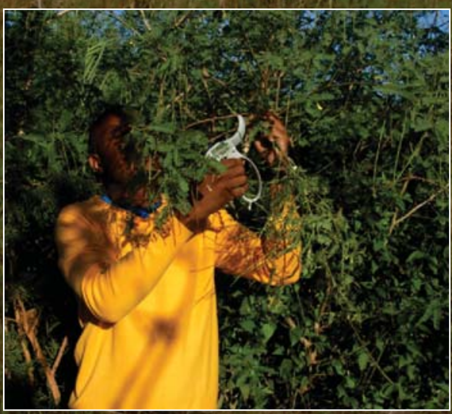
WATER USE OF AGROFORESTRY SYSTEMS FOR FOOD AND FORAGE PRODUCTION

M Musokwa, T Makhubedu, J McCosh, Z Shezi



TT 827/20

WATER USE OF AGROFORESTRY SYSTEMS FOR FOOD AND FORAGE PRODUCTION

Report to the
Water Research Commission

Authors: M Musokwa, T Makhubedu, J McCosh, Z Shezi

Inputs: S Lorentz, P Mafongoya and P Scogings

Editor: B Letty

WRC Report No. TT 827/20
ISBN 978-0-6392-0166-5

June 2020

Obtainable from
Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Water Use of Agroforestry Systems for Food, Forage and/or Biofuel Production* (WRC Project No. K5/2492//4).

DISCLAIMER

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

This is a summary of the findings of the study WATER USE OF AGROFORESTRY SYSTEMS FOR FOOD, FORAGE AND/OR BIOFUEL PRODUCTION (WRC Project K5/2492//4) implemented by the Institute of Natural Resources over the period April 2015-March 2020. Agroforestry is the intentional introduction or retention of woody species, especially nitrogen-fixing species, within crop and fodder production systems. The integration may be simultaneous or sequential, such that the different species are not grown at the same time within a given area of land. Agroforestry can provide a range of benefits including improved diets and income generation, reduced environmental degradation, improved soil fertility and structure, and climate resilience. In many agroforestry systems there is competition that exists between the woody species and the understorey crop for water, light or nutrients. Therefore, one of the main challenges of these systems is to determine a hedgerow pruning frequency that reduces the competition and maximises the amount of biomass for feeding livestock fodder and replenishing soil fertility.

Previous work investigating the influence of different agroforestry systems and species on soil water, water use efficiency and yields of the different components of the system has been funded by the Water Research Commission. The current study sought to broaden our understanding of the opportunities that agroforestry provides to strengthen smallholder agricultural systems. We took into account the factors that other studies have identified as hindrances to the adoption of agroforestry, such as the high labour requirements and the lack of available of planting material. The research was conducted at the research facility of the Department of Agriculture and Rural Development, Owen Sithole College of Agriculture (OSCA), and the privately owned Fountainhill Estate at Wartburg, KwaZulu-Natal Province. On-farm sites were also identified for participatory action research with smallholder farmers.

Different woody species, both indigenous and exotic, can be used in agroforestry systems. This study focused on multi-purpose, short-lived woody legumes. Many commonly-used agroforestry species such as *Leucaena leucocephala* and *Gleditsia triacanthos)* are listed as invasive alien plants that may not be propagated in South Africa and as it was difficult to obtain planting material for some other species *(e.g. Gliricidia sepium*), a decision was taken to focus on *Sesbania sesban* (referred to here as Sesbania), an indigenous species, and pigeon pea (*Cajanus cajan*), an agronomic crop, as the woody species in the trials.

Three systems, namely improved fallow, alley cropping and silvopastoral systems were tested. The improved fallow is a sequential system because land is planted with woody legumes for a period of time (generally two years as a minimum) to improve the soil fertility, after which the trees are removed and replaced with a cultivated crop (e.g. maize, sorghum or millet). In the current improved fallow trials, combinations of pigeon pea and Sesbania were established as the fallow tree crop with *Panicum maximum* (a pasture grass) or maize planted as the 'follower' crops. Since many farmers do not have enough land to take the full area out of production for two years, we also tested a system that included a maize crop in the first year while the trees were still small. The trials showed that the grass (*P. maximum)* yields were greater when it was intercropped with pigeon pea than with Sesbania because the latter competed more strongly for sunlight and water. When grown in combination with Sesbania, the grass *(P. maximum)* component only established properly in the second season. Similarly, maize grown in combination with pigeon pea performed better than maize grown with Sesbania. The biomass production of the tree species and the two systems was also compared when the fallows were cleared or cut back in September 2018. The Sesbania outperformed the pigeon pea for both systems. The effect of the fallow on soil properties was also studied and results showed that the improved fallows recorded lower bulk density and higher infiltration rates. The effect of improved fallows on soil macrofauna (species diversity and richness) was investigated. In comparison with continuous maize and a two-year natural fallow, the improved fallow plots had significantly greater species richness. There was a significant correlation between the amount of leaf litter and the diversity and richness indices for the plots. There were also positive correlations between infiltration rate and amount of leaf litter. It is suggested that the leaf litter provided by the woody legumes was a substrate for microbial activity, which also improved the infiltration rates. The effect of a two-year improved fallow on maize yields was compared against continuous maize. There was a positive correlation between maize yields (and soil macrofauna species richness. In the first season post fallow, the maize yields (both grain and stover) were superior to those of the continuous maize, as was the infiltration rate.

Alley cropping is an agroforestry system where woody plants are grown in hedgerows that are some distance apart and an understorey crop such as maize is grown in the alleys between the hedgerows. Alley cropping trials comprised Sesbania and pigeon pea hedgerows grown in combination with maize in alleys that were 3 m wide. Hedgerows are generally pruned to reduce competition with the crop grown in the alley and to provide a source of material for green manure or fodder. The effect of hedgerow cutting height on the system was investigated. Two cutting heights (50 and 75 cm) were compared with sole maize and with an alley system where the trees were only cut back once at the start of the season to allow for establishment of the maize crop. It was found that when hedgerows were pruned at a lower height this reduced hedgerow biomass production but did not have a positive effect on the production of the maize growing in the alley, probably due to the alley width. In another trial where woody species were compared, it was found that pigeon pea competed much less with the maize crop than did Sesbania.

Silvopastoral systems are those that include an intercropping of woody species and pasture species aimed at supporting livestock production. In the current trial, *P. maximum* was grown in alleys formed by hedgerows of periodically pruned pigeon pea. *P. maximum* was selected because it is fairly shade tolerant, growing naturally under tree canopies. Two pigeon pea cutting heights (60 and 90 cm) were compared with sole *P. maximum* and with a treatment where the pigeon pea was left uncut. The lower cutting height produced less pruned tree biomass. The silvopastoral systems, regardless of the cutting height, provided more – and better quality – fodder than did the systems that only provided grass.

Water use of the different agroforestry systems was investigated using Watermark sensors at three depths (200, 500 and 1200 mm). The pigeon pea was found to have less effect on the soil water content than the Sesbania, which is in agreement with the observed rooting patterns when trees were excavated – the tap roots of the Sesbania plants were deeper and their lateral roots spread further than those of the pigeon pea plants. The inclusion of a woody component increased the water productivity of the system in terms of both total dry matter (DM) production and crude protein yield per unit of water used, with the Sesbania being more water productive than the pigeon pea.

The loss of many Sesbania and pigeon pea plants as a result of a heavy frost in June 2018 at Wartburg highlights the importance of good hedgerow management so as to extend the longevity of the hedgerows as well as the amount of material produced. A late pruning before winter meant that regrowth required the use of carbohydrates stored in the roots. This meant there were insufficient carbohydrates available to recover from the defoliation caused by the frost. Thus In areas where frost occurs, it may be better to make use of improved fallows as the trees are better able to recover from frost if they are left unpruned.

At Ixopo/Highflats, smallholder farmers experimented with a number of systems using pigeon pea and Sesbania. Farmers generally found that the trees competed too severely with the maize to allow alley cropping, but saw value in growing them on their farms as a source of fodder – either fresh or dried. Rabbit production was also introduced to farmers as a means of adding value to agroforestry systems as they can be supplemented with leaves, twigs and seedpods of both Sesbania and pigeon pea.

Cost-benefit analyses were undertaken for these three systems. While the Sesbania/maize system did not look at all promising due to the cost associated with propagating and transplanting the seedlings, the other two systems – especially the silvopastoral system, looked reasonable except for the high cost of labour for managing the woody component. The viability of the systems improved substantially when the labour rate was calculated based on those used locally within communities (below minimum wage).The decisions of farmers to engage in agroforestry are unlikely to be made based only on the financial viability of the systems, but may be attractive from the perspective of diversifying their systems and providing multiple benefits.

The key conclusions and recommendations that have been drawn from this research project are that: (1) the choice of species and the spatial arrangement is very important if competition for light and water is to be minimised – the choice of species also depends on the climatic conditions of the area (for example many of the commonly used species are not frost tolerant) as well as the farmers' priorities; (2) temporal arrangements may be useful in avoiding competition but require access to sufficient land for cultivation; (3) agroforestry practices diversify farming systems and increase agro-biodiversity; (4) the inclusion of drought tolerant woody species such as pigeon pea can make farming systems more resilient and better suited to the anticipated effects of climate change (specifically erratic rainfall and higher temperatures); (5) the inclusion of new woody species with which people are unfamiliar may also require changes in their eating habits, or will require efforts to access new markets (e.g. pigeon pea grain).

One of the main characteristics of agroforestry systems is that they are complex and require continual assessment and adaptive management by farmers based on their own specific needs. If trees are being grown primarily for seed then they need to be managed to maximise seed/grain production. If they are being grown for soil improvement purposes and are providing a source of organic material for green manuring, then farmers need to decide how much they are prepared to trade soil improvement against fodder production. Farmers need to make decisions about how severely to cut back their trees as well as when to do it.

This research has generated a lot of new knowledge about planning and managing agroforestry systems. It has provided new guidance on how hedgerows should best be managed to limit competition, especially for water. It has provided evidence of the benefits of these systems compared with conventional monoculture cropping systems. While the timeframe of this project allowed for an evaluation of systems in terms of crop yields, water use and even on the effect on soil macrofauna, it did not allow for an evaluation of the effect on soil nutrient status, nor for a measure of how crop yields decline over time in monoculture systems. These are aspects that could only be addressed by longer term trials. While the trials were designed to test low external input systems for farmers that do not have resources to invest in fertiliser, there might be benefits from microdosing maize grown in alley cropping systems, and applying fertiliser to a silvopastoral system because both these types of system export material from the system and this loss of nutrients requires replenishment. For farmers feeding pruned material to livestock, this could be done in such a way that it facilitates the return of manure to the fields. Another aspect that requires future work is evaluation of the agroforestry systems in terms of animal performance. What is clear from the research is that agroforestry systems are diverse and offer a variety of opportunities to strengthen the resilience of existing farming systems of smallholder farmers. There are also opportunities to apply agroforestry in large-scale commercial farming systems. The design of the systems in terms of species choice and spatial and temporal arrangements depends on the specific needs of the farmers as well as the local physical and socio-economic context, but if designed and implemented according to specific objectives, it can create more resilient and sustainable farming systems.

ACKNOWLEDGEMENTS

The research in this project was initiated, managed and funded by the Water Research Commission, for whose assistance we are sincerely grateful. We would like to thank the KwaZulu-Natal Department of Agriculture and Rural Development, specifically Francois du Toit, Farm Manager at Owen Sithole College of Agriculture, for making a research site available. Similarly we would like to thank the management of Fountainhill Estate, specifically Ed Gevers, for providing a second research site. We would like to express our appreciation to the farmers at Ixopo/Highflats and the late Simon Mbele from Zwelisha, for working with us and sharing their experiences.

We also acknowledge the contribution of the reference group members:

Dr GR Backeberg	Water Research Commission (Chairperson 2015-2019)
Dr S Hlophe Ginindza	Water Research Commission (Chairperson 2019-2020)
Dr S Mpandeli	Water Research Commission
Dr R Heath	Forestry South Africa
Dr S Bezuidenhout	KZN Department of Agriculture and Rural Development
Dr D Marais	University of Pretoria
Dr M Gush	Council for Scientific and Industrial Research
Prof C Everson	University of KwaZulu-Natal
Prof P Chirwa	University of Pretoria
Ms MN Buthelezi	University of KwaZulu-Natal

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHS

LIST OF ABBREVIATIONS

AF	Agroforestry
ANOVA	Analysis of variance
BNF	Biological nitrogen fixation
CEC	Cation exchange capacity
DAP	Days after planting
DARD	Department of agriculture and rural development
DM	Dry matter
ERT	Electrical resistivity tomography
ET	Evapo-transpiration
FHE	Fountainhill Estate
GET	Geo Hydraulic and Environmental Technology (Pty) Ltd
INR	Institute of Natural Resources NPC
KZN	KwaZulu-Natal
LAI	Leaf area index
LER	Land equivalent ratio
LSD	Least significant difference
OPV	Open pollinated variety
OSCA	Owen Sithole College of Agriculture
RCBD	Randomised complete block design
RMS	Root mean square
RMSE	Root mean square error
SWC	Soil water content
SWS	Soil water storage
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
VWC	Volumetric water content
WAP	Weeks after planting
WP	Water productivity
WRC	Water Research Commission
WUE	Water use efficiency

This page was intentionally left blank

1 INTRODUCTION

This report (Deliverable 15) is the final deliverable associated with the Water Research Commission (WRC)-funded project "Water use of agro-forestry systems for food, forage and/or biofuel production (K5/2492//4)", which was implemented by the Institute of Natural Resources NPC (INR) in collaboration with University of KwaZulu-Natal and SRK Consulting. It builds on previous agroforestry work that has been supported by the WRC over the years. The project came at a time when the (then) Department of Agriculture, Forestry and Fisheries (DAFF) was developing their Agroforestry Strategy for South Africa and thus provided opportunity to inform the policy since that process was also coordinated by the INR.

The general aim of the project was **to develop agroforestry systems that make effective use of available water and improve rural livelihoods.** The specific aims were: (1) To review relevant research reports pertaining to agroforestry, simulation modelling, impacts on soil water and water use productivity ; (2) To identify sites and determine requirements of farmers that will inform choice of species (trees, shrubs and grasses) and the integration of trees, shrubs and forage into the farming system; (3) To identify and test best spatial and temporal arrangements (layouts) for agroforestry systems; (4) To measure water use of agro-forestry systems and their impacts on soil water status; (5) To determine economic and social benefits and costs of the agroforestry system; and (6) To develop guidelines for extension on agroforestry systems.

This project was motivated by the fairly limited application of agroforestry systems in South Africa, with many farmers not being aware of opportunities that exist and not being aware of the long-term benefits that could emerge from the inclusion of woody species in the current farming systems. The project aimed to further develop the knowledge base in terms of alternative spatial and temporal arrangements and to improve access to information available to extension officers and NGO field staff regarding different agroforestry systems.

Agroforestry has been defined as a landuse system where woody perennial trees are integrated into the same land management unit as agricultural crops and/or animals (Lundgren and Raintree 1982, cited by Nair, 1993). An agroforestry system normally has two or more species, one of which is a perennial woody species and has two or more outputs (e.g. food, fuel and fodder). Furthermore such systems are ecologically and economically more complex than a monocropping system (Nair 1993). Agroforestry systems may also be an effective mechanism for addressing the anticipated impacts of climate change (especially erratic rainfall events, increasing temperatures and reduced overall precipitation levels). The integration of trees and shrubs into cropping systems has the potential to improve the use of available water by intercepting water that has percolated through the root zone of the agronomic crop. However, trees can modify soil hydrological properties and thus impact on the crop component of the system, especially for species that have extensive root systems that spread horizontally and vertically (Siriri et al., 2012).

This report is based on a compilation of the various deliverables submitted by the project team over the five year timeframe. It covers research trials conducted at Owen Sithole College of Agriculture at Empangeni and Fountainhill Estate at Wartburg as well as pot trials conducted at University of KwaZulu-Natal in Pietermaritzburg and participatory action research (PAR) undertaken with smallholder farmers at Bergville and Highflats/Ixopo,

The first chapter of the report is a review of previous work on agroforestry funded by the WRC and a review of the literature. The second chapter covers site identification, while the third presents the findings regarding the testing of agroforestry arrangements (both spatial and temporal). Chapter four covers water use of agroforestry systems and is followed by Chapter 5 that documents farmers' experiences with agroforestry. Chapter 6 presents the cost benefit of analyses of three systems (silvopastoral, alley cropping and improved fallow). Capacity building efforts are contained in Chapter

7, while papers and presentations are summarised in Chapter 8. Finally the last chapter of the report is a conclusion that considers the extent to which the study addressed the objectives set upfront.

2 LITERATURE REVIEW

2.1 Introduction

This literature review was the first deliverable associated with the WRC-funded project "Water use of agro-forestry systems for food, forage and/or biofuel production". The first specific aim was: To review relevant research reports pertaining to agroforestry, simulation modelling, impacts on soil water and water use productivity.

The literature review provides a summary of previous agroforestry work undertaken by the WRC. It then provides a review of scientific articles that address different topics related to agroforestry systems.

The WRC has had a fairly long-term interest in agroforestry systems and this section of the literature review summarises the content and outcomes of five studies undertaken in the last 20 years. Following the individual summaries, a table is provided that provides a synthesis of the four key studies. The research team undertook to build on the work already supported by the WRC.

2.1.1 Effect of agroforestry species on soil moisture of cropping systems

A study was conducted by Everson et al. (2002) in the Upper Thukela Region over the period 1998-2001 to better understand the competition for water between trees and crops (maize specifically). Soil moisture profiles of the system were monitored to understand the effect of the competition. Furthermore, the water use of various tree species was compared in order to be able to make species recommendations. Lastly a study was conducted on the economics of the agroforestry system.

The on-farm trials considered four fodder tree species (*Acacia karroo, Leucaena leucocephala, Morus alba* and *Gleditsia triacanthos*) which were planted in an alley cropping system. Soil moisture and biomass of the maize and trees was determined throughout the study, as well as the effect of shading on the maize.

In terms of results, the *A. karroo* proved to be the most productive tree over the three year period. The *M. alba* showed the greater shading effect (>80%) because of its height and regular pruning would be recommended. The *A. karro*o recovered slowly from a pruning in 2000 and the authors suggest that it should not be pruned severely and should be maintained as a hedge. Competition between trees and maize for nutrients was also considered. It was found that over time the maize rows nearest the tree rows declined substantially (relative to the control).

There did not appear to be much competition for water as the surface soil water content of under the tree rows was not significantly different from that of the maize lines for both good rainfall periods and drier periods. There was a tendency for the soil profile to become drier over the 3-year period and the authors suggest that this may have been due to the trees maturing.

The study concluded that the maize production was reduced due to shading but overall the system was more productive due to provision of fodder and firewood.

2.1.2 Water use efficiency of multi-crop AF systems for small scale farmers in semi-arid areas

Rethman et al. (2007) conducted a study in Limpopo and Gauteng provinces over the period 2000-2003. This included on-farm research as well as trials on the Hatfield Experimental Field and at University of Pretoria (UP). The trials at Hatfield and UP compared sole crop stands of sorghum, cowpeas, sweet potatoes and *Leucaena leucocephala* with an alley cropping system that integrated leucaena hedgerows with the same crops. In Venda, the on-farm trials investigated silvopastoral systems for a small-scale dairy enterprise. A maize-leucaena alley cropping system was investigated at Sekakane and Chuene Maja and compared it against mono-cropped maize.

The trials showed that under semi-arid and arid conditions, the alley cropping systems faced challenges. Competition for light and water was monitored. It was suggested that row orientation at these latitudes does not have a major effect on light interception during the summer months but could be affected by the pruning practices. Interestingly, *Panicum maximum*, which is a tropical C4 perennial grass, did well under the leucaena canopy as it is shade tolerant and could also benefit from the higher fertility.

At Hatfield there was strong competition for water in the understorey rows closest to the trees (possibly because (1) recharge of the lower levels was not occurring due to unfavourable rainfall conditions and (2) sub-soil conditions impeding root penetration and). In terms of competition for water, results from Sekakane – where rainfall was low (360 mm for the season in a good year), showed that maize rows 3 m from the trees produced the best results while in a bad year the trees affected maize rows up to 5 m from them.

2.1.3 Agroforestry systems for improved productivity through the efficient use of water

Everson et al. (2012a) undertook research at Ukulinga Research Station in KwaZulu-Natal over the period 2002-2007. The study focused on *Jatropha curcas*, for which it developed a hedgerow intercropping model, that could in principle be applied to other species. The report also documents work undertaken to investigate a number of alley cropping systems (various tree species including Leucaena, black wattle, *M. alba* and *A. karroo* combined with maize (intercropped with cowpeas) as well as with pumpkin. The project yielded two PhD theses, the topics of which were:

- Heat and energy exchange above different surfaces using surface renewal (Michael G. Mengistu)
- Sensible heat flux and evaporation for sparse vegetation using temperature-variance and a dual source model (Michael G. Abraha).

The study showed that reduced crop yields were achieved in alley cropping systems, possibly because the trees were still in the establishment phase. In the case of the Jatropha, it was found that there was competition between the kikuyu and the trees, which reduced the production of the trees.

2.1.4 Effect of agroforestry and intercropping systems on fodder production in rural areas in SA

Everson et al. (2012b) reported on the outcomes of field trials conducted on the farm and at the homestead of smallholder dairy farmer Mr Mbhele in Bergville, KwaZulu-Natal. The objectives of the study were:

- To determine effect of AF systems on increasing fodder production
- To determine effect of AF practices on soil water availability for maize
- To determine whether the trees enhanced infiltration of water and prevented soil loss
- To compare water use of *Acacia karroo* and Leucaena, as indigenous and exotic tree species respectively.

Annual rainfall in the area falls between 712 and 805 mm and moderate frosts are common. The trial first evaluated an alley cropping system incorporating a temperate grass species (Cocksfoot and Tall fescue) and tree legumes (Leucaena and *Acacia karroo*). The trees were found to have a positive impact on the pasture production. Analysis of the nutritive value of the tree biomass was also conducted.

In addition to the silvopastoral system, Everson et al. (2012) also evaluated system where maize was intercropped with Dolichos lablab. The lablab was found to increase the maize yields and also increased the overall quality of the diet. Water use was investigated, using not only the Mbhele site, but also that of a previous WRC-funded study implemented by the authors at Mr Mahlobo's farm.
In addition to this, the palatability of the tree legume species was investigated as well as the accumulation of soil N associated with the different systems.

The study showed the benefits of both alley cropping tree legumes and temperate pastures as well as intercropping Dolichos Lablab with maize to improve fodder production. The limitations of using *A. karroo* were also highlighted. Lastly, the trial demonstrated the need to test AF systems under local farming conditions.

2.1.5 Water-use of grasslands, agroforestry and indigenous forests

The paper by Everson et al. (2011) documents water-use characteristics of a number of vegetation types including the silvopastoral system in the Upper Thukela Region described above in Section 3.1 (*A. karroo*, *M. alba*, *G. triacanthos* (Gleditsia/honey locust) and *Leucaena leucocephala* trees in association with tall fescue and cocksfoot. The inclusion of legume trees increased the pasture yields above those of sole stands. Considering water use, the study found that the Acacia trees used water in all seasons because of their evergreen nature, while Gleditsia – which is deciduous – had zero sap flow in July as it had shed all its leaves. The acacia, though indigenous, had high sap-flow rates in all seasons and thus had higher annual water use than the introduced deciduous species.

2.1.6 Modelling vegetation water use for different categories of vegetation

In addition to the AF studies, another WRC report with relevance to the current study is included in this section. The objectives of the project of Dye et al. (2008) was to develop a framework of understanding about major controls of evapo-transpiration in different types of vegetation and crops in South Africa. An output of the project was the development of a user-friendly water use prediction tool for use by non-specialists.

The WAVES (Water, Vegetation, Energy, Solute) model (http://www.clw.csiro.au/products/waves/) was selected as being most suitable as a basis for the model. It simulates energy, water, carbon and solute (salt) balances on a daily time step within a one-dimensional soil-plant-atmosphere system. Amongst other modifications, it required changes in terms of the user interface and links with the climate database in SA. The vegetation categories that it was to cover include some dryland crops, alien invasive trees, grasslands, savanna (including overstorey tree canopy and understorey grass canopy) and plantation forests.

The model simulates mean rainfall, surface run-off, rainfall interception by trees, rainfall interception by grasses, maximum ET, soil evaporation loss, total ET per annum and peak leaf area index (LAI) of the different components.

The report provides information about scintillometry (to estimate evaporative rates from land surfaces); the Bowen ratio energy balance which estimates the components of the energy balance (latent heat flux in particular – which is used to determine total evaporation above the vegetation cover); Eddy Covariance which is used to provide information about water and carbon fluxes which are indicators of water use efficiency; heat pulse velocity which is used to measure sap flow rates through woody stems in studies of transpiration roots. In addition the project made use of a LI-COR to estimate leaf area index (LAI) and used a CS615 time domain refrectory (TDR) probe to provide a continuous record of volumetric soil water in the surface soil horizon.

The authors make a recommendation that more vegetation types need to be parameterised for inclusion in the model.

2.1.7 Synthesis of WRC agroforestry studies

A summary of information about the four WRC-funded studies on agro-forestry is provided in Table 2.1. The main spatial arrangements that have been investigated are alley cropping systems. Since these have resulted in interspecific competition for light and water, it is suggested that alternative spatial and temporal arrangements be investigated for the current study. The review of scientific articles provides ideas about alternative systems that may prove more suitable for South African conditions, especially under semi-arid and arid conditions.

Table 2.1 Synthesis of information pertaining to three previous WRC-funded projects that involved investigations of agroforestry

TITLE	**The effect of the introduction of agroforestry species on the soil moisture regime of traditional cropping systems in rural areas**	**Water use efficiency of multi-crop agroforestry systems, with particular reference to small-scale farmers in semi-arid areas**	**Agroforestry systems for improved productivity through the efficient use of water**	**Effect of agroforestry and intercropping systems on fodder production in rural areas in SA**
AUTHORS	Everson C.S., Everson T.M., Van Niekerk W. and Von Maltitz G. 2002	Rethman N.F.G., Annandale J.G., Keen C.S. and Botha C.C. 2007	Everson C.S., Ghezehei S.B., Everson T.M. and Annandale J. 2012	Everson C.S, Mthembu B.E. and Everson T.M. 2012
TRIAL DATES	1998-2001	2000-2003	2002	2004-2008
LOCATION OF STUDY	• Upper Thukela, KZN – On farm trials on Mr Mahlobo's farm (Annual rainfall 750 mm)	• Pretoria – Gauteng Province (annual rainfall 732 mm). • Sekakane (200-400 mm rainfall), Shayandima (872 mm), Chuene Maja (400-600 mm rainfall) – Limpopo Province.	• Ukulinga Research Farm, KZN Annual rainfall 644-825 mm.	• Bergville, KwaZulu-Natal (712-805 mm annual rainfall)
TREE SPECIES USED	• *Acacia karroo* • *Leucaena leucocephala.* • *Morus alba* • *Gleditsia triacanthos*	• *Leucaena leucocephala*	*Leucaena leucocephala,* Mulberry *(Morus alba),* Sweet thorn *(Acacia karroo),* Fever tree *(Acacia xanthaphloea),* Black wattle *(Acacia mearnsii),* Physic nut *(Jatropha curcas),*	• *Acacia karroo* • *Leucaena leucocephala*

OTHER SPECIES USED	• Maize*(Zea mays)*	• Cowpeas *(Vigna unguiculata)* • Sweet potatoes *(Ipomoea batatas)* • Maize *(Zea mays)* • Sorghum *(Sorghum bicolor)*	Pigeon peas *(Cajanus cajun),* Maize *(Zea mays),* Cowpeas *(Vigna unguiculata),* Pumpkin *(Cucubita pepo),* Guinea grass *(Panicum maximum),* Weeping lovegrass *(Eragrostis curvula),* Kikuyu *(Pennisetum clandestinum),* Velvet *bean (Mucuna pruriens)*	• Maize (*Zea mays*) • Dolichos (*Lablab purpureus*) • Tall fescue (*Festuca arundinacea*) • Cocksfoot (*Dactylis glomerata)*

AF SPATIAL ARRANGE-MENTS	• Alley cropping (rows in a north-south direction). • Narrow and wide intra-row spacing of trees between 6 rows of maize. • Control: Sole crop of maize. Measures: • Volumetric soil moisture using time domain reflectrometry to measure soil water content and soil electrical conductivity. • Neutron probe technique used to monitor soil water content (and a calibration curve was developed from gravimetric samples). • Tree biomass (fodder, fuelwood). • Tree growth (height and diameter at 100 mm above ground). • Maize yield (grain, stem, leaf material). • Nutrient analysis of fodder. • Soil analyses. • Radiation measurements – line quantum data, single quantum data.	• Alley cropping (Leucaena hedgerows associated with various crops) Measures: • Tree survival • Fuelwood, leaf and pod yield • Soil water content • PAR • Understorey crop yields (components for human and animal consumption). The study planned to investigate the following benefits of agroforestry: • Decreased risk through product diversification. • Decreased evaporation from soil surface due to shading. • Improved water use efficiency due to interspecific complementarity of root systems.	**Alley cropping with pigeon peas, velvet beans and maize** • No results obtained **Alley cropping Leucaena, mulberry, *Acacia karroo* and maize.** Measures: • Stem diameter and tree height. • Tree pruning biomass (browse material and fuel wood. • Maize biomass (grain and stalk). Results obtained: • Didn't seem to improve maize production – in fact seemed to have reverse effect. **Alley cropping – Wattle and fever trees with maize, cowpeas and pumpkins.** Measures: • Soil nitrogen • Crop yield (grain, fruit). Results obtained: • Alley cropping reduced yields! Possibly because trees still establishing!	**Alley cropping Fescue and Cocksfoot (temperate pastures) with tree legumes** Measures: • Tree height at least every 3 months • Biomass (towards end of growing season when tree were cut to height of 0.75 m) • Nutritive value of fodder (trees and pastures) – subsamples of harvested biomass – especially for crude protein, NDF and ADF. • Biomass (grass and tree) • Sap flow measurements of the Acacias using Heat Pulse Velocity technique. • Automatic weather station to monitor climatic conditions. • Hobo loggers used to determine temperature trends. • Preferences for fodder (Leucaena versus *A. karroo*) – using (1) a cafeteria system to offer leaves and measure intake and (2) infield grazing. • Soil nitrogen accumulation – by incubating bags containing anion exchange and cation exchange resin beads in the field. • Soil samples analysed for ammonium nitrate and nitrate N.

			Silvopastoral system: Jatropha with kikuyu. Different Alley cropping spatial arrangements were tested (Jatropha in multiple rows within Kikuyu stands) Measures: • Water use of trees using the heat pulse velocity method (See detail). • Leaf area density. • Evaporation using the Eddy covariance method, the surface renewal method and the surface layer scintillometer. • Surface energy budgets using an OEBMS1 system. • Various factors that all contributed to the soil water balance model – including tree parameters, crop parameters, water balance & dynamics, radiation interception, tree & crop growth (including root biomass). • They investigated tree-grass competition (impact on Jatropha!), conducted preference trials using goats, pruning Jatropha.	Results obtained: • The trees had a positive impact on the pastures • Soil water contents were lowest in winter – and >100 mm lower in bare soil areas than in the tree rows – as a result of surface evaporation. • Sap flow rates of A. karroo were 20-25 l/day in summer. • Leucaena was much more palatable than *A. karroo.* • When grazing the alley cropping system, they ate pasture and largely ignored browse – especially the *A. karroo* (possibly due to tannins but also thorns – which need to be removed during drying and processing). • Soil N accumulation – inclusion of tree legumes raised soil inorganic N levels. Ammonium and nitrate values also increased. • Distance from the tree did not have significant effect on soil N but there were trends that N increased with distance from the tree. **Intercropping maize and Dolichos lablab**

			Alley cropping (Fodder banks) – Wattle, fever trees with *Eragrostis curvula* – • Similar yields (and variable differences). • Trees and vegetables – Alley cropping reduced crop yields.	Measures: • Yield (maize and lablab). • Nutritional value of maize and lablab. • Soil nitrogen accumulation – by incubating bags containing anion exchange and cation exchange resin beads in the field. Results obtained: • Intercropping increased total fodder yield. • Lablab generally increased maize production (not always grain yield). • Lablab increased overall diet quality. • Maize/lablab had higher soil N than sole maize. **Alternative site: Mr Mahlobo's trial used for water use measures.** *Morus alba, Gleditsia triacanthos* and *A. karroo* • Sap flow measurements of the Acacias using Heat Pulse Velocity technique. • Soil water content determined using access tubes and the Diviner 2000 system • Sap flow rates for G. triacanthos were 25-30 l/day

				while *M. alba* had max of 10 l/day (due to pruning) • Pruning interfered with water use measurements so measures were conservative. **Reinforcement of planted pastures invaded by unwanted grass species** • There was invasion by *Paspalum notatum* due to loss of vigour in Fescue and Cocksfoot • Different methods of reinforcement were investigated – direct-seeding (using minimum-till method), and cultivated strip method. Measures: • Dry weight rank yield analysis to determine species composition. Results obtained: • Tall fescue was more invaded than Cocksfoot. • Strip cultivation proved to be the more effective reinforcement method for Tall fescue. • Yields and quality improved through reinforcement practices.

				• For Cocksfoot, both reinforcement methods were effective.
METHODOLO-GIES USED	• TDR to measure soil water. • Neutron probe measurements of soil water. • A line quantum sensor was used to measure radiation = these are large radiation sensors that average over a large area. • Single quantum sensors were also used measure radiation.	Quantification of AF systems: • The land equivalent ratio provides a quantitative description of differences in biomass production between farming systems. • Local values for products were included to determine the true benefit. • Combustible energy for different products can also be calculated to indicate energy use efficiency – these showed the benefits of the alley cropping options over sole stands (but doesn't account for economic value of products). • Land equivalent ratios (LER) is defined as the ration of the area under sole cropping to the area under intercropping at the same level of management that gives ab equal amount of yield – this can be adjusted to account for product value. • Photosynthetically active radiation (PAR) between leucaena rows was measured using Decagon Sunfleck ceptometers.	• Use of allometric relationships to estimate growth and biomass of trees. • Computer model to simulate production process and extrapolate to on-farm (Using Annandale's Soil Water Balance) and various other features – including pruning! • Tree root growth & distribution – affects water and nutrient uptake. • Tree root modelling, Tree canopy growth modelling; – they were developed & tested. • A full soil profile description – soil samples using soil augers and core samplers at representative depths to the bottom of the 0.6 m soil profile. • They were analysed for soil type and texture, bulk density, volumetric soil water contents at field capacity and	• Dry weight rank yield analysis to determine species composition. • Sap flow measurements of the Acacias using Heat Pulse Velocity technique. • Soil water content determined using access tubes and the Diviner 2000 system • Soil nitrogen accumulation – by incubating bags containing anion exchange and cation exchange resin beads in the field. • Preferences for fodder (Leucaena versus *A. karroo*) – using (1) a cafeteria system to offer leaves and measure intake and (2) infield grazing. • Hobo loggers used to determine temperature trends.

		• TDR technology was used to quantify spatial and temporal water distribution patterns in the system.	permanent wilting point, soil hydraulic conductivity and soil water retention properties.	
RECOMMEN-DATIONS AND CONCLUSIONS	• Wider row spacing reduced tree fodder yield. • *Acacia karroo* was most productive for fodder production. • *M. alba* had the highest fuelwood production. • Leucaena was slow to establish but showed potential for fodder production. • *M. alba* was tallest and caused most shading (>80% PAR) thus negatively affecting the maize yields. • All species affected maize yields negatively, but seemingly not due to competition for water (due to good rainfall). • There seemed a tendency for soil water content to decline as the trees matured. • With the narrow intra-row spacing the trees seemed to develop a deeper root system and were better able to cope during the drought periods than the trees with the wider spacing. • A challenge of alley cropping is harvesting of the fodder	• Yields of the understorey crop frequently had a bell-shaped curve with yields highest in the middle of the alley ad lowest adjacent to the hedgerows. • The effects of row orientation showed some variation between months but neither NS not EW were consistently better. • At shallow depths, the leucaena rows seemed to result in higher soil water content due to shading and stem flow. • Soil zones adjacent to the trees had the lowest water contents at 0.2 m and 0.5 m (which is where agronomic crops would be extracting water). • The leucaena is able to use water deeper in the profile that would be unused in a monoculture – this leads to depletion of water during dry periods. • Interspecific competition for water was least at a distance of 4 m from the hedgerow.	• SA has focused on intensive production of agriculture and forestry, but has not considered integrated systems. • Lack of knowledge about crop-tree combinations that benefit people and the environment. • Saw a need for on-farm trials to allow farmers to test them. • Led to the development of a hedgerow intercropping model which can be applied to two-dimensional agroforestry systems including silvopastoral and alley-cropping systems – the model applies to any potential agroforestry species, but needs evaluation and calibration. • Consider silvopastoral systems with unpalatable tree species!	• The inclusion of tree legumes improved fodder production from temperate pastures. • Intercropping maize and lablab increased overall fodder production. • AF systems need to be tested under local farming conditions. • *A. karroo* had palatability issues for dairy cows although it was otherwise quite promising.

	and weeding the crop. Farmers suggested rather planting on fence boundaries or on contour bunds.	• As the soil profile dries out the leucaena made more use of soil water in shallower soil zones so increasing interspecific competition-		
OTHER ASPECTS	• Detailed description of TDR and neutron probe technique provided. • Geostatistical methods were used to develop a model and fitting technique to predict water content. • An economic analysis of the agroforestry system relative to monocropped maize was investigated. • Agroforestry.xls was an Excel model that compared agroforestry-derived value with a mono-cropped maize system.	• Considered different crop and agroforestry models: SWB (soil water balance), WaNuLCas (water, nutrient and light capture), BECVOL (Biomass estimate of canopy volume) and HyPAR (intended for simulation of AF systems in dry areas but abandoned). • WaNuLCas – very input intensive, can be modified, focuses on below ground interactions, uses root length to calculate water and nutrient uptake together with plant demand factors at a given soil water content, light capture calculated using leaf area indices and plant height. • SWB – models water balance and crop growth mechanistically using grass reference evapotranspiration and thermal time-based plant phenology. • BECVOL – an empirical model that is devised to estimate browse contribution to livestock nutrition, a non-		

		destructive method of estimation. • Rethman et al. suggest SWB probably best for SA with support from BEVCOL.		

2.2 Other published agroforestry work

This section of the literature review provides a summary of information extracted from scientific articles that deal with agroforestry.

2.2.1 What is agroforestry

Agroforestry (AF) is a land use practice that involves intentional retention or introduction of perennial species that result in mixtures of trees/shrubs in crop/animal production fields, which results in an ecological and economic interaction (MacDicken and Vergara, 1990). Unlike monoculture, agroforestry creates an agro-ecosystem that is similar to that of a natural system while improving the productivity and fertility of the agricultural land (Zerihum et al., 2014). Many studies have reported the significant role AF plays with respect to increasing agricultural productivity, soil erosion reduction, soil fertility improvement and increasing farm income (Kang and Akinnifesi, 2000; Neupane and Thapa 2001; Neupane et al., 2002). Furthermore, the integration of trees and shrubs into cropping systems has the potential to improve the use of available water by intercepting water that has percolated through the root zone of the agronomic crop. Tree roots that access groundwater can increase water use above the levels of rainwater input (Asbjornsen et al., 2011).

2.2.2 Benefits of agroforestry

Adoption of AF practices in poor-resourced communities has a high potential for improvement of diet, livelihoods, food security, household income and rural business development (Reyes et al., 2008; Kalaba et al., 2010; Asaah et al., 2011; Wambugu et al., 2011). Compared to monoculture farming systems, AF practices to provide a wide range of additional benefits (Kalaba et al., 2010). AF practises such as silvo-pastoralism allow for planting of diverse cash crops and trees on the same land and thus intensifies the agricultural production. In a crop-based AF system the farmer benefits both from the cash crop as well as the tree species. Famers have realised economic and environmental benefits from adoption and implementation of AF practises. The following subsections provide a summary of the economic and environmental benefits realised in farming communities where AF practises have been adopted.

2.2.3 Economic benefits of agroforestry

Various products such as edible fruits, vegetables (leaves), honey, wood and fodder, produced under AF systems have a potential to provide economic benefits for most smallholder farmers (Wambugu et al., 2011). Several studies (Reyes et al., 2009; Kalaba et al., 2010; Jamnadass et al., 2011) have reported significant increase in household annual gross income where AF practices were adopted compared to where traditional monoculture systems were used. In Tanzania, Reyes et al. (2009) found that with improved AF practices households obtained 13 times higher net income as compared to net incomes from traditional practices. Exotic indigenous fruits and fodder production under AF practices contributes significantly to annual households income in most Eastern and Southern African communities. A review by Jamnadass et al. (2011) highlighted a high potential to improve livelihoods and nutrition through production of indigenous fruits. However, according to Jamnadass et al. (2011) this could only be achieved through education about fruit production and the market channels for the produce. In livestock farming communities, farmers have realised high returns particularly from milk production through incorporation of fodder crops in their cash crop farming system (Wambugu et al., 2011; Franze et al., 2014). Generally, various products produced under AF practices have provided some economic incentive for farmers however fruits and fodder production have contributed significantly in this regard. The economic incentives from both fruits and fodders production are summarised in the following subsections.

Fruit production

The use of wild foods including fruits has been observed in various countries, including Malawi (Akinnifesi et al., 2006) Zimbabwe (Campbell, 1987) South Africa (Shackleton et al., 1998) and Zambia (Chidumayo and Siwela, 1988). In some areas of Southern Africa, rural dwellers earn an income from harvesting and selling of these foods (Balaka et al., 2010). A study by Campbell et al. (1997) in Zimbabwe found that that 42% of the natural food basket comes from harvesting indigenous fruits which contribute between 5.5 and 6.5% of the total household income (Akinnifesi et al., 2008). Where indigenous fruits trees exist, rural annual household income can be boosted by US 300-US 2000 per household through harvesting of indigenous fruits from the wild (Leakey et al., 2005 cited in Kalaba et al., 2010). Realising the potential for improvement of household income through harvesting of wild fruits, most of the farmers in Southern Africa have incorporated wild fruit tree in their AF practices to improve their household income. Domestication of indigenous fruit trees through AF systems promotes yields and resilience and offers a great potential for improvement of rural household income (Ofori et al., 2014). High economic benefits and improved social well-being have been observed in communities where participatory domestication methods have been adopted, particularly in central African regions where indigenous fruits are highly valued (Ofori et al., 2014).

Even though the potential for improving household income through domestication of wild fruit trees is high in Sub-Saharan Africa some authors (Leakey et al., 2005, Schreckenberg et al., 2006, Akinnifesi et al. 2008) argued that there is a significant knowledge gaps with regard to productivity, market value, net returns and other features of smallholder fruit production and markets. Public research capacity on promotion fruit production in sub-Saharan Africa is considered low compared to other regions such as Asia (www.asti.cgiar.org) cited in Jamnadass et al., 2011). Therefore, a combination of further research on fruits production (particularly indigenous fruits) and domestication of indigenous fruit trees through AF practices have potential to provide economic incentives for smallholder farmers in Sub-Saharan Africa and other regions. Domestic fruit trees and nut trees are also integrated in AF system by their economic contribution is not well documented.

Fodder

In the late 1900s, the International Centre for Research in Agroforestry (ICRAF) established AF research in Southern Africa which among others things was aimed mitigating the problem of shortages of fodder in smallholder farming communities (Rao and Kwesiga, 2003). This programme covered the following countries: Tanzania, Zambia, Malawi and Zimbabwe. A good body of knowledge was built through this research initiative and later studies have reported the success of AF in fodder production. In Tanzania, farmers have implemented Silvopastoralism (an AF practice combining trees and pastures) as a fodder system for milk production (Rubanza et al. 2006). Some of the systems used in Silvopastoralism include provide tree cover of approximately 20%. In 2010, a study by Wambugu et al. (2011) in East Africa found that fodder shrubs contributed US$ 3.8 million annually to farmer's income and estimated the future annual income to be US$81 million. There is a huge economic incentive for incorporation of fodder shrubs in AF practises, for smallholder farmers in Eastern and Southern African regions. However, Wambugu et al. (2011) estimated that 500 tree are required to feed one dairy cattle per year which might prove difficult for famers with limited farming space. In summary, farmers can earn an extra income by including fodder shrubs in their livestock-based farming systems.

Other economic benefits

Woody materials obtained from trees are used for firewood and fencing material in smallholder farming communities. From available literature little is reported about the economic benefits for the woody material produced under AF practices. However, famers make huge savings on fencing material by using the wood material harvested from their own farm for fencing material. This has what appear to be indirect economic benefits. Other indirect benefits include products such as honey, leave or vegetables (which are consumed at household level as they are produced in small quantities.

2.2.4 Environmental benefits

Everson et al. (2011) summarised the benefits of agroforestry practices using a diagram displayed in Figure 2.1. However, other authors have explored each of the benefits highlighted by Everson et al. (2011) as environmental benefits. A study by Thangata et al. (2007) found that trees and shrubs played vital role in maintaining ecological balance in farming systems and recommended extension of improved fallow technology to all smallholder farmers in the Southern Africa region.

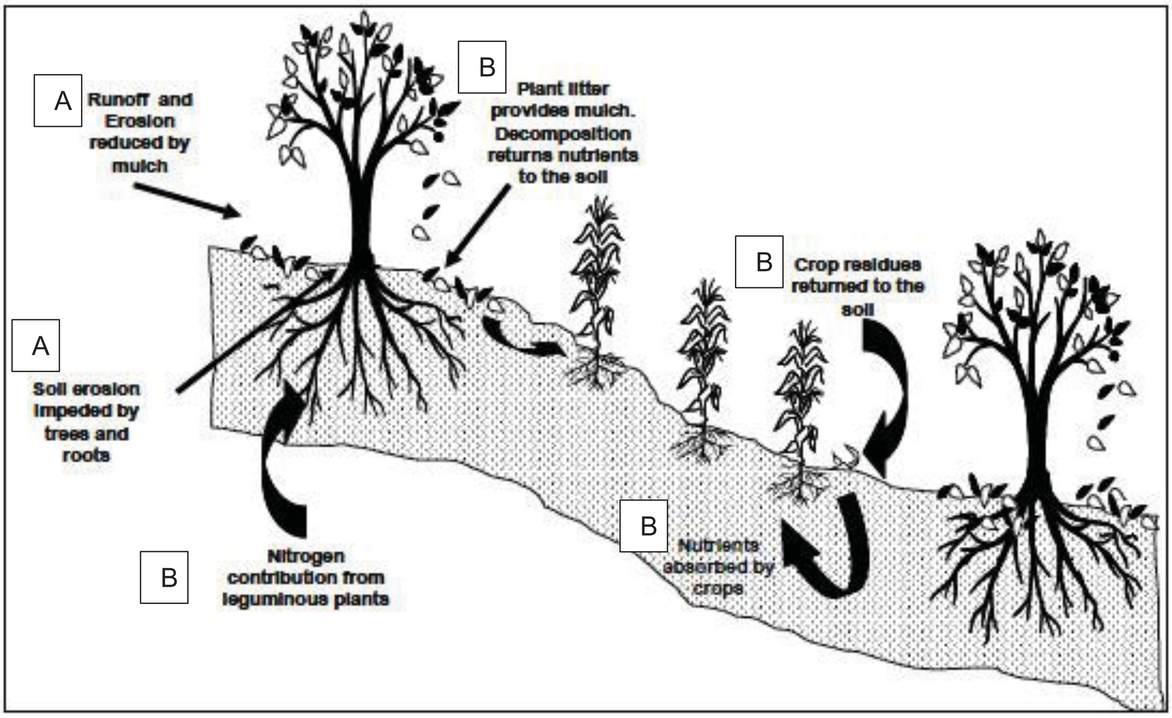


Figure 2.1: A schematic representation of potential for introducing agroforestry practices (Everson et al., 2001).

