viable.

The results of this trial indicate that planting indigenous and exotic agroforestry species in rural farming systems of the Upper Thukela region has the potential to increase the sustainability of these farming systems through supplementing animal forage, providing firewood and increasing income.

During the Farmers Days it was apparent that farmers in the area were more aware of the role that trees could play in providing additional fodder for their dairy animals, especially during winter when other alternative feeds were scarce. The economic analysis indicates that agroforestry is more economically viable than mono-cropped maize with high fertilizer input. The participation of farmers in the trial and the feedback of results through farmers' days and cross visits has resulted in a large number of people wishing to adopt this technology. In their evaluation of the project, farmers indicated that alley-cropping was difficult to manage and they wish to try other agroforestry systems such as group planting of trees. Irrespective of which agroforestry model is adopted it is apparent that the adoption of fodder trees into rural farming systems will increase milk production and take the pressure off the limited grazing land.

RECOMMENDATIONS

This study indicated that the introduction of fodder trees as an alley cropping system into maize fields increased fodder production. However, one of the problems of alley cropping is that it is difficult for the farmer to harvest the fodder and weed the cropland. Two systems suggested by the farmer are the planting of trees within the fence along the farm boundary, or along contour bunds in the maize fields. Further research is required to examine alternative agroforestry systems that will optimize management of crops and fodder trees in temperate, frost-prone areas of KwaZulu-Natal.

In recent years there has been a move by farmers away from the accepted annual ploughing and cropping system to "no till" systems. The impact of these techniques on agroforestry systems requires further investigation.

It is recommended that a popular article in the form of a leaflet be produced to disseminate the results of this study to other communities, extension officers, researchers and students.

REFERENCES

Bainbridge, R., Evans, G. C. & Rachman, O (1966). Light as an ecological factor. Oxford: Blackwells.

HKS report (1988). Vegetation and grazing evaluation – Upper Thukela Location. HKS Agriland, Agricultural and rural development consultants, Durabn.

Ansoult, M., De Baker, L.W. & Declercq, M. (1985). Statistical relationship between apparent dielectric constant and water content in porous media. *Soil Sci. Soc. Am. J.* 49:47-50.

Baker, J.M. & Lascano, R.J. (1989). The spatial sensitivity of time-domain reflectometry. *Soil Sci.* 147:378-384.

Camp, K.G. (1997). The bioresource groups of KwaZulu-Natal. Cedara Report No. N/A/97/6. Natural Resources Section, Cedara, Pietermaritzburg.

CARNET (1996) Dairy recording for small holding farmers in eastern and central Africa. Report of the Cattle Research Network Milk Recording Project. ILIR, Addis Ababa, Ethiopia.

Clarke, G.P.Y. & Dane, J.H. (1991). A simplified theory of point kriging and its extension to co-kriging and sampling optimisation. Bulletin 609, Alabama Agricultural Experiment Station, Auburn University.

Cressie, N.A.C. (1991). Statistics for spatial data. Wiley, New York.

Cronje, J.I. & Rethman, N.F.G. (1998). The mulberry tree as a fodder source. Poster presentation, GSSA Congress 33, Cedara, Department of Plant and Soil Science, University of Pretoria, South Africa.

Dalton, F.N. & Van Genuchten, M.T. (1986). The time-domain reflectometry method for measuring soil water content and salinity. *Geoderma* 38:237-250.

Everson, TM, Du Toit, J. & Everson, CS. (1998). Fodder flow in rural farming systems. Proceedings of a symposium on policy-making for the sustainable use of Southern African communal rangelands. Fort Hare, July. (ed) TD de Bruyn and PF Scogings. 135-141.

Fellner-Feldegg, H.R. (1969). The measurement of dielectrics in the time-domain. *J. of Phys. Chem.* 73(3):616-623.

Fritschen, L.J. & Gay, L.W. (1979). Environmental instrumentation. New York: Springer.

Hayhoe, H.N., Topp, G.C. & Bailey, W.G. (1983). Measurement of soil water contents and frozen soil depth during a thaw using time-domain reflectometry. *Atmosphere-Ocean* 21: 1077-1084.

Henderson L (2001). Alien weeds and invasive plants. Plant Protection Research Institute Handbook No 12, Agricultural Research Institute, Pretoria.

Hoekstra, P. & Delaney, A.J. (1974). Dielectric properties of soils at VHF and microwave frequencies. *Jour. of Geophys. Res.* 79(11):1699-1708.

Huxley, P. (1999) Tropical Agroforestry. Blackwell Science Ltd, London

Keng, J.C.W. & Topp, G.C. (1983). Measuring water contents of soil columns in the laboratory: A comparison of gamma ray attenuation and TDR techniques. *Can. J. of Soil Sci.* 63(1):37-43.

Klug, J.R. & Webster, R.M. (1993). Fodder production planning. Faculty of Agriculture, University of Natal, South Africa. Pp R-1-R-34.

Knight, J.H. (1992). Sensitivity of time domain reflectometry measurements to lateral variations in soil water content. *Water Resour. Res.* 28(9):2345-2352.

Jabbar, MA, Reynolds L, Larbi, A. and Smith, J. (1997) Nutritional and economic benefits of *Leucaena* and *Gliricidia* as feed supplements for small ruminants in humid West Africa. Tropical animal health and production, Vol 29 (1), pp 35-47.

Loague, K. (1992). Soil water content at R-5. Spatial and temporal variability. *J. Hydrol.*139:233-251

Manson, A.D., Milborrow, D.J., Miles, N., Farina, M.P.W. & Johnston, M.A. (1993). Explanation of the Cedara computerized fertilizer advisory service. Unpublished report, Cedara Agricultural Development Institute, Department of Agricultural Development, Private Bag X9059, 3200, Pietermaritzburg.

Ong, C.K., Corlett, J.E., Singh, R.P. & Black, C.R. (1991) Above and below ground interactions in agroforestry systems. *For. Ecol. Manage.* 45: 45-57

Patterson, D.E. & Smith, M.W. (1985). Unfrozen water content in saline soils: Results using time-domain reflectometry. *Can. Geotech. J.* 22(1):95-101.

Pauw, E. (1994). Evaluation of *Leucaena leucocephala* (Lam.) De Wit. MSc thesis, Department of Plant Science, University of Fort Hare, South Africa.

Philip, J.R., Knight, J.H. & Waechter, R.T. (1989). Unsaturated seepage and subterranean holes: Conspectus, and exclusion problem for circular cylindrical cavities. *Water Resour. Res.* 25: 16-28.

Reeves, T.L. & Smith, M.A. (1992). Time domain reflectometry for measuring soil water content in range surveys. *J. Range Manage*, 45:412-414.

Reginato, R. & Nakayama, F.S. (1987). Plastic standards for transferring neutron probe calibrations. *Proceedings of the international conference on Measurement of Soil and Plant Water status*. Vol. I.

Rosenberg, N.J. (1974). Microclimate in the biological environment. New York: Wiley.

Roothaert, R.L. (2000). The potential of indigenous and naturalized fodder trees and shrubs for intensive use in central Kenya. Doctoral thesis, Wageningen University, The Netherlands.

Schulze, R.E., Maharaj, M., Lynch, D., Howe, B.J. & Melvil-Thompson, B. (1997). South African Atlas of Agrohydrology and –Climatology. Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa.

Smith, J.M.B. (1993). Crop production planning. In: Klug, J.R. & Webster, R.M. (1993). Fodder production planning. Faculty of Agriculture, University of Natal, South Africa. Pp A4-1-A4-15

Topp, G.C. (1987). The application of time-domain reflectometry (TDR) to soil water content measurement. *Proceedings of international conference on Measurement of Soil and Plant Water status.* Vol. I.

Topp, G.C., Davis, J.L. & Annan, A.P. (1980). Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. *Water Resour. Res.* 16(3):574-582.