This section reports different aspects of AF which appears to have environmental benefits with emphasis on those which are reported in available literature.

<u>*Runoff and erosion reduction*</u>

This subsection summarises environmental benefits of AF practices from a runoff and erosion reduction point of view as denoted be letter A in Figure 4.1. Land degradation through soil erosion has been a major problem smallholder farming communities of southern Africa. In some regions, AF practises have been adopted mainly to mitigate the problem of soil erosion and land degradation (Rao and Kwesiga, 2003). In Australia, trees are planted on farms for protection the soil against erosion (Huth et al., 2003). Fine roots are a key factor for structural stability and protect the soil aggregates from disaggregation (Podwojewski et al., 2014).

The tree leaf litter provides a blanket of mulch (Everson et al., 2011) which is effective for preventing the erosive impact of rainfall during high intensity rainfall events. Moreover, tree canopies also prevent the impact of rain drops on the by lowing raindrop velocity.

In general, ground cover provided by litter falling from the tree and interception of rainfall by tree canopy are effective means of reducing runoff and loss of high nutrient top soil. On the other hand, tree roots hold the soil together while improving the infiltration and water holding capacity of the soil, thus making the soil less susceptible to erosion (Pollock et al., 2009). However, this is dependent on the tree species and the meteorological conditions of the area.

Nutrient cycling

AF technology is believed to promote a more efficient cycling of nutrients than monoculture agricultural practices (Zomer et al., 2007). This happen through transfer of nutrients from tree leaves litter to intercropped plants. After harvesting of intercropped plants, residues left on the ground are returned back into the soil through decomposition as organic matter. However, this happens more efficiently where AF is practiced with conservation agriculture practices. Generally, nutrient cycling is important for compensating nutrients lost through runoff and leaching in the same system. Furthermore, AF has also proved useful for the rehabilitation of land affected by salinity (Huth et al., 2003).

Biodiversity

Jama and Zeila (2005) and Zomer et al. (2007) expressed the importance of biodiversity conservation in dryland where biodiversity loss is a major problem. Activities such as excess fertilizer use in monoculture farming systems contribute to a loss of biodiversity (Rosenstock et al., 2014). AF systems which integrate various plant species promote biodiversity which (Chirwa and Quinion, 2012) considered it to be a huge social benefit. High biodiversity comes with a number of benefits which include improved soil fertility which is further discussed in the following subsection.

2.2.5 Improved soil fertility

Through the process of decomposition the blanket of mulch (from tree litter and cash crop residue) on the ground surface is incorporated into the soil profile as organic matter (see letter B in Figure 4.1). This improves soil fertility and provides an alternative to costly chemical fertilizer for smallholder famers (Thangata et al., 2007). Studies (Ajayi et al., 2004; Kwesiga et al., 1999; Kwesiga and Coe, 1994 cited in Mafongoya et al., 2006) which looked at appropriate technologies to replenish soil fertility in southern Africa revealed integration of tree fallows with leguminous trees or shrubs that accumulate nitrogen. In southern Africa, Mafongoya et al. (2006) reported a potential for growing three subsequent high-yielding maize crops in N-depleted but P-sufficient soils through the integration of two-year tree fallows of Sesbania (*Sesbania sesban [L] Merr*.) or Tephrosia (*Tephrosia vogelii Hook. F*.).

In summary, there is a huge cost saving potential for cash crop growers (e.g. maize) through integration of maize and trees.

2.2.6 Other benefits

An extra benefit gained from tree farming includes reduction in greenhouse emission which is established through high storage of carbon in the soil especially when mulching and conservation agriculture practices are applied (Mbow et al., 2014).

2.2.7 Spatial and temporal arrangements

Agroforestry systems are categorized into spatial and temporal arrangements of trees and crops (McAdam et al., 2009). Spatial arrangement speaks to the arrangement of trees, i.e. mixed (sparse or dense) or zoned, e.g. border tree planting, alternate rows or alternate strips/alley cropping, whereas the temporal arrangement speaks to arrangements that involve patterns in time. For example:

- Cyclical or shifting cultivation system: – 2-4 years of cropping and more than 15 years of fallow cycle.

- Taungya system[1]: – this is where the food crops and woody perennial trees are planted simultaneously and when the forest canopy closes, the food cropping ceases and when the forest is harvested, the crops and trees are re-established together again
- Integral or simultaneous cropping system: – where food crops and trees are established, harvested and re-established together continuously.

2.2.8 Agroforestry species

The selection criteria for species suitable for agroforestry systems are usually based on the species ability to generate higher cash income and their multiple uses (Sharma et al., 2011). AF work in South Africa has used a range of exotic and indigenous species including *Acacia karroo, Leucaena leucocephala, Morus alba and Gleditsa triacathos* (Everson et al., 2009; Everson et al., 2011). Another species that has gained popularity in the southern African countries (Zambia, Malawi and Tanzania) is *Faidherbia albida*. The interest in this crop is its leaf phenology; the tree drops its leaves in the wet/growing season and therefore fertilizes the associated crop, it also provides fodder in the dry season (www.worldagroforestry.org). Table 2.2 below presents a list of some of the AF trees suitable for South African climate.

Table 2.2: Indigenous agroforestry tree species suitable for South African climate

Scientific name	Local name	Uses
Acacia albida	Ana tree	N fixation, wood and fodder
Acacia erioloba	Camel thorn	Medicine, wood, food, fodder
Acacia tortilis subsp. Spirocarpa	Hairy umbrella thorn	Fodder (high protein), fuelwood
Bauhinia petersiana subsp. macrantha.	Coffee neat's foot	Food
Colophospermum mopane	Mopane	Food to mopane worms, wood for furniture and fencing poles
Euclea species	Guarri trees	Traditional medicine
Olea europaea subsp. africana	Wild olive	Medicine, furniture, wind breaks, soil erosion and tea
Acacia sieberana var woodii.	Paper bark thorn	Medicine, wood, edible gum
Boscia species	Shepherd's trees	Livestock feed, medicinal crop
Combretum species	Bush willows	Traditional medicine, wood for fence posts
Grewia species	Wild raisin bushes	
Portulacaria afra	Elephant bush	Livestock, game feed, medicine
Rhus viminalis	White karree	Food, wood
Sclerocarya birrea subsp. caffra.	Marula	Food beverage, fruit, Industrial use (cosmetics)
Tarchonanthus camphorates	Wild camphor bush	Windbreaks, medicine, fuelwood and charcoal
Terminalia species	Cluster-leaf trees	Control soil erosion, medicine

Note*: S. sesban* was excluded as an indigenised rather than indigenous species
Source: Underwood, 1993

2.2.9 Management of agroforestry systems: Pruning

The main management practice that is specific to AF systems is pruning. Intercropping in agroforestry systems has proved to have many advantages, however, research reveals that within these systems, competition between intercropped species may reduce or impair the growth and productivity of the

[1] Term for a system devised in Myanmar meaning "hill cultivation" and applied in other regions (See http://www.fao.org/docrep/005/y4744e/y4744e11.htm)

understorey crop. The most important management tool in AF used to eradicate the effect of competition is pruning. Pruning involves the mechanical removal of vegetative/flowering and fruiting growth from tree plants with the purposes of regulating size (Chesney, 2012).

Shoot pruning

In AF systems, one finds that trees grow and close their canopy which becomes a disadvantage to the understory crop because they get shaded (i.e. competition for light). As a result there becomes a need to cut the older shoots and reduce this competition as shown in Figure 2.2.

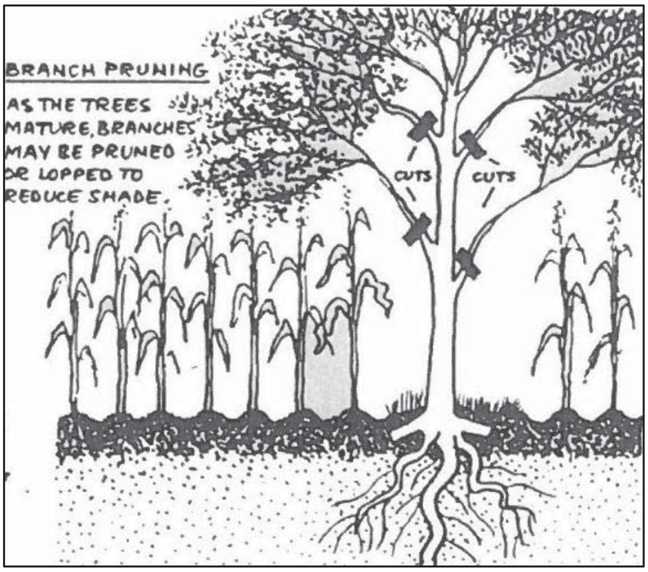


Figure 2.2: Shoot pruning (Assmo and Ericksson, 1999).

Shoot Pruning can be categorized into pollarding, coppicing and lopping and these cutting practices are used to achieve different goals. Pollarding is the cutting of branches performed at a height of 75-100 cm and lopping is the cutting off of branches leaving stubs of about 30-100 cm long and main stems of 150-200 cm. Coppicing is the most severe cutting practice of them all, since it involves cutting trees to the height of 10-30 cm above ground (Chesney, 2012). It is important that farmers understand the type of pruning appropriate for their tree species, because the method of pruning depends on the objective of the user. For example, where trees are being grown for timber production the lower branches are removed to reduce shading, while with a tree being grown as a hedgerow the trees can be pruned severely so that they leave only a short stump (e.g. 20 cm high) before each cropping season (Livesley et al., 2004).

Thakur and Sehgal (2003) investigated the effect of coppicing (by cutting the tree to 0.5 m) and pollarding (by cutting the stems to 1.0, 1.5 and 2.0 m height) when they were five years of age on tree growth and water use efficiency. It was found to affect the production of foliage and branch wood biomass (used for forage and firewood respectively). The stump height was maintained by removing regrown shoots every year. The effect of the different treatments on levels of transpiration was also investigated and generally transpiration rates increased with increasing pollarding height. Thakur and Sehgal (2003) concluded that 1.5 and 2.0 m are suitable heights for any multi-purpose tree species integrated within an agroforestry system. Another study by Bayala et al. (2008) investigated the use of crown pruning to rejuvenate mature indigenous fruit trees within cropping systems. The study compared different severities of pruning with respect to their effect on fruit production and crown recovery. Total pruning meant reducing all secondary branches to one metre from their bases. The authors concluded that heavy pruning may be a tool to improve the survival of old trees, but species differences in terms of responses to pruning were noted.

Root pruning

It is often stressed that below ground competition can be dealt with by selection of tree species with less competitive root architecture. However, even these tree types have some roots in the crop root zone. With this said, exploring other tree management practices such as root pruning is essential. Root pruning is a mechanism used to reduce the dominance of tree roots near the soil surface (Smith et al., 1999). Root pruning can be achieved by digging a 50-100 cm trench from the treeline and cut the exposed lateral roots as illustrated in Figure 2.3. With this practice, the plants can be encouraged to use their deeper roots to exploit residual water reserves and continue growth when they are no longer able to absorb water from the crop rooting zone (Ong et al., 2007).

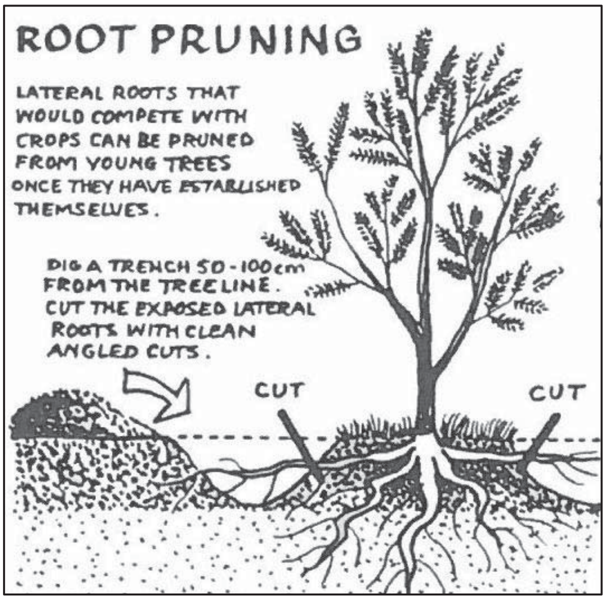


Figure 2.3: Root pruning (Assmo and Ericksson, 1999).

Other work has shown that root pruning to a depth of 0.6 m at a distance of 0.5 m from tree rows is sufficient to reduce roots in the surface horizons. Ong et al. (2007) conclude that a number of factors affect the level of water uptake that happens after root pruning. For example the initial root architecture and the proportion of the root system affected – and root development post pruning may actually lead to an increase in competition in the longer term and thus requires annual root pruning prior to every cropping season once initiated. Another disadvantage is that root pruning may interrupt hydraulic lift (i.e. the bi-directional flow of water between roots in deeper horizons and surface horizons). Hydraulic lift is important for shallow rooted crops especially during the dry season (Ong et al., 2007).

Root and shoot pruning can be used to modify the temporal patterns of resource use by trees and suppress competition (Schroth, 1999 – cited by Ong et al., 2007). Root pruning can however have the opposite effect and actually encourage the growth of fine tree roots in the surface layers (Ong and Leakey, 1999 cited by Ong et al., 2007).

2.2.10 Impacts of agroforestry on soil water characteristics

Agroforestry enhances water infiltration, improves soil water storage capacity, reduces runoff and changes the macroporosity and mesoporosity of the soil (Anderson et al., 2009). Many studies have proven that above ground stems and roots can reduce the runoff flow rate and enhance sedimentation and water infiltration (Dillah et al., 1989; Schimitt et al., 1999; Seobi et al., 2005). Bharati et al. (2002) found that infiltration rates were five times greater in multi-species riparian buffer than that of cultivated and grazed fields. Many AF trees have large and deep roots, that when they grow and decay, result in a greater proportion of larger pores in the soil. As a result, soil hydraulic properties are improved

(Cadisch et al., 2004 cited by Anderson et al., 2009). This benefit is very important in claypan soils since these soils have low hydraulic conductivity (Jamison and Peters 1967; Bouma, 1980).

A study by Wang et al. (2015) looked at the effect of agroforestry systems on soil infiltration over a period of 11 years. The study determined the regularity of infiltration and its relationship with rainfall temporal distribution. The results of the study showed that the temporal distribution of infiltration rate in alley cropping systems had a strong relationship with temporal distribution of rainfall when compared with monoculture systems. However, it was also realised that the alley cropping effect on infiltration capacity was only significant in shallow soil layers (Wang et al., 2015).

2.2.11 Water use and methods of measuring water use

It appears in many studies that annual cropping systems do not utilize available rainfall to its full potential. Significant losses from soil surface evaporation (up to 40%), runoff (26%) and deep drainage (33-40%) were reported by Ong et al. (1992, 1996, 2006, 2007); Rockstrom, 1997 cited by Lott et al., 2003. An Agroforestry system provides an opportunity to improve water use both spatially and temporally (Ong et al., 1996). Ong et al. (1996) also further expand and say that AFs may improve water use in two ways (1) by increasing the quantity of water used for tree or crop transpiration and (2) improve the productivity of water transpired by increasing biomass of tree and crops produced per unit water used.

Lott et al. (2003) investigated water use in a Grevillea-maize agroforestry system in semi-arid Kenya. They found that the agroforestry system used water more efficiently that annual cropping systems (in this case maize). At 3-4 years after planting, the trees were found to use 64-68% of annual rainfall and 25% of the water transpired was used during the dry season (i.e. using off-season rainfall as well as residual water in the soil profile). In one of the WRC projects, it was found that the sap flow rates of mature indigenous Acacia trees were 10 cm/h to 15 cm/h and consistently higher (20 cm/h to 30 cm/h) for fast growing young trees in all seasons and this indicated high water use (Everson, 2009). The evergreen nature of the indigenous Acacia trees also contributed to its ability to use water throughout the year.

The most frequently used technique for measuring water use is the sap flow measurement of transpiration (Righi, 2008). Together with the allometric estimates of biomass production, this was used to determine water use efficiency (Lott et al., 2003). Sap flow can be measured using constant temperature heat balance gauges calibrated for specific species – whether tree or crop (Lott et al., 2003). This method is based on the application of heat into a trunk segment and measuring the losses by axial (upward and downward) and radial (a constant is assumed for the energy flow migrating towards the inner plant according to its constitution) conduction and the variation of the thermal energy stored. However, the disadvantage of this method is its complexity and labour intensive nature which limits the number of plants which can be measured and hence the number of treatments that can be examined simultaneously.

2.2.12 Water use efficiency and productivity

Water use efficiency (WUE) is defined as the biomass produced per unit of water transpired (Everson et al., 2011), while water use productivity refers to the ratio of the net benefits from rainfed cropping (or other agricultural production systems), to the amount of water required to produce those benefits (Molden et al., 2010). Unlike water use efficiency, which calculates crop yield per unit water used, water use productivity considers broader objectives of producing more food, income, livelihoods and ecological benefits at less social and environmental cost per unit of water used (Green et al., 2011; Molden et al., 2007; Molden et al., 2010; Igbadun et al., 2005).

According to Ong et al. (2007), agroforestry can potentially improve water use productivity by either (1) increasing the quantity of water used for tree or crop transpiration or (2) improving the productivity of water transpired by increasing the biomass of trees and crops produced per unit of water used. In Kenya, *Acacia tortilis* and *Adansonia digitata* trees in savanna systems have been found to improve the microclimatic conditions of the understorey component. The thermal environment was moderated and incident radiation and atmospheric saturation vapour deficit was reduced and ultimately growth was improved (Belsky et al., 1989, 1993 cited by Ong et al., 2007)

Gebrekirstos et al. (2011) investigated the relationships between annual wood stable carbon isotope composition ($\delta^{13}C$), dry season midday plant water potential, and annual growth rate to assess the water use efficiency of agroforestry species. The results of the study revealed that species with lower mean $\delta^{13}C$ values showed high plant water potential and, hence, better growth during moist years. Thus, indicating low water use efficiency. On the other hand, species with lower water potentials showed relatively better growth performance and less increase in $\delta^{13}C$ in drought years, reflecting their high WUE and conservative water use strategy (Gebrekirstos et al., 2011).

2.2.13 Methods of determining biomass productivity

Standing dry matter, grain/straw yield, leaf area index, tree height and collar diameter are the most popular parameters measured when assessing the biomass productivity of AF systems.

Tree productivity can be determined by measuring height from ground level to tip of the youngest leaf at regular intervals, diameter at breast height (1.3 m), and measuring basal stem diameter just above the ground using Vernier calipers and a line painted on the stem as a reference point (Muthuri et al. 2005). Singh et al. (2004) measured tree height and collar diameter twice a year before crop sowing and after crop harvest. Tree biomass was determined by weighing fresh biomass and then oven drying samples at 80°C.

The crop growth analysis can make use of a combination of destructive measures and repetitive non-destructive measurements through the growth period for a sample of plants (for example smallest and largest basal stem diameter; height to tip of youngest leaf; height to the top of the canopy; and number of green, yellow and dead leaves). The destructive measures generally include measures of above-ground fresh and dry weights and leaf numbers at different intervals; and grain yield (dry weight), biomass (shoot dry weight) and cob number at maturity (Muthuri et al., 2005). The use of remote sensing to determine biomass productivity is another tool that could be considered under relevant contexts (Kumar and Muthanga, 2017).

2.2.14 Interactions and competition

In spite of all the benefits associated with agroforestry, competition between the crops and trees remains a challenge (Ong et al., 2006; Sun et al., 2008; Siriri et al., 2010 cited by Siriri, 2013). In the AF system there should be a better utilisation of resources such as light, water and nutrients, however, this can only happen if trees are complementary rather competitive with the associated crops (Ong et al., 2007). Cooper et al. (1996) suggests that spatial and temporal complementarity of trees and crops may minimize the competition. Spatial complementarity means the trees and crops would utilise different resource pools and temporal complementarity means trees and crops impose demands on available resources at different times (Black and Ong, 2000; Broadhead et al., 2003a, b; Ong et al., 2006 cited by Ong et al., 2007).

The main aim of agroforestry is to create interactions between woody perennials, herbaceous crops and pastures and their biotic and abiotic environments which improve the overall performance of the land use system and its sustainability (Schroth et al., 1995). These interactions are divided into two categories, i.e. aboveground and below ground interactions.

Above ground interactions

The introduction of trees in a natural or cultivated ecosystem has a number of other ecological impacts. Firstly, the canopy intercepts rainfall. In South Africa, recent measurement made by Bulcock and Jewitt (2012) in KwaZulu-Natal below different types of canopies shows the importance of water interception by the canopy (average of 15%) and by the litter (>7%) before its infiltration.

Furthermore, trees can modify the microclimatic conditions for understorey vegetation by reducing incident radiation, moderating the thermal environment and reducing the atmospheric saturation vapour pressure deficit thereby increasing growth (Ong et al., 2007). However, modifications such as shading (reduction of incident radiation due to the tree canopy) can actually reduce the yield of the understorey crop (Dufour et al., 2013). On the contrary, another study found that while the biomass production of grass declines when shaded by trees (in particular *Cenchrus ciliaris* growing under *Acacia tortilis*), the quality of the grass is improved through the accumulation of protein, starch, sugar and nitrogen (Mishra et al., 2010).

Mishra et al. (2010) also found that tree canopy of *A. tortilis* reduced the availability of photosynthetically active radiation (PAR) under the canopy, which lowered the temperature and raised the relative humidity. In combination these factors led to reduced evapo-transpiration, which resulted in increased soil moisture content. The canopy also resulted in an increase in height of the grass below, but was also associated with a decrease in the number of leaves and tillers per tuft, which reduced the leaf area index under the tree canopies. There was also an increase in the quantity of chlorophyll b, which is associated with shade-tolerant grasses (Mishra et al., 2010). Furthermore, the *C. ciliaris – A. tortilis* system showed higher soil moisture, organic carbon and available NPK under the tree canopy. It was determined that ≥55% PAR is required to obtain satisfactory biomass production (Mishra et al., 2010).

Some studies have shown that size of the tree crown rather than the density of the crown has a negative impact on above-ground net primary production of grass in an agroforestry system. Shading also resulted in a change in composition of the grassland, leading to a higher biomass of forbs, which are more tolerant of low levels of irradiance, having C_3 metabolism (Rusch et al., 2014).

In the Rusch et al. (2014) study, it seemed that in the seasonally-dry silvopastoral system in Central America, competition for light and not competition for water was the factor limiting grass biomass growth since the trees did not affect soil water content in the upper layers during the dry season.
Since evergreen trees have been to show to have more negative impacts on the understorey grasses than deciduous trees, the selection of trees for an agroforestry system is important (Rusch et al., 2014). Canopy pruning can ensure temporal complementarity between the trees and the understorey crop (Ghezehei et al. 2015). For example, in a Jatropha based system, the trees were pruned during a dry period and groundnuts were established in the alley. This actually improved the Jatropha growth by reducing weed competition (Ghezehei et al., 2015).

Below ground interactions

Below ground interactions can be facilitative, complementary or competitive. An example of a facilitative relationship is soil physical improvement or supply of hydraulically lifted water. Complementarity would be the case of trees using water that is below the rooting zone of the crop, while competitive interactions would be the case of trees using limited resources from the same pool as the crop (Fernandez et al., 2008).

Soil water content shows temporal and spatial variation as a result of the variability of soil properties and the existence of soil water sinks/sources (Beff et al., 2013). Ecohydrological processes in watersheds are tightly coupled with soil properties. For example, soil texture and soil depth control the available soil water, which in turn controls leaf area index (LAI), which increases under abundant soil moisture availability. The interactions between the spatial patterns of plant communities and soil patterns is recognised since plants are affected by soil moisture as well as nutrient availability and soil properties affect resource pools (Robinson et al., 2008).

Where subsoil conditions affect root penetration of the tree crop, there is greater competition with the crop for soil water. Furthermore, water balance simulations demonstrated that during dry periods when deeper soil layers are not recharged, there is more competition with the crop (Rethman et al., 2012). Competition for moisture, which generally is a problem close to the hedgerow of an alley cropping system, can result in severe reductions in crop yield. In fact yield reductions are mainly due to competition for water and under these conditions it is necessary to reduce the population of the tree species (Singh et al., 1989). However, Smith et al. (1999) noted that if the population is reduced in order to reduce their demand for water then this will diminish their benefits for nutrient cycling as well as their social and economic benefits. It is necessary to determine the optimum spacing where the benefits exceed the costs of competition.

Work done by Everson et al. (2009) in KwaZulu-Natal Province, South Africa explored soil-water competition in a hedgerow system using four tree species, namely Acacia karroo Hayne, *Leucaena leucocephala, Morus alba* and *Gleditsia triacanthos*. The area received good rainfall for the duration of the trial and the plants were not stressed (i.e. under these conditions the trees did not compete with the crop for water). Across all tree species, the soil water content in the upper 0.3 m did not differ significantly between the maize and tree rows so competition for water in the upper horizon was not responsible for the reduced maize yields. At greater soil depth, it was however clear that the trees with narrow spacing used more water than those at wider spacing. Light interception was also responsible for reducing maize yields in the line closest to the tree row – this might call for a wider gap between the tree and row and the first line of the crop. Everson et al. (2009) also mentioned that other authors are suggesting that in water-limited environments spatial complementarity may be limited to situations where the tree crop has access to deeper ground water reserves.

Generally it is understood that trees with few superficial lateral roots are more suited to AF as they will compete less with the crop, but a study of a *Grevillea robusta*-maize system in a semi-arid region (with annual rainfall 782 mm) revealed that there was no spatial separation of the two root systems and therefore there was still competition for water. In short there needs to be sufficient rainfall to allow for recharge of the soil below the rooting zone of the crop if complementary water use is to occur (Smith et al., 1999). Smith et al. (1999) found that when low rainfall was experienced, the length of maize roots was reduced by the inclusion of trees, but was not affected by proximity to the trees. When the rains were good and the trees were severely pruned then the tree roots did not have this effect. Complementarity between trees and crops in the AF system is most likely to be achieved when the trees have access to an alternative source of water (Smith et al., 1999). Alternatively, there needs to be sufficient drainage for large quantities of water to be stored beyond the root zone of the crop, but this is potentially not likely in semi-arid areas (Smith et al., 1999 cited Van Noordwijk et al., 1996).

Lehmann et al. (1998) investigated the effects of intercropping *Acacia saligna* and sorghum (4 m alley width) in a part of Kenya with an annual rainfall of 318 mm. The authors explored the effect on root distribution of the two components. Comparing alley cropping with sole cropping, it was found that the sorghum had more roots in the topsoil while the trees had more roots in the subsoil. Soil water depletion was higher under the tree row than in the alley. It was concluded that the alley cropping arrangement made more efficient use of the soil water between the hedgerows because the trees' roots could reach deeper while the sorghum was able to use topsoil water better (i.e. the trees made use of different root zones). Lehmann et al. (1998) found that the sorghum roots actually invaded into the main root zone of the trees. They suggested that this was due to greater N availability under the trees which may have stimulated root production of the sorghum – or the trees could have provided hydraulic lift and supplied water to the annual crop. The phenomenon of hydraulic lift was proposed as a possibility by Fernandez et al. (2008) considering an agroforestry system combining ponderosa pine trees and a Patagonian grass in a temperate semi-arid area. Evidence of hydraulic lift is the detection of reverse fluxes in roots during the night (Fernandez et al., 2008; Ludwig et al., 2003).

The impact on trees on soil microbial activity must also be considered. The extent will depend on the presence of nitrogen (especially through inputs of nitrogen-fixing legumes), soil temperature and water content (Kambakatu et al., 2013b). Gargaglione et al. (2014) in south Patagonia investigated tree-grass interactions for nitrogen (in particular facilitation from trees to the grass component). With N fertilizer application, the integration of trees into the grass pasture resulted in substantially greater N uptake by the grass. This was thought to be due to their improvement of water availability or by reducing competition for inorganic N between soil microbes and plants. The grass biomass was however negatively affected by the inclusion of trees possibly as a result of shading.

2.2.15 Modelling of agroforestry systems

Modelling is an important tool in research as it can be used to predict the future behaviour of vegetation under changing climatic or land use management practices (Ong et al., 2007). AF research is very time consuming as the trees take a long time to develop and actually display their impact in a system. Therefore modelling approaches may provide substantial time and financial savings when compared with field experiments (Ong et al., 2007). In addition, modelling of the physics of soil-plant-water interactions, allows for optimising spacing of trees and crops prior to establishment, given the soil, vegetation and climate conditions (Schlegel, et al., 2004; Cannavoa, et al., 2011). Models allow for the assessment of the distribution of water below surface in slopes terrains, so that agroforestry can be utilised effectively (Thompson, 2003; Ellis et al., 2006; Van Noordwijk et al., 2012). Physically based models can also be used in conjunction with decision support algorithms to provide optimised scenarios for physical, social and biological interactions. Indeed, these decision support algorithms have been used to design agroforestry systems to mimic pre-development, natural water cycles (Leroy et al., 1999; Leroy and Stirzaker, 1999; Hatton and Nulsen, 1999; Ewel, 1999; Ong and Leakey, 1999; Ellis, et al., 2004; García-Barrios and Ong, 2004).

The WaNuLCAS (water, nutrient and light capture in agroforestry) has been widely used by many researchers due to its nature. This model can be applied in different AF systems (simultaneous or sequential). Van Noordwijk et al. (2004) recommended this model to researchers who want to explore the continuum of options extending from improved fallows, through relay-planting of trees to rotational and simultaneous hedgerow intercropping. Furthermore, the model captures sufficient detail in simplistic algorithms so that specific scenarios can be assessed (Van Noordwijk et al., 2004 cited by Ong et al., 2007).

There are many other models used in AF research. For example, Dufour et al (2013) used a crop model called Simulateur mulTIdiscplinaire pour les Cultures Standard STICS to simulate crop productivity in full light and shade conditions to determine the effect of shading. The model showed that the wheat has critical periods when it requires light (specifically 30 days before flowering). Keesman et al. (2007) used a minimal mechanistic model describing the system dynamics to analyse the yield and land equivalent ratio (LER) of a silvopastoral AF system. LER is a measure of the productivity of a mixed cropping system. The model requires the following inputs: temperature, radiation, planting densities, initial biomass of tree and crop species and growth parameters. The model is able to describe temporal dynamics of tree biomass, tree leaf area, number of leaf shoots/tree, crop biomass, crop leaf area index and heat sum. This model requires that the system is under optimum crop management. Van der Werf et al (2007) developed a model known as Yield-SAFE (Yield estimator for long-term design of silvo-arable agroforestry in Europe). The model is suitable for use with long-term experiments where data availability is constrained. It is able to express the temporal dynamics of tree biomass; tree leaf area; number of shoots per tree; crop biomass; crop leaf area index; heat sum; and soil water content, while the main outputs are growth dynamics and final yields of trees and crops. The model requires that temperature, radiation and precipitation is inputted daily and planting densities, initial biomasses of trees and crops and soil parameters be specified. Huth et al. (2003) applied the Agricultural Production Systems Simulator (APSIM) to agroforestry systems to quantify the potential benefits and risks of incorporating trees as windbreaks within cropping systems. Thus it is able to quantify the economic trade-offs of this practice. More detailed, physically based models (e.g. HYDRUS2D/3D), have been used to assess the impacts of spacing and intercropping details on the water regime. Schlegel et al. (2004) used HYDRUS2D to evaluate the spacing effects on root zone water dynamics in an Amazonian AF system. They showed that the spacing as well as the root depth needs to be taken into account and point out that these considerations a likely to be more important in drier climates. HYDRUS2D has also been used effectively to derive trees spacing on a hillslope in order to optimise salinity and recharge control (Thompson, 2003).

This provides an indication of the range of models that different studies have used to better understand, design and predict AF systems.

2.2.16 Factors hindering adoption of agroforestry practices

Despite wide range of benefits AF systems can provide, adoption of this technology is still very low in some regions. The low adoption of AF technology is attributed to several barriers or challenges associated with it. Research studies have documented various factors which hinders the adoption of AF technologies. This section provides a summary of the potential barriers for adoption and upscaling of AF practices as identified in available literature. These factors are categorised as technical and non-technical and are discussed below.

Technology related barriers

Adoption of any technology comes with challenges which most of them are often directly linked to the changes which come with the technology (Wambugu et al., 2011). Kalaba et al. (2010) described the nature of AF practices as complex and knowledge-intensive, while Ajayi et al. (2003) and Wambugu et al. (2011) highlighted the long timeframes required for testing, modification and adoption of AF practices as the major challenge for up-scaling AF practices. Other authors have highlighted that most of the tree species used in agroforestry are invasive in nature – this is discussed further in the next sub-section. Ajayi et al. (2007) also highlighted soil type and management regime as technology-related barriers for adoption of AF practices. In most case, farmers are reluctant to adopt AF technologies mainly due to their complexity (Kabela et al., 2007) and the fact that propagation, management and harvesting takes place throughout the year (Wambugu et al., 2011).

In Eastern Cape Province of South Africa, a study by Zerihun et al. (2014) identified several key factors which hinder the adoption of AF practices among smallholder farming communities. Such factors include level of education, farmers' perception towards the technology and land tenure. Some of the factors are site-specific while others are commonly observed at different geographic areas.
Most of the challenges identified in available literature (Ajayi et al., 2007; McGinty et al., 2008; Chitakari and Torquebiau, 2010) are related to unavailability of resources required for successful adoption of AF practices. Such resources include:

- Availability of good quality seed
- Availability of high-quality germplasm
- Lack of fencing material – In Zimbabwe and Mozambique, the lack of fencing material to protect the crops and trees appeared to be the major challenge (Chitakari and Torquebiau, 2010)

- Lack of external financial and technical support – a study by McGinty et al. (2008) in Brazil and Chitakari and Torquebiau (2010) in Zimbabwe revealed that successful adoption of agroforestry cannot be achieved without external financial and technical support
- Land tenure – Authors (Chitakari and Torquebiau 2010; Mbow et al., 2014) considered AF (tree planting) as a long term investment which might be only appealing to famers secured land tenure. According to Chitakari and Torquebiau (2010) "lack of clearly defined land tenure weakens incentives for long-term investments in land to raise its productivity".

Plants with invasive characteristics

Several studies (Sharma, undated; Blanchard, 2011; Richardson et al., 2003) have highlighted the invasive characteristics of the trees and shrubs used in agroforestry as a major challenge for adoption of agroforestry technology. Not only are some of the exotic species such as Prosopis juliflora becoming invasive (Blanchard, 2011; Richardson et al., 2003), but others are proving to be economically unproductive (e.g. Faederbia *albida, Jojaba*) (Sharma, undated). The invasive nature of the trees and shrubs used in agroforestry is considered one of the reasons for the AF's lagging behind and urgent strategies to deal with this problem are needed (Richardson et al., 2003).

Access to planting material

Lack of access to good quality seed has been identified as a major challenge for up scaling of AF practice in Zimbabwe (Chitakira and Torquebiau, 2012) Malawi (Nyoka et al., 2011) and Tanzania (Reyes et al., 2008). Unavailability of seeds has led to lack of high-quality AF tree germplasm which has long been recognised as a major challenge to widespread of AF in Southern Africa (Nyoka et al., 2011; Place et al., 2012). Low tree growth and productivity are often associated with lack of access to better quality germplasm (Place et al., 2012). According to Nyoka et al. (2011) "successful adoption of agroforestry hinges on the development of a sustainable agroforestry tree germplasm supply system".

Non-technical barriers

Skill requirements

As highlighted by Kabela et al. (2010), AF is a knowledge-intensive technology. Farmers' level of education, which influences their perception of the technology, has also being highlighted as an obstacle for the adoption of AF practices. A study by Zerihun et al. (2014) in South Africa revealed that low level of education in smallholder farming communities is indeed one of the obstacles for adoption of AF technology.

Policy requirements for agroforestry

Policy appears to play an important component of promotion of agricultural technologies. Wide adoption of AF lies in the implementation of policies which are supportive of the integration of trees with crops and livestock (Mbow et al., 2014). The international agenda on the mitigation of climate change has provided policy-related opportunities for agroforestry (Mbow et al., 2014). It is evident that countries which have benefited greatly from AF are those that have policies which support and promote AF (Place et al., 2012).

In the context of South Africa, there is no clear policy which directly supports or promotes AF technology. However, the national strategic plan has prioritised forestry and natural resource management which are features of agroforestry (Muchara et al., 2015). Even though the national strategic plan does not speak directly to adoption of AF, several AF initiatives have received national attention from government. Agroforestry research in South Africa date three decades back and recent initiatives have potential to inform policy regarding AF in the country. According to Mbow et al. (2014) policies that institutionally segregate forestry from agriculture miss opportunities for synergy at landscape scale. In South Africa the merger of forestry, agriculture and fisheries into the Ministry of Agriculture, Forestry and Fisheries (AFF) in 2009 seems to bode well for AF in South Africa. A transdisciplinary approach to land use is currently being mooted as a solution to these problems, one focusing upon the principles and process of *agroforestry (*Underwood and Mack, 2010)*.*

Governance

Agroforestry has what Place et al. (2012) described as an "orphan" status in much government setting because in principle it belongs to many ministries or departments but in practice it belongs to none. It is promoted for various purposes which are not address by a single department such as being a runoff and erosion reduction practise, which is of interest to Department of Environmental Affairs, while as practise that optimises land productivity; it is of interest to departments of agriculture (Zerihun et al., 2014). In general, institutional arrangements which could give AF a "home" and support its promotion are needed for up scaling the adoption of AF.

Gender and agroforestry

Results show that both male and female headed households can adopt the technology (Thangata et al., 2007). Furthermore, women are as actively involved as men; however in many areas, their level of participation and benefits are constrained by cultural norms and a lack of resources (Kiptot et al., 2014). Quite often men get privileges which most women do not have.

A survey study a carried out by in Croppenstedt et al. (2013) in 16 African countries revealed that women are as likely to own land as men in 37% of the surveyed countries and only 2% of women have land titles. Case studies in Uganda, Burundi and Zambia established that regardless of the overall land security of farming households, women's rights to land and trees are always inferior to those of males (Place, 1995 cited in Place et al., 2012).

Generally, in Southern Africa, women have less access to productive resources and opportunities such education, land, labour, extension, financial service and technology (Zerihun et al., 2013; Kiptot et al., 2014). Considering that most of the African small farming families are headed by women, the adoption of AF will prove difficult in most regions.

Requirements for upscaling and adoption

Kwesiga et al. (2003) highlighted that effective partnerships among farmers, individuals and organisations are critical for success in scaling up AF practices. Collaboration of ICRAF with universities, colleges and schools in Southern Africa has built capacity in future researchers and extension agents. ICRAF has also recognised the need to enhance farmers' ability to observe, adapt and innovate and their local knowledge of agronomic practices and their ecosystems is recognised.

Research is needed so that strategies can respond to projected changes in opportunities for AF in Southern Africa. For example, strategies need to aim to:

- Improve marketing and processing of AF products
- Diversification of AF products and by-products
- Development and promotion of cost-effective substitutes for external inputs
- Options for mitigating environmental degradation and biodiversity losses
- Mechanisms for AF to address discussion on global warming
- Strategies for dissemination and capacity-building among stakeholders
- Improve collaboration between a broad range of actors.

As a solution to challenges adoption of AF, Coe et al. (2014) considered factors that will lead to successful scaling up of AF practices. They suggest that technologies need to address localised variation in the social, economic and ecological context. The authors also suggest that the users need to be involved in the co-development of new technologies and systems. They also highlight that effective delivery mechanisms and functioning markets are essential for scaling up AF practices – as well as a supportive policy and institutional environment. If AF systems are to be promoted as a form of "clean production", then the commitment of all stakeholders associated with the development of national policy needs to be achieved (Nahed-Toral et al., 2013).

2.3 Review of other agroforestry initiatives in South Africa

There have been a number of AF research and implementation initiatives which have tested and evaluated the feasibility or potential of AF, particularly for smallholder farming communities. This section provides a summary of some of the AF research initiatives in South Africa and also highlights their current status.

2.3.1 Case 1: INR/Goldfields/Southern African Nature Foundation Agroforestry project

The Institute of Natural Resources (INR) evaluated the AF implementation through a project which was run between 1992 and 1995 KwaZulu-Natal Province. This project was a continuation of an agroforestry research project which was initiated in 1986 and ended in 1991. Demonstration sites for this phase were at established at Nansindlela Training Centre near Inchanga and the Biyela community near Eshowe. Through this project, AF systems including fodder banks, fodder trees, arable land, vegetation-mulch gardens, barrier ridges, trees for poles, scattered trees in pasture and medicinal trees were implemented. These programmes were planned specifically for smallholder farmers and were believed to have a potential to improve the livelihoods of small-scale famers and gardeners in KwaZulu-Natal. Recently, the INR has visited the demonstration sites at Nansindlela and Biyela to see their current states and the outcome are reported below.

The Nansindlela Training Centre is no longer in operation and the area is unmaintained. The fences are no longer intact and livestock from the surrounding area have had access to the site. The leucaena woodlot still exists, though local community members have been harvesting poles. Some trees are still in place. A number of rows of different agroforestry species were established at the site but the only ones remaining are various Leucaena species. This highlights that the other species such as *Sesbania sesban*, have not persisted in the long term. Where the leucaena was established on contours, it has become tall and infested with other aliens, lantana in particular. There has been some germination and spread of leucaena to adjacent areas but the plants show evidence of having been browsed by livestock and have not been able to grow into trees. It would make an interesting study to determine the full extent that the leucaena (and other species) have spread from the original sites where they were planted

2.3.2 Case 2: Maize and Pigeon pea Intercropping Systems in Mpumalanga, South Africa

A Study by Mathews et al. (2001) in Mpumalanga Province, South Africa evaluated the performance of pigeon pea (*Cajanus Cajun*) cultivars with varying maturity periods with maize (*Zea mays*) in two intercropping systems. The trails were conducted in smallholder-farmers crop production systems as intercropping was an important aspect of this system. The results of this study indicated significant reduction in yield for both pigeon pea and maize under intercropping systems compared to monoculture systems. However, considering that pigeon pea and maize were most adopted intercropping Mathews et al. (2001) claimed intercropping of these two crops to be a good practise towards improving productivity is smallholder farming systems.

2.3.3 Case 3: Investigation of the potential of agroforestry in conservation of high value indigenous trees in the Eastern Cape

Mokulwe (1999) carried out research in the Umzimvubu District, Eastern Cape to examine the potential of agroforestry to address the following issues:

- Optimisation of land productivity
- Reduction in pressure on the indigenous forest
- Ensuring a sustainable supply of desired tree products and services
- Improving quality of life of the resource-poor rural households.

Several conclusions were drawn from this study which include that smallholders farmers were unknowingly practicing alley cropping AF system in the Umzimvubu District and that it does have a potential to reduce pressure on the indigenous forest.

In summary, despite numerous AF initiatives being started in South Africa, adoption of AF remains relatively low. The current situation at Nansindlela and Biyela appears to be an indication of a lack of knowledge transfer as the AF projects have left limited evidence on the ground. This confirms the remarks made by McGinty et al. (2008) and Chitakari and Torquebiau (2010) that the success of AF cannot be achieved without timely external financial and technical support.

2.4 Conclusion

The main conclusions from this literature review is that AF systems have the potential to improve fodder production and crop production, provide products such as fuelwood and ultimately improve food security and household nutrition. The interactions that exist between different components of the system, being both positive and negative have to be recognised. A key basis for promoting AF is the concept of the different components of the system using different pools of resources, especially water and soil nutrients, but this is frequently not the case and must be taken into account when designing spatial and temporal arrangements.

While much work has being done in the rest of Southern Africa, AF work in South Africa is fairly limited, with very little evidence of initiatives outside of those funded through the Water Research Commission. The current study provides an opportunity to build on previous work in South Africa, drawing on knowledge and experiences from outside of the country.

It is also clear from the literature that the outscaling and adoption of AF systems will require that the correct policy environment be in place. This will call for greater advocacy and policy engagement to ensure that AF is seen as set of practices that can improve food security and income generation for smallholder farmers engaging in crop and or livestock production.

2.5 References

Adinya, I.B., Enun, E.E. and Ijoma, J.U., 2010. Exploring profitability potentials in groundnut (arachis hypogaea) production through agroforestry practices: a case study in Nigeria. The Journal of Animal & Plant Sciences, 20(2): 123-131.

Ajayi, O.C., Akinnifesi, F.K., Gudeta, S. and Chakeredza, S., 2007. Adoption of Renewable Soil Fertility Replenishment Technologies in Southern African Region: Lessons Learnt and the Way Forward. Natural Resource Forum 31 (4): 306-317.

Ajayi, O.C., Franzel, S., Kuntashula, E. and Kwesiga, F., 2003. Adoption of improved fallow soil fertility management practices in Zambia: synthesis and emerging issues. Agroforestry systems 59 (3): 317-26.

Ajayi, O.C., Place, F., Akinnifesi, F.K. and Sileshi, G.W., 2011. Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). International journal of agricultural sustainability, 9(1): 129-136.

Akinnifesi, F.K., Kwesiga, F.R., Mhango, J., Chilanga, T., Mkonda, A., Kadu, C.A.C., Kadzere, I., Mithofer, D., Saka, J.D.K., Sileshi, G., Ramadhani, T. and Dhliwayo, P., 2006. Towards the development of Miombo fruit trees as commercial tree crops in southern Africa. Forests, Trees and Livelihoods 16: 103-121.

Akinnifesi, F.K., Sileshi, G., Ajayi, O.C., Chirwa, P.W., Kwesiga, F. and Harawa, R., 2008. Contributions of agroforestry research and development to livelihood of smallholder farmers in Southern Africa: 2. Fruit, medicinal, fuelwood and fodder tree systems. Agricultural Journal 3 (1): 76-88.

Anderson S.H., Udawatta, R.P., Seobi, T. and Garrett, H.E., 2009. Soil water content and infiltration in agroforestry buffer strips. *Agroforest Syst.* 75: 5-16.

Asaah, E.K., Tchoundjeu, Z., Leakey, R.R., Takousting, B., Njong, J. and Edang, I., 2011. Trees, agroforestry and multifunctional agriculture in Cameroon. *International Journal of Agricultural Sustainability*, *9*(1): 110-119.

Asbjornsen, H., Goldsmith, G.R., Alvarado-Barrientos, M.S., Rebel, K, Van Osch FP, Rietkerk M, Chen J, Gotsch S, Tobo'n C, Geisert DR, Gomez-Tagle, A., Vache, K. and Dawso, T.E. 2011. Ecohydrological advances and applications in plant-water relations research: a review. Journal of Plant Ecology, Vol 4, No 1-2: 3-22.

Assmo, P. and Ericksson, A., 1999. Soil Conservation in Arusha Region, Tanzania. Regional Land Maangement Unit, Nairobi, Kenya, 99 p.

Bayala, J., Ouedraogo, S.J. and Teklehaimanot, Z., 2008. Rejuvenating trees in agroforestry systems for better fruit production using crown pruning. *Agroforestry Systems* 72:187-194, ISSN 0167-4366

Beff L, Gunther T, Vandoorne B, Couvreur V and Javaux M. 2013. Three-dimensional monitoring of soil water content in a maize field using electrical resistivity tomography. Hydrology and Earth System Sciences 17, 595-609.

Bharati, L., Lee, K.H., Isenhart, T.M. and Schultz, R.C., 2002. Soil-water infiltration under crops, pasture, and established riparian buffer in Midwest USA. *Agrofor Syst* 56: 249-257.

Black, C.R. and Ong, C.K., 2000. Utilisation of light and water in tropical agriculture. *Agric. For. Meteorol.* 104: 25-47.

Bouma, J., 1980. Field measurement of soil hydraulic properties characterizing water movement through swelling clay soils. *J Hydrol* 45: 149-158.

Broadhead, J.S., Black, C.R. and Ong, C.K., 2003b. Tree leafing phenology and crop growth in semi-arid agroforestry systems. *Agroforestr Systems* 58: 137-148.

Broadhead, J.S., Ong, C.K. and Black, C.R., 2003a. Tree phenology and soil water in semi-arid agroforestry systems. *Forest Ecology and Management* 180: 61-73.

Bulcock H. H. and G. P. W. Jewitt, 2012. Field data collection and analysis of canopy and litter interception in commercial forest plantations in the KwaZulu-Natal Midlands, South Africa Hydrol. Earth Syst. Sci., 16, 3717-3728.

Cadisch, G., De Willigen, P., Suprayogo, D., Mobbs, D.C., Van Noordwijk, M. and Rowe, E.C., 2004. Catching and competing for mobile nutrients in soils. In: Van Noordwijk, M., Cadisch, G., Ong, C.K. (eds) Below-ground interactions in tropical agroecosystems. CABI Publishing, MA, USA, pp 171-191.

Cai, X., Rosegrant, M., 2003. Water Productivity in Agriculture. In: Kijne, J.W., Barker, R., Molden, D. (eds) Limits and Opportunities for Improvements. (CABIInternational, Cambridge, MA), pp 163-178.

Campbell, B.M., 1987. The use of wild fruits in Zimbabwe. Economic Botany 41:375-385.

Cannavoa, P., Sansouletb, J., Harmanda, J-M., Siles, P., Dreyerd, E. and Vaast, P., 2011. Agroforestry associating coffee and Inga densiflora results in complementarity for water uptake and decreases deep drainage in Costa Rica. *Agriculture, Ecosystems and Environment*. 140:1-13.

Chesney, P.E.K., (2012). Shoot pruning and impact on functional equilibrium between shoots and Roots in simultaneous agroforestry systems. www.intechopen.com

Chirwa, P.W. and Quinion, A.F., 2012. Impact of soil fertility replenishment agroforestry technology adoption on the livelihoods and food security of smallholder farmers in central and southern Malawi. INTECH Open Access Publisher

Chitakira, M. and Torquebiau, E., 2010. Barriers and coping mechanisms relating to agroforestry adoption by smallholder farmers in Zimbabwe. Journal of Agricultural Education and Extension, 16(2): 147-160.

Coe, R., Sinclair, F. and Barrios, E., 2014. Scaling up agroforestry requires research 'in' rather than 'for' development. Current Opinion in Environmental Sustainability, 6: 73-77.

Cooper, P. J.M., Leakey, R.R.B., Rao, M.R. and Reynolds, L., 1996. Agroforestry and the mitigation of land degradation in the humid and sub humid tropics of Africa. *Experimental Agriculture* 32: 235-290.

Dillaha, T.A., Reneau, R.B., Mostaghimi, S. and Lee, D., 1989. Vegetative filter strips for agricultural nonpoint-source pollution control. *Trans ASAE* 32: 513-519.

Dufour, L. Metay, A., Talbot, G. and Dupraz, C., 2013. Assessing light competition for cereal production in temperate agroforestry systems using experimentation and crop modelling. *Journal of Agronomy Crop Science* 199: 217-227.

Dye, P.J., Jarmain, C., le Maitre, D., Everson, C.S., Gush, M. and Clulow, A. 2008. Modelling vegetation water use for general application in different categories of vegetation. WRC REPORT NO 1319/1/08

Ellis, E.A., Bentrup, G. and Schoeneberger, M.M., 2004. Computer-based tools for decision support in agroforestry: Current state and future needs. *Agroforestry Systems* 61:401-421.

Ellis, T.W., Leguédois, S., Hairsine, P.B. and Tongway, D.J., 2006. Capture of overland flow by a tree belt on a pastured hillslope in south-eastern Australia. *Aus. J. Soil Research*. 44(2):117-125.

Everson, C.S., 2009. The effect of the introduction of agroforestry species on the soil moisture regime of traditional cropping systems in rural areas. Phase II: on farm trials of alternative agroforestry systems. Annual Progress Report for WRC Project No. K5/1351, 5 March 2009. Water Research Commission, Pretoria, South Africa

Everson, C.S., Dye, P.J., Gush, M.B. and Everson, T.M. 2011. Water use of grasslands, agroforestry systems and indigenous forests. Water SA Vol. 37 No. 5 WRC 40-Year Celebration Special Edition 2011. ISSN 0378-4738.

Everson, C.S., Everson, T.M., Van Niekerk, W. and Von Maltitz, G. 2002. The effect of the introduction of agroforestry species on the soil moisture regime of traditional cropping systems in rural areas. WRC Report No 780/1/02. ISBN No. 1 86845 947 0.

Everson, C.S., Ghezehei, S.B., Everson, T.M. and Annandale, J. 2012a. Agroforestry systems for improved productivity through the efficient use of water. WRC Report No. 1480/1/12. ISBN 978-1-4312-0261-4

Everson, C.S., Mthembu, B.E. and Everson, T.M. 2012b. Effect of agroforestry and intercropping systems on fodder production in rural areas in South Africa. WRC Report No. 1351/1/12. ISBN 978-1-4312-0258-0.

Everson, C.S., Everson, T.M. and Van Niekerk, W., 2009. Soil water competition in a temperate hedgerow agroforestry system in South Africa. *Journal of Agro Systems* 75: 211-222.

Ewel, J.J., 1999. Natural systems as models for the design of sustainable systems of land use. *Agroforestry Systems* 45: 1-21.

Fernández, M.E., Gyenge, J., Licata, J., Schlichter, T., Bond, B.J., 2008. Belowground interactions for water between trees and grasses in a temperate semiarid agroforestry system. *Agroforest Syst* 74: 185-197.

Franzel, S., Denning, G.L., Lilleso, J.P.B. And Mercado Jr, A.R., 2004. Scaling up the impact of agroforestry: lessons from three sites in Africa and Asia. Agroforestry System 61:329-344.

García-Barrios, L. and Ong, C.K., 2004. Ecological interactions, management lessons and design tools in tropical agroforestry systems. *Agroforestry Systems* 61:221-236.

Gargaglione, V., Peri P.L., Rubio, G., 2014. Tree-grass interactions for N in Nothofagus Antarctica silvopastoral systems: evidence of facilitation from trees to underneath grasses. *Agroforest Syst* 88: 779-790.

Gebrekirstos, A., Van Noordwijk, M., Neufeldt, H. and Mitlo¨hner R., 2011. Relationships of stable carbon isotopes, plant water potential and growth: an approach to assess water use efficiency and growth strategies of dry land agroforestry species. Trees 25: 95-102, DOI 10.1007/s00468-010-0467-0

Ghezehei, S.B., Everson, C.S. and Annandale, J.G. Can productivity and post-pruning growth of Jatropha curcas in silvopastoral systems be regulated by manipulating tree spacing/ arrangement without changing tree density? *Biomass and bioenergy* 74: 233-243.

Green, G.C., Day, J.A., Mitchell, S.A., Palmer, C., Laker, M.C. and Buckley, C.A., 2011. Water use efficiency. *Water SA* 37(5): 609-618.

Hatton, T.J. and Nulsen, R.A., 1999. Towards achieving functional ecosystem mimicry with respect to water cycling in southern Australian agriculture. *Agroforestry Systems* 45:203-214.

Huth, N.I., Carberry, P.S., Poulton, P.L., Brennan, L.E. and Keating B.A., 2003. A framework for simulating agroforestry options for the low rainfall areas of Australia using APSIM Europ. *J. Agronomy 18: 171-185*

Igbadun, H.E., Mahoo, H.F., Tarimo, A.K.P.R. and Salim, B., 2005. *Trends of productivity of water in rain-fed agriculture: historical perspectives.* Columbo, Sri Lanka: IWMI.
ISBN 978-1-77005-559-9.

Jama, B. and Zeila, A., 2005. Agroforestry in the drylands of eastern Africa: a call to action. ICRAF Working Paper no. 1. Nairobi: World Agroforestry Centre.

Jamison, V.C. and Peters, D.B., 1967. Slope length of claypan soil affects runoff. *Water Resour Res* 3: 471-480.

Jamnadass, R.H., Dawson, I.K., Franzel, S., Leakey, R.R.B., Mithöfer, D., Akinnifesi, F.K. and Tchoundjeu, Z., 2011. Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. International Forestry Review, 13(3): 338-354.

Kalaba, K.F., Chirwa, P., Syampungani, S. and Ajayi, C.O., 2010. Contribution of agroforestry to biodiversity and livelihoods improvement in rural communities of Southern African regions. In Tropical rainforests and agroforests under global change (pp. 461-476). Springer Berlin Heidelberg.

Kambatuku, J.R. Cramer, M.D., Ward, D., 2013b. Nitrogen fertilisation reduces grass-induced N2 fixation of tree seedlings of semi-arid savannas. Plant and Soil 365, 307-320.

Kang, B.T. and Akinnifesi, F.K., 2000. Agroforestry alternative land-use production systems for the tropics. *Nat. Res. Forum* 24: 137-151

Keesman, K.J., Van der Werf, W. and Van Keulen, H., 2007. Production ecology of agroforestry systems: A minimal mechanistic model and analytical derivation of the land equivalent ratio. *Mathematical Biosciences 209: 608-623*

Kiptot, E., Franzel, S. and Degrande, A., 2014. Gender, agroforestry and food security in Africa. *Current Opinion in Environmental Sustainability*, 6: 104-109.

Kumar, L. and Mutanga, O. 2017. Remote Sensing of Above-Ground Biomass. Remote Sensing 9(9): 935.

Kwesiga, FR., Franzel, S., Place, F., Phiri, D. and Simwanza CP., 1999. Sesbania sesban improved fallows in eastern Zambia: their inception, development and farmer enthusiasm. *Agroforestry Syst*, 47:49-66.

Kwesiga, F. and Coe R., 1994. The effect of short rotation Sesbania sesban planted fallows on maize yield. *For Ecol Manage* 64:199-208.

Lamb, D. and Borschmann, G., 1998. Agroforestry with high value trees. Rural Industries Research and Development Corporation RIRDC Publication No 98/142.

Leakey, R.R.B., Tchoundjeu, Z., Schreckenberg, K., Shackleton, S.E., Shackleton, C.M., 2005. Agroforestry Tree Products (AFTPs): Targeting poverty reduction and enhanced livelihoods. *International Journal of Agricultural Sustainability* 3: 1-23.

Lefroy, E.C. and Stirzaker, R.J. 1999. Agroforestry for water management in the cropping zone of southern Australia. *Agroforestry Systems* 45:277-302.

Lefroy, E.C., Hobbs, R.J., O'Connor, MH. And Pate, JS. 1999. What can agriculture learn from natural ecosystems? *Agroforesty Systems* 45:423-436.

Lehmann, J.P.I., Steglich, C., Gebauer, G., Huwe, B. and Zech, W., 1998. Below-ground interactions in dryland agroforestry. *Forest Ecology and Management* 111: 157-169.

Livesley, P S., Gregory, J. and Buresh, R.J., 2004. Competition in tree row agroforestry systems. 3. Soil water distribution and dynamics. J. of Plant and Soil 264: 129-139.

Lott, J.E., Khan, A.A.H., Black, C.R. and Ong, C.K., 2003. Water use in a Grevillea robusta-maize overstorey agroforestry system in semi-arid Kenya. *Forest Ecology and Management* 180: 45-59.

Ludwig, F., Dawson, T.E., De Kroon, H., Berendse, F., Prins, H.H.T., 2003. Hydraulic lift in Acacia tortilis trees on an East African savanna. Oecologia 134, 293-300.

Mafongoya, P.L., Bationo, A., Kihara, J. and Waswa, B.S., 2006. Appropriate technologies to replenish soil fertility in southern Africa. In Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities (pp. 29-43). Springer Netherlands.

Mbow, C., Smith, P., Skole, D., Duguma, L. and Bustamante, M., 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current Opinion in Environmental Sustainability*, *6*: 8-14.

McAdam, J.H., Burgess, P.J., Grave, A.R., Rigueiro-Rodriguez, A. and Mosquera-Lasada, M.R., 2009. Classification of Agroforestry systems in Europe.

McDicken, K.G. and Vergara, N.T., 1990. Introduction of agroforestry. In: McDicken, K.G. and Vergara, N.T. (eds) 1990. Agroforestry: classification and management. John Wiley and Sons, Inc., New York, pp 1-30.

Mishra, A.K., Tiwari, H.S. and Bhatt, R.K., 2010. Growth, biomass production and photosynthesis of Cenchrus ciliaris L. under Acacia tortilis (Forssk.) Hayne based silvopastoral systems in semi-arid tropics. *Journal of Environmental Biology* 31(6): 987-993.

Molden, D., Oweis, T., Pasquale, S., Kijne, J,. Hanjra, A., Bindraban, P., Bouman, B., Erenstein, T., Farahani, O., Hachum, H., Hoogeveen, H., Mahoo, J., Nangia, H., Peden, V., Sikka, D., Silva, A., Turral, P., Upadhyaya, H. and Zwart, S., 2007. Pathways for increasing agricultural water productivity. In Molden, D. (ed.) *Water for food, water for life: a comprehensive assessment of water management in agriculture*. London: Earthscan; Colombo, Sri Lanka: IWMI.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. and Kijne, J., 2010. Improving agricultural water productivity: between optimism and caution. *Agricultural Water Management* 97: 528-535.

Mukolwe, M., 1999. The potential of agroforestry in the conservation of high value indigenous trees a case study of umzimvubu district Eastern Cape (Doctoral dissertation, University of Natal).

Muthuri a, C.W. Ong, C.K., Black C.R., Ngumi, V.W. and Mati, B.M., 2005. Tree and crop productivity in Grevillea, Alnus and Paulownia-based agroforestry systems in semi-arid Kenya. *Forest Ecology and Management* 212: 23-39.

Neupane, R.P. and Thapa, G.B., 2001. Impact of agroforestry intervention on soil fertility in farm income under the subsistence farming system of the middle his, Nepal. *Agriculture, Ecosystems and Environment* 84(2): 157-167.

Neupane, R.P., Sharma, K.R. and Thapa, G.B., 2002. Adoption of agroforestry in the hills of Nepal: a logistic regression analysis. *Agricultural systems* 72(3): 177-196.

Nyoka, B.I., Mng'omba, S.A., Akinnifesi, F.K., Ajayi, O.C., Sileshi, G. and Jamnadass, R., 2011. Agroforestry tree seed production and supply systems in Malawi. *Small-Scale Forestry*, 10(4): 419-434.

Ofori, D.A., Gyau, A., Dawson, I.K., Asaah, E., Tchoundjeu, Z. and Jamnadass, R., 2014. Developing more productive African agroforestry systems and improving food and nutritional security through tree domestication. *Current Opinion in Environmental Sustainability*, *6*: 123-127.

Ong CK, Black CR, Marshall FM, Corlett JE (1996) Principles of resource capture and utilization of light and water. In: Ong CK, Huxley PA (eds) Tree-crop interactions in agroforestry systems: A physiological approach. CAB International, Wallingford, pp 73-158

Ong, C.K. and Leakey, R.R.B., 1999. Why tree-crop interactions in agroforestry appear at odds with tree-grass interactions in tropical savannahs. *Agroforestry Systems* 45: 109-129.

Ong, C.K., Anyango, S., Muthuri, C.W. and Black, C.R., 2007. Water use and water productivity of agroforestry systems in the semi-arid tropics. *Ann Arid Zone* 46: 255-84.

Ong, C.K., Black, C.R. and Muthuri, C.W., 2006. Modifying forests and agroforestry for improved water productivity in the semi-arid tropics. CAB Reviews: Perspectives in Agriculture, Veterinary Science, *Nutr Nat Resource* 65:1-19.

Ong, C.K., Odongo, J.C.W., Marshall, F.M., Black, C.R., 1992. Water use of agroforestry systems in semi-arid India. In: Calder, I.R., Hall, R.L., Adlard, P.G. (Eds.), Growth and Water Use of Forest Plantations. Wiley, Chichester, UK, pp. 347-358.

Pate, J.S. and Dawson, T.E., 1999. Assessing the performance of woody plants in uptake and utilisation of carbon, water and nutrients, Implications for designing agricultural mimic systems*. Agroforestry Systems* 45:245-275.

Pinto, L.F.G., Bernardes, M.S, Van Noordwijk, M., Pereira, A.R., Lusiana, B. and Mulia, R. Simulation of agroforestry systems with sugarcane in Piracicaba, Brazil. *Agricultural Systems*, 86:275-292.

Podwojewski P., Grellier, S. Mthimkhulu S., Titshall L., 2014 How tree encroachment and soil properties affect soil aggregate stability in an eroded range-land in South Africa. Soil Sci. Soc. of Am. J. 78: 1753-1764. doi:10.2136/sssaj2013.12.0511.

Rethman N.F.G, Annandale J.G., Keen C.S. and Botha C.C. 2007. Water-use efficiency of multi-crop agroforestry systems, with particular reference to small-scale farmers in semi-arid areas. WRC Report No. 1047/1/07. ISBN No 978-1-77005-579-7.

Reyes, T., 2008. Agroforestry systems for sustainable livelihoods and improved land management in the East Usambara Mountains, Tanzania. Tropical Forestry Reports.

Richardson, D.M., Binggeli, P. and Schroth, G., 2004. Invasive agroforestry trees: problems and solutions. *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press, Washington, DC, 371-396.

Righi, C.A., Lunz, A.M.P., Bernardes, M.S., Pereira, C.R., Teramoto, E.R. and Favarin J.L. 2008. Coffee water use in agroforestry system with rubber trees. R. Árvore, Viçosa-MG 32 (4): 781-792.

Robinson, D.A., Abdu, H., Jones, S.B., Seyfried, M., Lebron, I. and Knight, R. 2008. Eco-Geophysical Imaging of Watershed-Scale Soil Patterns Links with Plant Community Spatial patterns. Vadose Zone J. 7:1132-1138.

Rockstrom, J., 1997. On-farm agrohydrological analysis of the Sahelian yield crisis: rainfall partitioning, soil nutrients and water use efficiency of pearl millet. Ph.D. Thesis. University of Stockholm.

Rusch, G.M., Zapata, P.C., Casanoves, F., Casals, P., Ibrahim, M. and DeClerck, F. 2014. Determinants of grassland primary production in seasonally-dry silvopastoral systems in Central *America. Agroforest Syst* 88:517-526.

Schlegel, P., Huwe, B. and Teixeira, W. 2004. Modelling species and spacing effects on root zone water dynamics using HYDRUS-2D in an Amazonian agroforestry system. Agroforestry Systems. 60:277-289.

Schlegel, P., Huwe, B. and Teixeira, W.G., 2004. Modelling species and spacing effects on root zone water dynamics using Hydrus-2D in an Amazonian agroforestry system. *Agroforestry Systems* 60:277-289.

Schmitt, T.J., Dosskey, M.G. and Hoagland, K.D., 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. *J Environ Qual* 28: 1479-1489.

Schroth, G., 1999. A review of below ground interactions in agroforestry, focusing on mechanisms and management options. *Agroforestry Systems* 43: 5-34.

Seobi, T., Anderson, S.H., Udawatta, R.P. and Gantzer, C.J., 2005. Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. *Soil Sci Soc Am J* 69: 893-901.

Sharma, A.K., undated. Arid Zone Agroforestry: Dimensions and Directions for Sustainable Livelihoods. *Europe*, 11:0-4 Accessed 30/07/2015.

Singh, G., Bala, N., Mutha, S., Rathod, T.R. and Limba, N.K., 2004. Biomass Production of Tecomella undulata Agroforestry Systems in Arid India. *Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems,* 22(3): 205-216.

Singh, R.P., Ong, C.K., and Saharan, N., 1989.Above and below ground interactions in alley-cropping in semi-arid India. Agroforestry systems 9: 259-274.

Siriri, D., Ong, C.K., Wilson, J., Boffa, J.M. and Black, C.R., 2010. Tree species and pruning regime affect crop yield on bench terraces in SW Uganda. *Agroforestry Systems* 78:65-77, ISSN 0167-4366

Siriri, D., Wilson, J., Coe, R., Tenywa, M.M., Bekunda, M.A., Ong, C.K. and Black, C.R., 2013. Trees improve water storage and reduce soil evaporation in agroforestry systems on bench terraces in SW Uganda. *Agroforestry Systems*, 87 (1): 45-58.

Sun, H., Tang, Y. and Xie, J., 2008. Contour hedgerow intercropping in the mountains of China: a review. *Agroforest Syst* 73: 65-76.

Thakur, P.S. and Sehgal, S. 2003. Growth, leaf gas exchange and production of biomass in coppiced and pollarded agroforestry tree species. Journal of Tropical Forest Science 15(3): 432-440.

Thangata, P.H., Mudhara, M., Grier, C. and Hildebrand, P.E., 2007. Potential for Agroforestry Adoption in Southern Africa: A comparative study of improved fallow and green manure adoption in Malawi, Zambia and Zimbabwe. Ethnobotany Research and Applications, 5: 67-75.

Thompson, S. 2003. Using Hydrus 2D to Model Tree Belts for Salinity and Recharge Control. MSc. Centre for Water Research. University of Western Australia.

Underwood, M., 1993. Agroforestry defined – its Applicability to the Forestry Industry. *South African Forestry Journal* 167: 73-79.

Van der Werf, W., Keesman, K., Burgess, P., Graves, A., Pilbeamd, D., Incoll, L.D., Metselaara, K., Mayusa, M., Stappersa, R., Van Keulen, H., Palma, H. and Dupraz C., 2007. Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. *Ecological engineering* 2(9): 419-433.

Van Noordwijk, M., Hairiah, K., Guritno, B., Sugito, Y. and Ismunandar, S., 1996. Biological management of soil fertility for sustainable agriculture on acid upland soils in Lampung (Sumatra) *Agrivita*, 19: 131-136.

Van Noordwijk, M., Lusiana, B. and Ni'matul K., 2004. WaNuLCAS version 3.01: Background on a model of water, nutrient and light capture in agroforestry systems. International Centre for Research in Agroforestry (ICRAF), Bogor, Indonesia, 246 p.

Van Noordwijk, M., Mulia, R. and Bayala, J. 2012. Buffering soil water supply to crops by hydraulic equilibration in conservation agriculture with deep-rooted trees: application of a process-based tree-soil-crop simulation model to parkland agroforestry in Burkina Faso. Proc. 3rd International Conference on Conservation Agriculture in Southeast Asia, Hanoi, 2012:176-179.

Wambugu, C., Place, F. and Franzel, S., 2011. Research, development and scaling-up the adoption of fodder shrub innovations in East Africa. *International journal of agricultural sustainability*, *9*(1): 100-109.

Wang, L., Zhong, C., Gao, P., Xi, W. and Zhang, S., 2015. Soil infiltration characteristics in agroforestry systems and their relationships with the temporal distribution of rainfall on the loess plateau in China. *PLoS ONE* 10(4): e0124767. doi:10.1371/journal.

Zerihun, M.F., Muchie, M., and Worku, Z., 2014. Determinants of agroforestry technology adoption in Eastern Cape Province, South Africa. *Development Studies Research: An Open Access Journal*, 1(1): 382-394, DOI:10.1080/21665095.2014.977454.

Zomer, R.J., Bossio, D.A., Trabucco, A., Yuanjie, L., Gupta, D.C. and Singh, V.P., 2007. Trees and water: smallholder agroforestry on irrigated lands in Northern India (Vol. 122). IWMI.

3 SITE IDENTIFICATION

This chapter responds to the second specific objective of the project which was: To identify sites and determine requirements of farmers that will inform choice of species (trees, shrubs, and grasses) and the integration of trees, shrubs and forage into the farming system. Through engagement with various stakeholders, including researchers that undertook work on agroforestry systems, a number of potential sites for agroforestry were identified. The focus was initially on sites where there were already agroforestry species planted given the timeframes involved with growing woody species.

3.1 Methodology

The project team in collaboration with local partners undertook field visits to assess the opportunities that exist and the possibility of using various locations as research and demonstration sites for the current WRC agroforestry systems project. In total, seven sites were visited. A summary of climatic data for the sites is presented in Table 3.2. Three of the sites were in communal areas under the leadership of Traditional Authorities namely: (Zwelisha, Ixopo and Biyela) and four were research stations or land under private ownership (Dundee Research Station, Owen Sithole College of Agriculture, Nansindlela Training Centre and Fountainhill Estate).

This chapter provides a description, pictures, current status of all sites visited, as well as discussions and recommendations of what could possibly be done in each of the sites. A survey form to understand farmers' circumstances, preferences and requirements to inform feasible interventions that respond to their priority constraints was developed and used during the discussion with farmers at Ixopo and Zwelisha. The field trips were undertaken to:

- Create awareness amongst farmers about the agroforestry project,
- Establish the level of their interest and willingness to participate in the project,
- Ascertain the availability of resources such as land and fencing (i.e. ability to host/implement the project)
- Assess the possibility of tree establishment for the approaching growing season.

3.2 Description of the sites

3.2.1 Zwelisha, Bergville

This site is located in the communal area of Zwelisha village in Bergville under Okhahlamba Local Municipality. The Zwelisha village falls under Amangwane Traditional Authority. The name of a farmer visited is Mr Simon Mbhele a smallholder dairy and beef cattle farmer. In the period of 2005-2009 the farmer was involved in another WRC-funded agroforestry project where different fodder production systems were tested on his farm. The farmer was identified through interaction with the researchers who were involved in the previous research.

Three field trips were undertaken by the INR team to establish a working relationship with Mr Mbhele and to discuss some of the outcomes of the previous research and to make an assessment of the current status of the site. More information is provided about this site in Chapter 3.

3.2.2 Ixopo/Highflats, Ubuhlebezwe Local Municipality

Ixopo is situated on a tributary of the Mkhomazi River in the midlands of KwaZulu-Natal, and forms part of an important sugar farming and forestry area under Ubuhlebezwe Local Municipality. Ixopo is located approximately 85 km south east of Pietermaritzburg, capital of KwaZulu-Natal, and is strategically located at the intersection of four major provincial routes leading to Pietermaritzburg, the Drakensberg, the Eastern Cape and the South Coast. The area is under the leadership of Amazizi K and B, Emawusheni and Majikane Traditional Authorities.

The sites were identified through interactions with the KZN Department of Agriculture and Rural Development (DARD), which provides support to the association of smallholder livestock owners known as Ubuhlebezwe Livestock Association. This organization serves as an umbrella body for smallholder livestock owners. It comprises of individual livestock owners from the respective villages of Ixopo, and has executive leadership of twelve members. The DARD provides extension support through the association, wherein animal health care programs are discussed and livestock auctions. The association meets regularly once a month with members of the local dip tanks participating in the general meetings, and reporting back to the communities that they represent. The ten farmers that were interested in participating in the agroforestry project were located in eight sub-villages of the four Traditional Authorities in the Ixopo/Highflats area.

3.2.3 Biyela, Melmoth

INR worked in Biyela community between 1992 and 1995 on agroforestry and other natural resource management activities. The village of Biyela is situated outside Melmoth, a small town, and falls under Mthonjaneni Local Municipality. A field trip was undertaken to establish if the farmers involved at that time were still staying in the area and still engaging in agroforestry activities. If so, what/how have they taken the experiences forward? The team met Mr Agrippa Zondi who was an employee of INR working on the agroforestry project in the 1990s. He helped the team to locate the farmers. He mentioned that most of the farmers whom he worked with had passed on. The project had established an agroforestry interest group with 11 farmers. The team managed to see four farmers (Mrs Gumede, Mr Dumisani Nxumalo, Mrs Dube and the son of the late Mr Allen Shobede). The farmers in the area mainly grow indigenous vegetables (sweet potatoes and amadumbe) and fruit trees (guava, lemons, and oranges).

Site visits and discussions with farmers

Mrs Gumede

The first farmer visited was Mrs Gumede, a former member of the agroforestry interest group. The team went to her garden that has *Leucaena* and pine trees planted as windbreaks (Photograph 3.1). After the project had ended, she planted some medicinal plants that cure minor ailments *(isibhaha)*. She is using *Leucaena* in her garden as a soil fertility ameliorant and she does not use any chemical fertilizers in her vegetable garden. At the vegetable garden plot she had beans, and fruit trees (guava, mango, lemons and oranges) surrounding her house. The pine trees provide fencing and serve as windbreaks.

Photograph 3.1 Leucaena stand at Mrs Gumede's garden (A) and a garden surrounded by pine trees (right).

Dumisane Nxumalo

This is the farmer whose agroforestry work is documented in the 1995 project report (Peden and Trench, 1995). He has an integrated system in the garden with fruit trees, vegetables and rotates a pig sty in his garden to add fertility (Photograph 3.2). He shared that some of the trees that he has been planting were destroyed by runaway fires. Below the garden, there is a small gum tree plantation and he has a windbreak of pine trees (Photograph 3.3).

Photograph 3.2 Mr Nxumalo (A) and his garden with steep slope planted vegetables, orange and lemon trees (B).

Photograph 3.3 The height of 23 year old pine trees (from the original agroforestry project) planted as windbreaks.

Discussion and observation

From the four farmers visited, Mrs Gumede and Mr Nxumalo showed keen interest and shared lessons learnt on the previous project. Mrs Gumede was more interested in planting medicinal and fertilizer tree species that could survive in the area in her garden as she does not use any chemical fertilizers. She shared that the leucaena in her garden is helpful in maintaining soil fertility status.

Mr Nxumalo is more interested in fruit trees; this is evident in his garden. Although the garden is on a very steep slope, he is trying to minimize erosion by planting the trees on the edges of each vegetable patch. Furthermore he showed the team a separate piece of land that he and his brother want to use to increase their production. In terms of the previous agroforestry project, the pine trees planted as windbreaks in different households and at the local school have grown to their full potential.

In the households of Mr Shobede and Mrs Dube the pieces of land that were allocated for agroforestry are not being used for any type of farming, and there are no traces of the trees that were planted by the original project at both sites. At Mr Shobede's house, black wattle and other invasive species are encroaching into the site which was originally used for agroforestry.

It should be noted that the farmers visited do not have livestock so her interest is more on the use of agroforestry species to add fertility, repel insects pests, provide food and minimise soil erosion.

3.2.4 Owen Sithole College of Agriculture, Empangeni

Owen Sithole College of Agriculture (OSCA) is situated outside Empangeni town on the North Coast of KwaZulu-Natal under Umhlathuze Local Municipality. Empangeni is approximately 156 kilometres northeast of Durban, situated in hilly countryside, overlooking a flat coastal plain and the major harbour town of Richards Bay, which is only 15 kilometres away. The College at OSCA is managed by the KZN DARD, together with a research station. A trip was undertaken by the INR team to meet with Mr Francois Du Toit (the Farm manager who is in charge of the research station facilities).

A short meeting was held with the farm manager to discuss possibilities and objectives of the project. He gave the team the assurance that there were fields available for the project but he cited the problem of monkeys if we will be planting maize. He also suggested that we use the field in the portion of the farm where there is a permanent security guard.

3.2.5 Fountainhill Estate, Wartburg

Fountainhill Estate is owned by the Taeuber Management Trust (TMT) and has a long and distinguished history with INR as the Taeuber family was instrumental in establishing the INR. The farm is located in the uMshwathi Local Municipality, near Wartburg approximately 20 km northeast of Pietermaritzburg in KwaZulu-Natal.

TMT has a strong environmental and research focus and has been actively engaging the INR and the University of KwaZulu-Natal to encourage the use of the farm as a research site for sustainable and water efficient agriculture and natural resource management. The estate consists of arable land where sugarcane (563 ha) and avocados (50 ha) are grown as well as a commercial beef herd on irrigated and dryland pastures (180 ha). In addition to this, there is a 1400 ha conservation and wildlife area. Fountain Hill Estate encourages applied research with a focus on research and training at a tertiary level. It is therefore likely that a request to conduct agroforestry research supported by the WRC and with student involvement would be viewed favourably. Fountainhill would make a good research site, providing a controlled production environment, with good on-farm management and located close to the INR offices in Pietermaritzburg. The site was selected for both improved fallow and alley cropping trials and is described further within the rest of the report.

3.2.6 Dundee Research Station

The KZN DARD has a research station in this area. Dr Erika van Zyl a researcher based at Dundee Research Station was met to discuss the possibility of collaborating and to look at potential sites (Photograph 3.4). The tour of the farm identified the following possibilities:

- The 12 year old *Leucaena* plot – it has not propagated any seedlings, is utilised annually and has frosted back every winter so is still fairly short.
- The food security section has space for agroforestry – it contains some napier fodder that shows potential for inclusion in the system.
- The Lespedeza pastures – opportunities exist to include it as part of a self-medication strategy, building on a Masters research study of Dr Van Zyl.
- There are a number of Tagastaste trees (3 years old) at the site, which have proved to be intolerant of frost, highlighting that in much of the province they would not be suitable for agroforestry.

Photograph 3.4 Stand of 12-year old *Leucaena leucocephala* at Dundee Research Station.

3.2.7 Nansindlela Training Centre, Inchanga

The Nansindlela Training Centre, which is no longer in operation, is located near Cato Ridge. It was a facility used by INR up until 2003. It was also the site used for agroforestry demonstrations in the 1990s. Brigid Letty and Morag Peden (the project leader of the previous INR agroforestry project) visited the site in June 2015 to assess the opportunities to use it as a research site for the current WRC project (Photograph 3.5).

Nansindlela normally receives about 737 mm of rain per year, with most rainfall occurring during mid-summer. Temperatures range from a minimum of 0.9°C to a maximum of 40°C. The vegetation type of the area is Ngongoni Veld with frost index of -1.

The training centre was found to be abandoned and largely vandalised. The site was unfenced and was being grazed by livestock from the surrounding area. In terms of the agroforestry species established through the original project, the indigenous trees on the western boundary were still there but very large. The paulownia trees were still in place as was the row of *leucaena* on the contour bank across the middle of the plot, though infested with lantana. The *leucaena* had no spread substantially as seedlings that had germinated were heavily browsed. Below the old buildings there was still evidence of the *leucaena* woodlot, though some of this had been harvested by local people. The only species remaining from the AF species demonstration was the *Leucaena diversifolia*.

Due to the unmanaged nature of the centre, it was decided that it would not be a suitable site for the WRC research, although it would be interesting to use the site for a small investigation into the invasive nature of the two *leucaena* species under the local conditions. The lack of survival of the various agroforestry species established at the site does point to their lack of persistence under unmanaged (open access) conditions.

Photograph 3.5 Pictures from Nansindlela: old buildings (A), *leucaena* woodlot (B), *leucaena* on contour bank infested with lantana (C), *Leucaena diversifolia (D) browsed Leucaena leucocephala* seedlings (E).

A summary of all the sites investigated is presented in Table 3.1.

Table 3.1 The characteristics of the various sites are summarised in a table format below

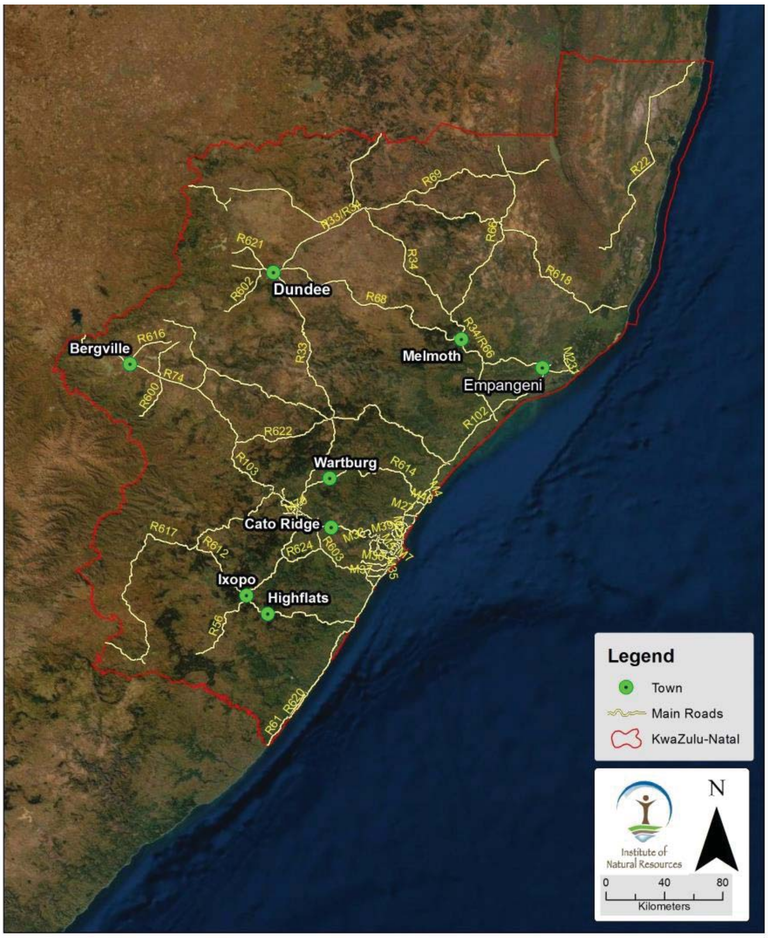
SITE	Existing agroforestry practices	Land ownership	Key climatic conditions (rainfall and frost occurrence)	Advantages as a potential site	Disadvantages as a potential site	Possible use of site (farmer research, formal trial site, demonstration, etc.)
Zwelisha, Bergville	Previous WRC-funded AF project – some Vachellia karroo trees remaining	Traditional Authority Area but site belongs to one household	- High rainfall area - Low frost occurrence	- Acacia trees have been established - The farmer has previous knowledge of AF - Existence of the dairy cows	- The site is isolated - Waterlogging potential	- Joint experimentation with the farmer
Ixopo/Highflats	No experience of AF though some passive AF occurring (intercropping citrus and field crops)	Traditional Authority area. Different households have access to gardens and fields.	- High rainfall area - Severe frost occurrence	- Several sites in the areas ‘ therefore, this provides a good opportunity for comparison - Opportunity for information sharing (since farmers are mobilised through famers association - May used as field school for farmers-dissemination point	- Identified sites not fenced - Long distance between sites	- Joint experimentation with the farmers
Biyela, Melmoth	Previous INR AF project and a few farmers still have some species in their home gardens.	Traditional Authority area. Different households have access to gardens and fields.	- High rainfall area - High frost occurrence	- Good climatic conditions for AF practices	- Farmers do not own livestock but fertilizer trees may be used	- Joint experimentation with the farmer
Owen Sithole College of Agriculture, Empangeni	No AF currently	State facility	- High rainfall area - High frost occurrence	- Suitable climatic and environmental condition for AF - The areas is fenced	- Limited choices of species selection because of wild animals	- Formal trial

SITE	Existing agroforestry practices	Land ownership	Key climatic conditions (rainfall and frost occurrence)	Advantages as a potential site	Disadvantages as a potential site	Possible use of site (farmer research, formal trial site, demonstration, etc.)
Fountainhill Estate, Wartburg	No AF currently	Private property with interest in sustainable agriculture and research	- High rainfall area - High frost occurrence	- Providing a controlled production environment, - Good on farm management and located close to the INR offices in Pietermaritzburg.		- Formal trial site
Dundee Research Station, Dundee	Some Leucaena trees	State facility	- High rainfall area - High frost occurrence	- Controlled environment - The farm manage has previous knowledge of AF	- Poor environmental conditions	- Formal trial site
Nansindlela Training Centre, Inchanga	Previous AF project site. Some leucaena remaining as well as other tree species, many of which are now very large	Private property, currently abandoned.	- High rainfall area - High frost occurrence	- Close to the INR Pietermaritzburg office	- Abandoned and largely vandalised - Unfenced and was grazed by livestock from the surrounding area	- Site not to be used except for a possible Honours study regarding the spread of Leucaena leucocephala.

Table 3.2: A summary of the climatic conditions for the various sites investigated

Cities and Towns	Potential sites	Frost index	Mean Annual Precipitation (mm)	Minimum Temperature (°C)	Maximum Temperature (°C)	Altitude (m)	Vegetation Type
Bergville	Zwelisha	205	820	-5.1	36.9	1295	Northern KZN Moist Grass
Dundee	Dundee Research station	216	738	-7.4	37.5	1212	Northern KZN Moist Grassland
Melmoth	Biyela	-1	859	0.8	40	610	Zululand Lowveld
Empangeni	Owen Sithole College of Agriculture	-1	1096	3.6	42	95	Maputaland Coastal Belt
	Emazabekwni	200	829	-1.4	38.8	905	Eastern Valley Bushveld
Ixopo	KwaNokweja	-1	958	2	36.3	740	KZN Coastal Belt
	KwaMhlabashane	-1	853	2.2	37.5	420	Midland Mistbelt Grass
Inchanga	Nasindlela Training Centre	-1	737	-0.9	40	650	Ngongoni Veld
Wartburg	Fountainhill	-1	805	-3.3	37.4	866	Ngongoni Veld

The location of all the sites investigated are shown in Photograph 3.6



Photograph 3.6 Map showing the location of the different sites that were investigated for the current agroforestry project.

3.3 Conclusion

At the end of the tour, the team together with the farmers and partners from research stations concluded that it is indeed feasible to establish agroforestry research and demonstrations plots in the following sites: Zwelisha, Ixopo, Owen Sithole Agricultural College, Dundee Research Station and Fountainhill Estate.

Farmers acknowledged that they need an appropriate fodder production system that will be affordable and sustainable. All smallholder livestock farmers have the same challenge of shortage of palatable fodder during the winter season so the agroforestry systems developed will aim to address this issue. Other benefits will also be realized in the process like soil fertility replenishment, food, soil erosion control. Generally, the starting point would be to start with a few farmers during the 2015/16 growing season then upscale to other farmers since will now have a reference point. All the on-farm sites will work as farmer field school and will incorporate the Participatory Innovation Development (PID) principles to stimulate farmer innovativeness and improve the sustainability and technology adoption by other farmers. Learning events to the research stations will also be organized for farmers to gain more exposure and give input on what would be demonstrated at the research stations. At the end of season a farmer-researcher participatory evaluation will be conducted. The project was acceptable to all the farmers met during the visits.

4 TESTING AGROFORESTRY ARRANGEMENTS

4.1 Introduction

This chapter consolidates all the work done over the timeframe of the project to test and document different agroforestry sites at various sites including research stations (Fountainhill Estate at Wartburg and OSCA at Empangeni) and farmers' fields at Zwelisha and Ixopo/Highflats.

4.2 Selection and sourcing of plant material

The woody species selected for the agroforestry trials were selected on the basis of being:

- Either indigenous trees or existing crops
- N-fixing species (i.e. legumes)
- Preferably fast-growing shrubs.

This led to the decision to source *Sesbania sesban,* pigeon pea (*Cajanus cajan*) and *Faedherbia albida*. In addition, opportunities to import *Gliricidia sepium* seed for experimental purposes were explored with Simon Hodgeson (Cover crop Solutions) as this is another species that is well recognised as an agro-forestry species and furthermore it is not listed as an invasive alien species. Since there was some concern regarding the use of *Sesbania sesban*, advice was sought from Professor Terry Olckers at UKZN who is an expert in the control of alien invasive plants. Prof Olckers was of the opinion that it would not be problematic.

4.2.1 Sesbania sesban

<u>*Purchase of seed*</u>

Initially, since there were some concerns about harvesting the correct species from natural populations, efforts were made to identify an on-line supplier. Silverhill Seeds, which is based in Cape Town and specialises in South African plants supplied seed. The seedlings were propagated by Watersmeet Nursery, a commercial nursery in Richmond, KZN (Photograph 4.1). The seedlings were planted out directly from the seedling trays.