Topp, G.C., Davis, J.L. & Annan, A.P. (1982). Electromagnetic determination of soil water using TDR: I. Applications to wetting fronts and steep gradients. *Soil. Sci. Soc. Am. J.* 46(4):672-678.

Topp, G.C., Davis, J.L. & Annan, A.P. (1982). Electromagnetic determination of soil water using TDR: II. Evaluation of installation and configuration of parallel transmission lines. *Soil. Sci. Soc. Am. J.* 46(4):678-684.

Topp, G.C., Davis, J.L., Bailey, W.G. & Zebchuk, W.D. (1984). The measurement of soil water content using a portable TDR hand probe. *Can. J. Soil Sci.* 64:313-321.

Unwin, D.M. (1980). *Microclimate measurement for ecologists.* London: Academic Press.

von Hippel, A. (1953). Dielectrics. In: Candon and Odishaw (Editors), Handbook of Physics. McGraw-Hill, New York.

Zegelin, S.J., White, I. & Jenkins, D.R. (1989). Improved field probes for soil water content and electrical conductivity measurement using time domain reflectometry. *Water Resour. Res.* 25: 2367-2376.

Appendix A. Principles of TDR

The physical principles that form the basis of the time domain reflectometry method have been described by Dalton & Van Genuchten (1986). This section gives a brief summary of the principles that relate to the dielectric constant.

When an instantaneous voltage V is applied across an ideal air-filled parallel plate capacitor with capacitance C_0, the electrical charge Q stored on the capacitor is given by:

$$Q = C_0 V \qquad (1)$$

If an insulating material is placed between the parallel plates, the electric charge will increase, and hence also the capacitance C. One can give an operational definition of the dielectric constant of the material in terms of the capacitance of the air-filled and material-filled capacitors:

$$C = C_0 \; \epsilon' / \epsilon_0 = C_0 \; \epsilon \qquad (2)$$

where ϵ' and ϵ_0 are the dielectric constant of the material and the air, respectively, and ϵ is the relative dielectric constant, or alternatively termed the relative permittivity. When the applied voltage is sinusoidal in time, i.e. of the form:

$$V = V_0 \, e^{i\omega t} \qquad (3)$$

where complex notation is used ($i^2 = -1$) and ω is the angular frequency, then the charging current I_c represents the time rate of change of the stored charge:

$$I_c = dQ/dt = C_0 \, dV/dt = i\omega C_0 V \qquad (4)$$

which will be 90 degrees out of phase with the applied voltage.

If the material between the capacitor plates is not a perfect insulator, as would be the case for a saline soil, then there will be a conduction or loss of current I_1 proportional to the material conductance G and applied voltage V such that $I_1 = GV$. The conductance current I_c is said to be in phase with the applied voltage. Both the loss current and the charge current are key properties that ultimately allow one to measure the electrical conductivity and dielectric constant simultaneously. The ratio of the loss current to the conductance current is called the dissipation factor D, or loss tangent (tanδ):

$$D = \tan\delta = I_l/I_c \qquad (5)$$

The total current I_t (charging current + loss current) becomes:

$$I_t = I_l + I_c = (G + i\omega C)V \qquad (6)$$

which shows that the total current can be viewed as a complex variable consisting of real and imaginary components. Since the loss current may be due to any energy consuming process and not just to conduction losses, it is convenient to introduce in analogy to equation 6 a complex dielectric constant (von Hippel 1953):

$$\epsilon^* = \epsilon' - i\epsilon'' \qquad (7)$$

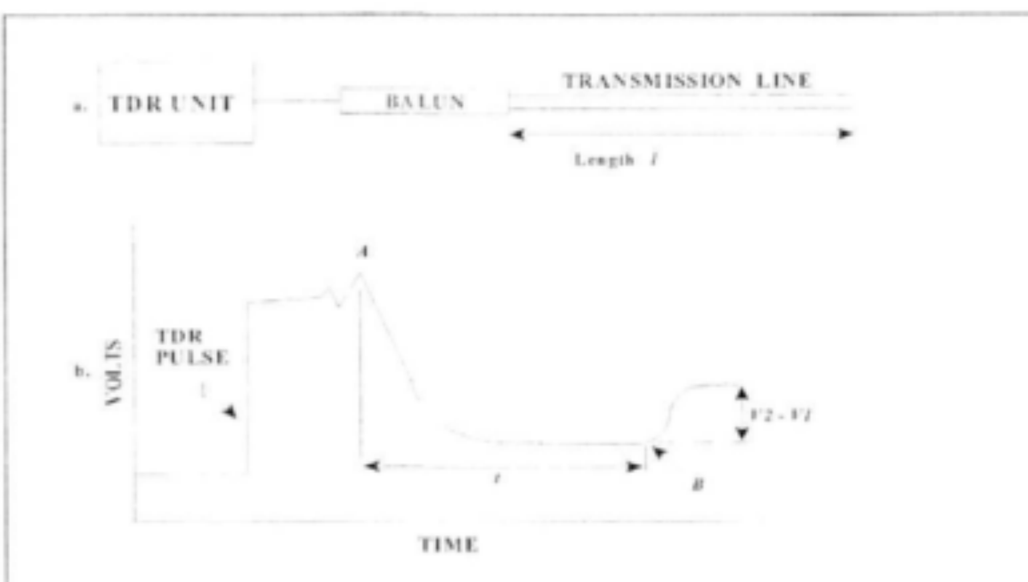
Using equations 2 and 7, the total current (equation 6) can now be expanded into a form that does not specifically include the loss current:

$$I_t = i\omega CV = i\omega\epsilon C_0 V/\epsilon_0 = (i\omega\epsilon' + \omega\epsilon'')\, C_0 V/\epsilon_0 \qquad (8)$$

The parameter ϵ'' is called the loss factor, whereas $\omega\epsilon''$ is equivalent to the dielectric conductivity. As was shown by Fellner-Feldegg (1969), it is possible to obtain in one measurement the frequency-dependent dielectric properties of a medium. Topp, Davis & Annan (1980) further demonstrated that the low-frequency or static component of the dielectric constant can be used to correlate with the soil water content.

TDR MEASUREMENTS OF THE DI-ELECTRIC CONSTANT

Time domain reflectometry involves measurements of the propagation of electromagnetic waves or signals. The propagation constants (such as velocity and attenuation) depend on the soil properties, especially on its water content and electrical conductivity. In the TDR technique a step voltage pulse or signal is propagated down a transmission line. Parallel pair transmission lines, as depicted in Figure 3.2a, are usually used for measurement in soil. The parallel rods or wires serve as conductors, and the soil in which the rods are installed, serves as the dielectric medium. The pair of rods acts as a wave-guide, and the signal propagates as a plane wave in the soil. The signal is reflected from the end of the transmission line in the soil back to the TDR receiver. The reflected signal of the TDR pulse is analyzed with an oscilloscope to estimate the dielectric constant of the medium (Reeves & Smith 1992).



The timing device in TDR (Fig. 3.2b) measures the time between sending a signal from point A and receiving the reflected signal at point B (Topp 1987). The time interval relates directly to the propagation velocity of the signal in the soil since the line length is known. The mode of propagation is similar to the way radio and television signals propagate through space. The propagation velocity is indicative of the volumetric water content, being smaller as water content increases. The TDR signal's propagation velocity is linked to the soil dielectric constant. The dielectric constant is an electrical property that represents the ratio of the dielectric permittivity of the media being measured to the dielectric permittivity of the free space (Hoekstra & Delaney 1974). Water, the component that governs the dielectric constant of the soil, has a dielectric constant of 80 as contrasted with values of 2-5 for soil solids. Ansout, De Baker & Declercq (1985), have described the theoretical relationship between the dielectric constant and water content.