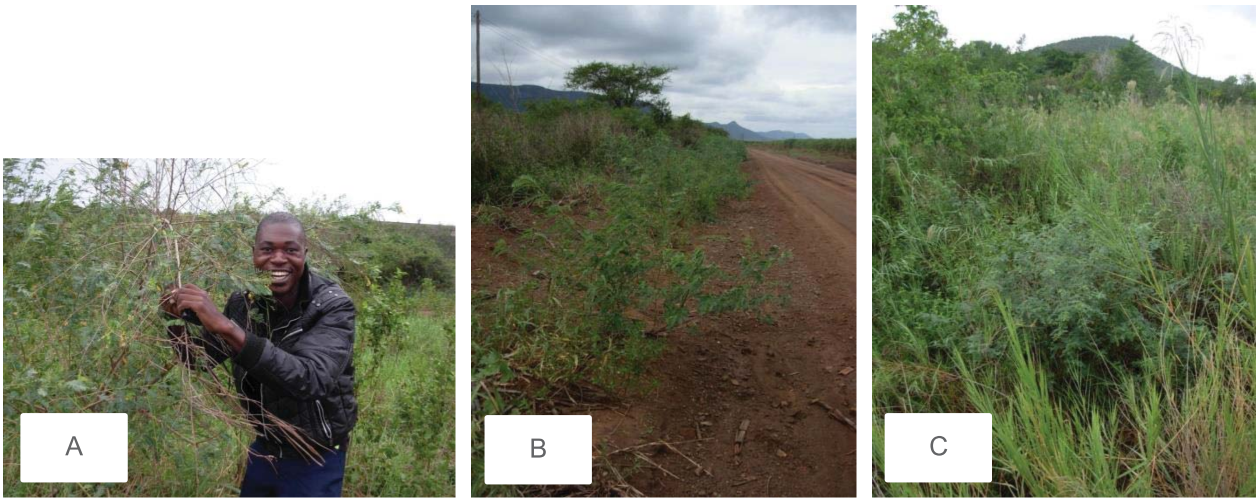
Photograph 4.1 *Sesbania* seeds being propagated at Watersmeet Nursery (A) and a transplanted seedling (B).

When the plants grew, it became apparent that the incorrect species had been supplied and that it was *Sesbania bispinosa* and not *Sesbania sesban*. *S. bispinosa* is not suitable for agroforestry activities in South Africa as it is recognised as an emerging weed and is also an annual species. A decision was taken to continue with the approach of sourcing seed from natural populations.

Collection of provenances for screening under glasshouse conditions

To enable evaluation of genetic variability among provenances of *Sesbania sesban*, four field trips were undertaken to search for natural stands of this N_2-fixing leguminous tree. *Sesbania sesban* populations (herein referred to as provenances) were found growing naturally at Amatigulu River, Zinkwazi River, Empangeni (at the entrance of Owen Sithole College of Agriculture), Richard’s Bay, Hluhluwe River, Mkhuze and along the Phongolo River (Photograph 4.2 and Photograph 4.3). Three specimens were collected from each site, labelled and pressed on site. Specimens were, however, not collected at Amatigulu River due to seed unavailability at the time of specimen collection. At the Zinkwazi River only green and immature seeds were available and were left for later collection but when the site was visited again the plant had been removed during flood conditions.

Photograph 4.2 *Sesbania sesban* at Empangeni SPCA (A) and at OSCA (B).



Photograph 4.3 *Sesbania sesban* at Hluhluwe (A), along a roadside at Mkhuze (B) and at Pongola in a riverbed (C).

Encounters with S. bispinosa

The process of collecting Sesbania sesban seed also led us to encounter much *Sesbania bispinosa* growing in similar areas, as shown in Photograph 4.4. This is likely to be the reason why the person collecting seed on behalf of Silverhill Seeds collecting the incorrect material with which we were supplied initially.

Photograph 4.4 *Sesbania bispinosa* at Richards Bay (A) and Pongola (B).

Observations of effects of pruning/browsing

While collecting *Sesbania sesban* seed at the entrance to OSCA, we came across plants that had been browsed by cattle and goats that have access to the area (Photograph 4.5). This not only showed that the plants are palatable to livestock, but also provided an indication of how they respond to browsing.

Photograph 4.5 A young *S. sesban* plant that has been browsed (A) and an older plant that has recovered from previous herbivory (B).

Interactions with herbariums for identification of plant materials

Prior to collection of *S. sesban* specimens and seed, we have arranged a briefing session with Christina Potgieter at the University of KwaZulu-Natal. The purpose of the briefing was to mainly educate the team on how to collect and press good specimens. Potgieter also referred us to Michael Cheek who works for the National Botanical Garden in Durban for assistance in identifying collected specimens. A total of seven specimens (namely; *Sesbania sesban* provenance BL 100, BL 101, BL 102, BL 103, TM 200, TM 201 and TM 203) were sent to the National Botanical Garden in Durban for identification. All specimens were identified as *Sesbania sesban* var. nubica by the National Botanical Garden in Durban.

Testing of S. sesban *germplasm*

During the first field excursion, only two provenances were found at Hluhluwe and Mkhuze. The viability of the collected seed materials was determined by conducting a simple germination test in 24-well plastic seedling trays containing seedling growth mix (Farmyard Organics) (Photograph 4.6). Prior to planting in 24-well plastic seedling trays, the seeds were scarified by soaking for 5 min in boiling water and left to imbibe ovemight (24 h). Seedling emergence commenced 21 days after planting. The seedlings were left to grow for further three months under controlled conditions before being planted into pots. The seedlings were irrigated once or twice a week with fresh tap water.

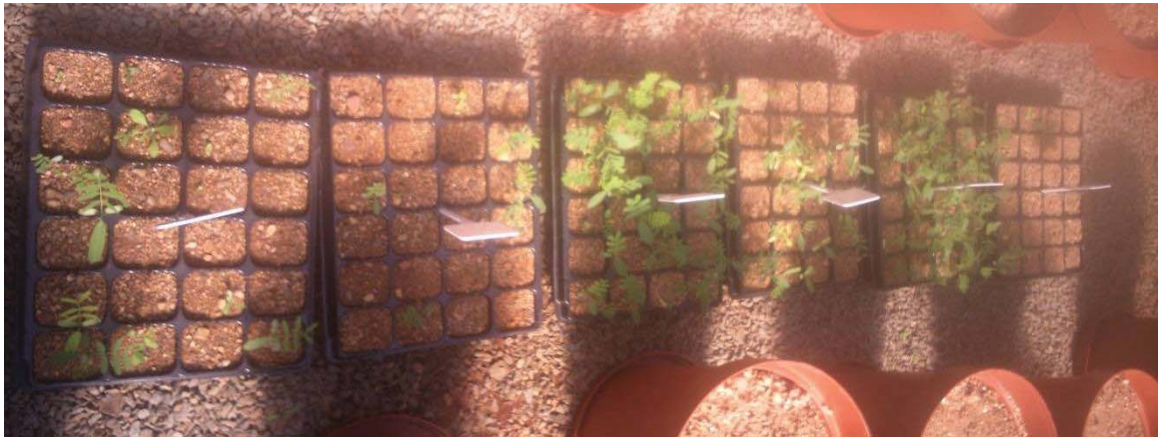
Photograph 4.6 Initial testing of methods to propagate *Sesbania sesban* seed.

After the last excursion, seeds of all six *S. sesban* provenances were planted out in seedling trays to compare germination and early growth. Seedling emergence commenced 7 days after planting (DAP) for BL101 and BL102 followed by BL103 and TM201 at 10 DAP. Provenance TM202 did not emerge from trays (Photograph 4.7 and Photograph 4.8). However, higher variability in terms of seedling emergence was observed and is summarised in Table 4.1.

Table 4.1 Germination status of six *Sesbania sesban* provenances planted into 24-well plastic seedling trays at UKZN

Provenance	Source	Planted	Germinated	Remarks
BL100	OSCA	10/06/2016	24/06/2016	Poor germination
BL101	OSCA	10/06/2016	17/06/2016	Most vigour
BL102	Hluhluwe	10/06/2016	17/06/2016	Good germination
BL103	Mkuze	10/06/2016	20/06/2016	Good germination
TM201	Richards Bay	10/06/2016	20/06/2016	Poor germination
TM202	Pongola	10/06/2016	-	No germination

Photograph 4.7 Germination of the *S. sesban* provenances on 11 July 2016 (TM201, BL100, BL102, BL103, BL101, TM202).



Photograph 4.8 Size of the seedlings on 1 August 2016 (TM201, BL100, BL102, BL103, BL101, TM202).

It is clear that BL101 and BL103 were the most vigorous provenances. The reasons for the poor germination of BL100 and TM202 were unclear. It may have been because the seed was not yet dry when harvested.

Choice of provenances and landraces

After careful considerations, *S. sesban* provenance BL101, BL102 and BL103 were considered the best provenances in terms of seedling emergence and vigour. However, due to low tree densities at Hluhluwe and clearing of *S. Sesbania* trees happening at Mkuze, BL101 was recommended for planting in the field at Fountainhill Estate (FHE) due to high tree densities at Empangeni.

4.2.2 *Faiderbia albida*

A total of 50 *Faiderbia albida* trees were supplied by Fevertree Nursery in Mpumalanga Province (Photograph 4.9). Of these, 25 were planted into *Panicum maximum* at OSCA/Empangeni. Others were planted out at farmers' homesteads in Ixopo to determine their suitability for the area.

Photograph 4.9 *Faderbia albida* trees delivered to INR, November 2016.

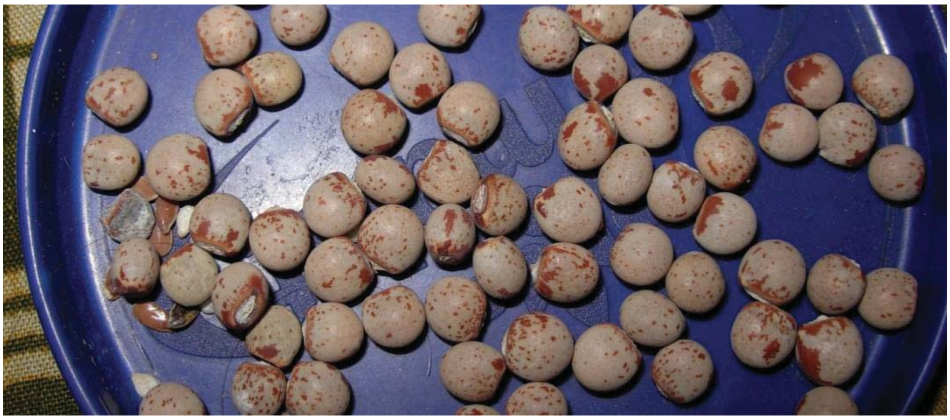
Faidherbia albida was planted into a *Panicum maximum* pasture at OSCA in December 2015. The purpose of establishing the trees at the research station is to determine whether they display reverse phenology as is recorded elsewhere and to be able to investigate water use at a later stage. A total of 25 trees have been planted at 5 x 5 m spacing as shown in Photograph 4.10. Despite the erratic rainfall over the years, all the trees survived, but growth has been very slow (Photograph 4.11).

Photograph 4.10 The *Faiderbia albida* trees at planting in December 2015.

Photograph 4.11 The *Faiderbia albida* trees in June 2016.

4.2.3 Pigeon pea

Some pigeon pea seed was made available by researchers at UKZN (Photograph 4.12). It was purchased from smallholder farmers in the uMkhanyakude District Municipality. Lindah Hlukayo, who had undertaken research on the landrace found that it took 7 months to reach maturity at Jozini where it was being grown in a trial. It is a perennial landrace although it can be grown as an annual crop.



Photograph 4.12 Local landrace of pigeon pea from Umkhanyakude District Municipality.

This seed was used for the improved fallow trial at FHE but seed obtained from a community member at Endaleni, Richmond was used to establish the trial at OSCA. Later, seed from the pigeon pea plants at OSCA was used to establish the alley cropping trials at FHE.

4.3 Sequential agroforestry system research

The trials testing a form of improved fallow were replicated at Wartburg and Empangeni. They were managed by Misheck Musokwa as they were used for his Masters and PhD research.

Title: Optimisation of water use in agroforestry systems: A case study of *Sesbania sesban* and *Cajanus cajan* (pigeon pea) intercropped with *Zea-mays* (maize) and *Panicum maximum* in KwaZulu-Natal province, South Africa

Major Aim: To develop a sustainable agroforestry system that will address negative impacts of agricultural production on both soil and water resources and improve farmers' productivity through the provision of livestock fodder and soil fertility replenishment in smallholder farming systems.

Specific objectives:

1) To compare water use of the two agroforestry tree species (*Sesbania sesban* and Pigeon pea – *cajanus cajan*) in a <u>sequential agroforestry system</u>.
2) To tentatively determine and quantify the impacts of agroforestry systems on hydrologic processes such as infiltration, evaporation, drainage and soil water availability
3) To describe and analyse/quantify the interactions between different agroforestry tree species, maize and guinea grass (P*anicum maximum)* in terms of yield and biomass production.

The proposed system was designed to improve the production of maize being grown by smallholder farmers. At a household level production generally takes place without inputs and yields are very low. Agroforestry (a sequential arrangement in particular) is seen as a cost-effective and environmentally friendly method of improving smallholder maize production.

The basis for the system was to have a two-year legume tree fallow followed by 2-3 years of maize production. Since farmers cannot afford to remove their land from maize production for the full fallow period, the following arrangement was proposed: Year 1: Legume tree species planted at 1 m x 1 m plant spacing; Maize rows planted between the tree rows at a 1 m inter-row spacing. Year 2: The legume trees are allowed to continue growing; the maize crop is not re-established as there will be too much shading. Year 3: The legume tree crop is cut down to ground level and the area is again planted to maize; and Year 4-5: The maize crop is grown annually until the yield declines to levels perceived to be unacceptably low. The trees are then re-established.

The tree/pasture system followed the same system but the grass was a perennial pasture and thus was not discontinued as was the maize in the second year.

4.3.1 Trial sites

<u>Fountain Hill Estate, Wartburg</u>

Fountain Hill Estate is owned by the Taeuber Management Trust and has a long and distinguished history with INR as the Taeuber family was instrumental in establishing the INR. The farm is located in the uMshwathi Local Municipality, near Wartburg, approximately 30 km north-east of Pietermaritzburg in KwaZulu-Natal and an area was set aside for the trials (Photograph 4.13) where they were laid out (Photograph 4.14).

Photograph 4.13 The land made available at Fountainhill Estate, Wartburg, for the agroforestry trial.

.

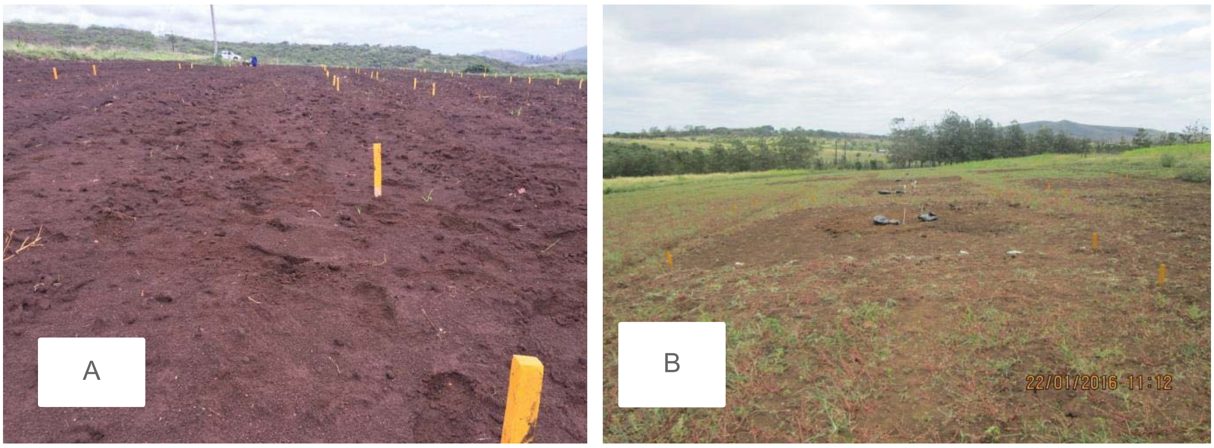
Photograph 4.14 Demarcation of the planting stations at Fountainhill Estate.

Owen Sithole College of Agriculture, Empangeni

Owen Sithole College of Agriculture (OSCA) is situated outside Empangeni town on the North Coast of KwaZulu-Natal under Umhlathuze Local Municipality. Empangeni is approximately 150 km north-east of Durban, situated in hilly countryside, overlooking a flat coastal plain and the major harbour town of Richards Bay, which is only 15 km away. The Owen Sithole College of Agriculture (OSCA) is managed by the KwaZulu-Natal Department of Agriculture and Rural Development (KZN DARD), together with a research station. A trip was undertaken by the INR team to meet with Mr Francois du Toit (the Farm manager who is in charge of the research station facilities). Photograph 4.15 shows the site allocated to agroforestry research at OSCA.

Photograph 4.15 Field with *Panicum maximum* identified for Faiderbia planting (A) and the site for the Sesbania/Pigeon pea trial (B).

At OSCA, initial land preparation also took place during the first week of December followed by field layout. The college fenced the field to avoid their goats from accessing the crop fields. Because planting was delayed due to the December break, the field was infested with weeds which were removed manually by hoeing (Photograph 4.16). The planting procedure was similar to the one explained above. At both sites there was no fertilizer application in both sites because the aim is to see the impact of the tree species on soil fertility.



Photograph 4.16 Field just after land preparation (A) and field at planting (B) at OSCA site.

4.3.2 Trials at Owen Sithole College of Agriculture, Empangeni

Introduction to the experimentation

To summarise, the first season (the 2015/16 season), there was drought (Figure 4.1) and the crops did not do well. In addition, the Sesbania plants used were *S. bispinosa* and not *S. sesban*. As a result, the trial was re-established in November 2016 (2016/17 season). This was then termed Season 1 of the improved fallow trial, with the 2015/16 season being called Season 0.

Season 0 (2015/2016)

At OSCA, land preparation also took place during the first week of December 2015 followed by field layout. The college fenced the field to avoid their goats from accessing the crop fields. Because planting was delayed due to the December break, the field was infested with weeds which were removed manually by hoeing. The planting procedure was similar to the one for Fountainhill Estate. At both sites there was no fertilizer application because the aim was to see the impact of the tree species on soil fertility.

However, the research at OSCA was badly affected by the drought (Figure 4.1). SASRI rainfall figures for Empangeni, compared against the long term means for the same period show how the first part of the season was very dry although since May there has been uncharacteristically high rainfall. The drought resulted in poor germination of the pigeon pea trees, which required that we replant in the 2016/17 season. The benefit of having the existing trees was that we had a source of seed for the new trials so the trees were thus only removed once the seed had been harvested.

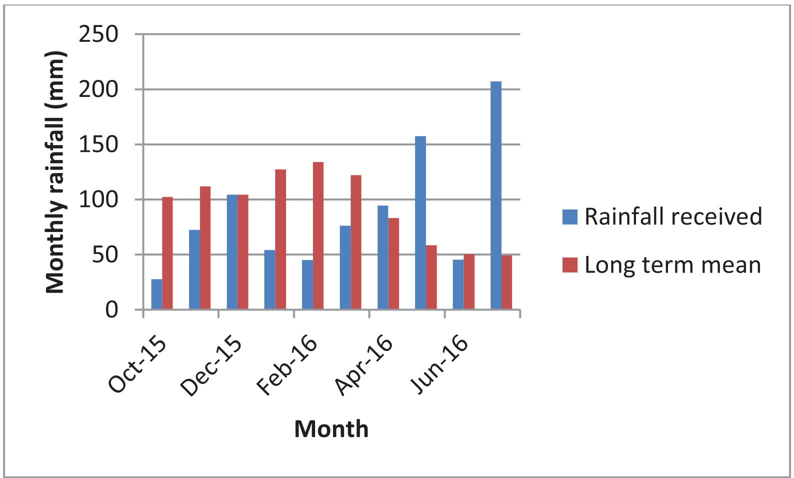
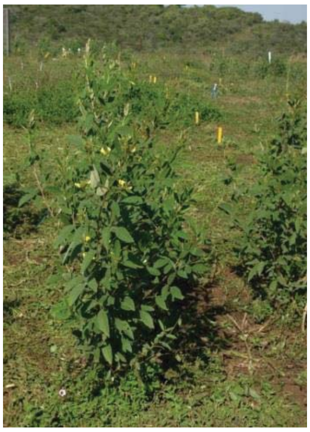


Figure 4.1 Rainfall received relative to long-term mean for Empangeni (Source: SASRI).

The summer rains were delayed (i.e. October and November received 46.7% of the long-term mean (LTM) and the period from October-January received only 57.97% of the LTM. Late rain received in May and July led to germination and growth of the pigeon pea crop which germinated very late (i.e. in March 2016 there was still no germination) (Photograph 4.18). *S. bispinosa* plants were removed before they set seed so as not to promote the dispersal of this emerging weed (Photograph 4.17).

Photograph 4.17 *Sesbania bispinosa* at OSCA in June 2016.



Photograph 4.18 Pigeon pea at OSCA in July 2016 (A) showing the production that took place in response to substantial rain received in May and June (B).

Season 1 (2016/17)

The trial was re-established in November 2016 due to drought that resulted in failure of the trial established in the 2015/2016 season. Some photographs from the two trials are shown in Photograph 4.19, Photograph 4.20 and Photograph 4.21.

Photograph 4.19 A pigeon pea/*Panicum maximum* plot at OSCA, June 2017.

Photograph 4.20 A Sesbania sesban-Panicum maximum plot at OSCA, June 2017.

Season 2 (2017/18)

This was the second year of the trial, and the second year of the two-year improved fallow plots. Maize was planted in sole maize plots, while the plots with trees were left to canopy. It was interesting to note that in the *S. sesban/P. maximum* plots, the grass component had become more competitive as it struggled in the first season.

The photographs below (Photograph 4.21, Photograph 4.22 and Photograph 4.23) show the status of the trial in January 2018.

Photograph 4.21 Sole maize plot in the improved fallow trial at OSCA, January 2018.

Photograph 4.22 Pigeon pea/*Panicum maximum* plot in the improved fallow trial at OSCA, January 2018.

Photograph 4.23 *Sesbania sesban*/*Panicum maximum* plot in the improved fallow trial at OSCA, January 2018.

Season 3 (2018/19)

This was the first year post fallow. In the sole Sesbania and sole pigeon pea plots, the woody component was removed in October 2018 and the plots were planted with *P. maximum*. In the plots that had a combination of Sesbania or pigeon pea with *P. maximum*, the trees were pruned back to 75 cm at the start of the growing system to simulate a silvopastoral system. This was not the original plan but since the maize crops were a disaster for the first two years due to monkeys and/or drought, a decision was taken to exclude the maize plots from the experiment and focus on silvopastoral systems.

4.3.3 Evaluation of *P. maximum* when intercropped with *S. sesban* and pigeon pea, OSCA

<u>*Methodology*</u>

Three months old *Sesbania sesban* seedlings were transplanted at 1 m x 1 m then they were watered. Pigeon pea (*Cajanus cajan)* seeds were direct seeded at spacing of 1 m x 1 m at 2 seeds per planting station. *Panicum maximum* seeds were drilled at respective rate of 7.5 kg/ha having an inter-row spacing of 0.25 m apart. Using a randomised complete block design (RCBD) Each treatment was allocated to a plot size of 6 x 8 m^2 and replicated three times, the treatments were distributed into:

Treatment 1: *Panicum maximum* + *Sesbania sesban*

Treatment 2: *Panicum maximum* + pigeon pea

Treatment 3: Sole *Panicum maximum*

Treatment 4: Sole *Sesbania sesban*

Treatment 5: Sole pigeon pea

The climatic conditions of the site for the first season are shown in Figure 4.2 while the field layout is shown in Table 4.2.

REP I	Pp	Pm	Ss	Pm + Ss	Pm + Pp
REP II	Pm + Ss	Ss	Pm	Pp	Pm + Pp
REP III	Pm	Pm + Ss	Pm + Pp	Pp	Ss

Key: Pp = pigeon pea, Ss = *Sesbania sesban*, Pm = *Panicum maximum*

Figure 4.2 Field layout involving *Panicum maximum* intercropped with legume trees at OSCA.

Table 4.2 Weather data for OSCA during 2016/2017 summer season

Month	Rainfall (mm)	Minimum Temperature (°C)	Maximum Temperature (°C)
November 2016	70	22	31
December 2016	18	21	30
January 2017	92	20	30
February 2017	120	21	30
March 2017	31	20	29
April 2017	12	17	28
May 2017	25	15	26

The representative soil samples were collected using a soil auger drilling to a depth of 20 cm at initial establishment of the trial. The samples were submitted for analysis to the laboratory of the Agriculture Research Station (Cedara), outside Pietermaritzburg. This consisted of the determination of mineral content, soil pH and soil texture using the near-infrared spectroscopy (NIRS) method. The soil texture is sandy clay loam and it has a pH (KCL) of 5.03. The results from the soil analyses are given in Table 4.3.

Table 4.3 Soil properties at start of the experiment in 2016 at Owen Sithole Agricultural College, KwaZulu-Natal, South Africa

Parameter	Value
Nitrogen (%)	0.23
Phosphorus mg/L	7
Potassium mg/L	139
Calcium mg/L	1394
Magnesium mg/L	746
Copper mg/L	19.1
Total cations cmol/L	13.55
Exchangeable acidity cmol/L	0.03
Organic Carbon (%)	3.3
pH (KCL)	5.03
Clay (%)	48

Source Cedara, 2016

Data collection

Dry matter yield of Panicum maximum

The dry matter yields were determined at the end of cropping season, six months after establishment. A 0.25 m^2 quadrant systematically placed on the diagonal at 3 points on the plot was used as sampling area. The *Panicum maximum* grass was cut back to a height of 15 cm above ground level with the aid of a sickle. The yields of *Panicum maximum* were determined for fresh and dry material. The dry biomass was obtained from the samples oven-dried over 3 days at 60°C.

Tree growth variables

A sample of nine trees was selected within the net plot of 5 m x 7 m and they were marked by strings so that the measurements will be repeated on the same trees in future. Morphological parameters such as root collar diameter and tree height was measured after six months. The latter was measured by placing a graduated stick along the bole and recording the height of the highest living tip. Diameter at 5 cm above ground level was measured with Vernier callipers. This measurement is referred to as the root collar diameter (Muthuri et al., 2005).

Statistical analysis

All data are presented as means of three replicates with standard error of difference (s.e.d.). Differences between treatments were tested with General Analysis of variance (ANOVA) using GENSTAT Release 18.2 (VSN International Ltd, 2016) and significant means separated using the Fisher protected LSD.

Results and discussion

Tree establishment/survival and growth

Significant differences ($P<0.05$) were observed in the establishment or survival rates. The highest establishment or survival rates were recorded in sole *Sesbania sesban* (98%), while pigeon pea + *Panicum maximum* had the least, with only 42%. Similarly highest height and root collar diameter were recorded in *Sesbania sesban* + *Panicum maximum* while the least height and root collar diameter were experienced on sole pigeon pea (1.388 m) and pigeon pea + *Panicum maximum* (17.91 mm) respectively (Table 4.4). Results on the growth performance of sole pigeon pea and intercrops showed that survival was very poor and this was probably due to the method of establishment and drought. Pigeon pea was directly seeded as compared to *sesbania sesban* that was raised from nursery seedlings and transplanted into the field. Soon after sowing of pigeon pea there was a period of drought that might have contributed to high mortality. Kwesiga et al. (1993) and Chirwa et al. (2004) reported similar results of poor establishment and high mortality in pigeon pea fallow under similar environmental conditions. The results from the study are consistent with results from a study by Kwesiga and Coe (1994) who found that pigeon pea was slow in terms of growth as compared to *Sesbania sesban* in establishment and the latter had the advantage since it was transplanted as compared to direct seeding. Treatments involving *S. sesban* were very rapid at initial establishment of the experiment that is why tree heights, root collar diameter was greater than treatments involving pigeon pea.

Table 4.4 Percentage establishment/survival rate, height and root collar diameter of pigeon pea and *Sesbania sesban* trees at Owen Sithole Agricultural College, Empangeni, KwaZulu-Natal

Treatment	Establishment/survival Percentage (%) of trees	Height (m)	Root collar diameter (mm)
Sole pigeon pea	58[a]	1.388[a]	22.99[ab]
pigeon pea + *Panicum maximum*	42[a]	1.512[ab]	17.91[a]
pigeon pea + Maize	57[a]	1.550[b]	18.99[a]
Sole *Sesbania sesban*	98[b]	2.144[c]	30.17[bc]
Sesbania sesban + Maize	97.3[b]	2.221[c]	29.87[bc]
Sesbania sesban + *Panicum maximum*	96.67[b]	2.249[c]	33.38[c]
Cv	15.5	4.3	21
s.e.d	9.47	0.065	4.39
P-value	<.001	<.001	0.023

Means in each column with different superscripts are significantly different ($p<0.05$), according to Fisher`s protected Lsd. S.e.d is standard error of differences and cv is the coefficient of variation.

Dry matter yield of P.maximum at the end of the first cropping season, six months after establishment

The yield of *Panicum maximum* was significantly higher ($P < 0.05$) when planted as a sole grass than when it was inter-planted with the *S. sesban* and pigeon pea. Sole *P. maximum* (541.7 kg/ha) outperformed all intercrops. Comparably, sole *P. maximum* (85%) had higher establishment cover or survival as compared to counterparts*, P. maximum* + pigeon pea (53%) and *P. maximum* + *S. sesban* (13.33%) in Table 4.5.

The high yield of *Panicum maximum* under the current study of 541 kg/ha DM when cropped solely, as compared to 36.8 kg/ha DM and 157 kg/ha DM when intercropped with *Sesbania sesban* and *pigeon pea* respectively, was far from those reported earlier (Oyenuga 1960). Reason for the low yields might be connected with competition in water, nutrients and possible with shading effect of the legume trees upon the grass notable on *S. sesban* in particular which grows vigorously as compared to pigeon pea. Although *Panicum maximum* is shade tolerant, the resultant effect would be a reduction in the plants' photosynthetic capability, as a considerable portion of the grass would be denied optimum performance that might otherwise lead to increased yield of the plants (Bogdan 1977). This probably suggests a wider spacing than as previously reported for *S. sesban* (Kwesiga 1993).

Table 4.5 Establishment or survival percentage (%) and dry matter yield of *Panicum maximum* at Owen Sithole Agricultural College, Empangeni, KwaZulu-Natal at end of first cropping season

Treatment	Establishment cover /survival (%)	Dry matter yield (kg/ha)
Panicum maximum + *Sesbania sesban*	13.33[a]	36.8[a]
Panicum maximum + pigeon pea	53.33[b]	157.5[a]
Sole *Panicum maximum*	85[b]	541.7[b]
Cv	34.7	47.2
s.e.d	14.3	94.6
P-value	0.019	0.013

Means in each column with different superscripts are significantly different ($p<0.05$), according to Fisher`s protected Lsd; **s**.e.d is standard error of differences and cv is the coefficient of variation.

Limitation

During the study the germination of *P. maximum* and pigeon pea was very poor. After several attempts of replanting, the germination improved but still not convincing. This was exacerbated by drought and also *Panicum maximum* generally does not establish well. Monkeys destroyed the maize during the stage of physiological maturity.

Evaluation of *Zea-mays* intercropped with *Sesbania sesban* and pigeon pea

Objective: To determine maize productivity when intercropped with Sesbania sesban or pigeon pea at Owen Sithole Agricultural College.

During the 2016/17 season, the maize grain was destroyed by monkeys but we managed to measure root collar diameter using Vernier calipers within the net plot. We also measured maize height.

Germination (%), root collar diameter and height of maize at OSCA, 2016/17 season

Treatment	Germination/establishment (%)	Root collar diameter in (mm)	Height in (m)
Maize + pigeon pea	65.0	17.12	1.19
Maize + *S. sesban*	50.0	19.93	1.05
Sole maize	60.0	18.38	1.09
Cv	15.6	20.7	10.6
s.e.d	7.45	3.126	0.0958
P-value	0.238	0.691	0.435

4.3.4 Season 3 (2018/19) following exclusion of maize

At OSCA the maize was unsuccessful over the years and for the 2018/19 growing season, all the treatments involving maize was discontinued and the plan for the last year of the trial was amended to allow for a focus on silvo-pastoral systems as shown in Table 4.6.

The objective of this study was to evaluate the effect of intercropping *Sesbania sesban* and *pigeon pea* on the dry matter yield of *Panicum maximum* in KwaZulu-Natal. The treatments applied in the trial in the 2017/18 season were:

- Treatment 1: *Panicum maximum* + *Sesbania sesban*

- Treatment 2: *Panicum maximum* + pigeon pea
- Treatment 3: Sole *Panicum maximum*
- Treatment 4: Sole *Sesbania sesban*
- Treatment 5: Sole pigeon pea.

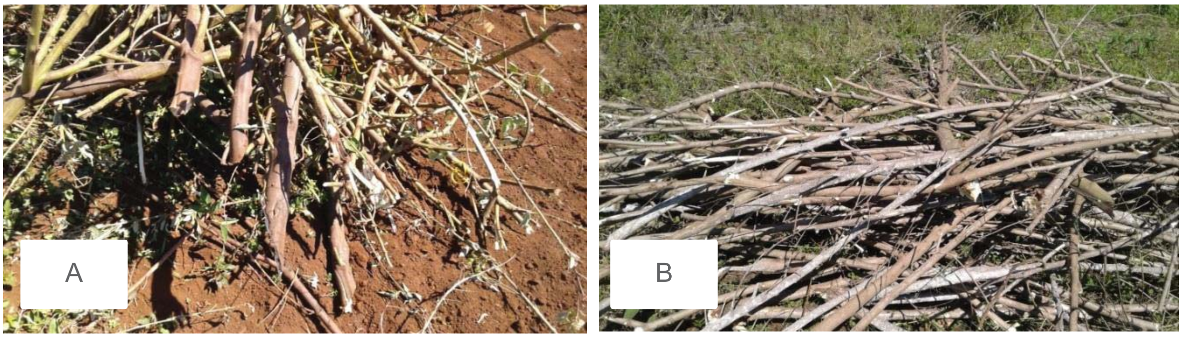
Table 4.6 Replacement of current cropping mixes at OSCA, Empangeni for 2018/19 season

Treatments	**Pigeon pea improved fallow**	***Sesbania sesban* Improved fallow**	**Continuous *P. maximum***	**Pigeon pea silvopostoral system**	***S. sesban* silvopastoral system**
2017/18	Pigeon pea	*S. sesban*	*P. maximum*	*Pigeon pea /P. maximum*	*S. sesban/P. maximum*
2018/19	*P. Maximum* (after 2-yr fallow)	*P Maximum* (after 2-yr fallow)	*P. maximum*	*Pruned pigeon pea/P. Maximum*	Pruned *S. sesban/P. maximum*

In the original trial design, these were going to be two year fallow plots, similar to the fallow plots that were going to be followed with maize. When the inclusion of maize was discontinued, then all plots that were to be planted with maize were dropped from the trial, leaving only those that were to be planted to *P. maximum*. Since *P. maximum* is perennial, and because it grows in shade, the decision was taken to rather cut back the trees than remove them completely. Thus a true silvopastoral system was incorporated into the trial. It allowed for comparison with sole *P. maximum* and with *P.maximum* established following a two year improved fallow.

The sole *S. sesban* and Sole *pigeon pea* plots provided true two-year fallows after which they were cleared and planted with *P. maximum* (Photograph 4.24). In the silvopastoral plots, the trees were pruned at 75 cm to reduce competition with the grass in terms of resources such as sunlight and water (Photograph 4.27). In September 2018 the trees in the fallow plots were removed in preparation for planting *Panicum maximum* as shown in Photograph 4.26 and Photograph 4.28*.* The amount of wood was quantified as fuel is one of the key benefits of fallow systems (Photograph 4.25). At the same time, the trees in the plots that already had *P. maximum* were pruned back to reduce competition and to provide a source of fodder.

Photograph 4.24 Clearing the pigeon pea (A) and *Sesbania sesban* (B) fallows in September 2018 at OSCA.



Photograph 4.25 Wood harvested from pigeon pea (A) and *Sesbania sesban* (B) when clearing the fallows at OSCA in September 2018.

Photograph 4.26 Fallow plot with the leaves and twigs of the *Sesbania sesban* trees returned as a mulch and woody material removed, OSCA, September 2018.

Photograph 4.27 Pruned *Sesbania sesban* trees in the silvopastoral system at OSCA in September 2018.

Photograph 4.28 Weeding (A) and then planting *Panicum maximum* into the plots (B) at OSCA in December 2018.

The *P. maximum* was harvested three times over the period between establishment in November 2016 and the end of the project timeframe:

- 6 month harvest: May 2017
- 12 month harvest: November 2017
- 18 month harvest: May 2018.

Methodology

Dry matter yield and growth parameters of P. maximum

Tiller height was measured randomly within each plot with the aid of a measuring tape, while the tiller numbers were counted. The dry matter yields were determined at the end of cropping season, after six months of establishment. The grass was cut back to a height of 15 cm above ground level with a sickle. The dry matter yields of *P. maximum* were determined after oven-drying samples for 3 days at 60°C.

Seed yield and tree growth variables

A sample of 9 trees was selected within each plot and they were marked by strings for repeated tree growth measurements. Root collar diameter and tree height was measured after 6, 12 and 18 months. The latter was measured by placing a graduated stick along the bole and recording the height of the highest living tip. Diameter at 5 cm above ground level was measured with Vernier callipers. This measurement is referred to as the root collar diameter (Muthuri et al., 2005). The pod and seed yield were recorded on the trees that were measured for growth variables.

Determining the effect of the fallow on soil characteristics

In July 2018, infiltration rates were determined for the different plots to find a way of showing the improved soil structure associated with the tree fallows (Photograph 4.29).

Photograph 4.29 Infiltration rates being determined at OSCA in July 2018.

Statistical analysis

Differences between treatments were tested with General Analysis of variance (ANOVA) using GENSTAT Release 18.2. (VSN International Ltd, 2016) and significant means separated using the Fisher protected LSD.

Results and discussion

Tree establishment, growth rate, pod and seed yield

There was significant differences between species (P<0.05) for tree establishment and survival. The highest tree survival and establishment was recorded on sole *S. sesban* while the lowest was observed on pigeon pea + *P. maximum* plots (Figure 4.3).

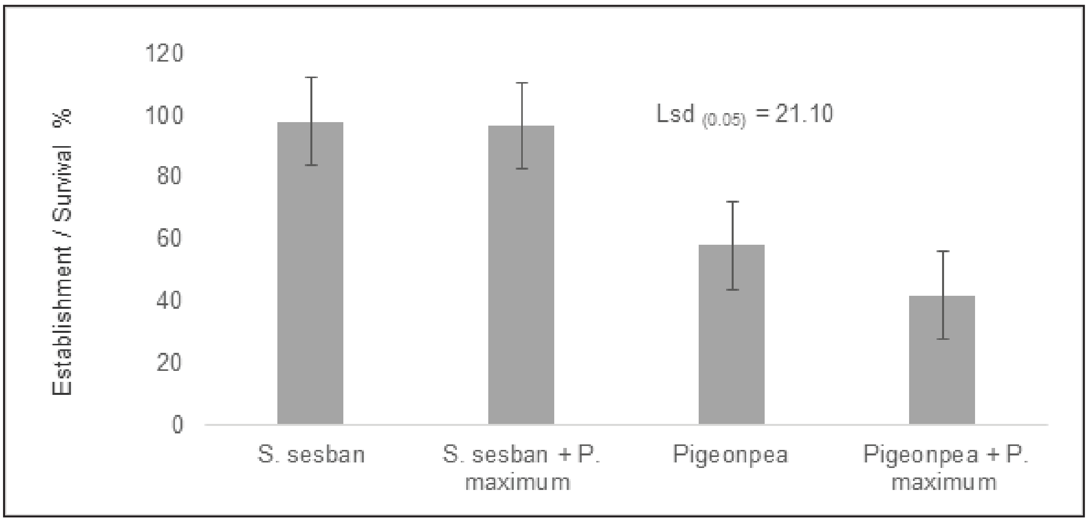


Figure 4.3 Establishment and survival percentage (%) of trees at Empangeni.

Results of sole pigeon pea and the pigeon pea intercrop showed that survival was very poor and this was probably due to the method of establishment and the effect of drought. Pigeon pea was directly seeded as compared to *S. sesban* that was raised from nursery seedlings and transplanted into the field. Soon after sowing of pigeon pea there was a period of drought that might have contributed to high mortality. Kwesiga et al. (1993) and Chirwa et al. (2004) reported similar results of poor establishment and high mortality in pigeon pea fallows under similar environmental conditions. Kwesiga and Coe (1994) also found that pigeon pea was slow in establishing as compared to *S. sesban* and suggested that the latter had the advantage since it was transplanted as compared to direct seeding.

Significant differences between treatments (P<0.05) were observed for tree height and root collar diameter. In three measurement times (6, 12 and 18 months) notable differences were observed for the two species for tree height as shown in Table 4.7. Treatments with *S. sesban* had greater height as compared to counterpart (pigeon pea). For root collar diameter, there were significant differences between treatments at 6 and 12 months as shown in Table 4.8, with Sesbania generally having greater root collar diameter than the pigeon pea, although there were not significant differences between treatments with the same tree species. For treatments involving *S. sesban,* growth was very rapid at initial establishment of the experiment that is why tree height and root collar diameter was greater than for treatments involving pigeon pea. In terms of seed yield, as shown in Table 4.9 there was a significant difference between the treatments with and without *P. maximum* for both tree species. The trees in the sole plots produced more seed than those in the mixed plots.

Table 4.7 Height of pigeon pea and *S. sesban* trees at Empangeni, KwaZulu-Natal

	Tree Height (m)		
Treatments	6 months	12 months	18 months
P. maximum + pigeon pea	1.51[a]	1.70[a]	1.92[a]
pigeon pea	1.39[a]	1.56[a]	1.97[a]
P. maximum + *S. Sesban*	2.25[b]	2.40[b]	2.78[b]
S. sesban	2.14[b]	2.49[b]	2.79[b]
CV	2.30	4.6	3.8
Lsd $_{(0.05)}$	0.08	0.1872	0.1816
P-value	<.001	<.001	<.001

Means in each column with different superscripts are significantly different (p<0.05), according to Fisher`s protected Lsd. S.e.d is standard error of differences and cv is the coefficient of variation.

Table 4.8 Root collar diameter for pigeon pea and *S. sesban* trees at Empangeni

	Root collar diameter of trees (mm)		
Treatments	6 months	12 months	18 months
P. maximum + pigeon pea	17.91[a]	19.17[a]	21.6
pigeon pea	22.99[ab]	24.97[ab]	29.2
P. maximum + *S. Sesban*	30.17[bc]	31.7[b]	36.6
S. sesban	33.38[c]	34.9[b]	35.3
CV	19.8	18.3	18
LSD$_{(0.05)}$	10.35	10.13	11.03
P-value	0.038	0.034	0.053

Means in each column with different superscripts are significantly different (P<0.05), according to Fisher`s protected Lsd. S.e.d is standard error of differences and cv is the coefficient of variation.

Table 4.9 Pod and seed yield of pigeon pea and *S. sesban* at Empangeni for 2016/2017 season

Treatment	Pod yield (kg/ha)	Seed yield (kg/ha)
S. sesban + *P. maximum*	193.6[a]	159.6[a]
S. sesban	319.9[a]	284.1[b]
pigeon pea + *P. maximum*	862.7[b]	746.3[c]
Sole pigeon pea	1240.3[b]	1066.7[d]
CV	8.7	8.5
LSD$_{(0.05)}$	113.732	95.453
P-value	<.001	<.001

Means in each column with different superscripts are significantly different (p<0.05), according to Fisher`s protected Lsd. S.e.d is standard error of differences and cv is the coefficient of variation.

Growth parameters of Panicum maximum

As shown in Table 4.10 as well as Figure 4.4 and Figure 4.5, there was a positive relationship between dry matter yield and leaf parameters (numbers and height of tillers) across all harvesting events (6, 12 and 18 months). The amount of dry matter production relies basically on the plant tillering and leaf development and growth processes (De Bona and Monteiro, 2010a), which was the reason for the positive relationship.

Table 4.10 shows the effect of intercropping different legume trees (pigeon pea and *S. sesban*) on dry matter yield of *P. maximum*. Sole *P. maximum* had the highest yield. Yields were reduced by intercropping, with *S. sesban* seemingly having the greatest negative effect on yield.

Table 4.10 Dry matter yield of *Panicum maximum* for 3 harvests at Owen Sithole Agricultural College, Empangeni KwaZulu-Natal

	Dry matter (kg/ha) harvesting times			
Treatment	**1st**	**2nd**	**3rd**	**Total**
P. maximum + *S. sesban*	36.3[a]	282[a]	555[a]	874[a]
P. maximum + pigeon pea	157.2[b]	926.7[b]	1129[b]	2212[b]
Sole *P. maximum*	541.2[c]	1209.3[b]	1557[b]	3307[c]
CV	0.5	28.8	21.7	21.7
$LSD_{(0.05)}$	2.699	526.8	532.2	1047.5
P-value	<.001	0.019	0.016	0.008

Means in each column with different superscripts are significantly different (P<0.05), according to Fisher`s protected Lsd.

These results agree with Wandera *et al.* (2000) who recorded a decline in yield of Napier grass intercrops as compared with sole grass. This might be due to competitive effect of legume trees on *P. maximum* (Kaushal et al., 2009). Shading of more than 50% of the incident radiation can have a detrimental effect on the biomass production of tropical forage grasses (Abraham et al., 2014). This might be reason behind difference on yields. Although *P. maximum* is shade tolerant, the resultant effect would be a reduction in the plants 'photosynthetic rates (Santiago-Hernandez et al., 2016). No significant differences were observed between sole *P. maximum* and *P. maximum*/pigeon pea intercrop on the second and third harvest these results agrees with Kyriazopoulos et al., 2012; Paciullo et al., 2014 where they found that under moderate shading, dry matter yield production may be similar in sole pastures or intercrops.

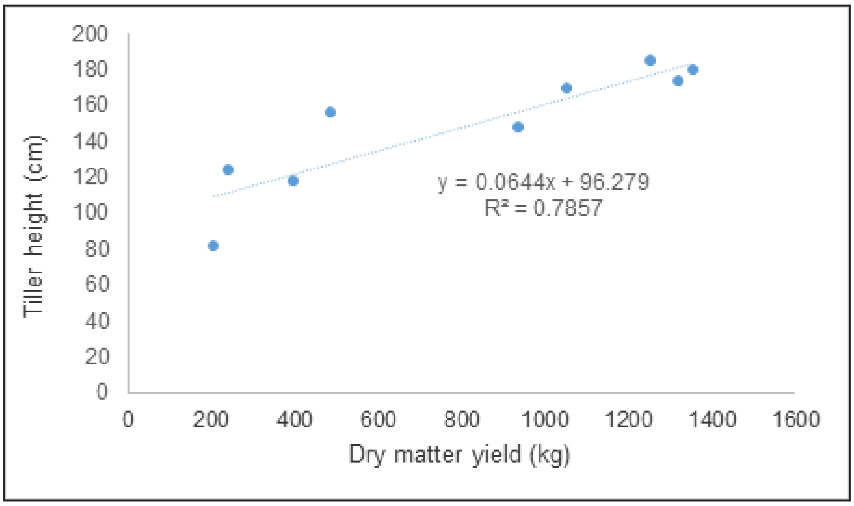


Figure 4.4 Tiller height correlated with dry matter yield at 12 months at Empangeni.