For soil there is a simple approximate relationship between signal propagation velocity, V, and the dielectric constant:

$$V = c/\sqrt{\varepsilon} \qquad (9)$$

where c is the propagation velocity of an electromagnetic wave in free space (3 X 10^8 ms^{-1}):

The velocity, V, is obtained from knowledge of the length of the transmission line, l, in the soil (the travel distance is $2l$) and by measurement of signal travel time, t, in the soil using a time-domain reflectometer (Fig. 3.1a). The dielectric constant, results from substitution into equation (1) and re-arrangement to

$$\varepsilon = (ct/2l)^2 \qquad (10)$$

Once an estimate for ε is obtained with equation 10, the dielectric constant must still be correlated with the volumetric soil water content (θ_v). Topp *et al.* (1980) found that was primarily a function of volumetric water content θ_v, and most soil types can be represented by the following empirical relationship between ε and θ_v:

$$\theta_v = (-530 + 292\,\varepsilon - 5.5\,\varepsilon^2 + 0.043\,\varepsilon^3)/10000 \qquad (11)$$

3.2.3 TDR instrumentation

Instrumentation for determining TDR has been described by various authors (Topp *et al.* 1984; Zegelin, White & Jenkins 1989; Reeves & Smith 1992). The basic design is a probe comprising parallel rods or wave guides which act as a balanced transmission line and are connected to the TDR unit (oscilloscope) (Fig. 3.1a). When the probe is inserted into the soil, the soil around and between the wave guides also becomes part of the transmission line. The dielectric constant of the soil is determined by interpreting the reflected signal on the oscilloscope of the Time Domain Reflectometer (Topp *et al.* 1982).

One of the disadvantages of the first TDR system was that the coaxial transmission line used in the laboratory situation was unsuitable for the field. A later development was the use of the more convenient and practical parallel pair transmission lines, consisting simply of two parallel rod conductors embedded in the soil. This resulted in signal and information loss at the coaxial cable/probe interface. To overcome this, shielded twin lead TV antenna cable was connected from each soil transmission line to a common plug-in board or switching apparatus mounted on a post. This impedance matching transformer, called a balun, is situated between the balanced TDR lines and the unbalanced line. The balun is connected to coaxial cable on its unbalanced side and to about 100mm length of balanced cable on the other side. After the electrical connections are made, this apparatus is encased in resin for waterproof protection. The other end of the balanced cable is connected to a pair of pin plugs for attachment to the plug-in board.

Because of the high price of commercially available probes, and the large number required for this experiment (168), a considerable amount of time was committed to developing a locally made TDR probe. This was done with the assistance of the Electronic Engineering Department of the University of Natal. The first probe developed was based on the shielded twin lead antenna design. This was successfully developed, but was never produced in quantity as the manufacture of the special TV antenna cable was terminated worldwide. To overcome this problem a component was designed from electronic circuit board, which perfectly matched the impedance of the balun and TV antenna of the first probe. These probes were successfully manufactured and used for the soil water experiment. The probe is a two-rod probe with 300 mm stainless steel rods; the "balun" connects the coaxial cable from the reflectometer to the heavy gauge wire connecting to the probes.

A number of TDR instruments that are battery powered and portable for easy use in field measurements are now available commercially. One of the most commonly used is the Tektronix model 1502B cable tester described by Topp (1987). The cable tester produces a low-frequency analog output that can be plotted on an X-Y plotter, transmitted to a computer or micrologger for analysis or displayed on a cathode ray tube screen and photographed. Travel times have usually been determined by graphical interpretation as described by Topp *et al* (1982a) and Hayhoe, Topp & Bailey 1983. From the travel times one can calculates the water content using equations (9) and (10).

Campbell Scientific Inc. have developed a convenient TDR field instrument (based on the Textronix 1502B TDR Cable Tester), which automatically measures the travel times, solves equations (9) and (10) and displays θ_v (Topp 1987). The unit is battery operated, has data storage and downloading capability, and can accommodate a variety of operator-selected TDR line lengths. The Campbell system was used in the present study.

MULTIPLEXING

Mutiplexing is essentially a stepping device that allows a single micrologger to sequentially measure many sensors. The Campbell SDMX50 used in this study is an eight to one 50-ohm coax multiplexer with BNC connectors. The coax cable coming from the 1502B connects to the common. The eight multiplexed connections are used to connect additional multiplexers or probes. The probes connect directly to the multiplexer via the BNC connectors. Up to three levels of multiplexers may be used, connecting to a maximum of 512 (8^3) soil probes on a fully expanded system (Figure 3.3).

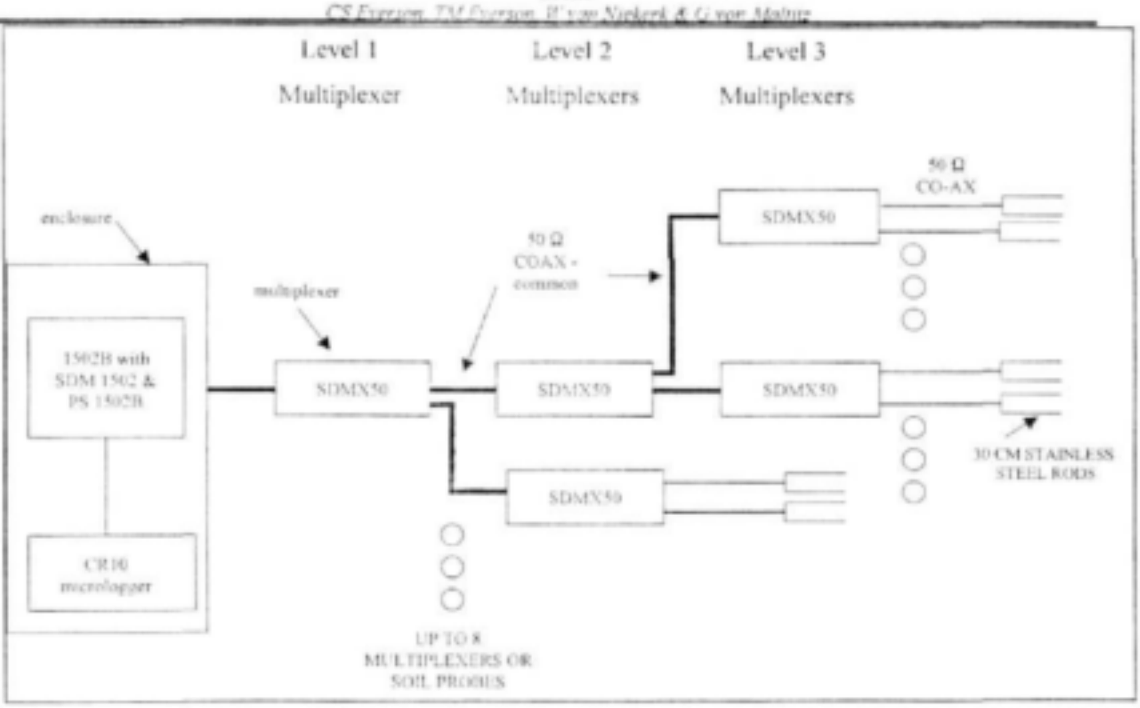


Figure 3.3 Diagrammatic representation of TDR unit with three levels of multiplexers and probes.

TDR TRANSMISSION LINE INSTALLATION

Installation of transmission lines may be either vertical or horizontal lines. Baker & Lascano (1989) found that the spatial resolution of TDR using horizontal lines is confined to an area of 1000mm^2 surrounding the waveguides, while the perpendicular plane is narrow (30mm). Thus a good resolution is obtained when the waveguides are horizontal. However, in areas where frost is frequent, seasonal frost may displace horizontal probes. Topp (1987) recommends horizontal lines for water content profiles and vertical lines for total water estimates in the rooting zone. While vertical probes have fewer disturbances and involve less time to install, there can be a problem with preferential water movement along the vertical lines. Topp & Davis (1985) showed that both transmission lines have equivalent values, with horizontal lines having less variation. Ultimately, the choice of vertical versus horizontal depends on the application, type of information required and the period of observation (Patterson & Smith 1985). Because we were initially interested in measuring the soil moisture content in the upper soil layer to determine moisture competition between the maize and trees, the probes were installed vertically. The TDR moisture content measured in this study is therefore the integrated value for the top 300 mm of soil.