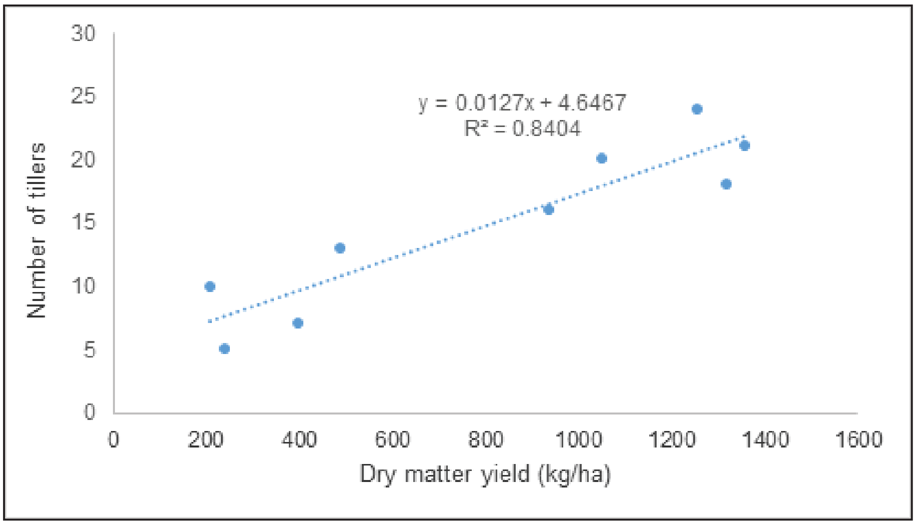


Figure 4.5 Number of tillers correlated with dry matter yield at 12 months at Empangeni.

Land productivity

The land productivity of the farming system is evaluated by Land Equivalent Ratio (LER) and the portion of land saved (Undie et al., 2012). LER combines the yields of two or more different crops into one index for comparison with sole cropping of or among intercrop systems (Workayehu, 2014). Workayehu (2014) argued that LER is calculated by dividing the amount of the intercropped yield by the amount of the monocropped yield for each crop in the field. Considering the total land productivity as indicated by LER significant difference ($P<0.05$), were observed (Figure 4.6).

The *P. maximum*/pigeon pea intercrop had LER greater than 1 as shown in Figure 4.6, which indicated that this combination was more beneficial than either *P. maximum* or *S. sesban* monocropping. When *P. maximum* was intercropped with *S. sesban* the ratio was less than 1, which means intercropping negatively affected the growth and yield of *P. maximum* and *S. sesban* (Dhima et al., 2007; Workayehu 2014). The LER of 1.37 indicates 37% greater yield for *P. maximum*/pigeon pea intercrop or 37% greater area required for monocropping system.

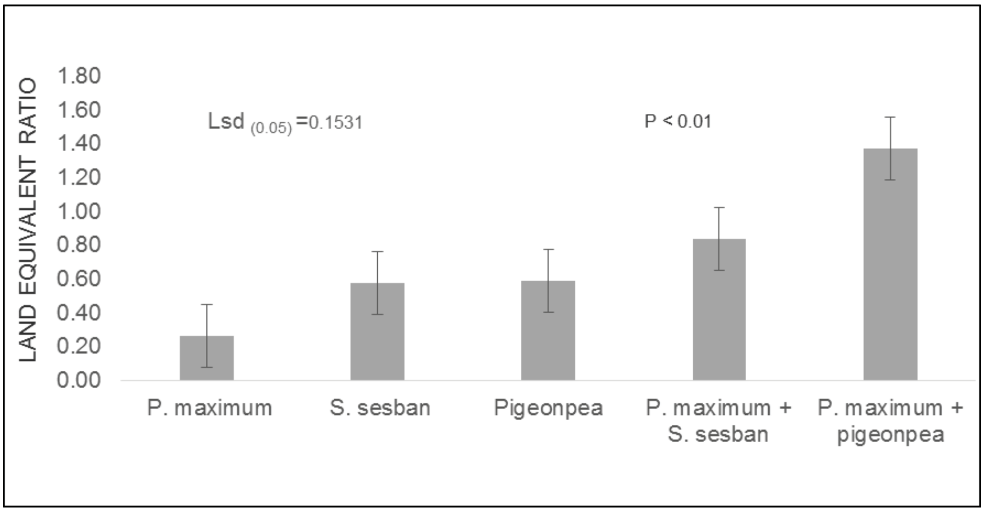


Figure 4.6 Land equivalent ratio for different fodder systems at Empangeni, KwaZulu-Natal in 2016/17-2017/18 season.

Sole *P. maximum* had higher total DM yield as compared to both intercrops. *P. maximum* intercropped with pigeon pea had a relatively similar yield to sole *P. maximum* on the second and third harvest, which makes it a suitable mixture compared with *S. sesban.* However, *P. maximum* intercropped with pigeon pea had higher land use efficiency as shown by the higher LER. Planting *P. maximum* with pigeon pea is more beneficial than with *S. sesban* or as a sole crop in terms of addressing a shortage of arable land. The practice of integrating pigeon pea trees in *P. maximum* pastures saves a substantial 37% land which can subsequently be used for other crop production. Pigeon pea is recommended in agroforestry systems due to its higher LER and the production of grain for human and livestock consumption and firewood. A farmer who buys concentrate can reduce costs by combining *P. maximum* with pigeon pea because this will provide a balanced diet.

Effects of agroforestry systems on aggregate stability, bulk density and infiltration rate

Significant differences ($P \leq 0.005$) were recorded for physical soil properties through different agroforestry systems (Table 4.11). At fallow clearing, the highest aggregate stability (9.87 m/mm) and infiltration rate (32 mm/hr) were observed for two-year *S. sesban* fallows as compared to sole *P. maximum* which had the lowest values (8.01 m/mm and 23.10 mm/hr respectively). The highest bulk density was experienced for sole *P. maximum* (1.31 g/cm$^{3)}$, which was significantly higher than all the treatments that had included trees.

Table 4.11 Effects of different agroforestry systems on aggregate stability, bulk density and infiltration rate at Owen Sithole Agricultural College, KwaZulu-Natal: Means in each column with different superscripts are significantly different (P<0.05), according to Fisher`s protected Lsd.

Treatment	Aggregate stability (m/mm)	Bulk density (g/cm^3)	Infiltration rate (mm/hr)
Two-year *S. sesban*	9.87^a	1.06^a	32.00^a
Two-year pigeon pea	9.65^a	1.10^a	29.00^b
P. maximum +*S. sesban*	9.39^a	1.12^a	29.47^b
P. maximum + pigeon pea	9.82^a	1.13^a	28.00^b
Sole *P.maximum*	8.01 b	1.31^b	23.10^c
LSD (0.05)	1.034	0.037	1.902
P-Value	0.003	<.001	<.001
CV	4.3	6.2	4.2

The result in Table 4.11 revealed significant difference (P 0.05) on aggregate stability, bulk density and infiltration rate. The improvement on aggregate stability, bulk density and infiltration rate could be attributed to formation and addition humus from decomposition of high-quality litter provided by *Sesbania sesban* and pigeon pea trees. This observation confirms with Ogunwole (2005) who found that improvement in physical soil properties depends on the quality of residue cover. The higher aggregate stability in Sesbania and pigeon pea fallows at both fallow clearing and at fourth crop harvest was probably due to the higher organic matter content as compared with sole *P. maximum*. Chirwa et al. (2004) reported similar results in Sesbania and pigeon pea fallows in Zambia. Generally, the observed mean range of bulk density in the study (1.06-1.31 g/cm^3), is ideal for optimum root growth since it is less than 1.40g/cm^3 (Eche et al., 2013). The higher infiltration rate in Sesbania and pigeon pea fallows and both intercrops is likely also due to the improvement in soil physical properties mentioned. Mapa and Gunasena (1995) cited that higher aggregate stability allows higher macro-porosities hence higher infiltration rates and diminishes soil erosion. Our study agrees with Chirwa et al. (2004) who found higher infiltration rates in two-year Sesbania and pigeon pea fallows.

Overall yields of Panicum maximum intercropped with pigeon pea and S. sesban

Significant differences ($P \leq 0.05$) were recorded between treatments for the dry matter yield through the agroforestry systems (Table 4.12). Fodder production from *P. maximum* was low in first harvest (6 months after planting) and it increased in subsequent harvesting periods (12 & 18, 24 months). Continuous sole *Panicum maximum* outperformed both intercrops at initial harvesting period up to the fourth harvest, then it gradually decreased on the fifth (1617 kg/ha) harvest from fourth (1683 kg/ha) harvest. Both intercrops continued steadily increasing. At fifth harvest in May 2019, *P. maximum* intercropped with pigeon pea was greater than all treatments.

Considering the *P.maximum* DM yields after the 2-year fallows, there were significant (P≤ 0.05) differences in terms of *P. maximum* dry matter yields for the May 2019 harvest (Table 4.12). There was no significant difference between *P. maximum* grown after two-year *S. sesban* or *P. maximum* planted after two-year pigeon pea. *P. maximum*/pigeon pea intercrop outperformed the continuous sole *P. maximum*. There was no significant difference between sole *P. maximum* and the *P. maximum/S. sesban* intercrop.

Table 4.12 Dry matter yield of *Panicum maximum* as affected by different land use systems at Owen Sithole Agricultural College, Empangeni KwaZulu-Natal: Means in each column with different superscripts are significantly different (P≤0.05), according to Fisher`s protected Lsd

Treatment	Dry matter yield (kg/ha)					
	May 2017	Nov 2017	May 2018	Nov 2018	May 2019	Total over 2 seasons
P. maximum + *S. sesban*	36^{c}	282.0^{b}	555^{b}	1257^{c}	1857^{bc}	3987^{b}
P. maximum + pigeon pea	157^{b}	926.7^{a}	1129^{a}	1853^{a}	2020^{b}	6086^{a}
Continuous sole *P. maximum*	541^{a}	1209.3^{a}	1557^{a}	1683^{b}	1617^{c}	6607^{a}
P. max after pigeon pea	-	-	-	-	2617^{a}	2617^{c}
P. max after *S. sesban*	-	-	-	-	3170^{a}	3170^{c}
LSD $_{(0.05)}$	2.70	526.8	532.2	196.5	365.8	534.6
P-value	<.001	0.019	0.016	<.001	<.001	<.001
CV	0.5	28.8	21.7	2.7	8.6	37.6

Means in each column with different superscripts are significantly different (P<0.05), according to Fisher`s protected Lsd.

P. maximum grass grown after two-year *S. sesban* had higher dry matter yield on the first harvest post-fallow followed by *P. maximum* intercropped with pigeon pea, while the sole continuous *P. maximum* had the lowest yield. The increase in dry matter yield in Sesbania and pigeon pea fallow system could be due to the presence of plant-available N from decomposing above ground biomass litter and improved soil physical soil properties. The results corroborate those of Kwesiga and Coe (1994) and Chirwa et al. (2004), where maize grain increased after two-year Sesbania/pigeon pea and pigeon pea fallows respectively. The decomposition of Sesbania and pigeon pea roots facilitated the release of N which also contributed to the improved maize yields. Chirwa et al. (2004) attributed the increase in maize yields after sesbania and pigeon pea fallow to available plant N and improved physical soil properties. Maroko et al. (1997) attributed the increase in crop yields after a Sesbania fallow to rapid mineralisation of Sesbania litter which is the probable reason why the *P. maximum* yield after the Sesbania fallows were greater than *P. maximum* on pigeon pea fallows. The decline in dry matter yield after fifth harvest on continuous sole *Panicum maximum* grass may be attributed to decline in aggregate stability and infiltration rate and soil fertility. Sanchez (1976) found that the major reason for the decline in yield is soil fertility depletion and deterioration of physical soil properties.

Aboveground biomass of Sesbania and pigeon pea plants in November 2018

Significant differences between treatments (p ≤0.05) were noted for leaf litter, twigs, fuelwood and total biomass at the time of clearing the two-year fallows and pruning back the woody component in the silvoposatoral treatments, which took place 2 years of establishment (Table 4.13). After 2 years the highest leaf litter was from the 2-year Sesbania fallows although it was not significantly different to 2-year pigeon pea fallows. Both pruned intercrops had the lowest leaf litter. Sesbania fallows assembled greater wood and total above-ground biomass than pigeon pea fallows (Table 4.13).

Table 4.13 Aboveground biomass of Sesbania and pigeon pea trees in September 2018

Treatment	Dry matter yield (kg/ha)			
	Leaf litter	Twigs	Fuel Wood	Total biomass
P. maximum + *S. sesban* (pruned at 75 cm)	350[b]	1802[b]	*	2152[a]
P. maximum + pigeon pea (pruned at 75 cm)	440[b]	1140[a]	*	1897[a]
2 year pigeon pea fallow	757[ab]	1613[ab]	4558	7338[b]
2 year Sesbania fallow	1167[a]	3160[c]	12180	15780[c]
LSD $_{(0.05)}$	552.2	543.0	*	179.8
P-value	0.039	<.001	*	<.001
CV	40.7	14.1	*	13.3

* No measurement since the treatments were cut at 75 cm

<u>Conclusions</u>

Results from this study showed that *Sesbania sesban* and pigeon pea in fallow systems significantly improve physical properties of soil which later increased dry matter yield as compared to sole *P. maximum* grass. Also the result has revealed that *Sesbania sesban* fallow significantly performed better in increasing dry matter yield of *P. maximum* and improving infiltration rate than pigeon pea although there was no significant different on aggregate stability and bulk density. It is recommended that farmers should be trained more on how to replenish their degraded areas and increase their forage yields in their fields using improved fallow system. Also for easy adoption, farmers should be educated more on the services and environmental functions of trees on crop land.

4.3.5 Improved fallow trial at Wartburg: Effect on soil macrofauna and selected physical soil properties

The objective of this experiment was to evaluate macrofauna order diversity, richness and abundance and physical soil properties of a two-year pigeon pea improved fallow versus a continuous maize monocropping system. It was hypothesised that a two-year pigeon pea fallow would result in increased macrofauna communities compared with a continuous maize monocropping system, which will result in reduced faunal diversity.

<u>Methodology</u>

The trial was established in the 2015/16 season, continued over the 2016/17 season and the fallow was terminated in the 2017/2018 season. The experiment was carried out using randomised complete block design replicated three times. The experiment had 5 treatments:

- Two year continuous maize without fertilizer
- Two year pigeon pea fallow
- Maize intercropped with pigeon pea during first season and pigeon pea alone in the second season (maize + pigeon pea – then pigeon pea)

- Sparse *Panicum maximum* grass (due to poor germination) intercropped with pigeon pea during first season and pigeon pea alone in the second season (grass + pigeon pea – then pigeon pea)
- Two-year natural fallow (grass and forbs including annual weeds).

Pigeon pea fallows were planted in pure stands at a spacing of 1 x 1 m by direct seeding. An open pollinated (OPV) maize variety, Okavango, was planted. In the mixed crop plots, maize had 1 m x 0.4 m spacing, while sole maize plots had 0.8 m x 0.5 m spacing.

Leaf litter traps of 4 m^2 were installed in all plots with pigeon pea to measure leaf litter for 7 months. After weighing, leaves and twigs were incorporated into the soil using a hoe. Trees were felled to ground level after two years of growth in October 2017. Stumps and root systems were left in the soil. The above ground biomass of trees was measured at fallow clearing by separating the biomass components into foliage (leaves and twigs), branches and stems. These components were then weighed as green after which samples of each component were collected on plot basis and oven dried at 70˚C constant moisture.

Soil fauna sampling

Macrofauna sampling was done after fallow termination in November 2017 during the rainy season using the method previously explained by Anderson and Ingram (1993). Macrofauna samples were collected from improved fallow, natural fallow and monoculture maize grown continuously without fertilizer. Steel monoliths measuring 25 × 25 × 25 cm were driven into the soil using a steel hammer on all plots of each treatment (replicated three times on randomly selected positions). After removing the soil from the monoliths, macrofauna were hand-sorted from each sample and then preserved in glass bottles containing 70% ethanol (Dangerfield, 1997). Here macrofauna is defined as an invertebrate group found within soil samples, which has more than 90% of its specimens visible to the naked eye (Lavelle et al., 2003). All the organisms collected were classified according to their typical ecological behaviour. These data allowed the computation of diversity (Shannon-Weaver index, H') and abundance (number of collected individuals per surface unit area).

Measurement of bulk density, porosity, infiltration and aggregate stability

The physical soil properties were measured at the fallow termination in November 2017. Bulk density was determined using a modified core method (Shaver et al., 2002). Samples were collected across improved fallows, natural fallow and maize grown continuously without fertiliser. Soil total porosity was then calculated using bulk density figures. A soil core containing an undisturbed sample was placed in the oven for 24 hours at 105°C to dry. The length and diameter of the soil core was measured and dry bulk density was calculated as the mass of solids divided by the volume of soil in the metal core. Measurements were recorded from double rings inserted diagonally in a systematic design in the net plot at 0, 0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, and 30 minutes. A constant infiltration rate was assumed to have been reached when five similar consecutive measurements were obtained (Ren et al., 2012). The average readings were used to calculate infiltration rate per plot using the model of Kostiakov (1932). Aggregate stability was measured using a modified wet-sieving technique (Yoder, 1936) employing the apparatus designed by Van Bavel (1952). Aggregate mean weight diameter (MWD) was calculated according to Van Bavel (1949).

Statistical analysis

Species diversity and richness on soil fauna was analysed using EstimateS for generating Shannon Wiener diversity indices which were now both and physical soil properties subjected to general analysis of variance (ANOVA) using GENSTAT software version 14.2 (GENSTAT, 2016). Mean comparisons for the individual treatments was done using both Least Significant Difference of means (LSD, $P < 0.05$) and the Fisher`s Protected Test. Correlation and regression analysis were computed using Microsoft excel on leaf litter against soil macrofauna diversity, species richness, infiltration rate and aggregate stability. Infiltration rate was regressed against aggregate stability.

Results and discussion

Information pertaining to the trial site at Fountainhill Estate at Wartburg is presented in Table 4.14 and Figure 4.7.

Table 4.14 Soil chemical and physical soil properties at Fountainhill Estate Farm, Wartburg

Parameter	Value
Nitrogen (%)	0.06
Phosphorus mg/L	20.4
Potassium mg/L	114.2
Calcium mg/L	488
Magnesium mg/L	95.6
Copper mg/L	2.98
Total Cations cmol/L	3.59
Organic Carbon (%)	0.65
pH (KCL)	4.37
Clay (%)	16

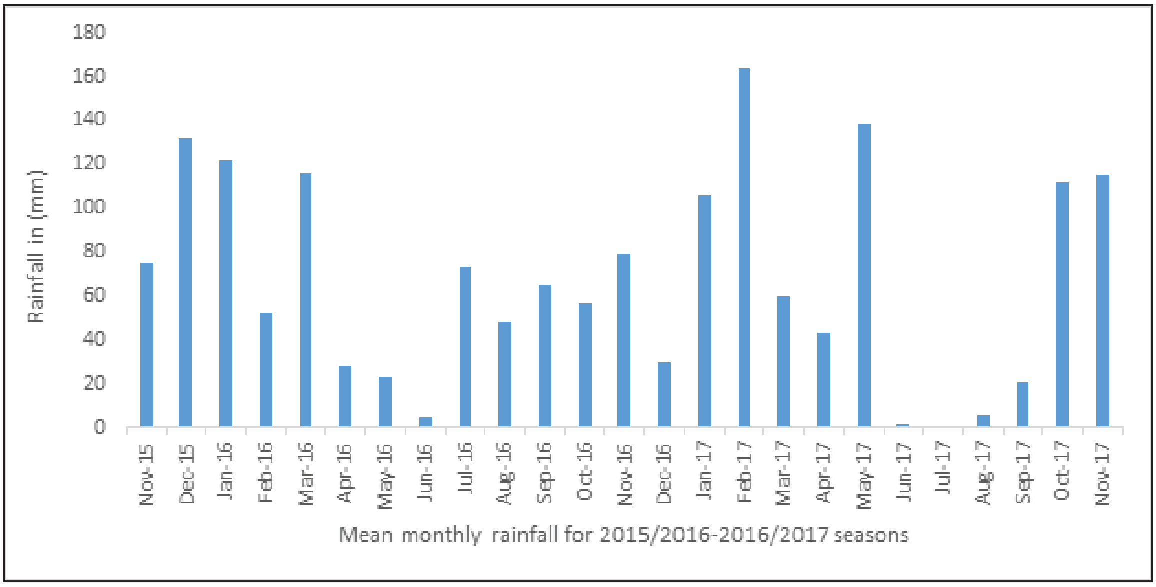


Figure 4.7 Mean monthly rainfall for 2015/2016-2016/2017 seasons at Fountainhill, Wartburg.

Soil macrofauna species diversity, richness and abundance

Significant differences in terms of species diversity and richness (P<0.05) were observed across treatments. The two year pigeon pea fallow had significantly higher species diversity index (1.75) as compared to the two year continuous maize (0.98) and the grass + pigeon pea – then pigeon pea (0.78a) as shown in Table 4.15.

The highest species richness was also found in two year pigeon pea fallow, maize + pigeon pea – then pigeon pea and two year grass + pigeon pea, where anthropogenic disturbance was minimal. Meloidae (beetles), Pheidole (ants), Technomyrmex (ants), Camponotus (ants) and Oligochaeta (earthworms) were the most 5 dominant orders of macrofauna observed in almost all treatments, with two year pigeon pea fallow plots harbouring more individuals as compared to other treatments as shown in Table 4.16.

The majority of the soil macrofauna were less abundant under continuous maize as presented in Figure 4.8. Higher abundance of these macrofauna under two year pigeon pea fallow is probably due to the practice that maintains a year round canopy, leaf litter, amelioration of the surface soil temperature and moisture by tree leaf biomass incorporated into the soil. These results are in agreement with findings from other parts of India (Rossi and Blanchart 2005; Tripathi et al., 2005) and elsewhere (Moc¸o et al., 2009).

Table 4.15 Shannon Wiener diversity indices (H') values for macrofauna species diversity and richness under different treatments during 2017 season

Treatments	Species Diversity (H`) values	Species Richness (H`)
Grass + pigeon pea – then pigeon pea	0.78[a]	10.56[bc]
Two year continuous maize	0.98[a]	6.00[a]
Maize + pigeon pea – then pigeon pea	1.62[b]	13.33[c]
Two year natural fallow	1.66[b]	9.67[b]
Two year pigeon pea (improved fallow)	1.75[b]	17.44[d]
P-value	<.001	<.001
$LSD_{(0.05)}$	0.33	3.49
Cv	13.0	16.3

Values followed by same superscript letters are not significantly different at P<0.05 according to Fisher`s Protected LSD.

The lower diversity and abundance in continuously maize cropping systems could be due to lack of habitat heterogeneity and food resources. Continuous maize monocropping may lead to soil erosion, which further diminishes the abundance and diversity of soil macrofauna by physically detaching them, eradicating their microhabitats and changing the microclimatic conditions within the soil.

According to Rahman et al. (2012), annual continuous monocropping systems have lower diversity and abundance of soil macrofauna as compared to agroforestry systems. This may have a detrimental effect on the flow of organic matter and nutrients, in turn adversely affecting soil fertility and crop productivity. The structural complexity and the niches contributed by the trees may boost the belowground communities.

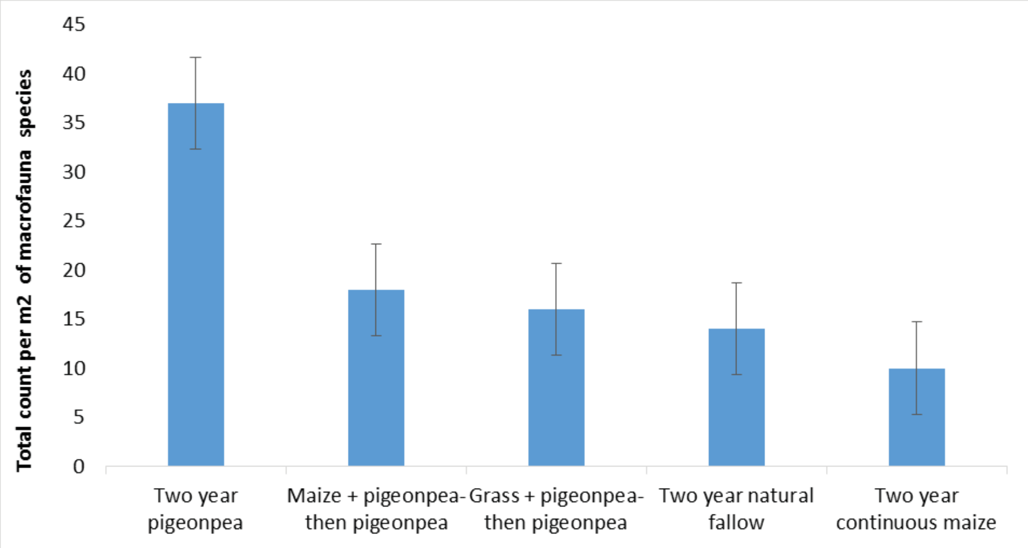


Figure 4.8 Soil macrofauna species abundance at Fountainhill, Wartburg (Total counts per m^2).

The two year pigeon pea fallow plots had greater abundance and diversity of soil macrofauna because they had a well-developed litter layer and had experienced less human interference. This is further supported by the positive correlation between cumulative tree leaf biomass and species diversity (R^2 = 0.73), but less so by the correlation with species richness (R^2 = 0.57) among pigeon pea plots. Therefore it is logical to hypothesise that abundance, diversity and richness species tend to increases with increase in biomass of the leaf litter fall. Generally the graphs are showing linear relationship between soil macrofauna species richness, diversity and abundance against leaf litter, which is in line with the findings of Moc¸o et al. (2009).

Table 4.16 Soil macrofauna morpho-species recorded at Fountainhill, Wartburg, South Africa after two years of agroforestry system (improved fallows).

Common name	Morpho-species	2 yr Pp	Mz+Pp - Pp	Gs+Pp - Pp	2 yr Nf	2 yr Mz
Earthworms	Oligochaeta sp.1	24	5	3	0	0
Earthworms	Oligochaeta sp.2	13	0	0	8	0
Earthworms	Oligochaeta sp.3	7	1	4	3	0
Bug	Cydnidae sp.1	2	2	1	4	0
Ants	Camponotus sp.1	55	11	10	29	0
Ants	Crematogaster sp.1	0	0	6	0	0
Ants	Pheidole sp.2	120	20	156	0	43
Beetle	Chrysomelidae sp.2	0	0	1	0	0
Beetle	Tenebrionidae sp.1	0	2	0	2	0
Beetle	Tenebrionidae sp.2	7	0	0	2	1
Beetle	Tenebrionidae sp.3	2	0	1	0	0
Beetle	Tenebrionidae sp.4	4	0	1	0	0
Beetle larvae	Scarabaeidae sp.1	12	1	0	1	2
Millipede	Diplopoda sp.1	0	1	0	1	1
Millipede	Diplopoda sp.2	1	0	0	0	0
Millipede	Diplopoda sp.3	3	0	0	0	0
Millipede	Diplopoda sp.4	2	0	2	0	0
Ant	Technomyrmex sp.1	136	26	0	0	15
Butterfly larvae	Lepidoptera sp.1	0	1	0	0	0
Cocoon	Lepidoptera sp.2	2	1	1	0	0
Larvae of Lepidoptera	Lepidoptera sp.3	10	0	1	0	0
Larvae of Lepidoptera	Lepidoptera sp.4	2	0	0	0	0
Larvae of Lepidoptera	Lepidoptera sp.5	15	0	0	0	0
Larvae of Lepidoptera	Lepidoptera sp.6	1	0	0	0	0
Beetle larvae	Coleoptera sp.1	0	1	0	0	1
Beetle larvae	Coleoptera sp.2	0	3	0	3	0
Beetle larvae	Coleoptera sp.3	0	1	0	1	0
Beetle larvae	Coleoptera sp.4	1	0	0	0	0
Beetle larvae	Coleoptera sp.5	1	0	0	0	0
Centipede	Chilopoda sp.1	2	2	0	2	0
Woodlouse	Oniscidea sp.1	1	0	2	0	2
Bugs	Delphacidae sp.1	0	0	0	2	0
Termite	Termitidae sp.1	25	0	0	0	13
Ant	Myrmicaria sp.1	0	1	0	0	0
Bug	Hemiptera sp.1	0	1	0	1	0
Bug	Hemiptera sp.2	1	0	0	0	0
Termite	Rhinotermitidae sp.1	0	0	0	0	1
Spider	Arachnida sp.2	10	0	1	0	0
Cricket	Gryllidae sp.1	0	0	1	0	0
Beetle	Meloidae sp.1	458	1	191	77	59
	Total (individuals)	**917**	**81**	**382**	**136**	**138**

2yr Pp = 2 years of pigeon pea fallow, Mz + Pp-Pp = maize + pigeon pea – then pigeon pea, Gs + Pp-Pp = 2 year grass + pigeon pea, 2yr Nf = 2 years of natural fallow, 2yr Mz = 2 year continuous maize (control).

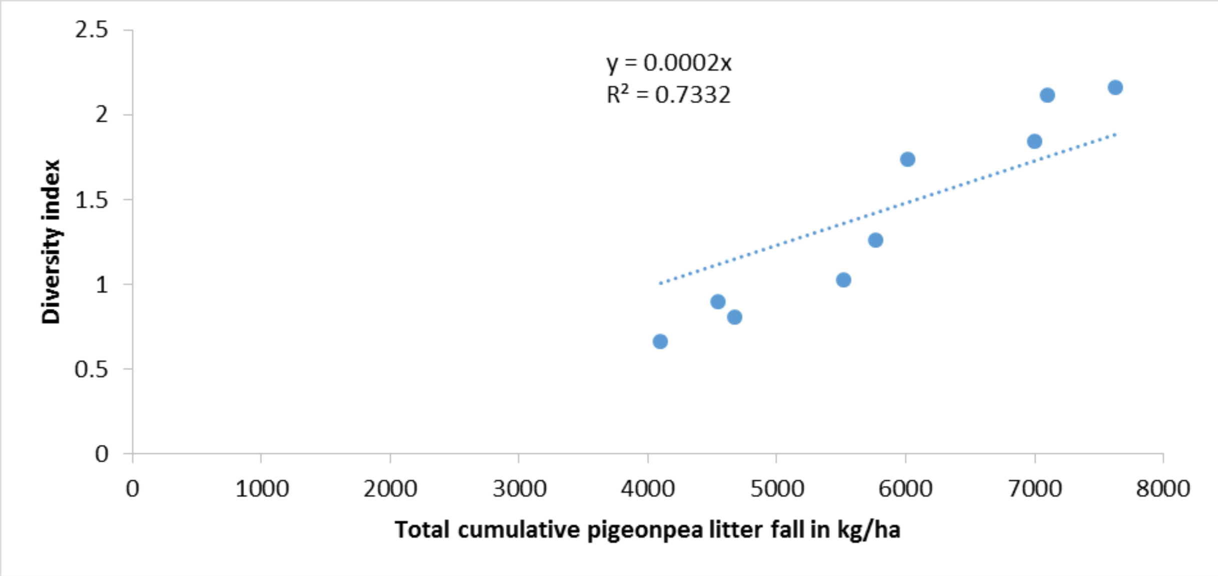


Figure 4.9 Correlation of diversity index with total cumulative pigeon pea leaf litter fall at Wartburg, 2017.

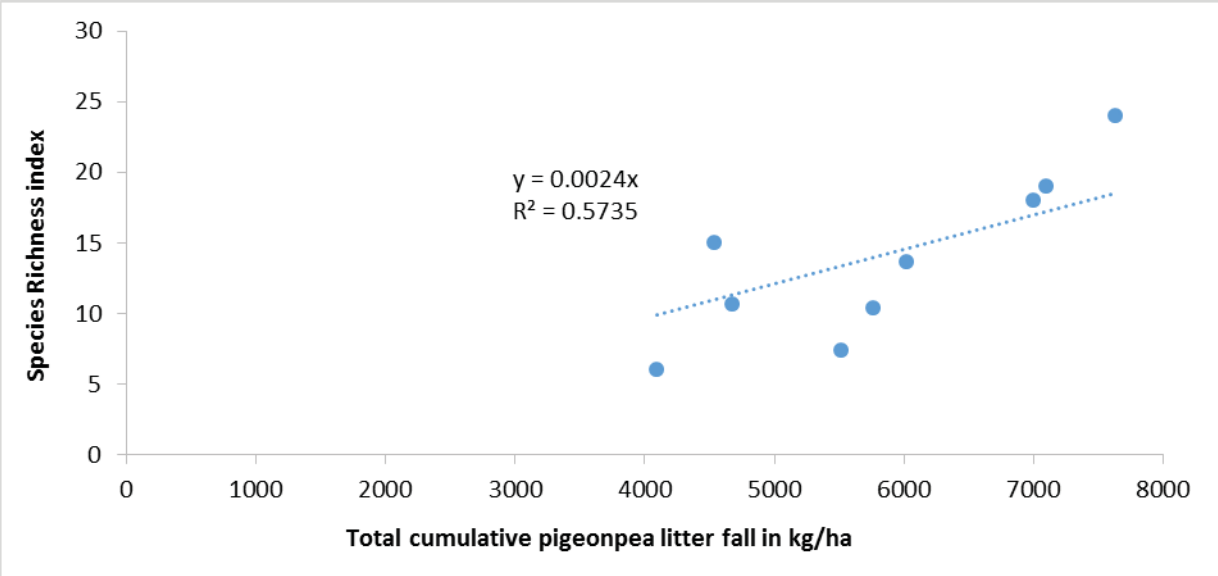


Figure 4.10 Correlation of macrofauna species richness with total cumulative pigeon pea leaf litter at Wartburg, KwaZulu-Natal 2017.

It can be suggested that diversity, richness and abundance of soil macrofauna is lower in annual monocrops than in agroforestry systems. Microclimate factors such as higher soil water content, lower soil temperature, and incident radiation probably favoured the soil macrofauna to thrive under pigeon pea fallows as compared to continuous maize cropping systems. Legume trees (pigeon pea) used in improved fallows will affect soil function as they act on the determinants of soil function including climate, edaphic factors and quality of organic matter (Lavelle et al., 2003). Studies and syntheses by Giller et al. (1997); Lavelle et al. (2003) and Susilo et al. (2004) indicated that even when abundance is low, soil macrofauna are significant regulators of nutrient turnover both directly through their feeding activities and indirectly through their influence on soil structure and biological processes.

Pigeon pea tree cover in improved fallows reduces soil degradation by reducing the impact of rain drops and sudden changes in the relative humidity. Sileshi and Mafongoya (2006) argued that the increase in earthworms, millipedes and termites under improved fallows is attributed to high biomass and litter on the soil surface this is probably the reason why we had abundance of these in two year pigeon pea fallow. Earthworms and millipedes were significantly abundant in agroforestry systems compared with annual monocropping fields (Rahman et al., 2012). Therefore, it can be concluded that diversity, species richness and abundance of soil macrofauna increases from annual monocropping systems to improved fallows agroforestry systems.

Physical soil properties (Bulk density, porosity, infiltration and aggregate stability)

The bulk density measured at fallow clearance was significantly differently between treatments ($P< 0.05$), being lowest under the two year pigeon pea fallow (1.22 g/cm^3) and the grass + pigeon pea then pigeon pea (1.26 g/cm^3) plots as compared to the two year continuous maize without fertilizer (1.46 g/cm^3) and the natural fallow (1.43 g/cm^3), as shown in Table 4.17. A significant difference ($P< 0.05$) was also observed for porosity across the treatments. Maize + pigeon pea – then pigeon pea had the highest porosity (67%) while the lowest soil porosity was experienced for two year continuous maize as shown in Table 4.17. Significant differences ($P<0.05$) were also observed at fallow termination for infiltration rate. The two year pigeon pea fallow had the highest infiltration rate, while the lowest rate was recorded in the two year continuous maize plots. Mean weight diameter of soil aggregates was significantly different on the treatments at fallow termination ($P<0.05$). The highest mean weight diameter of stable aggregates was recorded in the two year pigeon pea fallow, followed by the two year grass + pigeon pea plots. The lowest mean weight diameter for soil aggregates was recorded in the two year continuous maize (control) (5.02 mm) as shown in Table 4.18.

Table 4.17 Selected soil physical properties of treatments at Wartburg, November 2017

	Bulk density (g/cm^3)	Porosity (%)	Infiltration rate (mm/m)
Two year pigeon pea fallow	1.22^{a}	54^{ab}	29.81^{c}
Grass + pigeon pea – then pigeon pea	1.26^{a}	53^{ab}	20.99^{b}
Maize + pigeon pea – then pigeon pea	1.36^{ab}	67^{b}	15.97^{ab}
Two year natural fallow	1.43^{b}	46^{a}	19.11^{ab}
Two year continuous maize	1.46^{b}	45^{a}	12.44^{a}
$LSD_{(0.05)}$	0.15	14.7	7.47
P-value	0.015	0.044-	0.006
CV	9.4	23.3	20.2

Values followed by same superscript letters are not significantly different at $P<0.05$ according to Fisher`s Protected LSD.

Table 4.18 Mean Weight Diameter of soil aggregates of treatments at Wartburg, November 2017

Treatments	Mean Weight Diameter (mm)
Two year continuous maize	5.02^{a}
Maize + pigeon pea – then pigeon pea	11.20^{c}
Two year Natural fallow	8.99^{b}
Grass + pigeon pea – then pigeon pea	10.13^{bc}
Two year pigeon pea fallow	11.45^{c}
$LSD_{(0.05)}$	1.604
P-value	<.001
CV	4.4

Values followed by same superscript letters are not significantly different at $P<0.05$ according to Fisher`s Protected LSD.

The higher mean weight diameter of soil aggregates at fallow termination in both the two-year pigeon pea fallow and in the grass + pigeon pea-then pigeon pea plots was probably due to high organic matter content as compared to continuous maize. Mapa and Gunasena (1995) reported similar results in hedgerow intercropping. The higher bulk density under two-year continuous maize cropping could be attributed to the non-availability of organic matter on the soil surface while the presence of pigeon pea leaf litter on two year fallow plots tended to lower the bulk density. The results from this experiment confirm the earlier findings by Liu et al. (2006) who reported high bulk density after continuous monocropping. The increased bulk density could be linked to high soil compaction under the continuous maize cropping, which could impede root growth to exploit nutrients, hence leading to lower maize grain yields.

The management practices and type of vegetative cover can influence soil physical properties over time. These findings support earlier work by Amusan et al. (2006) who reported inverse relationships between bulk density and porosity of soils under different cropping systems. Increased development of roots of pigeon pea trees and frequent litter fall kept the soil in the improved fallow system persistently protected thereby resulting in improved soil physical properties. The lower bulk density under pigeon pea fallow can have a positive effect on the development of roots, especially in maize crop, because when soil bulk density increases, soil strength increases and soil aeration decreases, leading to adverse effects on root growth (Nambiar and Sands, 1992).

Positive relationships between the biomass of leaf litter accumulation against infiltration (R^2 =0.60), and aggregate stability (R^2 =0.67) was observed (Figure 4.11 and Figure 4.12). Showing that agroforestry systems that produce more biomass leaf litter that is returned to the soil surface are highly likely to have positive effects of soil aggregate stability and infiltration.

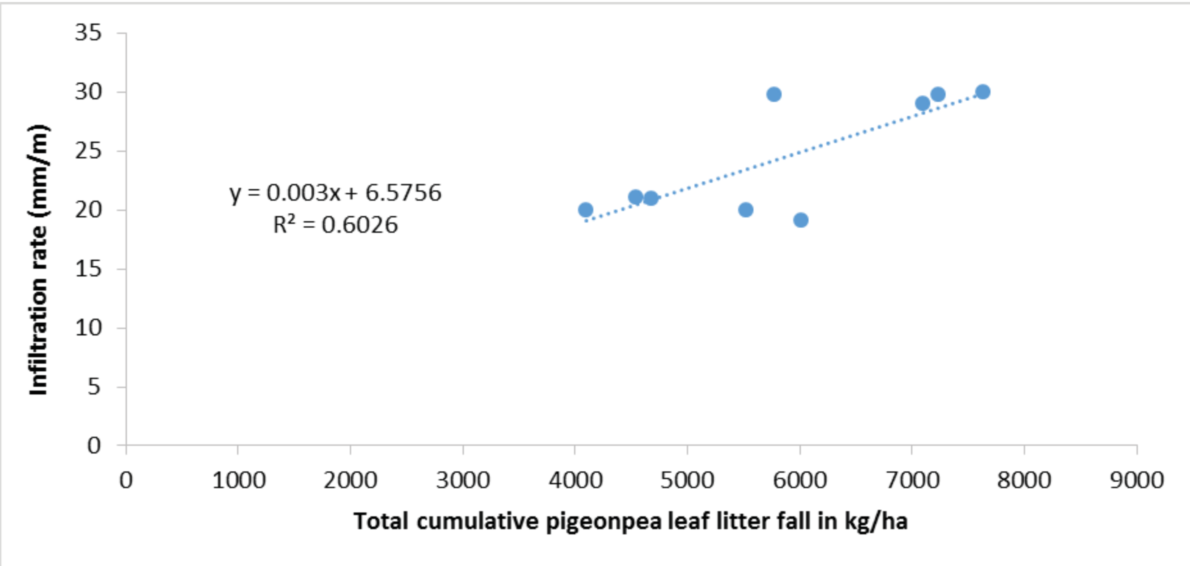


Figure 4.11 Correlation of infiltration rate with total cumulative pigeon pea leaf litter fall at Wartburg, South Africa, 2017.

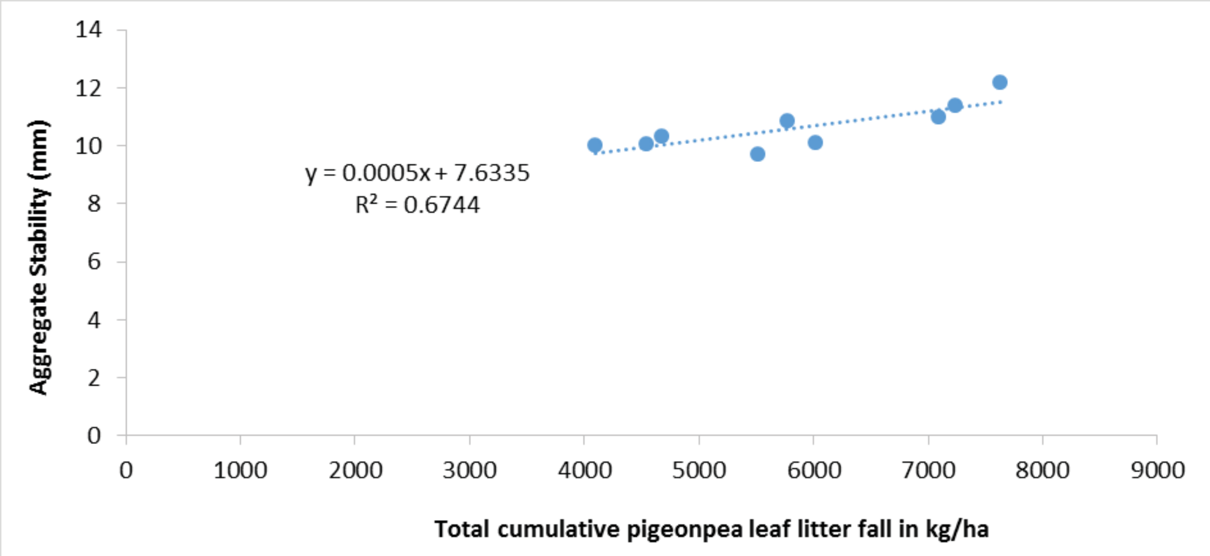


Figure 4.12 Correlation of aggregate stability with total cumulative pigeon pea leaf litter fall at Wartburg.

A positive relationship ($R^2 = 0.72$) exists between aggregate stability and infiltration as shown in Figure 4.13. Therefore it can be hypothesised that an increase in soil aggregates would lead to greater infiltration rates, thereby reducing runoff and erosion.

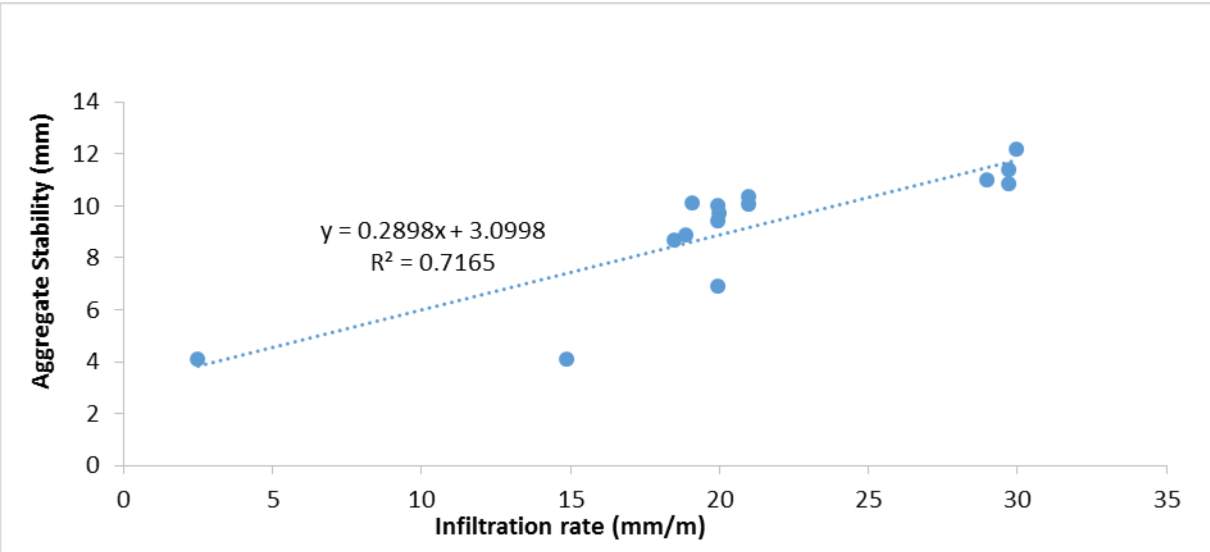


Figure 4.13 Correlation of aggregate stability with infiltration rate in agroforestry systems at Wartburg, 2017.