One factor that has been open to debate in TDR transmission line installation is the spacing and diameter of rods. The volume measured by TDR can be varied by changing the separation of the wires making up the transmission lines (Keng & Topp 1983). The transmission lines associated with most TDR instruments are the coaxial or unbalanced type. The standard sizes of rods used in early studies were 6.4 mm or 12.7 mm in diameter (Topp *et al.* 1982). Although Topp & Davis (1985) used 12.7 mm diameter rods for vertical transmission lines, they found that it was unnecessary to use pilot holes if smaller diameter rods were used. They suggest using 3 mm diameter rods for lines up to 0.5 m long and 6 mm diameter rods for lengths greater than 0.5 m.

If the wire diameter is small compared to the spacing between the electrodes, then a high-energy density develops around the wire (Knight 1992). This means that any local non-uniformity around the wires will have a great effect on the apparent measured water content of the sample. In order to minimize this the wire diameter should be as large as possible compared to the electrode spacing. This poses a dilemma as probes constructed of thin wire minimize soil compaction and disturbance. In addition, for probes embedded horizontally in a field soil Philip, Knight & Waechter (1989) show that the probe wires should be thin to avoid too much disturbance to downward flow and any consequent water build up on the upper surface. Knight (1992) recommends that the ratio of electrode spacing to wire diameter should not be greater than about 10. The design of a practical probe must be a compromise between these conflicting requirements. We found the best configuration for our probes to be 4 mm rods spaced 20 mm apart.

ASSIGNING ADDRESSES

The SDM1502 and SDMX50 are Synchronous Devices for Measurement (**SDM**); the datalogger communicates with these devices via control ports 1, 2 and 3. Addresses set in the devices allow the datalogger to communicate with the correct device. The addresses assigned the SDM1502 (set with switches) determine the addresses (in base 4) that need to be assigned to the multiplexers (set with jumpers). The multiplexer with its input connected to the cable from the 1502B is level 1, level 2 multiplexers are those connected to the level 1 multiplexer, level 3 multiplexers are those connected to the level 2 multiplexer (only 3 levels are allowed).

Appendix B. Details of multiplexer addresses.

Key:
CH= channel,
Mux =multiplexer with respective number,
A B, C, D = row number for plot position
1-6= column number for plot position (e.g. A1 is the top left plot in the trial).
Aw=Acacia wide, An=Acacia narrow. Similarly for Leucaena (L), Mulberry (M) and Gleditsia (G).
r1..r6 =maize row number in a plot and rT corresponds to the tree row.

Multiplexer No.1 (MUX#1)
SDM1502 address = 11 (1010 Base 4:closed:open: closed: open)
Level 1. address of SMDX50 = 12 (MSD=1; LSD=2)
CH1=Mux2; CH2=Mux3;
CH3=Mux4;CH4=Mux5CH5=Mux6; CH6=Mux7;
CH7=Mux8; CH8=Free

Multiplexer No.2 (MUX#2) From: MUX#1 CH1
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=Mux17; CH2=Mux18; CH3=Mux19;
CH4=Mux 20; CH5=Mux21; CH6=Mux22;
CH7=Mux23; CH8=Mux24.

Multiplexer No.3 (MUX#3) From: MUX#1 CH2
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1= probe1:A3r4Lw=; CH2=probe2:A3r5Lw;
CH3 =probe3:A3r6Lw; CH4 =probe4:B3r1Gn; CH5 =probe5: A4r4An; CH6=probe6: A4r5An;
CH7=probe7:A4r6An; CH8=probe8:B4r1Mw.

Multiplexer No.4 (MUX#4) From: MUX#1 CH3

SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=probe9:B3r2Gn; CH2=probe10: B3r3Gn;
CH3= probe11: B3rTGn; CH4=probe12: B3r4Gn;
CH5=probe 13: B4r2Mw; CH6= probe14:B4r3Mw;
CH7=probe15: B4rTMw; CH8=probe16: B4r4Mw.

Multiplexer No.5 (MUX#5) From: MUX#1 CH4
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=probe17:B3r5Gn; CH2=probe18:B3r6Gn;
CH3=probe19:C3r1Gw; CH4=probe20: C3r2Gw;
CH5=probe21: B4r5Mw; CH6=
probe22:B4r6Mw;CH7=probe23: C4r1Ln;CH8=
probe24:C4r2Ln.

Multiplexer No.6 (MUX#6) From: MUX#1 CH5
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=probe25:C3r3Gw;CH2=probe26:C3rTGw;
CH3= probe27 :C3r4Gw; CH4=probe 28: C3r5Gw;
CH5=probe29:C4r3Ln; CH6=probe30: C4rTLn;
CH7=probe31:C4 r4Ln; CH8=probe32: C4r5Ln.

Multiplexer No.7 (MUX#7) From: MUX#1 CH6
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=probe33:C3r6Gw;CH2=probe34:D3r1Aw;CH3=probe35:D3r2Aw; CH4=probe36:D3r3Aw;
CH5=probe37:C4r6Ln;CH6=probe38:D4r1Mn;CH7=probe39:D4r2Mn;CH8=probe40:D4r3Mn.

Multiplexer No.8 (MUX#8) From: MUX#1 CH7
SDM1502 address = 11
Level 2. address of SMDX50 = 13 (MSD=1; LSD=3)
CH1=Mux9;CH2=Mux10;CH3=Mux11;CH4=MMux. 12; CH5=Mux13; CH6=Mux14;CH7=15; CH8=
Mux16.

Multiplexer No.9 (MUX#9) From: MUX#8 CH1
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe41:A2r1Lw;CH2=probe42:A2r2Lw;CH3= probe43:A2r3Lw; CH4=probe44: A2rTLw;
CH5=probe45: A3r1Lw; CH6=probe46:A3r2Lw;
CH7=probe47: A3r3Lw; CH8=probe48:A3rTLw.

Multiplexer No.10 (MUX#10) From:MUX#8 CH2
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe49: A2r4Lw; CH2=probe50:A2r5Lw;
CH3=probe51:A2r6Lw; CH4=probe52:B2r1Gn;
CH5=probe 53:B2r2Gn; CH6=probe54:B2r3Gn;
CH7=probe55: B2rTGn; CH8=probe56:B2r4Gn.

Multiplexer No.11 (MUX#11) From:MUX#8 CH3
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe57:B2r5Gn;CH2=probe58:B2r6Gn;CH3=probe59:C2r1Gw;CH4=probe60:C2r2Gw;CH5=probe61:C2r3Gw;CH6=probe62:C2rTGw;CH7=probe63:C2 r4Gw;CH8=probe64:C2r5Gw.

Multiplexer No.12 (MUX#12) From:MUX#8 CH4
SDM1502 address = 11
Level 3. address of SMDX50 = 20
(MSD=2;LSD=0)
CH1=probe65:C2r6Gw;CH2=probe66:D2r1Aw;CH3= probe67:D2r2Aw;CH4=probe68:D2r3Aw;

CH5=probe69:D3rTAw;CH6=probe70:D3r4Aw;CH7=probe71:D3r5Aw;CH8=probe72:D3r6Aw.

Multiplexer No.13 (MUX#13) From:MUX#8 CH5
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe73:D1rTMn;CH2=probe74:D1r4Mn;CH3=probe75 :D1r5Mn;CH4=probe76:D1r6Mn; CH5=probe77:D2rTAw;CH6=probe78:D2r4Aw;CH7=probe79:D2r5Aw;CH8=probe80:D2r6Aw.