In the study, high infiltration rate in the two-year pigeon pea fallow could have been due to the improvement in the soil physical properties (improved soil aggregation, increased porosity and decreased soil bulk density). Similar results were reported by Chirwa et al. (2004) where high soil aggregate and infiltration rates were higher in the two-year pigeon pea fallow plot as compared to two-year continuous maize. The increase in soil macrofauna abundance has been correlated with increased soil water infiltration (Mando and Miedema 1997). Mapa and Gunasena (1995) found that higher stable aggregates facilitate higher macro-porosities, higher infiltration rate and reduce soil erosion. Accumulation of plant litter produced by the pigeon pea trees allows greater infiltration of rainwater thereby preventing the quick loss of soil moisture and increasing the soil water holding capacity. Species diversity in agroecosystem is important because of their differences in ecologically behaviour which in turn influence soil structural properties such as aggregate stability, porosity and water infiltration (Brown et al., 2000; Six et al. 2004; Bottinelli et al., 2015). These results show that pigeon pea based cropping systems will have a higher infiltration. This has an effect on increased water infiltration and decreased bulk density, which reduces surface water runoff and hence decreases erosion as compared with continuous maize cropping systems. This means that during periods of water stress, maize grown after a pigeon pea fallow will perform better than the continuous maize crop (if neither is provided with fertilizer). This indicates that soil physical properties are modified by the types of cropping systems and management practices employed (Azam 2008).

Organic matter added by pigeon pea trees is an ideal substrate for microbial activity, which acts as an agent for improving the stability of the aggregates (Udawatta et al., 2008). This will promote better pore distribution and because decomposing organic matter components are less dense than the mineral components, this leads to lowering of surface soil bulk density (Tolk. 2003). Macrofauna ingest considerable amounts of soil and dead plant material, thereby contributing to the blending of organic matter and mineral soils. This improves aggregate stability and increases the surface of organic material so that it is more readily colonised and decomposed by soil microflora (Lavelle et al., 2003). This is probably the reason why the aggregate stability was higher on the two-year pigeon pea and the grass + pigeon pea – then pigeon pea plots than for continuous maize plots. Susilo et al. (2004) argued that ants, beetles and millipedes are more common in the litter layer as compared with the soil. Consistently, ants, beetles and millipedes were more abundant under the two-year pigeon pea fallow, where there was much leaf litter on the surface with little soil disturbances. Soil macrofauna carry out essential functions associated to the growth conditions of plants. Earthworms and termites increase soil porosity by burrowing through the soil (Lavelle et al., 2003; Susilo et al., 2004). This is probably why bulk density was lower and infiltration rates and porosity were higher in two-year pigeon pea, the grass + pigeon pea – then pigeon pea and the maize + pigeon pea – then pigeon pea than with the continuous maize plots. Variations in the soil physical properties observed in continuous maize cropping and the two-year pigeon pea fallow are attributable to a low soil disturbance in the latter coupled with mulching effects of frequent additions of organic matter through leaf litter fall.

Conclusion

This study showed that improved fallow agroforestry systems had significantly greater fauna diversity, abundance, and richness. The accumulation of pigeon pea leaf litter inputs showed positive effect on soil macrofauna diversity, richness, abundance and improved aggregate stability and infiltration rate. The correlation of macrofauna with physical soil properties (aggregate stability and infiltration rate) attributes was very high. Leaf litter accumulation under this study can be used to predict macrofauna diversity, richness and abundance, infiltration rates and aggregate stability. Infiltration rates can be predicted by aggregate stability as shown by this study. Where there is limited equipment to measure infiltration rates and aggregate stability or personnel to identify those soil macrofauna functional groups, leaf litter characteristics can be used to predict these variables. Further studies must concentrate on the functional diversity of the fauna groups. Future research is necessary to confirm whether increases in these soil macrofauna indices and improved physical soil properties are responsible for the increase in crop productivity.

4.3.6 Improved fallow trials at Wartburg: Results of 2015/16 season (*S. bispinosa*)

In the first season, there was an error with the Sesbania seed supplied by a seed company and thus *Sesbania bispinosa*, which is an annual, was planted instead of *Sesbania sesban*.

Methodology

The experiment was established at Fountainhill Estate (latitude 29°27'2" S; longitude 30°32'42" E and altitude 853 m above sea level) in the uMshwathi Local Municipality, near Wartburg approximately 30 km northeast of Pietermaritzburg in KwaZulu-Natal, South Africa. The site has an annual precipitation of 805 mm per annum. The minimum temperature is 3.3°C and the maximum is 37.4°C, with a frost index of -1. The weather conditions experienced over the trial period are shown in Figure 4.14.

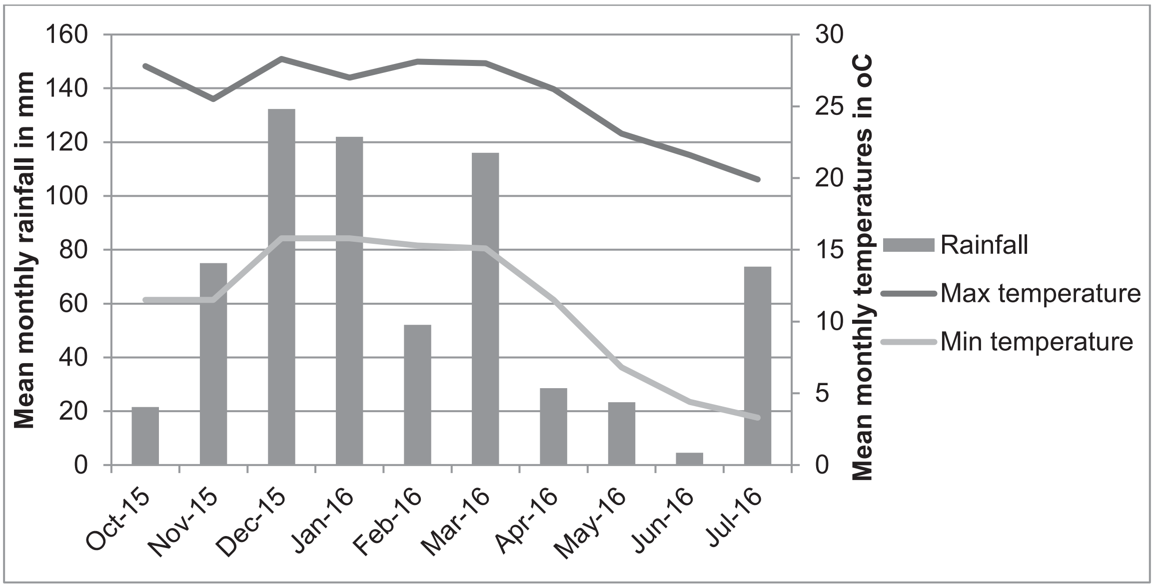


Figure 4.14 Monthly rainfall, mean maximum minimum temperatures for 2015-16 growing season at Wartburg-Fountainhill Estate site.

The experiment had 8 treatments (1) sole maize, (2) sole *panicum maximum (*3) sole pigeon pea, (4) sole *S. bispinosa* (5) maize + *S. bispinosa,* (6) maize + pigeon pea, (7) *panicum maximum* + *S. bispinosa* and (8) *panicum maximum* + pigeon peas. The experiment was laid out in a randomised complete block design (RCBD) replicated three times as shown in Table 4.19.

Table 4.19 Plot layout at Fountainhill Estate

1 Mz & SB	2 Mz & PP	3 PP	4 Mz	5 SB	6 PM & PP	7 PM & SB	8 PM
9 Mz & PP	10 PM & SB	11 PP	12 PM & PP	13 Mz	14 PM	15 Mz & SB	16 SB
17 PM & PP	18 Mz & SB	19 PP	20 Mz	21 PM	22 Mz & PP	23 PM & SB	24 SB

Where Mz=maize, SB=*S. bispinosa*, PP=pigeon pea, PM=*Panicum maximum*

Textbox 1: Summary of measurements

The trial measurements are summarised as:

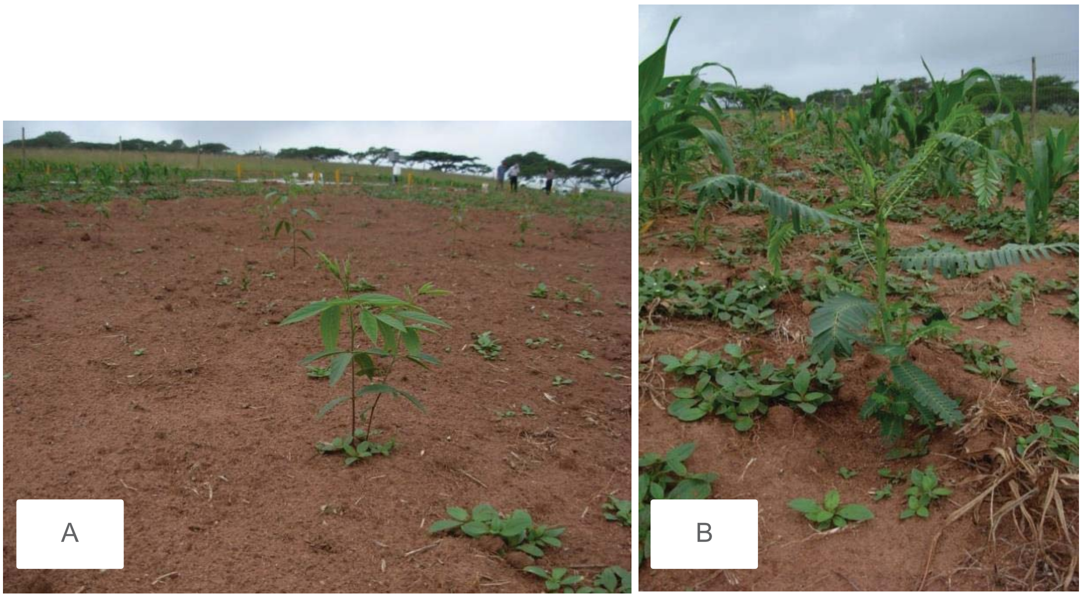
- Total Area = 85 m x 22 m = 1,870 m^2
- Total Area of each plot = 8 m x 6 m= 48 m^2
- Total number of plots = 24
- Passage widths between plots = 2 m

Plant populations and arrangements:

- Tree species
    - Total number of trees per plot = 48
    - Spacing of 1 m inter-row and 1 m in-row
- Maize
    - Plant population: 25,000 plants/ha
    - Mixed crop plots: Inter-row spacing 1 m; In-row spacing 0.4 m.
    - Sole crop plots: Inter-row spacing 0.8 m; In-row spacing 0.5 m.
- Grass species (*Panicum maximum*)
    - Broadcast at a rate of 10 kg/ha.

The Sesbania seedlings were planted into seedling trays in mid-October 2015 at a commercial nursery and were transplanted into the field in mid-January 2016. The pigeon peas were direct seeded at the same time, together with the maize and grass.

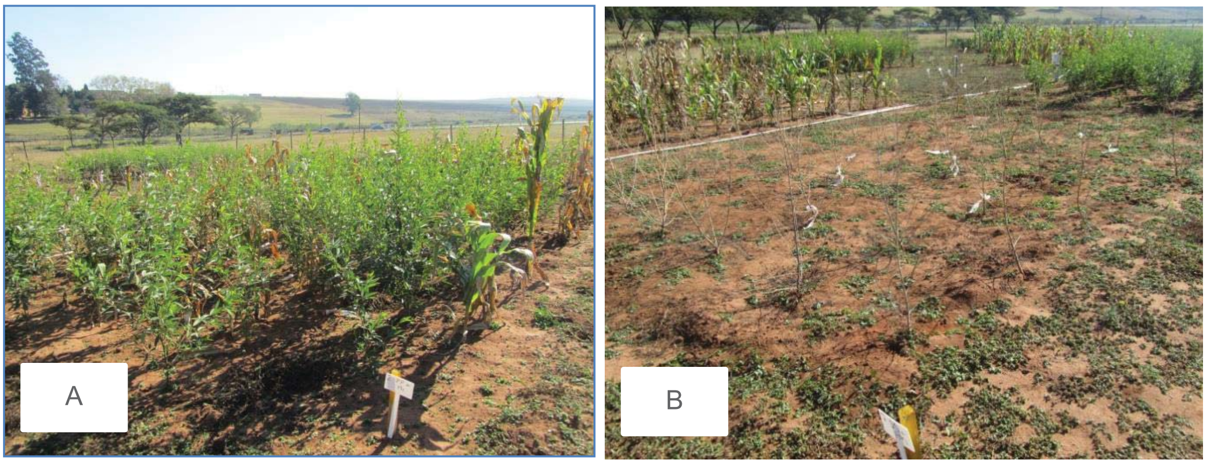
Photograph 4.30 to Photograph 4.33 show the growth and senescence of the crops over the period February to June 2016. In July the pigeon pea was affected by frost and the plants lost most of their leaves.



Photograph 4.30 Pigeon pea (A) and *S. bispinosa* (B) at Fountainhill Estate in February 2016.

Photograph 4.31 *S. bispinosa* at Fountainhill Estate in April 2016.

Photograph 4.32 Maize/pigeon pea plot at Fountainhill in April 2016.



Photograph 4.33 A maize/pigeon pea plot (A) and a *S. bispinosa* plot (B) at Fountainhill in June 2016.

Representative soil samples were taken from the trial site using a soil auger at 0-20 cm soil depths across 8 points within the experimental field before planting. Laboratory analyses were done at Cedara on the soil samples to determine pH, N, P, K, Mg, Ca and percentage organic carbon. The results of the analysis are presented in Table 4.20. The layout of the plots from which the samples were taken is shown in Figure 4.15.

FHE8 1	FHE7 2	FHE6 3	FHE5 4	FHE4 5	FHE3 6	FHE2 7	FHE1 8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24

Figure 4.15 Layout of the site showing which plots were covered by each composite soil sample.

The samples were collected across the three replications where 15 sub samples were mixed to form a sample. The analysis shows that the experimental site is acidic. In terms of NPK, only potassium was adequate while phosphorus and nitrogen levels were low. The plots relating to FHE 1 showed better results in terms of growth as compared to those that were within FHE 8. This might have been caused by slightly higher concentration of cations, as is shown in Table 4.20.

Table 4.20 Soil analysis for Wartburg-Fountainhill Estate

ID	N%	P mg/L	K mg/L	Ca mg/L	Mg mg/L	Cu mg/L	Total Cations cmol/L	pH (KCL)	O.C	Clay %
FHE1	0.06	19	124	518	89	2.9	3.68	4.61	<0.5	15
FHE2	0.05	24	123	519	92	2.9	3.72	4.33	0.8	17
FHE3	0.06	24	121	518	94	2.7	3.76	4.32	0.5	15
FHE4	<0.05	17	100	415	102	3.3	3.31	4.23	<0.5	19
FHE5	<0.05	18	103	470	101	3.1	3.50	4.36	<0.5	14
FHE6	<0.05	30	117	333	63	2.4	2.65	4.11	<0.5	15
FHE7	<0.05	19	94	352	68	1.8	2.70	4.23	<0.5	15
FHE8	0.5	22	81	369	76	1.8	2.81	4.23	0.5	16

Two agroforestry tree species (pigeon peas and *S. bispinosa*) were planted at spacing of 1 m inter-row and 1 m intra-row spacing, while the mixed crop of trees and maize had 1 m inter-row and 0.4 m intra row-spacing. Sole maize had 0.8 m inter-row and 0.5 m intra-row spacing with 120 plants per plot but the same maize plant population was maintained of 25 000 plants/hectare. Each treatment was replicated three times consisting a total of 15 plots (6 m x 8 m) representing five treatment. A total of 576 trees were planted for the whole trial while each replication had 192 trees which translate to 48 trees per plot. The trial area was sprayed with 3 L/ha of glyphosate prior to ploughing. The field was then ploughed using a disc plough in December 2015. Planting was done on the second week of January 2016 but it stretched up to second week of February since poor germination for maize and pigeon peas. Three marked strings with 1 m, 0.5 m and 0.4 m spacings were used for marking the planting stations. Raised seedlings of *S. bispinosa* (planted into seedling trays in mid-October 2015) were transplanted and were watered after transplanting. Pigeon pea was direct seeded with 2 seeds per planting station. An open pollinated maize variety called Okavango was used for the experiment and it was selected on the basis that smallholder farmers usually grow yellow maize for livestock feed. Being an open pollinated variety, farmers normally retain the seed and grow it in subsequent years. Weeds were controlled twice during the entire growing season using hand-hoes. Aphids were noticed on pigeon peas and *S. bispinosa.* A solution of soapy water was applied at a rate of 4.9 L/ha and canola oil was used as sticker at rate of 1.9 L/ha was used to control them.

<u>Data collection</u>

Panicum maximum

During the establishment of the experiment, *P. maximum* emergence was very poor at Fountainhill and OSCA. After several attempts of replanting with higher seeding rate, the emergence did not improve and it was decided to send the seed for a germination test at UKZN with a view of fixing the challenge the following season. This report presents feedback from the germination tests, which indicated that while the germination rates seemed fairly low, these levels are said to be acceptable according to the industry standards. Preliminary emergence results of the new batch of seed which was purchased from a second supplier show that it appears to have higher germination rates and should prove satisfactory for next season. Feedback pertaining to the germination test is included in Textbox 2 below.

Textbox 2: Feedback from germination test for *Panicum maximum* seed

Dr Tafadzwaunashe Mabhaudhi from UKZN assisted with a germination test and provided the following feedback:

- I could not do a viability test (TZ test) due to the size of the seeds
- I did a standard germination test based on the guidelines provided by the International Seed Testing Association, i.e. 25°C for 21-28 days.
- I decided to terminate the test at 21 days because there were no further gains
- Average germination was > 10%
- The industry required minimum germinability according to SANSOR is 10%; so by that standard, the seed was ok
- According to farmers that I checked with who grow white buffalo (*Panicum maximum* jacq), this was acceptable
- The suggestion, in the next round of planting, would be to use a high seeding rate to counter the low germination rates of the seed.

A paper by Strauss et al. (2010) confirms that the current standard requirement for minimum germination rate for *P. maximum,* according to the Plant Improvement Act, is 10%. The lack of germination achieved at both sites is likely to be due to the poor rainfall that was received during the early part of the growing season – especially at OSCA. Additional seed was sourced from a second supplier and this has been propagated in the greenhouse at UKZN to confirm that it germinates before planting into the field site.

Pigeon pea and S. bispinosa

Data collected on pigeon pea and *S. bispinosa* were days to emergence or establishment, days to 50% flowering, days to 50% pod formation, days to 50% physiological maturity, tree height, collar diameter and canopy diameter were measured after 95 days of establishment. Root collar diameter was measured by Vernier callipers while tree height and canopy diameter was measured using a graduated measuring stick. Tree productivity was determined by measuring height from ground level to the tip of the youngest leaf and measuring basal stem diameter just above the ground using Vernier callipers (Muthuri et al., 2005). Three rows in the middle of the plot were used for tree measurements, namely seed yield (kg/ha), pod mass (kg/ha), accumulative aboveground fresh and dry biomass. Seed yield was determined from the three middle rows. The mass of seeds was oven-dried at 80°C for 48 hours.

During pod formation around July 2016 the pigeon pea was affected by frost so we could not get the seed yields. In order to calculate land equivalent ratios (LER) we used Hluyako et al. (2017), results from Makhathini which is in the same province with our site, furthermore that is from where the seed we planted was obtained (Table 4.23). LER verifies the effectiveness of the intercropping for using resources of the environment compared to sole cropping (Dhima et al., 2007). When LER is greater than 1, the intercropping favours the growth and yield of species. In contrast, when LER is lower than 1 intercropping negatively affects the growth and yield grown in mixtures (Ofori and Stern, 1987; Dhima et al., 2007).The LER values were calculated as LER $=LER_{maize} + LER_{tree}$ Where LER_{maize} = (Ymi/Ym) and LER_{tree} = (Yti/Yt), where Ymi= maize yields as intercrop, Ym= sole maize yields, Yti = Seed yield of tree as intercrop and Yt= sole seed yield of tree.

Maize

Days to 90% emergence, days to 50% flowering, and days to 50% physiological maturity were recorded. A phenological event was deemed to have occurred if it was observed in at least 50% of plants. Days to maturity was defined in terms of physiological maturity when at least 50% of leaves in at least 50% of plants had senesced. Maize at physiological maturity was harvested from all replicate plots of each treatment and subjected to 80°C for 48 hours in an oven at the end of cropping season. A net plot area was harvested from each plot (i.e. leaving the outer maize row on each side of the plot and the last planting station at either end of the row. Plants harvested from the net plot area were pooled before separating them into stover and cobs. A subsample of 10 plants in the net plot of maize stover was oven dried at 80°C for 48 hours to determine stover yield on a dry mass basis at the end of cropping season. All the grain from the net plot was shelled and weighed, cob mass was determined.

Results

This section contains the results of the experiment carried out to determine maize yields in cropping systems containing maize, pigeon pea and *S. bispinosa* at Fountainhill Estate during 2015/16 season.

Growth and development of maize, S. bispinosa and pigeon peas

As shown below in Figure 4.16, sole maize gave the highest number of days to 90% emergence of maize as compared to maize-tree intercrops. In terms of days to 50% flowering and physiological maturity, sole maize again gave more days as compared to maize-tree intercrops.

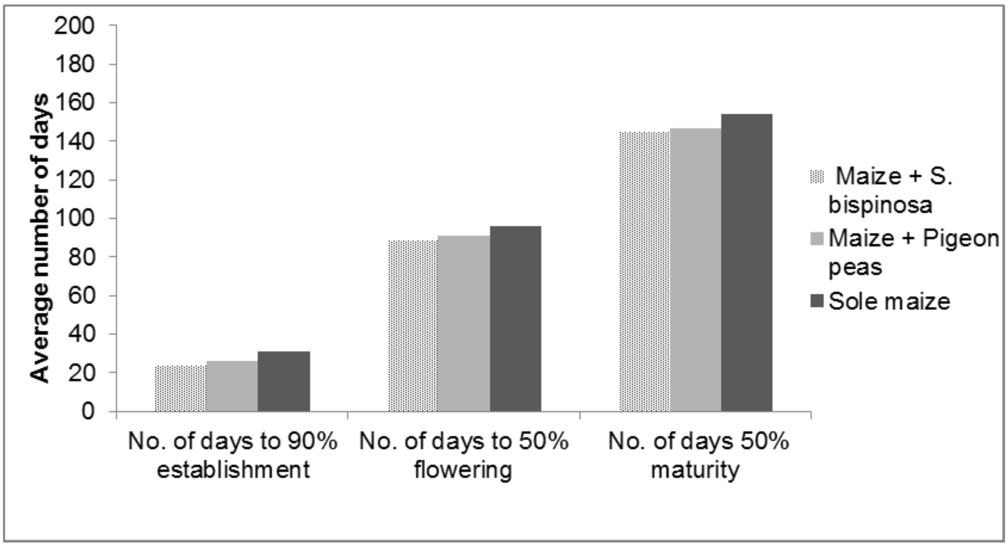


Figure 4.16 Growth parameters of maize in sole maize and intercrop treatments at Fountainhill Estate in 2015/16 summer season.

For *S. bispinosa*, the numbers of days to 90% survival after transplanting were the same for both sole *S. bispinosa* and *S. bispinosa* intercropped with maize plots. *S. bispinosa* intercropped with maize took more days to 50% flowering, pod formation and physiological maturity as compared to sole *S. bispinosa*, as shown in Figure 4.17.

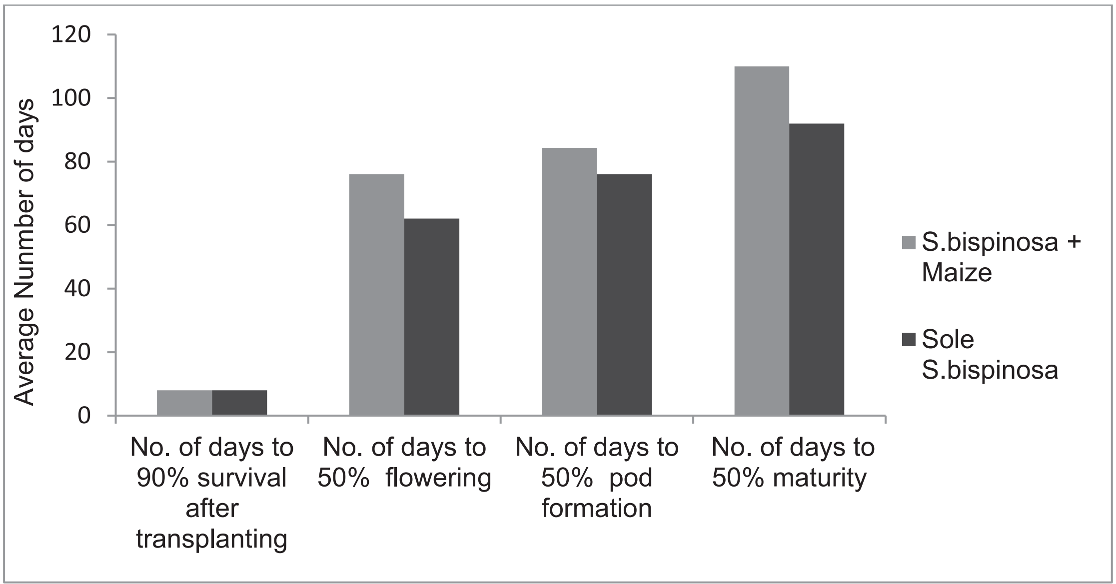


Figure 4.17 Growth rate trend of *S. bispinosa* at Fountainhill Estate in 2015/16.

Figure 4.18 shows the number of days to 90% establishment and number of days to 50% flowering for pigeon pea. There were no differences between treatments for number of days to 90% emergence or number of days to 50% flowering.

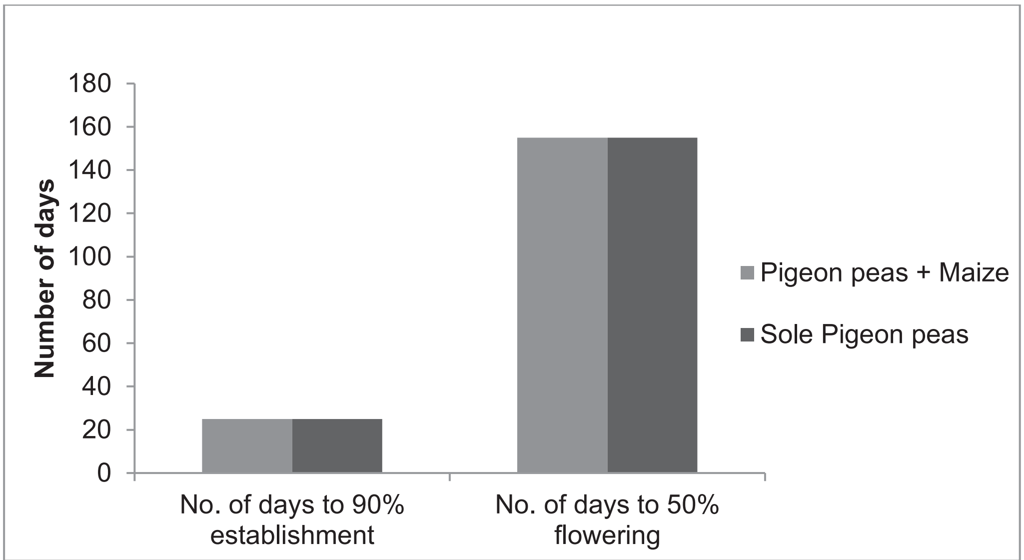


Figure 4.18 Growth rate of pigeon peas at Fountainhill Estate in 2015/16 season.

Root collar, canopy diameter and tree height of pigeon peas and S. bispinosa

Tree productivity was determined by measuring height from ground level to tip of the youngest leaf, root collar diameter just above the ground at 5 cm and canopy diameter measured as two points North-East and South-West. Table 4.21 shows the results of these 3 parameters at pod filling stage (i.e. end of the growth period for the *S. bispinosa*). Significant difference was noted only for canopy diameter. Sole *S. bispinosa* plots had highest canopy cover (1,375 m) while pigeon peas + maize had the least (0.64 m).

Pertaining to tree height and root collar diameter, the analysis indicates that there were no significant differences across the treatments.

The slow initial growth of the pigeon peas relative to the *S. bispinosa* is clearly visible in Figure 4.19.

Table 4.21 Root collar, canopy diameter and tree height at pod filling stage (170 days) at Fountainhill Estate in 2015/16 season

Species	Canopy diameter (m)	Tree height (m)	Root collar diameter (mm)
Sole pigeon peas	0.6437[a]	1.56[a]	19.39[a]
Pigeon peas + maize	0.6293[a]	1.49[a]	20.16[a]
S. bispinosa + maize	0.9946[bc]	1.60[a]	15.16[a]
Sole *S. bispinosa*	1.375[c]	1.89[a]	22.17[a]
$LSD_{(0.05)}$	0.524	0.608	8.652

Values followed by same superscript letters are not significantly different at P<0.05 according to Fisher`s Protected LSD

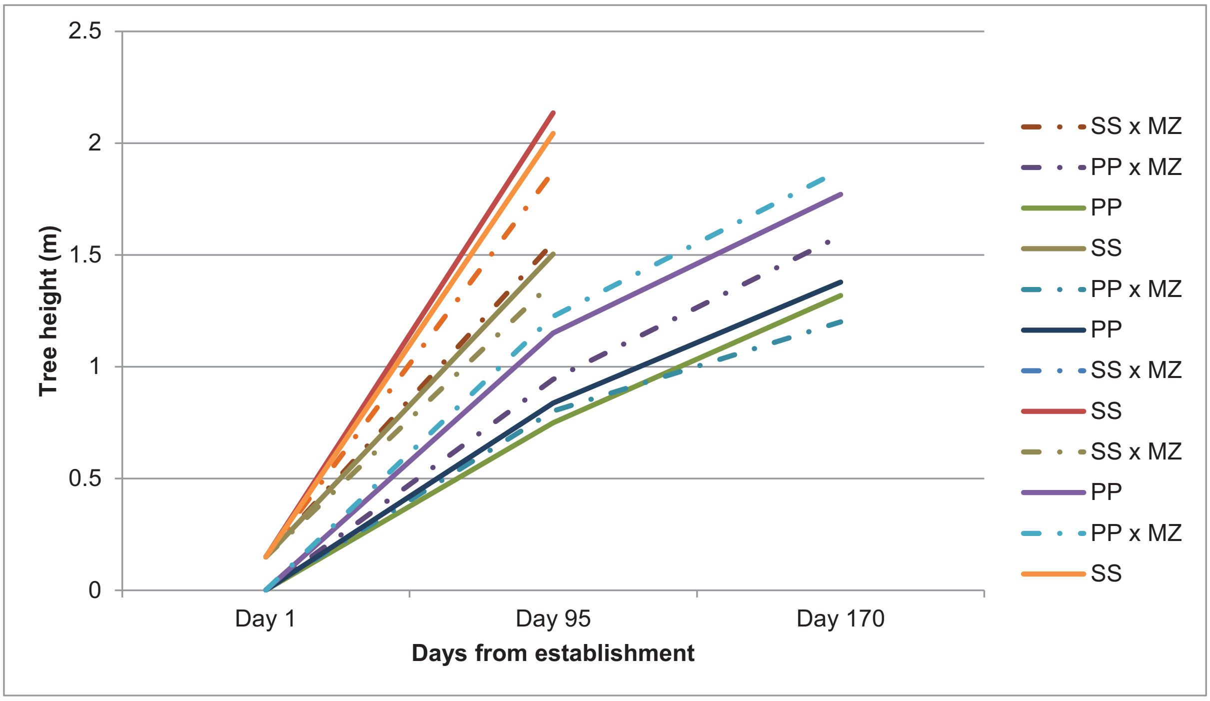


Figure 4.19 Tree height of the pigeon peas and S. bispinosa from establishment to pod filling stage.

Dry matter accumulation and grain yields

Data for aboveground dry cumulative biomass at 110 days after establishment of *S. bispinosa*, pigeon peas are presented in Figure 4.20. There were significant differences (p<0.05) in relation to dry cumulative biomass, sole *S. bispinosa* outperformed all treatments which had 315 kg/ha. The least was attained on sole pigeon peas which had 82.3 kg/ha.

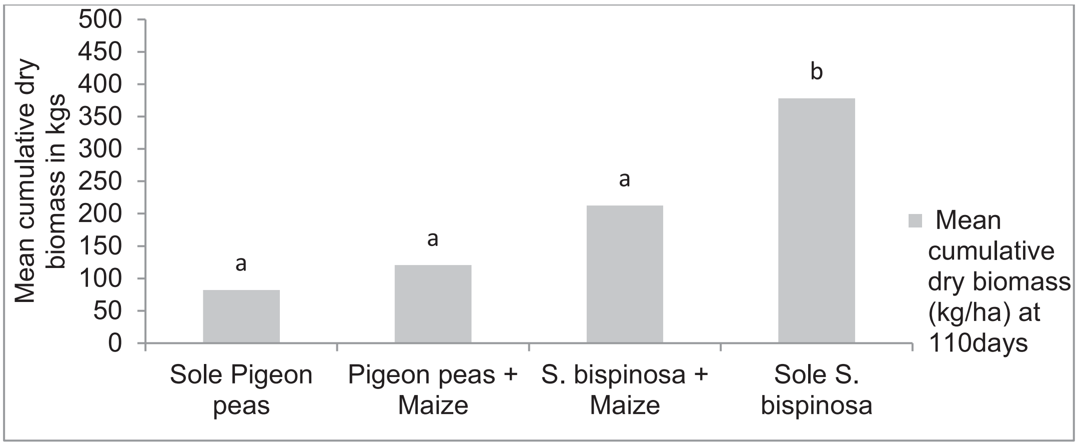


Figure 4.20 Cumulative dry aboveground biomass of trees after 110 days for different treatments during the 2015/16 season at Fountainhill Estate site.

Although not statistically significant, differences were noted for seed yield, as shown in Figure 4.21with sole *S. bispinosa* treatments producing an average of 207 kg/ha while *S. bispinosa* intercropped with maize yielded only 58 kg/ha.

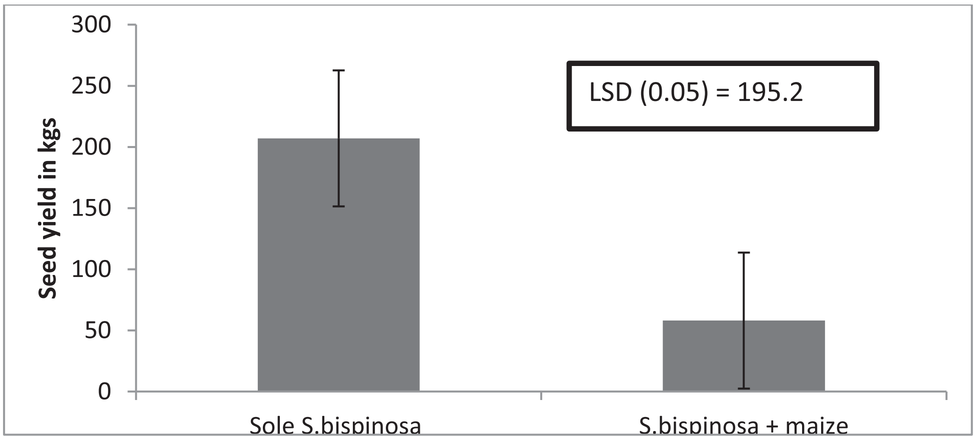


Figure 4.21 Seed yield of *S. bispinosa* at Fountainhill during 2015/16 cropping season.

Similarly, the results show no statistical difference for pod yield between the Sole *S. bispinosa* and *S. bispinosa* intercropped with maize. The average seed yields were 238 kg/ha and 91 kg/ha respectively, as shown in Figure 4.22.

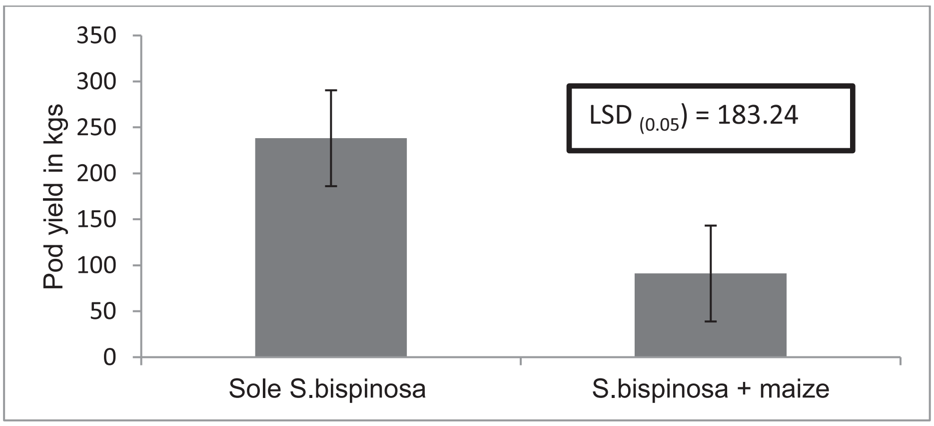


Figure 4.22 Pod yield of *S. bispinosa* at Fountainhill during 2015/16 cropping season.

There were significant differences (P<0.05) in terms of maize grain, cob mass and stover yields across all treatments (Table 4.22). Grain yield, cob mass and stover mass were significantly higher in sole maize treatments as compared with the intercrop counterparts. The three parameters were statistically similar for maize intercropped with *S. bispinosa* and maize intercropped with pigeon peas

Table 4.22 Maize grain, cob mass and stover yields at Fountainhill Estate in 2015/16 summer season

Treatments	Grain yield (kg/ha)	Cob mass (kg/ha)	Stover mass (kg/ha)
Maize + *S. bispinosa*	538[a]	742[a]	101.7[a]
Maize + Pigeon peas	604[a]	762[a]	107.9[a]
Sole Maize	1867[b]	2753[b]	314.2[b]
LSD ($_{0.05}$)	446.6	543.7	72.5

Values followed by same superscript letters are not significantly different at P<0.05 according to Fisher`s Protected LSD

Pigeon pea yields on sole stand was assumed to be 1,220 kg/ha, 1,100 kg/ha and 1,000 kg/ha. The assumption was 10% reduction in yield on intercrop plots so the yields for pigeon peas + maize were 1098 kg/ha, 990 kg/ha and 900 kg/ha (Table 4.23).

Table 4.23 Pigeon pea seed yield at Makhathini, KwaZulu-Natal – data from Hluyako et al. (2017)

Treatments	Seed yield (kg/ha)
Pigeon pea + Maize	1098
Pigeon pea	1220
Pigeon pea + Maize	990
Pigeon pea	1100
Pigeon pea	1000
Pigeon pea + Maize	900

Note: Yields in intercrop was assumed to decrease by 10% according to Natarajan and Mafongoya (1992)

Land equivalent ratios, when maize was grown in association with pigeon pea the ratio was 1.2 meanwhile when maize was intercropped with *S. bispinosa* the ratio was 0.6 (Table 4.24)

Table 4.24 Land equivalent ratios when maize intercropped with pigeon peas and *S. bispinosa* in 2015/16 summer season

Treatments	Land equivalent ratio
Maize + Pigeon peas	1.2
Maize + S. *bispinosa*	0.6

Discussion

Growth and development

Overall, higher numbers of days to 90% establishment were observed across all maize treatments due to replanting that was done to counteract poor emergence. Erratic rainfall that was received during the early growing season might have contributed to poor emergence. Furthermore the plots which had sole maize were eaten by birds which led to greater number of days to 90% establishment. The reason for the maize intercrops having less bird damage than the sole stands might be the presence of trees, which provided some protection.

With *S. bispinosa*, which was transplanted, the number of days to 90% survival after transplanting was the same for both the sole *S. bispinosa* and *S. bispinosa*-maize intercrop. The establishment of Sesbania was generally good. According to Kwesiga and Coe (1994), Sesbania species require transplanting for good establishment.

As mentioned in the results, there was no difference in establishment or growth rates between the sole pigeon pea and the pigeon pea intercrop. This suggests that the maize did not impact on the number of days to reach 50% flowering.

Tree height, root collar and canopy diameter

Pigeon pea's initial slow growth was evidenced during the initial phase of the establishment as compared to counterpart *S. bispinosa*. Our results are consistent with results from a study by Kwesiga and Coe (1994) who found that pigeon pea was slow in terms of growth as compared to Sesbania in establishment. *S. bispinosa* growth was very rapid at initial establishment of the experiment that is why tree heights, root collar and canopy diameter was greater than for pigeon peas. As the season progressed, pigeon peas started vigorous growth thereby tallying with *S. bispinosa* in terms of root collar diameter and height. At pod formation there were no significant differences in terms of root collar diameter and height. Significant differences were noted on sole I which had higher canopy as compared to sole pigeon peas. This is probably because of the erectile (upward) growth pattern of pigeon peas as compared to planophile (branching) growth pattern of *S. bispinosa*.

Tree biomass and yields

Highest total aboveground biomass yield was recorded from sole S. *bispinosa* and lowest on sole pigeon peas. The probable causes for getting higher dry biomass yield might be due to more vigorous growth and higher branching of *S. bispinosa* as compared to pigeon peas. Our studies concurs with Kamanga et al. (1998) who found that significantly high biomass was recorded from S. *sesbania* while pigeon peas produced low biomass.

Sole *S. bispinosa* produced higher seed yield as compared to *S. bispinosa* – maize plots, although statistically there was no difference. The adverse effect on yield of the tree seed due to intercropping occurred mainly due to competition among companion plants for light, space, nutrients and water. Also it happened in assignment of treatments that 2 plots of sole *S. bispinosa* were allotted to FHE 1 where the CEC was slightly higher as compared to other sampled sites.

Dry matter accumulation and grain yields

Maize grain, cob mass and stover yields were significantly higher in sole maize plots as compared to intercrops. This might have been caused by competition for available resources like water, light, space and nutrients. This was for both *S. bispinosa* as well as pigeon peas although other studies have shown that pigeon peas grow slowly initially and do not compete for resources with the associate crop (Valenzuela and Smith, 2002).

Our finding was in line with Mathews et al. (2001) who found that yields of both maize and pigeon peas in intercropping systems were generally lower than in monocropping systems in Mpumalanga. Singh and Sinha (1962) also found that maize intercropped with *S.bispinosa* has generally lower yields compared with sole maize. Our study also concurs with the results of Kwesiga et al. (1999) who found that intercropping maize with trees during the first year of the 2-year fallow has a negative effect on both maize yields and tree survival. In his findings, maize yields in intercrop were 29% to 39% lower than in a sole-crop, similar to the results for the current trial. In our trial, the poor results obtained in the intercropped treatments may have been slightly exacerbated by monkeys, which caused a little damage during the grain filling stage. Other factors that may have impacted on the yields obtained from the trial were delayed and erratic rainfall that the experimental site received during the trial period, as well as the acidic character of the soils, which ultimately contributes to locking up of nutrients, making it difficult for plants to absorb them.

Land Equivalent ratios (LER)

When maize was grown in association with pigeon pea land equivalent ratio was greater than 1, which indicated that intercropping was more beneficial than sole cropping. When maize was intercropped with *S.bispinosa* the ratio was less than 1, which means intercropping negatively affected the growth and yield of maize and S.bispinosa. (Ofori and Stern, 1987; Dhima et al., 2007)

Conclusion

Preliminary results indicate that sole maize plots outperformed maize tree intercrops in grain yields, cob mass and stover however, data from land equivalent ratios showed that maize-pigeon pea intercropping was more productive as compared to maize-*S.bispinosa* intercrop which had a negative effect on productivity. Pigeon pea can be integrated into smallholder farming systems. It has an important role in food security, balanced diet and alleviation of poverty because it can be used in diverse ways as a source of food and fodder, as well as a mechanism to improve soil fertility.

4.3.7 Root morphology, depth and nodulation

A study of the rooting patterns of *S. bispinosa*, pigeon pea and maize was undertaken at the Wartburg site. The depth of roots and root morphology were evaluated to understand the competitiveness of this species (Photograph 4.34). In addition some photographs of examples of *Sesbania bispinosa*, pigeon pea and maize are shown in Photograph 4.35 in an effort to compare the rooting depths of the two species.

Photograph 4.34 Measuring roots of *S. bispinosa* plants growing in OSCA (2016).

Photograph 4.35 Root structure of pigeon peas (A), *S. bispinosa* (B) and maize (C).

4.3.8 Pigeon pea improved fallow trial at Wartburg: Relationship between maize yield and soil properties

Methodology

A randomised complete block design replicated three times was used with 5 treatments described below in Table 4.25.

Table 4.25 Experimental design for years 1 to 3

Treatment	Year 1	Year 2	Year 3
T1	Maize	Maize	Maize
T2	Natural fallow	Natural fallow	Maize
T3	pigeon pea + grass	pigeon pea	Maize
T4	pigeon pea + maize	pigeon pea	Maize
T5	pigeon pea	pigeon pea	Maize

Plots were 8 m by 6 m with a net plot area 5 m x 7 m. Pigeon pea fallows were planted as pure stands at a spacing of 1 m by 1 m. The two-year fallow durations were chosen for this study after recommendation by Mafongoya and Dzowela, (1999), based on fallow fertility replenishment. Pigeon pea fallow trees were clear felled at ground level in November 2017 after two years of fallow then were planted with a maize crop (Photograph 4.36). Stumps and root systems were left in the ground. Maize open pollinated variety (OPV) Border King was planted at 90 cm between rows and 30 cm within rows. Two seeds were planted per hole and then thinned to one plant to give a maize population of 37,000 plants/ha. All the plots were managed following the recommended agronomic practices for weeding, while T2, representing natural fallow under weed, was not weeded during the two-year fallow period**.** At maturity, maize was harvested. The mass of grain and stover was recorded in the entire net plot. Subsamples of grain yield and stover were taken from each net plot and air-dried. At the end, maize grain samples were sun dried until they reached 12% moisture content. These data was used to calculate dry mass on plot basis and extrapolated to a per hectare basis.

Photograph 4.36 Third growing season of the improved fallow trial at FHE, Wartburg in January 2018.

Results

Maize grain and stover yield correlation to soil macrofauna species richness

Figure 4.23 and Figure 4.24 indicate the relationship between soil macrofauna species richness at the end of a fallow and the grain and stover yield of the subsequent maize crop. The relationship was highly positive for both grain and stover with same correlation coefficient ($r^2 = 0.91$).