Multiplexer No.14 (MUX#14) From:MUX#8 CH6
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe81:C1r3Ln;CH2=probe82:C1rTLn;CH3=probe83:C1r4Ln;CH4=probe84:C1r5Ln;CH5=probe85:C1r6Ln;CH6=probe86:D1r1Mn;CH7=probe87:D1r2Mn;CH8=probe88:D1r3Mn.

Multiplexer No.15 (MUX#15) From:MUX#8 CH7
SDM1502 address = 11
Level 3. address of SMDX50=20(MSD=2; LSD=0)
CH1=probe89:B1r2Mw;CH2=probe90:B1r3Mw;CH3=probe91:B1rTMw;CH4=probe92:B1r4Mw;CH5=probe93:B1r5Mw;CH6=probe94:B1r6Mw;CH7=probe95C1r1Ln;CH8=probe96:C1r2Ln.

Multiplexer No.16 (MUX#16) From:MUX#8 CH8
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe97:A1r1An;CH2=probe98:A1r2An;CH3=probe99:A1r3An;CH4=probe100:A1rTAn;CH5=probe101:A1r4An;CH6=probe102:A1r5An;CH7=probe103:A1r6An;CH8=probe104:B1r1Mw.

Multiplexer No.17 (MUX#17): From Mux#2,CH1
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe105:C5r6Lw;CH2=probe106:D5r1Gw;CH3=probe107:D5r2Gw;CH4=probe108:D5r3Gw;CH5=probe109:D4rTMn;CH6=probe110:D4r4Mn;CH7=probe111:D4r5Mn;CH8=probe112:D4r6Mn.

Multiplexer No.18 (MUX#18) From:MUX#2 CH2
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe113:B5r5An;CH2=probe114:B5r6An;CH3=probe115:C5r1Lw;CH4=probe116:C5r2Lw;CH5=probe117:C5r3Lw;CH6=probe118:C5rTLw;CH7=probe119:C5r4Lw; CH8=probe120: C5r5Lw.

Multiplexer No.19(MUX#19) From: MUX#2 CH3
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe121:A5r4Ln;CH2=probe122:A5r5Ln;CH3=probe123:A5r6Ln;CH4=probe124:B5r1An;CH5=probe125:B5r2An;CH6=probe126:B5r3An;CH7=probe127:B5rTAn;CH8=probe128:B5r4An.

Multiplexer No.20(MUX#20) From: MUX#2 CH4
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe129:A4r1An;CH2=probe130:A4r2An;CH3=probe131:A4r3An;CH4=probe132:A4rTAn;CH5=probe133:A5r1Ln;CH6=probe134:A5r2Ln;CH7=probe135:A5r3Ln;CH8=probe136:A5rTLn.

Multiplexer No.21(MUX#21) From: MUX#2 CH5
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2;LSD=0)
CH1=probe137:D5rTGw;CH2=probe138:D5r4Gw; CH3=probe139:D5r5Gw;CH4=probe140:D5r6Gw; CH5=probe141:D6rTGn;CH6=probe142:D6r4Gn;CH7=probe143:D6r5Gn;CH8=probe144:D6r6Gn.

Multiplexer No.22(MUX#22) From: MUX#2 CH6
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe145:C6r3Aw;CH2=probe146:C6rTAw; CH3=probe147:C6r4Aw;CH4=probe148:C6r5Aw;CH5=probe149:C6r6Aw;CH6=probe150:D6r1Gn;CH7=probe151:D6r2Gn;CH8=probe152:D6r3Gn.

Multiplexer No.23(MUX#23) From: MUX#2 CH7
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe153:B6r2Mw;CH2=probe154:B6r3Mw; CH3=probe155:B6rTMw;CH4=probe156:B6r4Mw; CH5=probe157:B6r5Mw;CH6=probe158:B6r6Mw; CH7=probe159:C6r1Aw;CH8=probe160:C6r2Aw.

Multiplexer No.24(MUX#24) From: MUX#2 CH8
SDM1502 address = 11
Level 3. address of SMDX50 = 20 (MSD=2; LSD=0)
CH1=probe161:A6r1Mn;CH2=probe162:A6r2Mn;CH3=probe163:A6r3Mn;CH4=probe164:A6rTMn; CH5=probe165:A6r4Mn;CH6=probe166: A6r5Mn;CH7=probe167:A6r6Mn;CH8=probe168:B6r1Mw.

Appendix C. Soil Moisture ANOVA results

ANOVA 1: 1999

Output file from Genstat, on observed and predicted water content.

Data file:
SPLOT = 1 == tree lines
= 2 == maize lines (values averaged over all 6 lines in each plot)

Analysis of variance for actual water content

***** Analysis of variance *****

Variate: observed

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0131514	0.0065757	6.03	
REP.variety stratum					
variety	7	0.0226383	0.0032340	2.96	0.040
Residual	14	0.0152750	0.0010911	1.41	
REP.variety.*Units* stratum					
SPLOT	1	0.0019508	0.0019508	2.51	0.134
variety.SPLOT	7	0.0036269	0.0005181	0.67	0.696
Residual	15(1)	0.0116370	0.0007758		
Total	46(1)	0.0658030			

Can conclude that there was a significant difference between species (at the 5% level) but unlikely to be any significant differences between SPLOT values (i.e. Between tree lines and maize lines).

Note: Split plot design was used to compare tree and maize lines within each plot to one another and not the overall means values.

***** Tables of means *****
Variate: observed

Grand mean 0.2357

variety	AN	AW	GN	GW	LN	LW	MN
	0.2674	0.2483	0.2215	0.2083	0.2176	0.2691	0.2213

variety	MW
	0.2321

Need to differ by approx 0.06, therefore no obvious significant differences

SPLOT	1	2
	0.2293	0.2421

Need to differ by approx .024 to be significantly different, only differ by 0.00128.

variety	SPLOT	1	2
AN		0.2527	0.2822
AW		0.2434	0.2531
GN		0.2101	0.2329
GW		0.1947	0.2219
LN		0.2138	0.2215
LW		0.2832	0.2549
MN		0.2162	0.2265
MW		0.2206	0.2436

*** Standard errors of differences of means ***

Use 3*s.e.d to work out approx. differences needed

Table	variety	SPLOT	variety SPLOT
rep.	6	24	3
s.e.d.	0.01907	0.00804	0.02495
d.f.	14	15	27.85

<u>Analysis of variance for predicted water content</u>

***** Analysis of variance *****

Variate: predicted

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0130393	0.0065197	6.65	
REP.variety stratum					
variety	7	0.0074028	0.0010575	1.08	0.426
Residual	14	0.0137197	0.0009800	2.71	
REP.variety.*Units* stratum					
SPLOT	1	0.0000600	0.0000600	0.17	0.689
variety.SPLOT	7	0.0028289	0.0004041	1.12	0.398
Residual	16	0.0057762	0.0003610		
Total	47	0.0428269			

Can conclude that there were no significant differences between the soil water contents of the different varieties as well as between the tree and maize lines.

**** Tables of means *****

Variate: predicte

Grand mean 0.2349

variety	AN	AW	GN	GW	LN	LW	MN
	0.2575	0.2438	0.2271	0.2211	0.2182	0.2450	0.2347

variety	MW
	0.2318

SPLOT	1	2
	0.2360	0.2338

Same as above, but even less differences between them

variety	SPLOT	1	2
AN		0.2778	0.2372
AW		0.2416	0.2459
GN		0.2252	0.2291
GW		0.2186	0.2235
LN		0.2111	0.2252
LW		0.2446	0.2454
MN		0.2350	0.2345
MW		0.2342	0.2294

*** Standard errors of differences of means ***

Table	variety	SPLOT	variety SPLOT
rep.	6	24	3
s.e.d.	0.01807	0.00548	0.02114
d.f.	14	16	23.43

ANOVA 2: 1999

Output file from Genstat showing two ANOVA's performed to see if there is any significant differences between the observed and predicted values of both the tree and maize lines.

Note: SPLOT = 1 == observed
SPLOT = 2 == expected

***** Analysis of variance *****

Variate: tree

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0119734	0.0059867	6.08	
REP.variety stratum					
variety	7	0.0207339	0.0029620	3.01	0.038
Residual	14	0.0137830	0.0009845	1.60	
REP.variety.*Units* stratum					
SPLOT	1	0.0005786	0.0005786	0.94	0.348
variety.SPLOT	7	0.0043890	0.0006270	1.02	0.459
Residual	15(1)	0.0092554	0.0006170		
Total	46(1)	0.0585451			

This ANOVA shows that the values of the tree lines water content differed significantly between the different varieties

of tree, but more importantly due to the large f probability (0.348) we can conclude that there is no significant differences between the observed and predicted water content values. Once again a split plot experiment was used to compare the observed and predicted values for each plot, rather than their overall means.

```
***** Tables of means *****
Variate: tree
Grand mean  0.2325

  variety       AN       AW       GN       GW       LN       LW       MN
            0.2652   0.2425   0.2176   0.2067   0.2124   0.2628   0.2256

  variety       MW
            0.2274

    SPLOT        1        2
            0.2291   0.2360

  variety    SPLOT        1        2
       AN            0.2527   0.2778
       AW            0.2434   0.2416
       GN            0.2101   0.2252
       GW            0.1947   0.2186
       LN            0.2137   0.2111
       LW            0.2811   0.2446
       MN            0.2162   0.2350
       MW            0.2206   0.2342


*** Standard errors of differences of means ***

Table                 variety       SPLOT      variety
                                                SPLOT
rep.                        6          24           3
s.e.d.                0.01812     0.00717     0.02310
d.f.                       14          15       27.11
```

Analysis of variance on maize values

```
***** Analysis of variance *****
Variate: maize
Source of variation       d.f.        s.s.        m.s.     v.r.  F pr.
REP stratum                  2   0.0145419   0.0072710     5.85

REP.variety stratum
variety                      7   0.0078425   0.0011204     0.90  0.532
Residual                    14   0.0174129   0.0012438     3.53

REP.variety.*Units* stratum
SPLOT                        1   0.0008278   0.0008278     2.35  0.145
variety.SPLOT                7   0.0028611   0.0004087     1.16  0.377
Residual                    16   0.0056364   0.0003523

Total                       47   0.0491227
```

This shows that the soil water content values for the maize lines did not differ significantly for the different tree lines, and also that there is no significant difference between the observed and expected maize values. The slightly lower F probability for this test, than for the above ANOVA, is probably due to the averaging that the maize lines were subject to.

```
***** Tables of means *****

Variate: maize
Grand mean  0.2379

variety  AN      AW      GN      GW      LN      LW      MN      MW
       0.2597  0.2495  0.2310  0.2227  0.2233  0.2502  0.2305 0.2365

    SPLOT          1         2
              0.2421    0.2338

  variety    SPLOT          1         2
       AN              0.2822    0.2372
       AW              0.2531    0.2459
       GN              0.2329    0.2291
       GW              0.2219    0.2235
       LN              0.2215    0.2252
       LW              0.2549    0.2454
       MN              0.2265    0.2345
       MW              0.2436    0.2294

*** Standard errors of differences of means ***
Table              variety        SPLOT      variety
                                               SPLOT
rep.                     6           24            3
s.e.d.             0.02036      0.00542      0.02307
d.f.                    14           16        21.54
variety                                      0.01532
```

Overall, from these two ANOVA's, it can be concluded that there were no significant differences between the observed and predicted values, and as such the model used to obtain the predicted values is an adequate one to describe the data set.

ANALYSIS OF VARIANCE: 2000
Output file from Genstat, two ANOVA's on observed and predicted water content.

<u>ANOVA 1: 2000</u>
Data file:
SPLOT = 1 == maize lines (values averaged over all 6 lines in each plot)
      = 2 == tree lines

Note: Split plot design has been used in order to compare tree and maize lines within each plot to one another and not the overall means values.

```
***** Analysis of variance *****
Variate: values                   Observed values

Source of variation       d.f.(m.v.)       s.s.         m.s.      v.r.  F pr.

REP stratum                   2        0.0151020  0.0075510     6.07

REP.variety stratum
variety                       7        0.0098345  0.0014049     1.13  0.399
Residual                     14        0.0174092  0.0012435     1.93

REP.variety.*Units* stratum
SPLOT                         1        0.0000062  0.0000062     0.01  0.923
variety.SPLOT                 7        0.0103200  0.0014743     2.29  0.084
Residual                     15(1)     0.0096623  0.0006442

Total                        46(1)     0.0595530
```

Can conclude that there is no significant difference between varieties (at the 5% level) and that there is no significant difference between SPLOT values (ie. Between tree lines and maize lines), for the observed values.

```
***** Tables of means *****
Variate: values

Grand mean  0.3028

 variety      AN      AW      GN      GW      LN      LW      MN
          0.2884  0.3130  0.2722  0.3005  0.3069  0.3122  0.3141
 variety      MW                Need to differ by approx 0.06108 to be
          0.3151                significantly different.

   SPLOT       1       2        Need to differ by approx 0.022199 to
                                be significantly different.
          0.3032  0.3024

 variety   SPLOT       1       2      Need to differ by approx 0.07524
                                      to be significantly different.
      AN          0.2973  0.2795
      AW          0.3066  0.3193
      GN          0.3050  0.2393
      GW          0.3028  0.2983
      LN          0.3046  0.3092
      LW          0.2961  0.3282
      MN          0.2982  0.3300
      MW          0.3146  0.3157
```

```
*** Standard errors of differences of means ***

Table                  variety       SPLOT      variety
                                                 SPLOT
rep.                         6          24           3
s.e.d.                 0.02036     0.00733     0.02508
d.f.                        14          15       25.80
Except when comparing means with the same level(s) of
 variety                                       0.02072
 d.f.                                               15

(Not adjusted for missing values)
```

Use 3*s.e.d to work out approx differences needed

```
***** Missing values *****

Variate: values

 Unit  estimate
   26    0.3550

Max. no. iterations 6


***** Analysis of variance *****
Variate: value
```

Predicted values

```
Source of variation      d.f.(m.v.)        s.s.         m.s.    v.r.  F pr.

REP stratum                    2     0.02074569 0.01037285   25.74

REP.variety stratum
variety                        7     0.00151301 0.00021614    0.54  0.793
Residual                      14     0.00564179 0.00040299   10.81

REP.variety.*Units* stratum
SPLOT                          1     0.00007119 0.00007119    1.91  0.187
variety.SPLOT                  7     0.00018130 0.00002590    0.69  0.676
Residual                   15(1)     0.00055937 0.00003729

Total                      46(1)     0.02587623
```

Can conclude that there is no significant difference between varieties (at the 5% level) and there is no significant differences between SPLOT values (ie. Between tree lines and maize lines) for the predicted values.

```
***** Tables of means *****
Variate: value
Grand mean  0.30385

 variety        AN       AW       GN       GW       LN       LW       MN
           0.29766  0.30651  0.30427  0.30335  0.30712  0.29593  0.30099

 variety        MW               Need to differ by approx 0.03477 to be
           0.31501               significantly different.

   SPLOT         1        2          Need to differ by approx 0.005289 to
                                     be significantly different.
           0.30264  0.30507

 variety    SPLOT        1        2          Need to differ by approx
                                             0.036342 to be significantly
                                             different.
      AN           0.29729  0.29803
      AW           0.30542  0.30760
      GN           0.30684  0.30169
      GW           0.30280  0.30389
      LN           0.30562  0.30863
      LW           0.29125  0.30060
      MN           0.29816  0.30382
      MW           0.31372  0.31631


*** Standard errors of differences of means ***

Table                 variety       SPLOT     variety          Use 3*s.e.d to
                                                               work out
                                                               approximate
                                                               differences
                                                               needed
                                                SPLOT
rep.                        6          24           3
s.e.d.               0.011590    0.001763    0.012114
d.f.                       14          15       16.58
Except when comparing means with the same level(s) of
 variety                                     0.004986
 d.f.                                              15
```

Thus we can conclude that both the observed and predicted values show that there were no significant differences between the tree and maize lines.