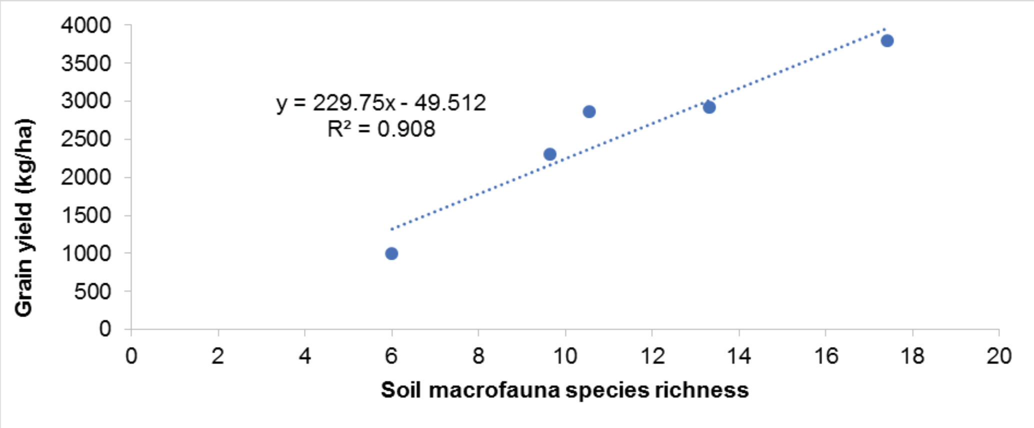


Figure 4.23 Grain yield against soil macro fauna species richness at Wartburg during 2017-2018 cropping season.

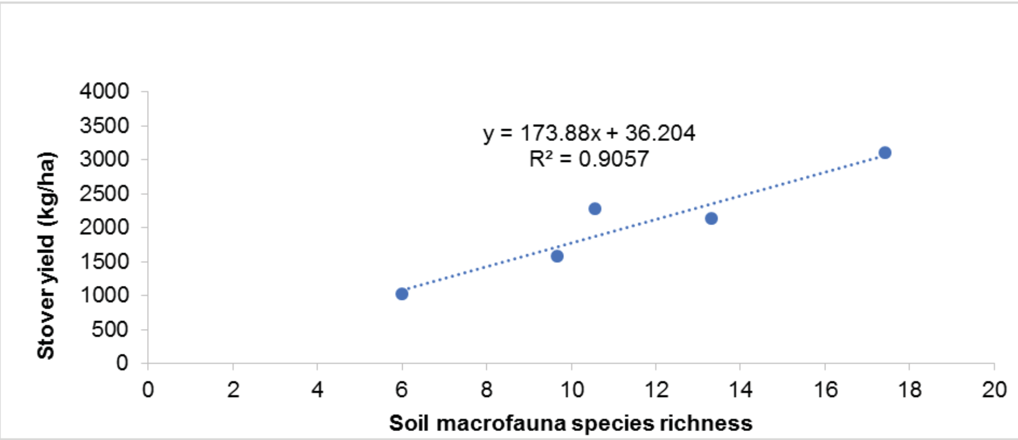


Figure 4.24 Stover yield against soil macro fauna species richness during 2017-2018 cropping season at Wartburg.

Maize grain and stover yield

Analysis of variance of maize grain and stover yield showed significant differences ($P < 0.05$) among treatments. Improved fallows, as compared to continuous maize without fertilizer or natural grass fallows increased grain and stover yield of post-fallow maize. The highest grain yield of 3787 kg/ ha was in T5 followed by T4 (2,922 kg/ha) and T3 (2,852 kg/ha) and the least was in continuous maize – T1 (993 kg/ha). As was the case with stover, the highest yield of 3,104 kg/ha was recorded in T5 followed by T3 and T4 which have 2,264 kg/ha and 2,125 kg/ha respectively and the least was in continuous maize T1 (1021 kg/ha; Table 4.26). Maize grain was in this order: T5 > T4 ≥ T3 >T2 >T1, while stover yield was in this order T5 > T3 ≥ T4 >T2 >T1.

Table 4.26 Effect of two-year pigeon pea fallow on maize grain and stover yield (kg/ha) in the first year (2017/2018) cropping season after fallow at Wartburg in KwaZulu-Natal, South Africa

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)
T1	993^{a}	1021^{a}
T2	2294^{b}	1578^{b}
T3	2852^{c}	2264^{c}
T4	2922^{c}	2125^{c}
T5	3787^{d}	3104^{d}
LSD $_{(0.05)}$	514	451.6
P-value	<.001	<.001
CV	10.6	11.9

Values followed by same superscript letters are not significantly different at P<0.05 according to Fisher`s Protected LSD.

Maize grain and stover yield correlation to soil macrofauna abundance

Maize grain yield was weakly correlated with soil macrofauna abundance (r^2 = 0.48), whilst stover had a fair correlation (r^2 = 0.69).

Maize grain and stover yield correlation to soil infiltration rate

The increase in infiltration rate the end of a pigeon pea fallow was positively related to the grain (r^2 = 0.73) and stover (r^2 = 0.81) yield. Highest infiltration rate was experienced with highest grain and highest stover yield (Figure 4.25).

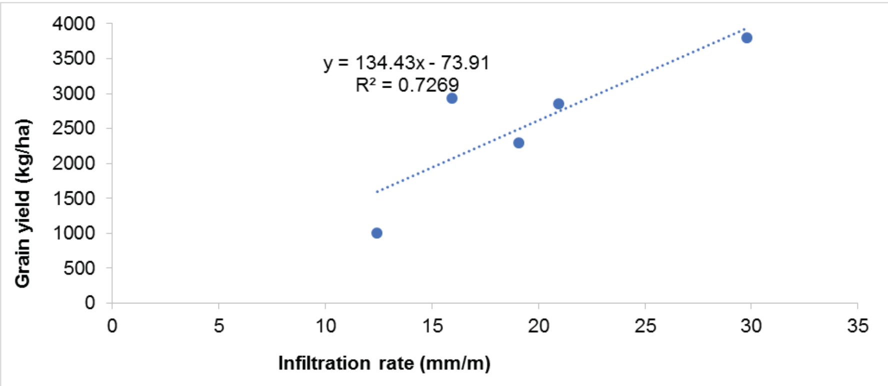


Figure 4.25 Grain yield against infiltration rate during 2017-2018 cropping season at Wartburg.

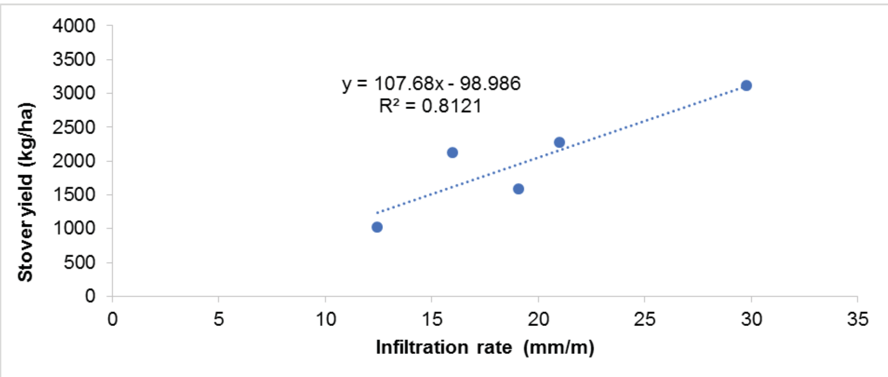


Figure 4.26 Stover yield against infiltration during 2017-2018 cropping season at Wartburg.

Maize grain and stover yield correlation soil aggregate stability

The increase in grain and stover yield at the end of a pigeon pea fallow was strongly related to the soil aggregate stability, $r^2 = 0.92$ and $r^2 = 0.77$ respectively, as shown in Figure 4.27 and Figure 4.28. Highest grain and stover yield was observed on plots with the higher soil aggregate stability.

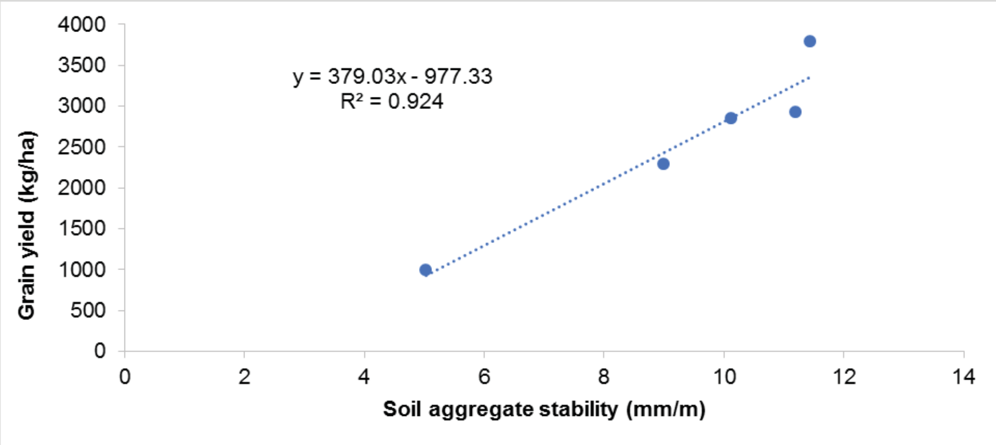


Figure 4.27 Grain yield against soil aggregate stability during 2017-2018 cropping season at Wartburg.

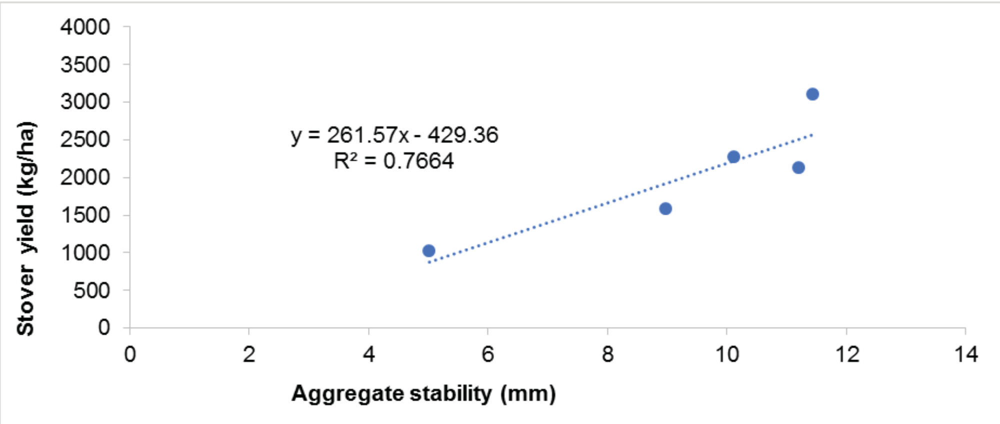


Figure 4.28 Stover yield against soil aggregate stability during 2017-2018 cropping season at Wartburg.

Relationship between maize grain and stover yield against soil bulk density

There was a negative relationship between grain yield and soil bulk density. This was the same for stover yield. Thus, the plots with lower bulk density at the end of the fallow produced higher yields. Stover yield had a relatively higher correlation ($r^2 = 0.89$) as compared to grain yield ($r^2 = 0.76$). There was a fair correlation ($r^2 = 0.60$) between maize grain yield and pigeon pea leaf litter accumulation (Figure 4.29).

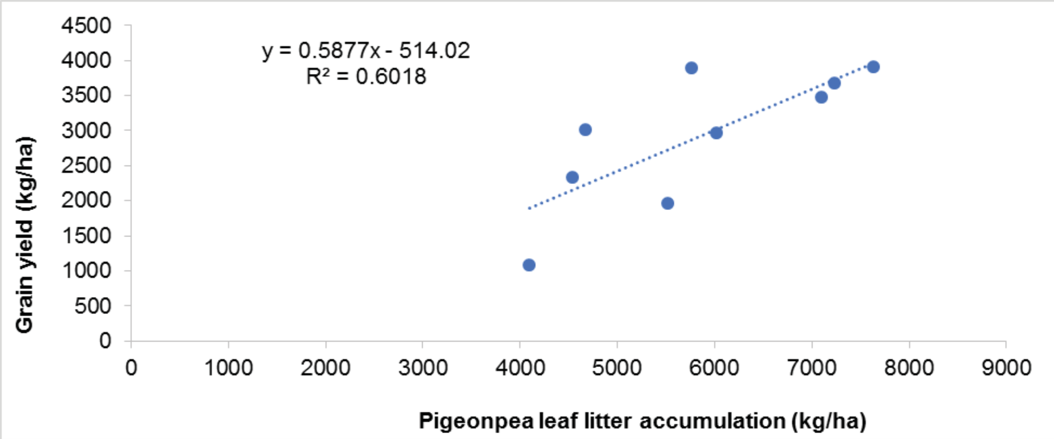


Figure 4.29 Relationship between grain yield and pigeon pea leaf litter accumulation at Wartburg, KZN.

Discussion

Maize grain and stover yields were significantly higher for the two-year pigeon pea fallow (T5) as compared to other treatments. Continuous maize without fertilizer (T1) had the lowest grain and stover yields. These results corroborate findings of Abunyewa and Karbo (2005) where they found that maize yields increased after two years of pigeon pea fallows as compared to continuous monocropping. The impact of pigeon pea fallows on soil biological properties may be assessed by changes in soil macrofauna abundance and species richness. Rahman et al. (2012) also argued that annual continuous monocropping systems have lower abundance of soil macro fauna as compared to agroforestry systems.

During the decomposition process, soil macrofauna facilitates the organic forms of nutrients in the pigeon pea leaf litter to be changed into inorganic forms (Lavelle et al., 2003; Susilo et al., 2004) that can be absorbed by the maize crop thereby increasing yields. This can be indicated by a strong positive correlation between soil macrofauna species richness ($r^2 = 0.99$) and both grain and stover yield. Almost all of the variability in grain and stover yield can be explained by soil macro fauna species richness. The relationship between soil macrofauna abundance and maize grain ($r^2 = 0.48$) was relatively low as compared with stover yield ($r^2 = 0.69$). Soil macro fauna species abundance and richness in agroecosystem are important due to their roles in ecologically behaviour which in turn impact soil structural properties such as water infiltration and aggregate stability (Six et al., 2004; Bottinelli et al., 2015). Commonly used indicators of soil physical properties improvement is aggregate stability, infiltration rates and lowering of bulk density as shown in Musokwa et al. (2019). Studies and syntheses (Lavelle et al., 2003; Susilo et al., 2004) show that even when soil macrofauna abundance is low, they are significant regulators of nutrient turnover both directly via their feeding activities and indirectly through their impact on soil structure and biological processes. Soil macrofauna perform important roles related to the growth conditions of plants. For example earthworms and termites decrease soil bulk density and increases soil water porosity which in turn increases infiltration by tunnelling through the soil (Lavelle et al., 2003; Susilo et al., 2004). Decomposition of roots of herbaceous legumes leads to an improvement in infiltration, soil aggregation and lowering of soil bulk density (Sheoran et al., 2010). Improved soil aggregation under pigeon pea fallows could have lowered the soil bulk density. Bulky density can be used an indicator to determine whether the soil is too compact to allow root penetration or adequate aeration (McCarty et al., 2016). The lower the bulk density, the easier the roots will penetrate the soil and exploit soil nutrients (Rowell, 1994). The results from this experiment confirm the earlier findings by Liu et al (2006) who reported high bulk density after continuous monocropping. The increased bulk density could be linked to high soil compaction under the continuous maize cropping, which could have impeded root growth and their ability to exploit nutrients hence resulting in lower maize grain yields.

The significant positive regression coefficients observed between infiltration rates (r^2 = 0.73 and r^2 = 0.81), soil bulk density (r^2 =0.89 and r^2 = 0.76) and soil aggregate stability (r^2 = 0.92 and R^2 = 0.77) against maize grain and stover yields suggested that changes in the soil physical properties brought about by pigeon pea fallows had significant effect on these yields. Studies conducted in eastern Zambia (Phiri et al., 2003; Chirwa et al., 2004) have shown that legume fallows can increase water infiltration and improve soil physical properties thereby increasing yields. In another similar study by Torquebiau and Kwesiga (1996), an improvement in bulk density after two years of tree fallow was reported.

The activities of soil fauna and decaying roots of trees leave channels which further increases infiltration into soil (Blanchart et al., 2004) and storage capacity for water, which is becoming increasingly important in agricultural sustainability under climate change variability (Sileshi and Mafongoya, 2006). In similar studies conducted by Chirwa et al. (2007) and Nyamadzawo et al. (2008) they found that rotation of maize with pigeon pea fallows can result in more effective water utilisation as compared to continuous maize monoculture. This is the reason why the study had higher positive correlation between maize grain and stover yield against infiltration rate hence high water use efficiency. Improved tree fallows have been shown to improve water use efficiency (Sileshi et al., 2011). In another study by Shukla et al. (2004), similar results between maize grain yield and soil aggregate stability were reported. They attributed this to improved soil aggregation, which might have increased soil moisture through higher infiltration and enhanced plant-soil water relationships. The discussion above indicates that there is positive correlation between biological and physical soil properties on maize grain and stover yield. Pigeon pea fallows improved biological and physical soil properties which in turn had a significant effect on maize and stover yield.

Conclusion

The study indicated that two-year pigeon pea fallow was effective in increasing the yields of maize grain and stover compared with unfertilised continuous maize and the natural grass fallow. Bulk density, infiltration rate, aggregate stability, soil macrofauna species richness and abundance had significant effect on the maize grain and stover yield. This farming system involving pigeon pea as improved fallows showed that soil physical and biological properties are directly related to maize grain and stover yield. The system increased soil aggregate stability and decreased the bulk density therefore there is increased potential for rapid capture of water (both rainfall and irrigated), greater infiltration and increased water use efficiency for the system. The decreased bulk density and increased infiltration and aggregate stability also decreased the potential for runoff, erosion, and evaporation. By increasing the potential for faster water capture, more water is available for maize crop use. This ultimately leads to a more efficient, sustainable, and economically viable system. Under climate change conditions, maize crops may go through dry spells, hence the fallows will create more resilient maize cropping system.

2018/19 season (second maize crop post fallow)

The trial was replanted with maize in November 2018 but due to poor germination some plots had to be replanted in January 2018. This is the second maize season post-fallow. This may be due to the weather conditions, which saw 17 days in excess of 30°C in December, of which 5 were in excess of 35°C and the maximum temperature reported was 42°C and the average was 30.6°C. The rainfall in this period was 120 mm (Source: SASRI Weatherweb). Unfortunately the 2018/19 crop was abandoned because of a combination of drought and monkey damage.

4.4 Alley cropping trials at Fountainhill Estate, Wartburg

4.4.1 Key elements of the experimentation

Predictions related to the key elements of the experiments are presented below.

I. Reduced height of the hedgerows will improve the production of the understorey crop grown in the alleys
II. Cutting the rows to a lower height will lead to a higher proportion of leaf: stem than for higher hedgerows

4.4.2 Experimental site, land preparation, soil sampling and planting materials

Four field experiments were established at Fountainhill Estate in Wartburg, South Africa. The area was cultivated with a disc plough and harrowed before pegging. In each sample plot, at three spots, soil samples were collected at 0-20, 20-40, 40-60 and 60-80 cm depths using an auger. The samples were bulked together in each plot as composite samples and conveyed into paper bags for storage and later testing. Soil samples from only one experiment were sent to Cedara Agricultural College for analysis of physical and chemical properties. The results are shown Table 4.27.

Table 4.27 Properties of soil along the profile wall before the initiation alley experiments at Fountainhill Estate, Wartburg

Soil properties	Unit	Depth (cm)			
		0-20	20-40	40-60	60-80
Clay	%	21.75	21.75	27.25	30.5
pH	KCl	4.24	4.305	4.4825	4.4925
Org.	%	0.8	0.5	0.5	0.5
N	%	0.0725	0.05	0.05	0.05
P	mg/L	15.75	9.5	4	4
K	mg/L	82.75	44.75	43.5	42.75
Ca	mg/L	419.25	371.5	495.25	498
Mg	mg/L	101.5	106.5	150.5	185.75
Total	cmol/L	3.5125	3.29	3.965	4.2725
Exch.	cmol/L	0.375	0.45	0.155	0.1475
Zn	mg/L	3.85	2.625	0.825	0.625
Mn	mg/L	46.75	50	26.75	21.25
Cu	mg/L	2.95	3	2.525	2.375

4.4.3 Summary of the four components of the alley cropping trials

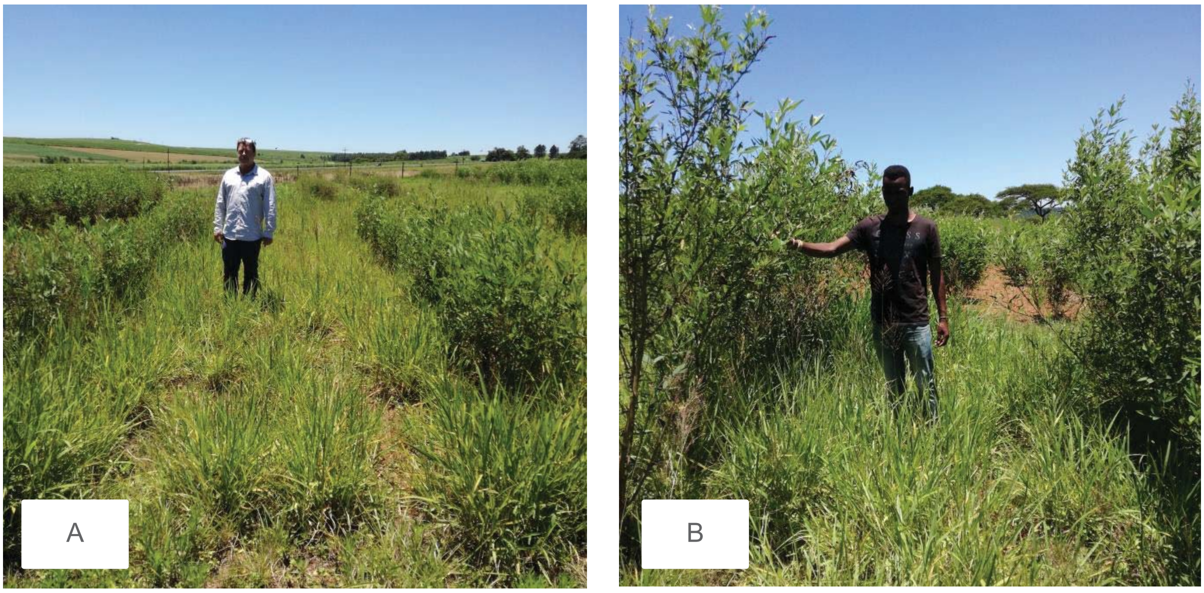
Trial 1: Investigating the effect of retaining or removing prunings

When hedges are pruned to reduce competition with the understorey crop they can either be removed and fed to livestock or retained as mulch within the field to improve soil fertility. The effect of removing or retaining the prunings was investigated in this trial shown below in Photograph 4.37.

Photograph 4.37 The effect of retaining prunings was already visible in December 2017, Trial 1 at FHE, Wartburg.

Trial 2: Investigating effect of tree cutting height in a silvopastoral system

This trial investigated the effect of pruning height on the performance of the pigeon pea/*Panicum maximum* alley cropping system (Photograph 4.38).



Photograph 4.38 Comparison of grass production in pruned and uncut treatments of the pigeon pea/*Panicum maximum* trial at FHE, Wartburg in January 2018.

Trial 3: Investigating effect of tree cutting height in a maize/Sesbania system

This trial looked at two different cutting heights. Initially an uncut treatment was included but after the first season it was clear that it would not be possible to re-establish the maize without cutting the Sesbania back at the time of planting. This option is important to investigate as it reduces the labour requirements for the system, but the maize yield is unlikely to be satisfactory due to competition for light and water (Photograph 4.39).

Photograph 4.39 Competition from Sesbania is already a problem in plots that were only cut at time of planting maize in Trial 3 at FHE, Wartburg in January 2018.

Trial 4: Investigation of effects of non-legume on biological nitrogen fixation of shrubs

The biological nitrogen fixation (BNF) trial was established to determine whether N2 fixation by woody legumes was increased when they were grown in combination with a non-legume crop that was competing for soil nitrogen (Photograph 4.40).

Photograph 4.40 A Sesbania/maize intercrop after pruning in Trial 4 at FHE, Wartburg in January 2018.

4.4.4 Field Experiment 1: Evaluating the effects of pruning residue management on tree growth and maize yield

Introduction

Research questions

What is the effect of retaining prunings on tree regrowth and yields of alley maize?

Hypotheses testing

The retention of prunings will favour biomass production (maize and tree components)

<u>*Methodology*</u>

Tree and crop establishment

S. sesban trees were established from seedlings raised in poly bags for 60 d in a glasshouse (24°C). The most homogeneous seedlings of *S. sesban*, according to leaf surface area, biomass and height, were selected for transplanting in the field to minimise non-treatment variation among the trees. Pigeon pea was established from direct seeding. Two seeds were sown per hole and, at 90 d after establishment; the seedlings were thinned to one per hole.

Individual plot sizes measured 7 m x 10 m, separated by 2 m wide path. Plots include three hedgerows of *S. sesban* or pigeon pea with maize in the alleys. The alley width is 3 m and the distance between the maize rows and hedgerows is 0.75 m. Trees were spaced at 0.75 m within and 3 m between rows giving a density of 3,900 trees per hectare (ha).

Four maize (OPV Border king) rows were planted between the alleys, at 0.3 m within and 0.5 m between rows giving a population of 38,095 plants/ha (Photograph 4.41). Two maize seeds were planted per hole (≈0.1 m depth), but later thinned to one at four weeks after planting. No synthetic fertilizers were applied to plots throughout the duration of this experiment. Plots were weeded twice using hand hoes in the 2016/17 growing season.

Photograph 4.41 One of the maize-pigeon pea alley cropping plots at Fountainhill, February 2017.

Pruning treatments

Pruning treatments and the experimental design used for this experiment are summarised in Table 4.28. At pruning, trees were cut back to 75 cm height using secateurs. Prunings were either applied as nutrient sources for the alley maize (retained) or fodder for livestock (removed). Therefore, the prunings were spread evenly in plots designated for retaining prunings. In plots designated for harvesting livestock fodder, the prunings were removed from plots and supplied to small-scale farmers at Swayimane near Wartburg.

Table 4.28 Species, management and pruning treatments

Cropping system	Tree management	Treatments	Replicates	Trial design
Alley cropping	Pruning at 75 cm height	SS+Mz Remove	3	Randomised complete block design
		SS+Mz Retain	3	
		PP+Mz Remove	3	
		PP+Mz Retain	3	

The alley experiment commenced in November 2016 and ran until June 2018. The experimental treatments consisted of two woody legumes (*S. sesban* and pigeon pea), two pruning residue treatments, and four sampling dates. The treatments were arranged in a randomised complete block design (RCBD) with 3 replicates. *S. sesban* trees were established from seedlings raised in poly bags for 60 d in a glasshouse (24^{o}C). The most homogeneous seedlings of *S. sesban*, according to leaf surface area, biomass and height, were selected for transplanting in the field to minimize non-treatment variation among the trees. Pigeon pea was established from direct seeding. Two seeds were sown per hole and, at 90 d after establishment; the seedlings were thinned to one per hole. Alley plots were 10 m x 7 m and included three hedgerows with 13 trees each.

The alley width was 3 m and the distance between the maize rows and hedgerows was 0.75 m. Trees were spaced at 0.75 m within and 3 m between rows giving a density of 3 900 trees per hectare (ha). Four maize (OPV Border king) rows were planted between the alleys, at 0.3 m within and 0.5 m between rows giving a population of 38, 095 plants/ha. Two maize seeds were planted per hole (≈0.1 m depth), but later thinned to one at four weeks after planting. No synthetic fertilizers were applied to plots throughout the duration of this experiment. Plots were weeded using hand hoes during the two cropping seasons.

Plants were first pruned in April 2017 (6 months after planting) and additional prunings were conducted in November 2017 and February and June 2018. Sampling biomass of tree regrowth was conducted at each pruning from four randomly selected trees in the middle rows. Pruning biomass of wood (>5 mm diameter), twigs (<5 mm diameter) and leaves was determined separately after drying for 96 h at 60°C. After cutting the trees, all woody plant materials (>5 mm diameter) were removed from the plots for firewood. For the purpose of comparing retaining (soil fertility improvement) versus removing (livestock fodder) tree prunings, twigs and leaves were evenly spread in the plots as mulch some plots whereas in other plots these biomass components were removed for feeding livestock. Unfertilized maize from adjacent experiment and *P. maximum* grass from adjacent paths were collected at the time of pruning and used as non-fixing reference plants. All collected samples were finely ground (0.45 mm) into powder for the determination of total N (%N), δ^{15}N and δ^{13}C at the University of Pretoria, South Africa.

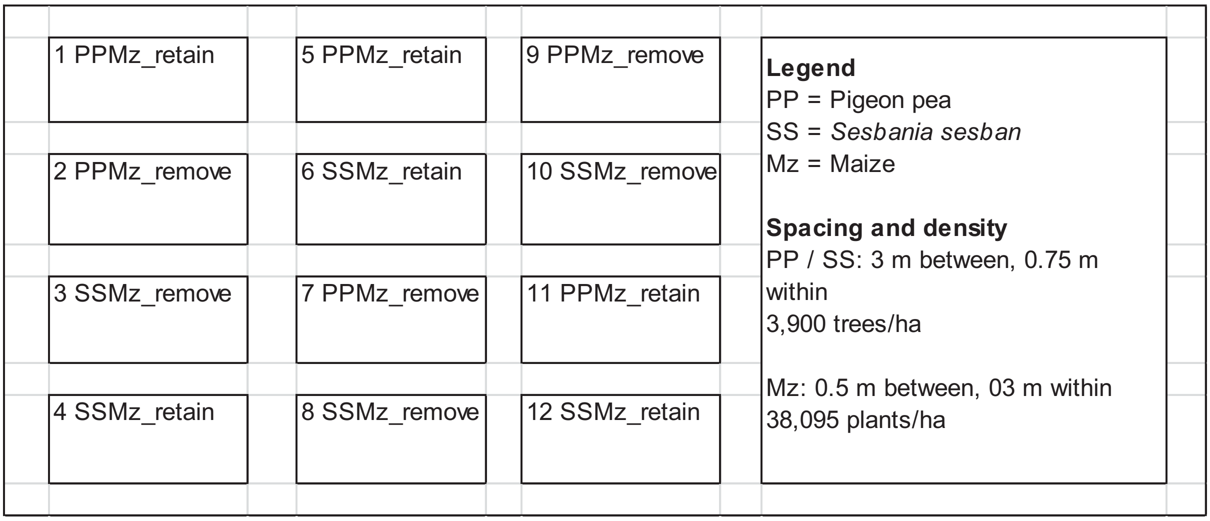


Figure 4.30 Layout of plots for the trial comparing the effects of retention versus removal of prunings.

Statistical analysis

All data collected were tested for normality using the Shapiro-Wilk test prior to analyses. Analysis of variance (ANOVA) was done using the GenStat software package (version 18; VSN International, UK). A 1-Way or 2-Way ANOVA was carried out to compare treatment means and where significant differences were found, the Duncan Multiple Range Test (DMRT) was used to separate treatment means at $p \leq 0.5$.

<u>*Results*</u>

Maize yields

Data from a 2-Way ANOVA revealed no significant effect of treatment and tree species by treatment interaction for stover weight, cob weight and grain yield. However, the main effect of tree species was significant for all maize yield components except for stover weight (Table 4.29)

Yields of maize in alleys formed by hedgerows of pigeon pea had significantly greater cob weight and grain yield as compared with maize grown in *S. sesban* alleys (Figure 4.31). Grain yield produced thereof was 8.73 and 6.72 tons per hectare in pigeon pea and *S. sesban* alleys, respectively. Lower grain yield in *S. sesban* alleys could be attributed to competition for resources because of its vigorous growth nature. In contrast, higher grain yield in pigeon pea could be mainly due to its slow canopy development. Previous studies have also demonstrated that pigeon pea does not compete with maize in the first growing season.

Table 4.29 A 2-Way ANOVA for yield attributes of maize grown in alleys formed by hedgerows of two agroforestry tree species

Variables						
Dependent	Independent	SS	df	MS	F-ratio	P-value
Stover weight	Tree species	8784023	1	8784023	3.53	0.0973
	Treatment	3839166	1	3839166	1.54	0.2497
	Tree species*treatment	5132338	1	5132338	2.06	0.1892
	Error	19934977	8	2491872		
Cob weight	Tree species	12203281	1	1220328 1	2.22	0.0223
	Treatment	961324	1	961324	0.17	0.4506
	Tree species*treatment	359085	1	359085	0.07	0.6409
	Error	12227427	8	1528428		
Grain yield	Tree species	5494761	1	5494761	9.62	0.0146
	Treatment	251153	1	251153	0.44	0.5258
	Tree species*treatment	14823	1	14823	0.03	0.8759
	Error	4568262	8	571033		

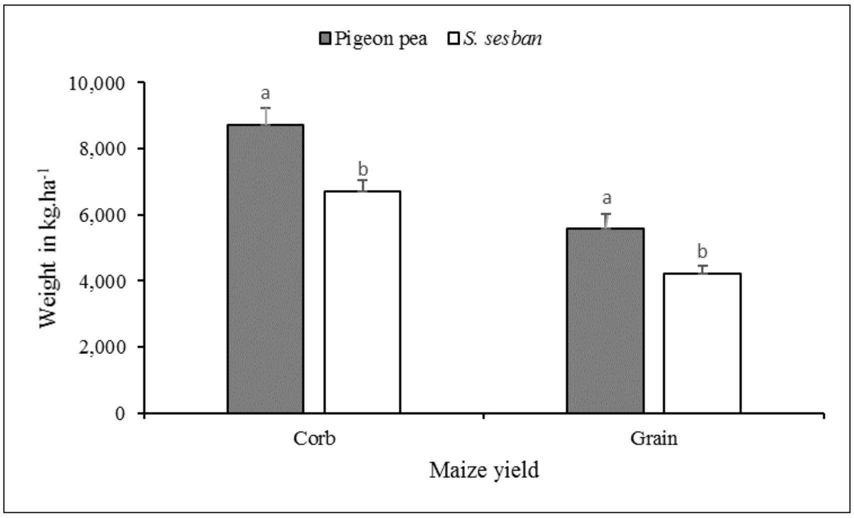


Figure 4.31 Cob and grain yield of maize interplanted in alleys formed by pigeon pea and *S. sesban.* Letters on vertical bars compare means between trees

A 2-Way ANOVA revealed no significant effect of treatment and tree species by treatment interaction for all measured variables (Table 4.30). However, the main effect of tree species was highly significant.

Tree biomass

For all aboveground components removed during pruning, the effect of tree species was significant, with yields being greater for *Sesbania sesban* than pigeon pea (Figure 4.32). Although the trees were cut at the same height, *S. sesban* accumulated significantly greater total pruning DM yield as well as pruning components (i.e. leaf, branch and wood) as compared with pigeon pea. These findings clearly demonstrate that pigeon pea establishes very slowly as compared with other commonly used tropical agroforestry trees.

Table 4.30 A 2-Way ANOVA for leaf, branch, wood and total prunings dry matter yield of two leguminous hedgerow tree species

Variables						
Dependent	Independent	SS	df	MS	F-ratio	P-value
Leaf	Tree species	0.664	1	0.664	7.63	0.009
	Treatment	0.219	1	0.219	2.52	0.108
	Tree species*treatment	0.003	1	0.003	0.04	0.671
	Error	3.829	44	0.087		
Branch	Tree species	1.830	1	1.830	44.01	<.000
	Treatment	0.133	1	0.133	3.19	0.068
	Tree species*treatment	0.000	1	0.000	0.00	0.804
	Error	1.829	44	0.042		
Wood	Tree species	3.875	1	3.875	23.90	<.000
	Treatment	0.373	1	0.373	2.30	0.242
	Tree species*treatment	0.286	1	0.286	1.76	0.182
	Error	7.134	44	0.162		
Total prunings	Tree species	17.222	1	17.222	29.51	<.000
	Treatment	2.098	1	2.098	3.59	0.074
	Tree species*treatment	0.233	1	0.233	0.40	0.302
	Error	25.685	44	0.584		

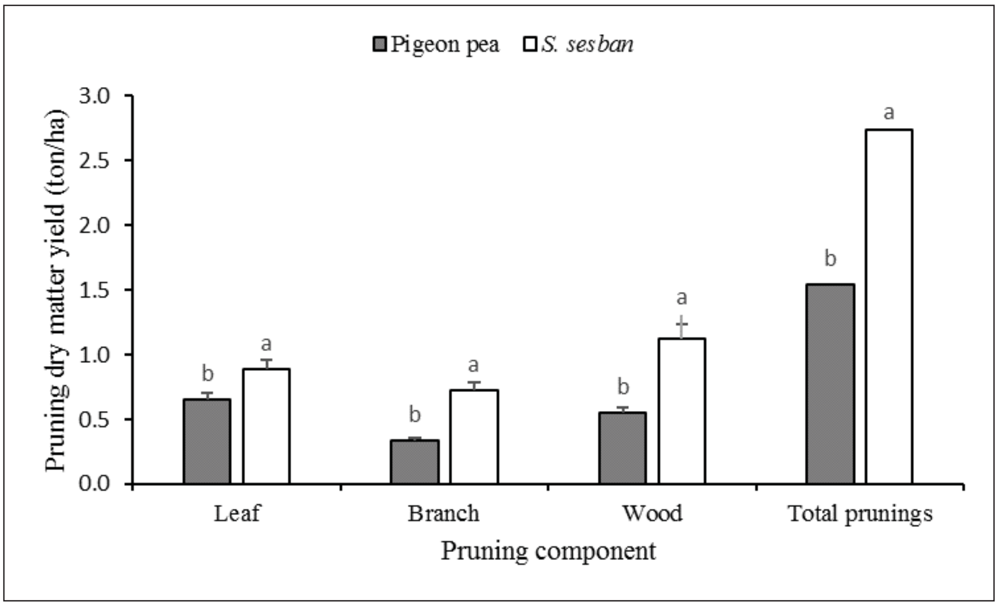


Figure 4.32 Dry matter yield of pruned components harvested from pigeon pea and *S. sesban.* Letters on vertical bars compare treatment means within each pruning component.

Termination of the trial

The high mortality rates of the *Sesbania sesban* trees led to a decision to only continue with the pigeon pea plots. Although there were mortalities in these plots too, the trial was continued because it was anticipated that the current maize crop would still benefit from the retention of prunings during 2018.

For the 2018/19 growing season, the trial was planted in November 2018. When the trial was visited in January 2018, it was interesting to see that the plots where the prunings had previously been retained had a higher weed cover than the plots where the prunings had been removed. This is likely to be because the weeds took advantage of the more favourable conditions of the 'retain plots'. As a result of this, they were able to outcompete the maize and thus the maize in the 'remove' plots looked better than that in the 'retain plots', which was opposite to what was expected. The plots were all weeded in January 2019 (Photograph 4.42).

There was only 97.3 mm rainfall between 1 December 2018 and 7 January 2019, when the trial was visited. Over this same period, there were 10 days when the maximum temperature exceeded 30^{o}C, with 6 of those exceeding 35^{o}C. As a result of these conditions, the maize was in a poor state when the trial was visited.

Photograph 4.42 Weed infestation appeared to be higher in the plots where prunings were retained (A) than in plots where they were removed (B).

4.4.5 Field experiment 2: Effects of forage harvesting intensity on biomass production,

Introduction

Research questions

What is the effect of hedgerow tree cutting height on production of herbage interplanted Guinea grass (*Panicum maximum*)?

Objectives

To determine the effect of hedgerow cutting height in a pigeon pea/Guinea grass alley cropping system on production of herbage and grain,

Hypotheses testing

- Reduced height of the pigeon pea hedgerows will improve the production of the *P. maximum* grown in the alleys
- Cutting the pigeon pea rows to a lower height will lead to a higher proportion of leaf: stem than for higher hedgerows

Methodology

Tree and crop establishment

Pigeon pea and Guinea grass (*Panicum maximum*) were established from direct seeding. For pigeon pea, two seeds were sown per hole and, at 90 d after establishment; the seedlings were thinned to one per hole. The grass was planted in the alley cropping plots and sole plots at a rate of 7 kg/ha, with the alley cropping plots having no grass within 50 cm of the tree lines.

Individual plot sizes measured 7 m x 10 m, separated by 2 m wide path. Plots include three hedgerows of pigeon pea with Guinea grass in the alleys, sole pigeon pea and guinea grass. The pigeon pea monoculture tree plots were planted at 1.5 m within and 1.5 m between rows, resulting in a density of 7,143 trees/ha. No synthetic fertilizers were applied to both trees and grass components duration establishment of this experiment. Plots were hand weeded for the 2015/2016 growing season.

Pruning treatments

Pruning treatments and the experimental design used for this experiment are summarised in Table 4.31. Pruning was conducted in May 2017 the subsequent prunings will be conducted in November of 2017 and February of 2018. At pruning, trees were cut back to 0.6 m or 0.9 m, depending on the treatment, using secateurs. Grass in all plots was cut at 10 cm above the ground.

In this experiment, tree prunings and harvested grass are solely used as fodder for livestock. Therefore, the prunings and harvested grass were removed from plots and supplied to household farmers at Swayimane near Wartburg. Residual number of branches and buds available for resprouting after pruning were counted in all plots and recorded.

Table 4.31 Species, management and treatments for the pigeon pea-*Panicum maximum* trial at Fountainhill

Cropping system	Management	Treatments	Replicates	Trial design
Alley cropping	Grass cut at 10 cm above the ground Pigeon pea pruned at 0, 60 and 90 cm height	PP+PM 0 cm	3	Randomized complete block design
		PP+PM 60 cm	3	
		PP+PM 90 cm	3	
		Sole PP	3	
		Sole PM	3	

1 PPPM0	6 PPPM90	11 Sole PP	**Legend** PP = Pigeon pea PM = *Panicum maximum*
2 PPPM60	7 PPPM0	12 PPPM90	**Spacing and density** Sole PP: 1.5 between, 1 m within
3 PPPM90	8 Sole PP	13 PPPM60	Sole tree density: 8,333/ha
4 Sole PM	9 PPPM60	14 Sole PM	PPPM: 3 m between, 0.75 m within Hedgerow tree density: 3,900/ha
5 Sole PP	10 Sole PM	15 PPPM0	PM: 0.5 m between, Rate 7 kg/ha

Figure 4.33 Experimental layout for assessing two forage harvesting intensities in a pigeon pea-*Panicum maximum* hedgerow system

Statistical analysis

Analysis of variance (ANOVA) was done using the GenStat software package (version 18; VSN International, UK). A 1-Way or 2-Way ANOVA was carried out to compare treatment means and where significant differences were found, the Duncan Multiple Range Test (DMRT) was used to separate treatment means at $p \leq 0.5$.

<u>Results and discussion</u>

Pigeon pea component

Data for 1-Way ANOVA showed that cutting height (i.e. 60 cm versus 90 cm) had a significant effect on yields of branch and wood but not for leaf and total prunings. According to our hypothesis, the trees pruned at 60 cm height were expected to accumulate significantly higher yields of prunings in comparison with those pruned at 90 cm. In this case, however, DM yield of total prunings was statistically similar for both cutting heights (Figure 4.34). Lower than expected total pruning DM could be attributed to higher productivity of *P. maximum* in the alleys of trees pruned at 60 cm which could have suppressed growth of pigeon pea (Figure 4.35). In terms of branch DM production, trees pruned 60 cm produced more branch DM as compared to trees pruned at 90 cm. In contrast, wood DM yield was higher in trees pruned at 90 cm relative to those pruned at 60 cm (Figure 4.34).

Table 4.32 A 1-Way ANOVA for leaf, branch, wood and total prunings dry matter yield of pigeon pea trees subjected to two pruning intensities

Variables						
Dependent	Independent	SS	df	MS	F-ratio	P-value
Leaf	Cutting height	0.18	1	0.1766	1.49	0.2352
	Error	2.61	22	0.1185		
Branch	Cutting height	0.09	1	0.0851	6.10	0.0217
	Error	0.31	22	0.0139		
Wood	Cutting height	0.24	1	0.2419	4.82	0.0390
	Error	1.10	22	0.0502		
Total prunings	Cutting height	0.05	1	0.0505	0.12	0.7313
	Error	9.19	22	0.4175		

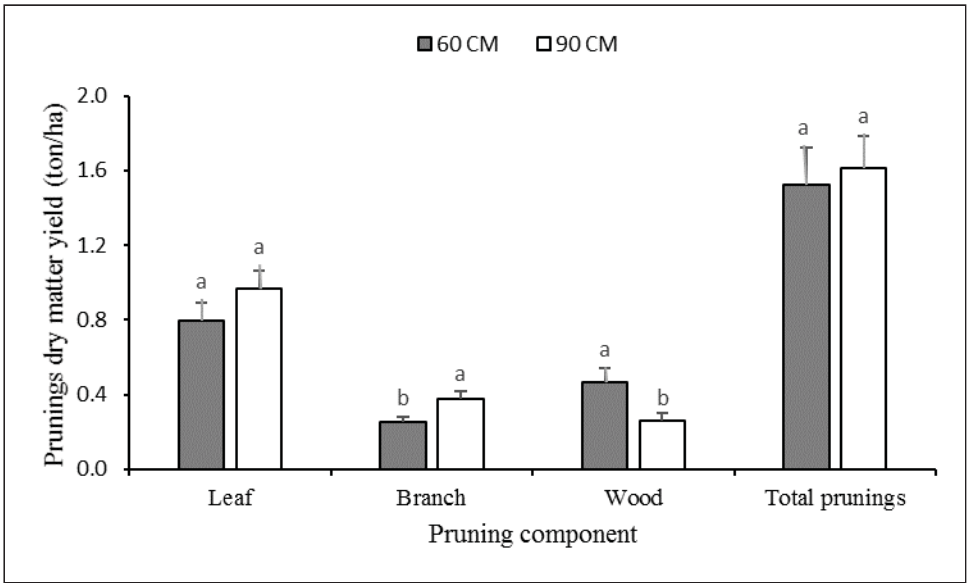


Figure 4.34 Dry matter yield of pruning components harvested from pigeon pea. Letters on vertical bars compare treatment means within each pruning component.

Panicum maximum *component*

The yields of *Panicum maximum* under the three treatments were evaluated. Again, there was substantial variation in the germination/establishment of the *Panicum maximum*, which masked any effect of treatment.

Where we had the strongest grass crop (which was in the plots that we intended to cut at 60 cm), the tree growth was substantially impacted.