<u>ANOVA 2: 2000</u>

Output file from Genstat showing two ANOVA's performed to see if there are any significant differences between the observed and predicted values of both the tree and maize lines.
SPLOT = 1 == observed values (values averaged over all 6 lines in each plot)

= 2 == predicted values (values averaged over all 6 lines in each plot)
Note: Split plot design has been used in order to compare tree and maize lines within each plot to one another and not the overall means values.

```
***** Analysis of variance *****
Variate: maize

Source of variation      d.f.        s.s.         m.s.     v.r.  F pr.

REP stratum                 2  0.230E_01  0.115E_01   26.13

REP.variety stratum
variety                     7  0.174E_02  0.248E_03    0.56  0.773
Residual                   14  0.616E_02  0.440E_03   77.26

REP.variety.*Units* stratum
SPLOT                       1  0.318E_05  0.318E_05    0.56  0.466
variety.SPLOT               7  0.424E_04  0.606E_05    1.06  0.429
Residual                   16  0.911E_04  0.570E_05

Total                      47  0.310E_01
```

Can conclude that are no significant difference between the varieties (at the 5% level)and there is also unlikely to be any significant differences between SPLOT values (i.e. the observed and actual values). The lower F value (than for the next test, is probably due to the averaging of the maize lines.

```
***** Tables of means *****

Variate: maize
Grand mean  0.30289

 variety        AN       AW       GN       GW       LN       LW       MN
           0.29729  0.30603  0.30593  0.30280  0.30511  0.29369  0.29816
 variety        MW
           0.31415
```

Need to differ by approx 0.06336 to be significantly different.

```
   SPLOT         1        2

           0.30315  0.30264
```

Need to differ by approx 0.002067 to be significantly different.

```
 variety    SPLOT         1        2
     AN             0.29729  0.29729
     AW             0.30664  0.30542
     GN             0.30502  0.30684
     GW             0.30280  0.30280
     LN             0.30459  0.30562
     LW             0.29612  0.29125
```

Need to differ by approx 0.01219 to be significantly different.

```
      MN              0.29816  0.29816
      MW              0.31459  0.31372

*** Standard errors of differences of means *** Use  3*s.e.d  to  work  out
                                                 approx
                                                 differences needed
Table              variety        SPLOT      variety
                                               SPLOT
rep.                     6           24            3
s.e.d.            0.012112     0.000689     0.012190
d.f.                    14           16        14.36
Except when comparing means with the same level(s) of
 variety                                    0.001949
 d.f.                                             16
SPLOT = 1 == observed values
      = 2 == predicted values

***** Analysis of variance *****

Variate: tree
Source of variation     d.f.(m.v.)       s.s.         m.s.     v.r.  F pr.

REP stratum                 2       0.0111256  0.0055628     5.15

REP.variety stratum
variety                     7       0.0103472  0.0014782     1.37  0.297
Residual                13(1)       0.0140510  0.0010808     1.57

REP.variety.*Units* stratum
SPLOT                       1       0.0000801  0.0000801     0.12  0.737
variety.SPLOT               7       0.0087010  0.0012430     1.81  0.158
Residual                15(1)       0.0103022  0.0006868

Total                   45(2)       0.0543788
```

Can conclude that were no significant differences between the varieties (at the 5% level).

```
***** Tables of means *****
Variate: tree
Grand mean  0.3019

  variety  AN     AW      GN      GW      LN      LW      MN      MW
        0.2888 0.3135  0.2705  0.3011  0.3089 0.3144  0.3169  0.3015
```

Need to differ by approx 0.05694 to be significantly different.

```
    SPLOT        1        2    Need to differ by approx 0.02271 to be
            0.3007   0.3032    significantly different.

  variety    SPLOT        1          2        Need   to   differ   by   approx.
                                              0.07281   to   be   significantly
                                              different.
      AN             0.2795    0.2980
      AW             0.3193    0.3076
      GN             0.2393    0.3017
```

GW	0.2983	0.3039
LN	0.3092	0.3086
LW	0.3282	0.3006
MN	0.3300	0.3038
MW	0.3014	0.3016

```
*** Standard errors of differences of means ***
Table                variety      SPLOT     variety
                                            SPLOT
rep.                       6         24          3
s.e.d.               0.01898    0.00757    0.02427
d.f.                      13         15      25.76
```

Use 3*s.e.d to work out approx differences needed.

Overall, form these ANOVA's it can be concluded that there is no significant differences between the observed and predicted values, and as such the model used to obtain the predicted values is an adequate one to describe the data set.

ANOVA 1: 2001

Output file from Genstat, two ANOVA's on observed and predicted water content.

Data file:
SPLOT = 1 == tree lines
= 2 == maize lines (values averaged over all 6 lines in each plot)

Analysis of variance for actual water content

```
***** Analysis of variance *****

Variate: observed

Source of variation      d.f.(m.v.)      s.s.       m.s.      v.r.  F pr.

REP stratum                   2     0.0131514  0.0065757    6.03

REP.variety stratum
variety                       7     0.0226383  0.0032340    2.96  0.040
Residual                     14     0.0152750  0.0010911    1.41

REP.variety.*Units* stratum
SPLOT                         1     0.0019508  0.0019508    2.51  0.134
variety.SPLOT                 7     0.0036269  0.0005181    0.67  0.696
Residual                  15(1)     0.0116370  0.0007758

Total                     46(1)     0.0658030
```

Can conclude that may be a significant difference between varieties (at the 5% level) but unlikely to be any significant

differences between SPLOT values (i.e. Between tree lines and maize lines).

Note: Split plot design has been used in order to compare tree and maize lines within each plot to one another and not the overall means values.

```
***** Tables of means *****
Variate: observed
Grand mean  0.2357

variety    AN      AW      GN      GW      LN      LW      MN      MW
       0.2674  0.2483  0.2215  0.2083  0.2176  0.2691  0.2213
```

Need to differ by approx 0.06, therefore no sig.differences

```
    SPLOT         1         2

              0.2293    0.2421
```

Need to differ by approx 0.024 to be significantly different, only differ by 0.00128.

Variety	SPLOT 1	2
AN	0.2527	0.2822
AW	0.2434	0.2531
GN	0.2101	0.2329
GW	0.1947	0.2219
LN	0.2138	0.2215
LW	0.2832	0.2549
MN	0.2162	0.2265
MW	0.2206	0.2436

*** Standard errors of differences of means ***

Use 3*s.e.d to work out approx. differences needed

Table	variety	SPLOT	variety SPLOT
rep.	6	24	3
s.e.d.	0.01907	0.00804	0.02495
d.f.	14	15	27.85
Except when comparing means with the same level(s) of			
variety			0.02274
d.f.			15

(Not adjusted for missing values)

Analysis of variance for predicted water content

***** Analysis of variance *****

Variate: predicted

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0130393	0.0065197	6.65	
REP.variety stratum					
variety	7	0.0074028	0.0010575	1.08	0.426
Residual	14	0.0137197	0.0009800	2.71	
REP.variety.*Units* stratum					
SPLOT	1	0.0000600	0.0000600	0.17	0.689
variety.SPLOT	7	0.0028289	0.0004041	1.12	0.398
Residual	16	0.0057762	0.0003610		
Total	47	0.0428269			

Can conclude that there is no significant differences between the water values of the different varieties as well as between the tree and maize lines.

***** Tables of means *****

Variate: predicte

Grand mean 0.2349

variety	AN	AW	GN	GW	LN	LW	MN	MW
	0.2575	0.2438	0.2271	0.2211	0.2182	0.2450	0.2347	0.2318

SPLOT	1	2
	0.2360	0.2338

Same as above, but even less differences between them

variety	SPLOT	1	2
AN		0.2778	0.2372
AW		0.2416	0.2459
GN		0.2252	0.2291
GW		0.2186	0.2235
LN		0.2111	0.2252
LW		0.2446	0.2454
MN		0.2350	0.2345
MW		0.2342	0.2294

*** Standard errors of differences of means ***

Table	variety	SPLOT	variety SPLOT
rep.	6	24	3
s.e.d.	0.01807	0.00548	0.02114
d.f.	14	16	23.43

Except when comparing means with the same level(s) of
variety 0.01551

d.f. 16

ANOVA 2:2001

Output file from Genstat showing two ANOVA's performed to see if there is any significant differences between the observed and predicted values of both the tree and maize lines.

Note: SPLOT = 1 == observed
SPLOT = 2 == expected

Analysis of variance on tree values

```
***** Analysis of variance *****

Variate: tree

Source of variation       d.f.(m.v.)       s.s.        m.s.      v.r.  F pr.

REP stratum                    2       0.0119734  0.0059867    6.08

REP.variety stratum
variety                        7       0.0207339  0.0029620    3.01  0.038
Residual                      14       0.0137830  0.0009845    1.60

REP.variety.*Units* stratum
SPLOT                          1       0.0005786  0.0005786    0.94  0.348
variety.SPLOT                  7       0.0043890  0.0006270    1.02  0.459
Residual                      15(1)    0.0092554  0.0006170

Total                         46(1)    0.0585451
```

This ANOVA shows that the values of the tree lines water content does differ between the different varieties of tree, but more importantly due to the large f probability (0.348) we can conclude that there were no significant differences between the observed and predicted water content values. Once again a split plot experiment is used in order to compare the observed and predicted values for each plot, rather than their overall means.

```
***** Tables of means *****
Variate: tree
Grand mean  0.2325

  variety    AN      AW      GN      GW      LN      LW      MN      MW
          0.2652  0.2425  0.2176  0.2067  0.2124  0.2628  0.2256  0.2274

     SPLOT        1        2
             0.2291   0.2360
```

variety	SPLOT	1	2
AN		0.2527	0.2778
AW		0.2434	0.2416
GN		0.2101	0.2252
GW		0.1947	0.2186
LN		0.2137	0.2111
LW		0.2811	0.2446
MN		0.2162	0.2350
MW		0.2206	0.2342

*** Standard errors of differences of means ***

Table	variety	SPLOT	variety SPLOT
rep.	6	24	3
s.e.d.	0.01812	0.00717	0.02310
d.f.	14	15	27.11
Except when comparing means with the same level(s) of			
variety			0.02028
d.f.			15

Analysis of variance on maize values

***** Analysis of variance *****

Variate: maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0145419	0.0072710	5.85	
REP.variety stratum					
variety	7	0.0078425	0.0011204	0.90	0.532
Residual	14	0.0174129	0.0012438	3.53	
REP.variety.*Units* stratum					
SPLOT	1	0.0008278	0.0008278	2.35	0.145
variety.SPLOT	7	0.0028611	0.0004087	1.16	0.377
Residual	16	0.0056364	0.0003523		
Total	47	0.0491227			

This shows that the water content values for the maize lines do not differ significantly for the different tree lines, and also that there is no significant difference between the observed and expected maize values. The slightly lower F probability for this test, than for the above ANOVA, is probably due to the averaging that the maize lines were subject to.

***** Tables of means *****

```
Variate: maize

Grand mean  0.2379

  variety       AN       AW       GN       GW       LN       LW       MN
            0.2597   0.2495   0.2310   0.2227   0.2233   0.2502   0.2305

  variety       MW
            0.2365

    SPLOT        1        2
            0.2421   0.2338

  variety    SPLOT        1        2
       AN            0.2822   0.2372
       AW            0.2531   0.2459
       GN            0.2329   0.2291
       GW            0.2219   0.2235
       LN            0.2215   0.2252
       LW            0.2549   0.2454
       MN            0.2265   0.2345
       MW            0.2436   0.2294


*** Standard errors of differences of means ***

Table                    variety        SPLOT      variety
                                                     SPLOT
rep.                           6           24            3
s.e.d.                   0.02036      0.00542      0.02307
d.f.                          14           16        21.54
Except when comparing means with the same level(s) of
 variety                                           0.01532
 d.f.                                                   16
```

Overall, from these ANOVA's it can be concluded that there is no significant differences between the observed and predicted values, and as such the model used to obtain the predicted values is an adequate one to describe the data set.

Other related WRC reports available:

Determination of the relationship between transpiration rate and declining available water for *Eucalyptus grandis*

PJ Dye, AG Poulter, S Soko & D Maphanga

Previous studies of the water relations of *Eucalyptus* have taken place under conditions of adequate water supplies in the soil and subsoil. This project attempted to clarify at what level of soil-water content water stress would set in and transpiration begin to decline, what other factors affect the onset and the intensification of water stress and associated decline in transpiration, and what the relative contributions of water held at various depths in the soil and subsoil are towards sustaining transpiration.

In attempting to answer these questions, elaborate measures were taken to induce plantation water stress by preventing rain from recharging soil-water. Soil-water measurements to a depth of 8 m confirmed that soil had dried out to at least that depth. Deep drilling revealed live tree roots 28 m below the surface, confirming that the accessibility of deep soil water to roots was preventing the development of material water stress, even after more than a year of withholding water. While the results of this project did not provide answers to all questions implicit in the objectives, they did provide valuable new insights into the extent to which trees are able to access water in deep strata when grown on deep soils. Under such conditions new plantations may continue to use water at near-potential rates for several years after establishment, until all accessible stored water has been depleted.

Report Number: 441/1/97 **ISBN: 1 86845 305 7**

Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa

TJ Bembridge

Despite huge investments, with a few exceptions, the performance of most small-scale farmer irrigation schemes in South Africa falls far short of the expectations of engineers, politicians, development agencies and the participants themselves. Due to financial constraints over the past few years, provincial governments have withdrawn their support from a number of schemes. This has resulted in considerably reduced efficiency and, in some cases, almost complete collapse of certain schemes.

The aim of the study was to contribute to the knowledge of the constraints facing small-scale irrigation schemes in the Eastern Cape, KwaZulu-Natal and Northern Provinces through an overview of 184 schemes in the three provinces, followed by four case studies of >top down= bureaucratically-managed schemes. The aim of the research was to devise general guidelines and strategies for rehabilitating small-scale farmer irrigation schemes in South Africa. Problems and constraints tended to centre around poor maintenance of infrastructure and equipment, lack of institutional support in terms of land tenure, credit, marketing, draught power, extension, research and, in some cases, high energy costs. There were also problems of marginal soils and water quality and quantity.

One of four households was headed by a female, a high proportion of people were illiterate in the upper age groups, and they had limited resources. Approximately three in five households were living in varying degrees of poverty. In many cases, modernisation and rehabilitation are only justified on the grounds of food security and poverty relief, provided that interest and redemption of rehabilitation costs are completely subsidised.

A checklist and discussion of general basic elements which need to be considered in rehabilitating selected irrigation schemes includes the need for a participative approach in establishing human potential and environmental constraints, topography and soils, land use and related factors and infrastructure and water supplies, all aimed at assessing scheme viability.

The success of scheme operation and maintenance, depends on farmer participation, formation of WUAs, upgrading infrastructure, operational and maintenance guidelines, as well as institutional support, including credit, marketing, inputs, mechanisation, extension, research and training.

Report Number: 891/1/00 **ISBN: 1 86845 683 8**

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