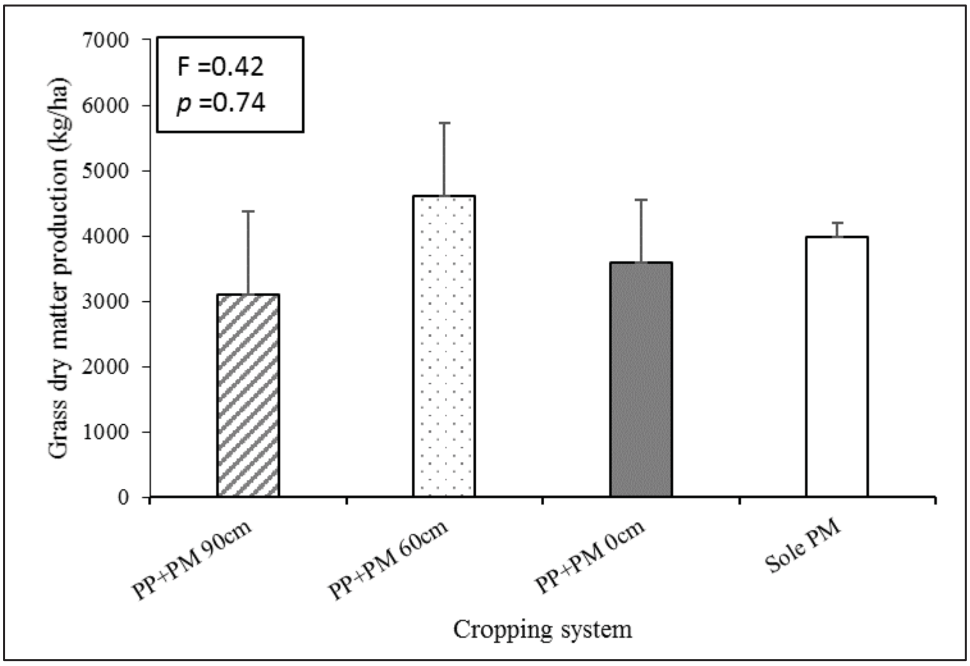


Figure 4.35 Dry matter yields of *P. maximum* grown in sole plots and in alleys under varying hedgerow tree management.

4.4.6 Field Experiment 3: Evaluating the effects of pruning intensity on tree growth and maize yield

Introduction

Research questions

What is the effect of hedgerow tree cutting intensity on production of herbage, grain and stover of interplanted maize crop?

Objectives

To evaluate the effect of hedgerow cutting height in a *S. sesban*/*maize* alley cropping system on production of herbage, grain and stover

Hypotheses testing

- Reduced height of the *S. sesban* hedgerows will improve the production of the maize crop grown in the alleys
- Cutting the *S. sesban* rows to a lower height will lead to a higher proportion of leaf: stem than for higher hedgerows

Methodology

Tree and crop establishment

S. sesban trees were established from seedlings raised in poly bags for 60 d in a glasshouse (24°C). The most homogeneous seedlings of *S. sesban*, according to leaf surface area, biomass and height, were selected for transplanting in the field to minimise non-treatment variation among the trees. Individual plot sizes measured 7 m x 10 m, separated by 2 m wide path. Plots include three hedgerows of *S. sesban* with maize in the alleys. The alley width is 3 m and the distance between the maize rows and hedgerows is 0.75 m. Trees were spaced at 0.75 m within and 3 m between rows giving a density of 3 900 trees per hectare (ha). The monoculture tree plots were planted at 1.5 m within and 1.5 m between rows, resulting in a density of 7,143 trees/ha.

Four maize rows were planted between the alleys, at 0.3 m within and 0.5 m between rows giving a population of 38,095 plants/ha. The monoculture maize plots were planted at a spacing of 0.5 m within and 0.5 m between rows, giving a density of 40 000 plants/ha. Two maize seeds were planted per hole (≈0.1 m depth), but later thinned to one at four weeks after planting. No synthetic fertilizers were applied to plots throughout the duration of this experiment. Plots were weeded twice using hand hoes in the 2016/17 growing season.

Pruning treatments

Pruning treatments and the experimental design used for this experiment are summarised in Table 4.33. Pruning was conducted in May 2017 the subsequent prunings will be conducted in November of 2017 and February of 2018. At pruning, trees were cut back to a height of 0.5 m or 0.75 m, depending on the treatment, using secateurs. In this experiment, the tree prunings are used as nutrient sources for the alley maize. After pruning, they were spread evenly in all plots. Residual numbers of branches and buds available for resprouting after pruning were counted in all plots and recorded.

Table 4.33 Species, management and treatments for the *Sesbania sesban*-maize trial

Cropping system	Management	Treatments	Replicates	Trial design
Alley cropping	*S. sesban* pruned at 0, 50 and 75 cm height	SS+Mz 0 cm	3	Randomized complete block design
		SS+Mz 50 cm	3	
		SS+Mz 75 cm	3	
		Sole SS	3	
		Sole Mz	3	

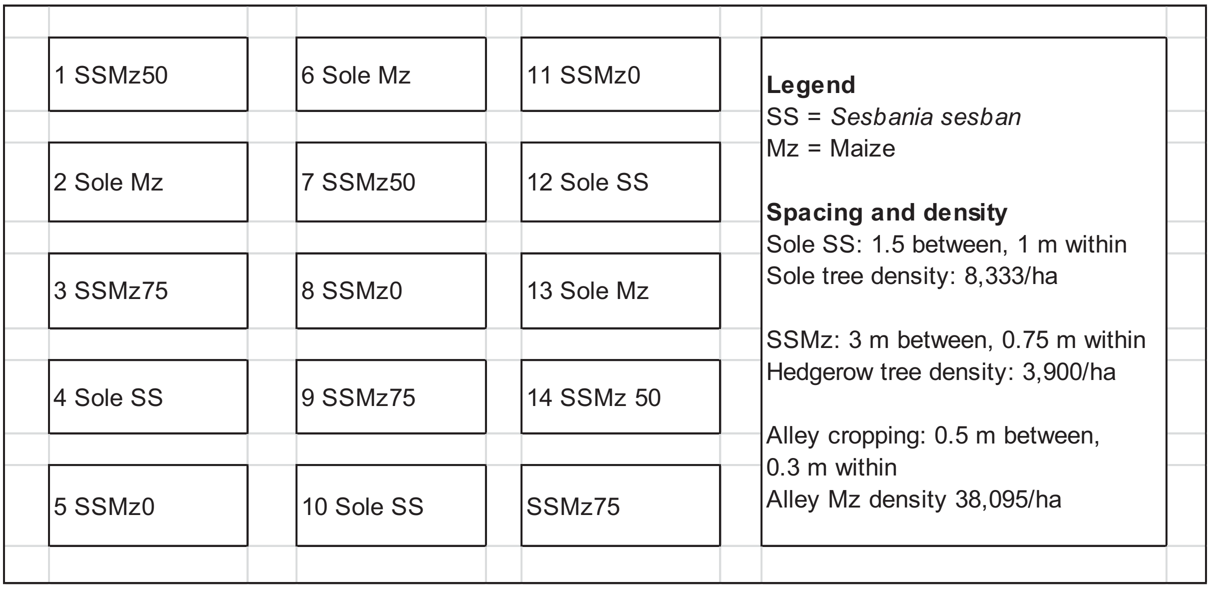


Figure 4.36 Experimental layout for assessing two pruning intensities in a hedgerow system,

Statistical analysis

Analysis of variance (ANOVA) was done using the GenStat software package (version 18; VSN International, UK). A 1-Way ANOVA was carried out to compare treatment means and where significant differences were found, the Duncan Multiple Range Test was used to separate treatment means at $p \leq 0.5$.

Results

A 1-Way ANOVA revealed a significant effect of cutting height on wood and total prunings but not for leaf and branch (Table 4.34). As was expected, wood and total prunings DM yield of plants were greater in trees pruned at 50 cm height as compared with those pruned at 75 cm height (Figure 4.37).

Table 4.34 A 1-Way ANOVA for leaf, branch, wood and total prunings dry matter yield of *S. sesban* trees subjected to two pruning intensities

Variables						
Dependent	Independent	SS	df	MS	F-ratio	P-value
Leaf	Cutting height	0.51	1	0.5058	2.10	0.1613
	Error	5.29	22	0.2407		
Branch	Cutting height	0.89	1	0.8939	3.96	0.0592
	Error	4.97	22	0.2258		
Wood	Cutting height	7.15	1	7.1487	6.68	0.0169
	Error	23.56	22	1.0709		
Total prunings	Cutting height	18.76	1	18.7647	5.01	0.0357
	Error	82.44	22	3.7472		

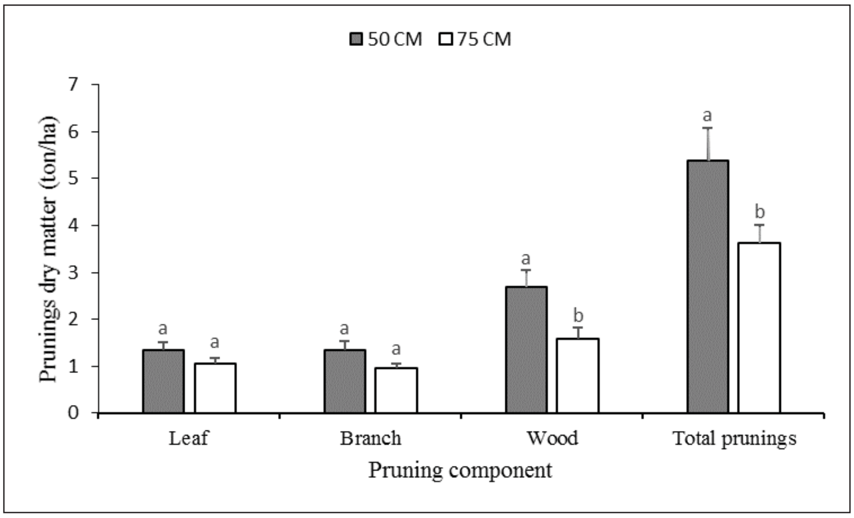


Figure 4.37 Dry matter yield of pruned components harvested from *S. sesban.* Letters on vertical bars compare treatment means within each pruning component

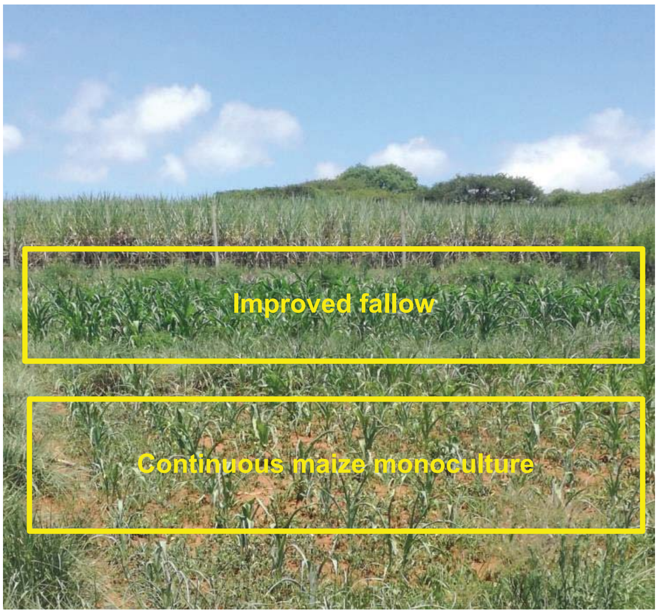
Note: Maize was not harvested in the 2016/2017 growing season. The tree effects on maize yield would not have been detected because the first pruning was conducted at the end of May, which was after the maize had already dried off.

Redesign of Trial 3 following mortality of pruned S. Sesban plants

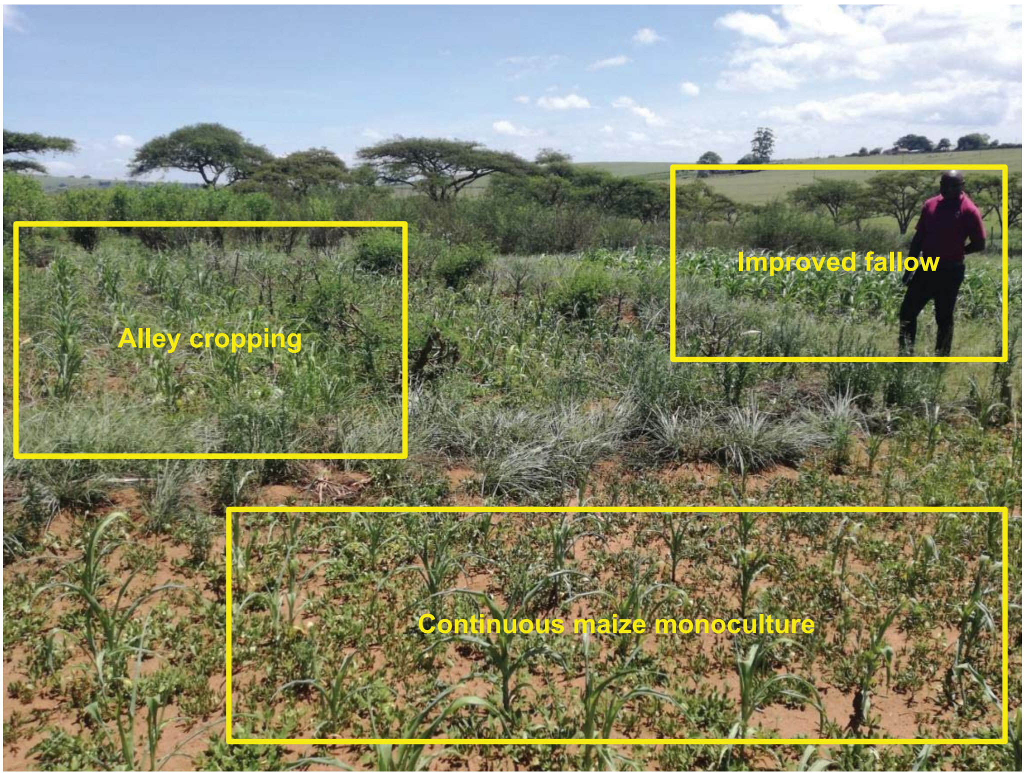
Due to the high rate of mortalities in the plots with cut hedgerows, the decision was taken to proceed as follows this season:

- The sole maize plots were replanted with maize
- The sole Sesbania plots (improved fallow) were cleared and planted to maize
- The uncut alley plots (which had only been cut at initial maize planting – November 2017) were cut and planted to maize.

The purpose of this is to compare alley cropping and an improved fallow against continuous monocropping with maize (Photograph 4.43 and Photograph 4.44). Under the climatic conditions experienced this season, it was apparent that the maize in the improved fallow plots was doing far better than the other treatments. The maize in the alley plots appeared to be doing much better than the sole plots (in terms of height and colour), but this was possibly because there had not been much regrowth of the Sesbania post-pruning.



Photograph 4.43 The visual difference in the maize in the improved fallow plot relative to the continuous monocropping maize plot.



Photograph 4.44 A visual comparison of the three treatments in Trial 3 showing comparative differences in the status of the maize on 7 January 2019.

Methodology

Due to the high rate of mortalities of *S. sesban* plants in the plots with cut hedgerows, it was necessary to amend the trial. The SSMz0 plots, in which the *S. sesban* plants were only cut once in the season, showed lower mortality rates and allowed for a comparison of sole maize plots, maize following a two year improved fallow with *S. sesban* trees, and an alley cropping system. Thus the trial was implemented as follows:

- The sole maize plots were replanted with maize
- The sole Sesbania plots (improved fallow) were cleared and planted to maize
- The uncut alley plots (which had only been cut at initial maize planting – November 2017) were cut and planted to maize.

Results

During the early stages, the maize in the alley plots appeared to be doing much better than the sole plots (in terms of height and colour), but this was possibly because there had not been much regrowth of the Sesbania post-pruning.

Maize stover results

Monkeys harvested the maize cobs early on so it was not possible to measure grain yield and thus results focus on the stover component.

The maize planted in the plots that had been under a two-year improved fallow produced significantly more stover DM (kg/ha) than the alley crop, but there was not a significant over the sole maize plots and there was no difference between the alley and the sole maize treatments (Figure 4.38, Table 4.35). In terms of In terms of plant height, the plants in the fallow were significantly taller than those in the sole maize plots, but not significantly different from those in the alley plots. For stem diameter, the plants in the alley plots had significantly thinner stems than both other treatments, which did not differ from each other ($p<0.05$).

Table 4.35 Maize stover yield and characteristics for sole maize, alley cropping and post fallow production at Fountainhill Estate, Wartburg, April 2019

Variable	Mean	se	F value	P value
Stover DM (kg/ha)			11.34	0.009
Alley	2.947^{b}	308		
Sole maize	3.969^{ab}	145		
Fallow	5.865^{a}	682		
Plant height (cm)			6.64	0.03
Alley	139.5^{ab}	4.585		
Sole maize	132.5^{b}	6.431		
Fallow	160.5^{a}	5.84		
Stem diameter (cm)			18.82	0.003
Alley	14.15^{b}	0.44		
Sole maize	17.38^{a}	0.548		
Fallow	19.92^{a}	0.916		

Overall one can conclude that the maize stover from the crop grown after the two-year Sesbania fallow was superior to the alley cropping system but did not outperform the sole maize. As a result, one cannot assume that the post-fallow crop would have produced more maize grain than the sole maize.

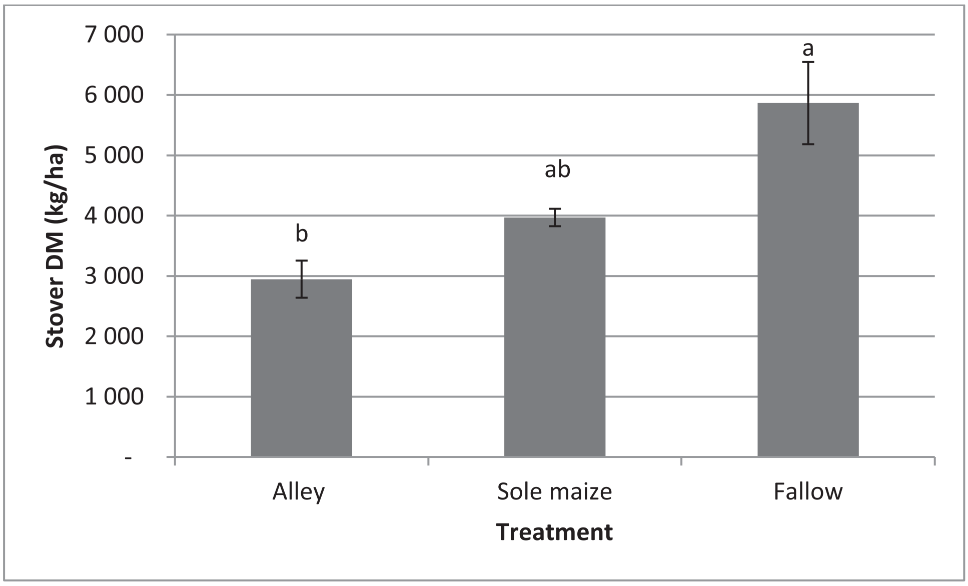


Figure 4.38 Comparison of stover DM yields from alley cropping, sole maize and an improved fallow, Fountainhill Estate, April 2019.

Practical implications

One of the challenges was that the Sesbania plants, though they had been cut off at ground level, showed a substantial amount of coppicing, which was unexpected. This may be one of the reasons why the maize in the fallow plots did not perform as well as was expected. It highlights the need to control coppice that grows between the maize.

Material added at the end of the fallow

Of the approximately 50 tons/ha of material harvested at the end of the fallow, approximately 11 tons was returned to the plot, while the wood and branches were removed for use as fuel as shown in Table 4.36.

Table 4.36 Amount of material harvested when the S. sesban trees were cut down at the end of the two-year improved fallow

Component	DM (kg/ha)
Wood	19,557
Branch	20,714
Leaf	2,042
Twig	4,034
Seed	4,896
TOTAL	51,243

4.4.7 Field Experiment 4: Assessing the influence of pruning on biomass production, N2 fixation and N contribution by two agroforestry species

Introduction

Research questions

- Do legumes growing in association with cereal crops remove lesser amounts of N from the soil compared with cereal since part of its N requirement is met by symbiotic N_2 fixation?
- What is the effect of periodic pruning and tree age on N_2 fixation?
- Is there any agreement between different methods used to estimate N_2 fixation in tree legumes?

Objectives

- To evaluate and compare N_2 fixation (%Ndfa) and N yield by *S. sesban* and pigeon pea grown in sole cropping and in hedgerow association with maize
- To analyze seasonal variation in N_2 fixation of *Sesbania sesban* and pigeon pea in hedgerow cropping system using the ^{15}N natural abundance, ureide and the total N balance methods
- To estimates and compare %Ndfa values obtained with the ^{15}N natural abundance, xylem sap ureide or the N balance methods to evaluate the relationship between the methods for measuring N_2 fixation.

Hypotheses testing

- N_2-fixing trees that are intercropped with non N_2-fixing crops (e.g. maize) are likely to derive greater proportions of N from the atmosphere than those in sole cropping
- There is seasonal variation in N2 fixation levels of the two hedgerow tree species

- There is a positive correlation in %Ndfa values obtained with either the ^{15}N natural abundance, xylem sap ureide or the N balance methods

Methodology

Tree and crop establishment

S. sesban trees were established from seedlings raised in poly bags for 60 d in a glasshouse (24°C). The most homogeneous seedlings of *S. sesban*, according to leaf surface area, biomass and height, were selected for transplanting in the field to minimize non-treatment variation among the trees. Pigeon peas were established from direct seeding. Two seeds were sown per hole and, at 90 d after establishment; the seedlings were thinned to one per hole.

Individual plot sizes measured 7 m x 10 m, separated by 2 m wide path. Plots include three hedgerows of *S. sesban* or pigeon pea with maize in the alleys and both tree species in monocultures. The alley width is 3 m and the distance between the maize rows and hedgerows is 0.75 m. Trees were spaced at 0.75 m within and 3 m between rows giving a density of 3,900 trees per hectare (ha). The monoculture tree plots were planted at 1.5 m within and 1.5 m between rows, resulting in a density of 7,143 trees/ha.

Four maize (OPV Border king) rows were planted between the alleys, at 0.3 m within and 0.5 m between rows giving a population of 38, 095 plants/ha. Two maize seeds were planted per hole (≈0.1 m depth), but later thinned to one at four weeks after planting. No synthetic fertilizers were applied to plots throughout the duration of this experiment. Plots were weeded twice using hand hoes in the 2016/17 growing season.

Pruning treatments

Pruning treatments and the experimental design used for this experiment are summarised in Table 4.37. Pruning was conducted in April 2017 the subsequent prunings will be conducted in November of 2017 and February of 2018. At pruning, trees were cut back to 75 cm height using secateurs. Prunings are either applied as nutrient sources for the alley maize (retained) or fodder for livestock (removed). Therefore, the prunings were spread evenly in plots designated for retaining prunings. In plots designated for harvesting livestock fodder, the prunings were removed from plots and supplied to household farmers at Swayimane near Wartburg. Residual number of branches and buds available for resprouting after pruning were counted in all plots and recorded.

Treatments, trial design and layout

The arrangements for the trial are summarised below.

Table 4.37 Management, treatment, replicate and experimental design for evaluating seasonal variation in N_2 fixation by pigeon pea and *S. sesban* grown in monoculture and in hedgerow system with maize

Agroforestry system	Management	Treatment	Replicate	Trial design
Alley cropping system	Tree pruning at 0.75 m height	SS+Mz	3	Randomized complete block design
		Sole SS	3	
Monoculture		PP+Mz	3	
		Sole PP	3	

1 Sole PP	5 PPMz	9 Sole SS	**Legend** PP = Pigeon pea SS = *Sesbania sesban* Mz = Maize
2 SSMz	6 Sole SS	10 SSMz	**Spacing and density** Sole PP/SS: 1.5 m between, 1 m within
3 Sole SS	7 Sole PP	11 PPMz	PP / SS with maize: 3 m between, 0.75 m within 3,900 trees/ha
4 PPMz	8 SSMz	12 Sole PP	Mz: 0.5 m between, 03 m within 38,095 plants/ha

Figure 4.39 Trial layout for evaluating seasonal variation in N_2 fixation by pigeon pea and *S. sesban* grown in monoculture and in hedgerow system with maize.

Sampling for biomass, TNC, total N (%N) and natural abundance (^{15}N)

Sampling was conducted at pruning from four randomly selected trees in the middle hedgerow. At each pruning stage, harvested prunings were partitioned into wood, branches and leaves, weighed, oven-dried at 60ºC for 5 days (d) and weighed again for determinations of dry matter (DM) yield. Non N_2-fixing *P. maximum* and maize which, in this case, are assumed to represent a measure of the isotopic signature of plant available soil mineral N for the N_2-fixing trees were also collected during sampling and oven-dried. Dried DM yield samples were finely ground into powder for the determination of tissue N concentration (%N) and natural abundance (^{15}N) at the University of Pretoria.

The xylem sap of detached stems from the five randomly selected plants will be immediately extracted using a hand-held vacuum extraction pump. Extracted sap will be put into Eppendorf tubes, kept chilled on ice, and frozen at -15°C prior to assays. Sampling will be done between 09h00 and 12h00 hours because of diurnal fluctuations in relative ureide-N (Herridge et al., 1988). Assays will be determined in the laboratory using a spectrophotometer. Because *S. sesban* is a major amide transporter, xylem sap was only extracted from pigeon pea trees.

Statistical analysis

Analysis of variance (ANOVA) was done using the GenStat software package (version 18; VSN International, UK). A 1-Way or 2-Way ANOVA was carried out to compare treatment means and where significant differences were found, the Duncan Multiple Range Test (DMRT) was used to separate treatment means at $p \le 0.5$.

Results and discussion

The preliminary results of the trial are provided below. The analysis of variance revealed significant tree species x cropping system interaction for leaf and branch dry matter (DM) yield (Table 4.38). Although there were no significant interactions for wood and total prunings, the main effects of tree species were significant for these parameters. Furthermore, the main effect of cropping system was only significant for total prunings.

Table 4.38 A 2-Way ANOVA for leaf, branch, wood and total prunings dry matter yield of *S. sesban* and pigeon pea trees grown in monoculture or in association with maize

Variables						
Dependent	Independent	SS	df	MS	F-ratio	P-value
Leaf	Tree	1296	1	1296	0.32	0.572
	Cropping system	22898	1	22898	5.72	0.021
	Tree*Cropping system	36347	1	36347	9.08	0.004
	Error	172091	43	4002		
Branch	Tree	76454	1	76454	32.62	<.000
	Cropping system	11633	1	11633	4.96	0.031
	Tree*Cropping system	11195	1	11195	4.78	0.034
	Error	100773	43	2344		
Wood	Tree	1423228	1	1423228	161.00	<.000
	Cropping system	33183	1	33183	3.75	0.059
	Tree*Cropping system	5969	1	5969	0.68	0.416
	Error	380107	43	8840		
Total prunings	Tree	79.9363	1	79.9363	70.80	<.000
	Cropping system	42.014	1	42.014	37.21	<.000
	Tree*Cropping system	0.0714	1	0.0714	0.06	0.803
	Error	48.5461	43	1.129		

Total pruning dry matter yields were significantly higher in monoculture tree legumes as compared with alley cropping trees (Figure 4.35). This difference, however, could be largely due to 22% lower tree population in alley cropping relative to monoculture system. Among the tree species, *S. sesban* accumulated significantly greater total prunings DM relative to pigeon pea (Figure 4.35). Total pruning DM produced by *S. sesban* was nearly 2-fold greater than that produced by pigeon pea. *S. sesban* also yielded 3.5-fold greater wood DM as compared to pigeon pea (Figure 4.37). This observation could be related to slower establishment of canopy development by pigeon pea in the first year.

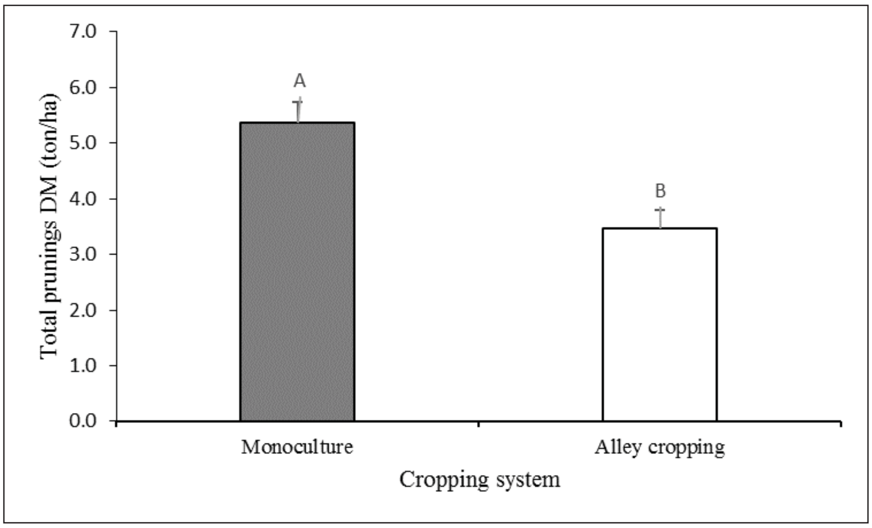


Figure 4.40 Dry matter yield of total prunings harvested from monoculture and alley cropping systems.

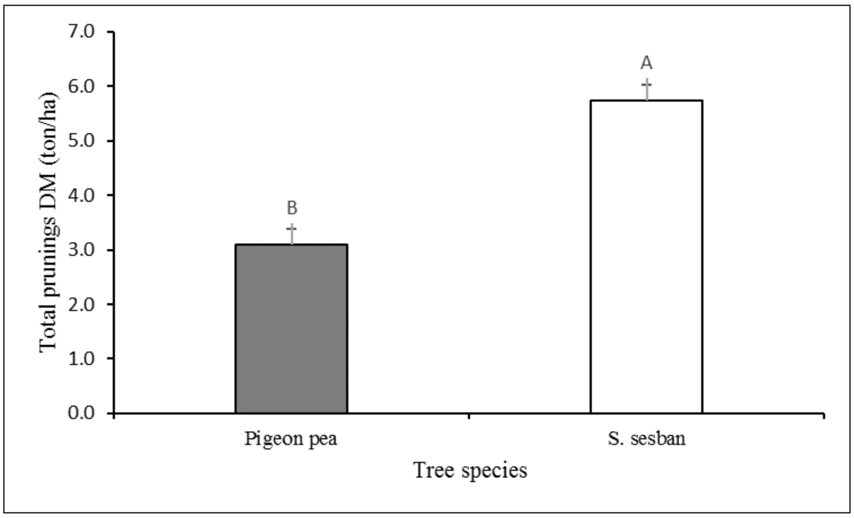


Figure 4.41 Dry matter yield of total prunings harvested from pigeon pea and *S. sesban* grown in monoculture and in association with maize.

Figure 4.42 Dry matter yield of wood produced by pigeon pea and *S. sesban* trees.

Monoculture pigeon pea trees produced significantly higher edible biomass (leaf) as compared with *S. sesban* (Figure 4.39). In contrast, *S. sesban* produced greater leaf biomass relative to pigeon pea when grown in alley cropping. Leaf production of pigeon pea was significantly higher in monoculture than in alley cropping. However, *S. sesban* produced similar leaf biomass irrespective of the cropping system (Figure 4.39). In both cropping systems, *S. sesban* accumulated significantly higher branch DM than pigeon pea (Figure 4.43). As with leaf DM, pigeon pea had significantly greater branch DM when grown in monoculture than in alley cropping system whereas *S. sesban* produced similar branch biomass in both cropping systems.

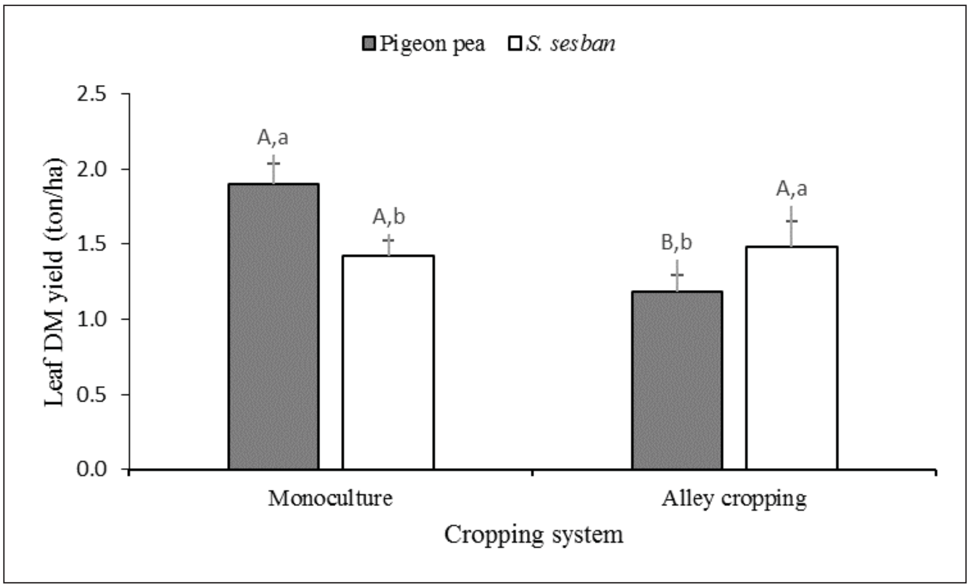


Figure 4.13 The effect of tree species x cropping system interaction on leaf dry matter production. Uppercase letters compare treatment means between cropping systems and lowercase letters compare means between tree species.

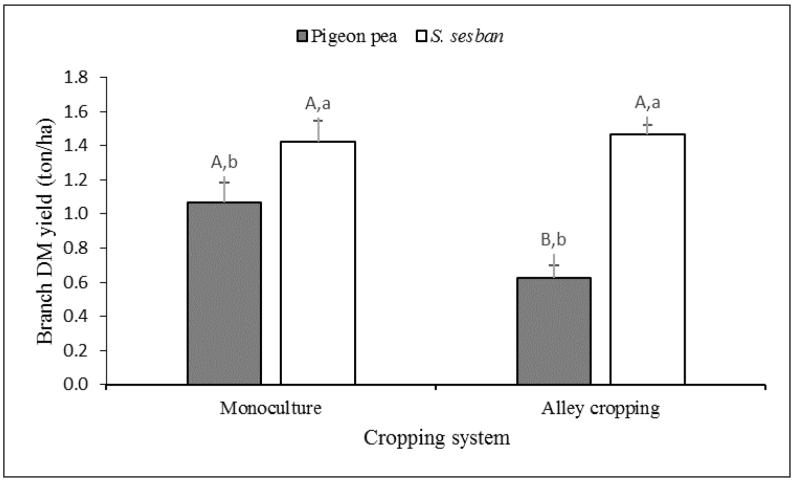


Figure 4.43 The effect of tree species x cropping system interaction on branch dry matter production. Uppercase letters compare treatment means between cropping systems and lowercase letters compare means between tree species.

4.4.8 Investigation of amount of residual material after a cutting event (Trials 2 and 3)

In an effort to understand how the *S. sesban* plants and the pigeon pea plants responded to pruning of hedgerows, the amount of material above and below the cutting point was measured in March 2019. The plants were cut off at the specified height and the material removed was separated into its components. The same was then done for the residual material cut off at ground level.

Pigeon pea

Since the pigeon pea/*P. maximum* trial had been terminated due to the high mortality rates amongst the cut pigeon peas, it was necessary to use plants from the BNF trial (trial 4) and it was only possible to simulate a 90 cm cutting height. Since there were some young recruits (seedlings that had germinated and grown), these were used to simulate the first cut applied to a tree in a hedgerow. The old Trial 4 (BNF trial) pigeon peas were used to simulate a second or third cutting event.

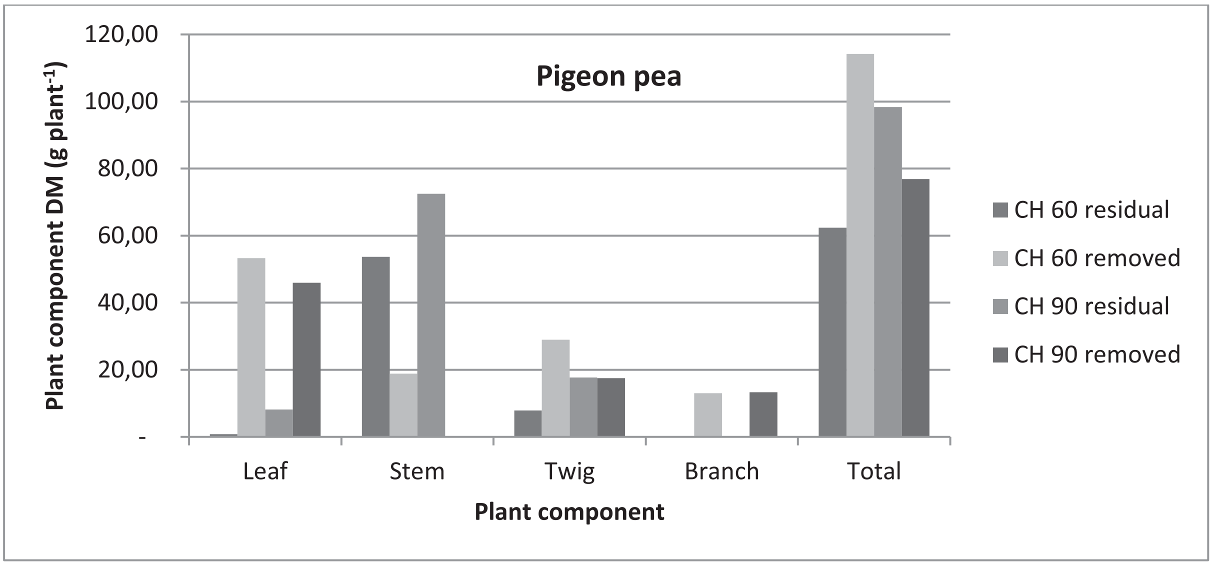


Figure 4.44 Residual and removed material from pigeon pea with 60 and 90 cm cutting heights when simulating the initial cut.

With the simulated initial cut, plants with the 90 cm cutting height had some stem removed, but it was less than half of the residual stem. The 90 cm cutting height left some leaf which would have assisted with regrowth ability compared with the 60 cm cutting height. In terms of total plant material, the plants with 60 cm cutting height had more removed than residual material, which was the opposite for the 90 cm cutting height.

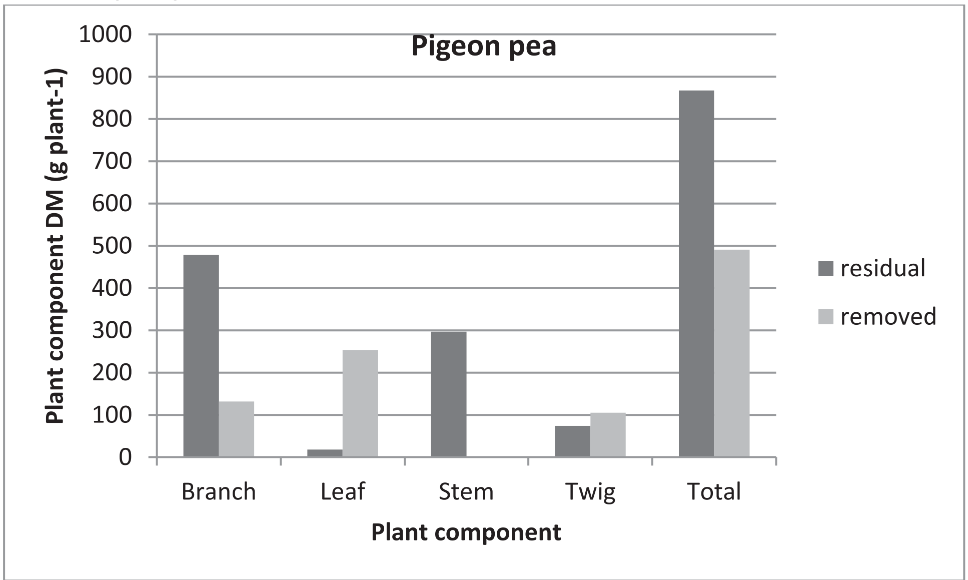


Figure 4.45 Residual and removed material from a pigeon pea with a 90 cm cutting height when simulating a second or third cutting event.

When simulating a second or third cut, the amount removed was substantially less than the amount of residual material. The amount of residual branch was greater than the amount of residual stem, which demonstrates that branches may be more important for the storage of carbohydrates than is the residual stem. Another important point to note is that there was very residual leaf after cutting, indicating that the plants would be unlikely to rely on photosynthates to support regrowth.

Sesbania sesban

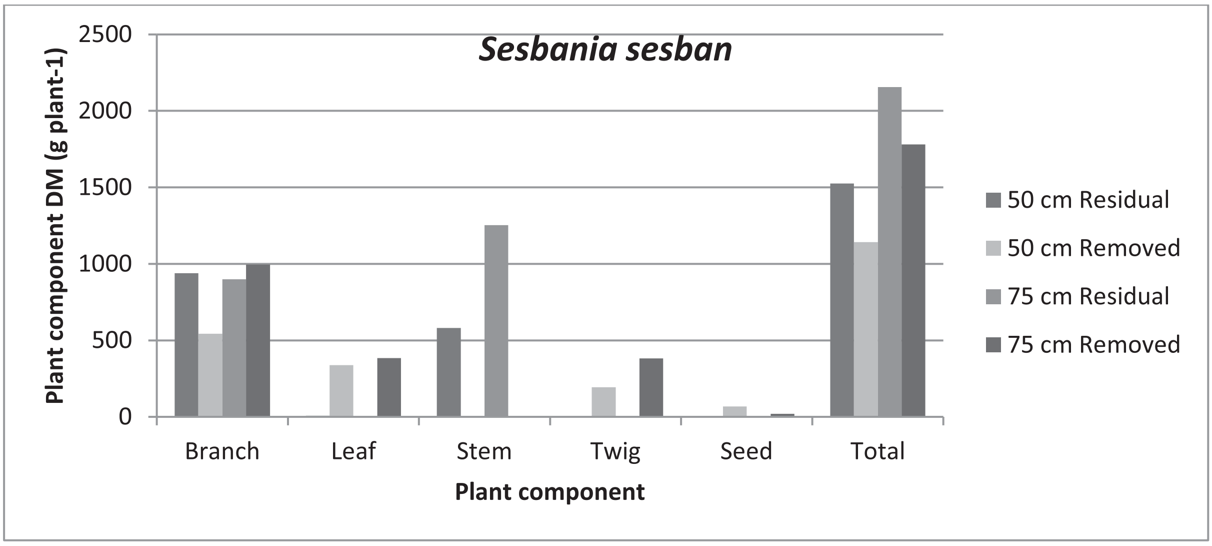


Figure 4.46 Residual and removed material from S. sesban with 50 and 75 cm cutting heights when simulating a second or third cutting event.

With both *S. Sesbania* cutting heights, the total amount of plant material removed was less than the total amount of residual material. The 75 cm plants had substantially higher residual stem DM than did the 50 cm cutting height (

Photograph 4.45), but they had similar amounts of residual branch (and the amount of branch was actually greater than the amount of residual stem of plants with the 50 cm cutting height). This could be the reason why the plants cut at 75 cm did not have lower mortalities relative to the 50 cm cutting height.

Photograph 4.45 Comparison of residual woody material of *S. sesban* from 50 cm and 75 cm cutting heights.

4.4.9 Photographs of the trials

Some photographs from the trials are provided below.

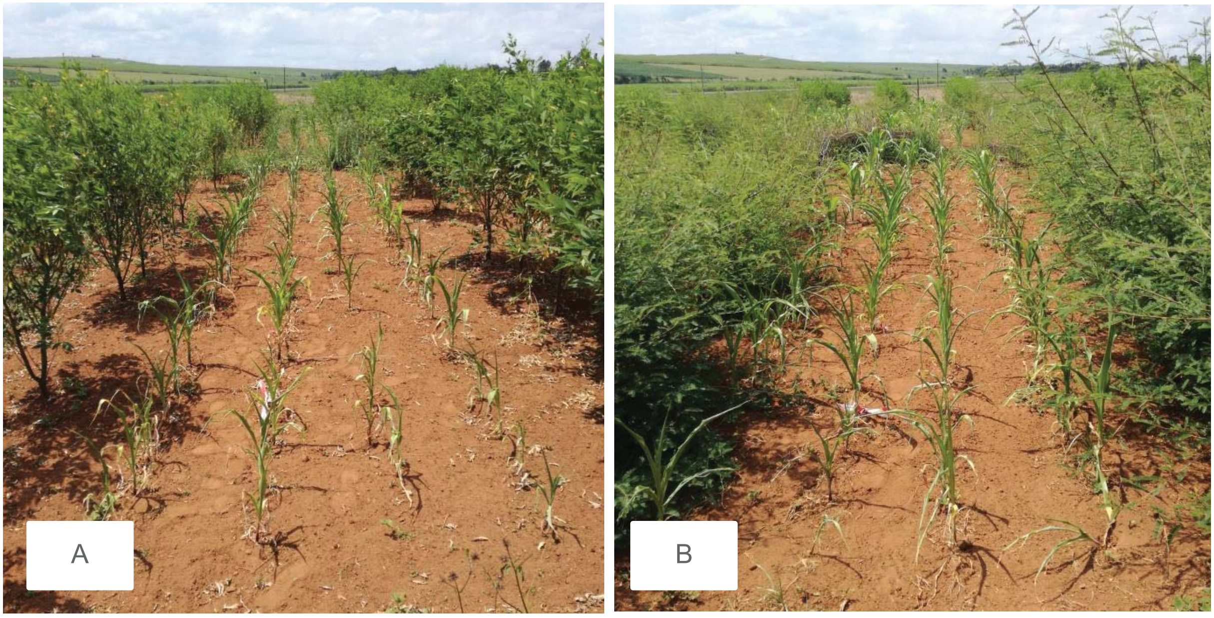
Trial 1: Management of prunings

In the first season when there was little competition from the hedgerows the maize produced well (Photograph 4.46). They hedgerows were cut back for the first time in autumn, after the maize harvest (Photograph 4.47).

Photograph 4.46 One of the *Sesbania sesban*-maize alley cropping plots at Fountainhill, February 2017.

Photograph 4.47 Alley cropping trials after application of the cutting treatments for pigeon pea (A) and *Sesbania sesban* in April 2016 (B).

Due to the poor growth of the Sesbania plants in this trial, the effect of the competition seemed greatest in the pigeon pea plots when the site was visited on 22 January 2018. Furthermore, the volumetric water content readings from the top 20 cm of soil showed that some plots were drier than others and this could be the reason for the very poor performance of the Sesbania in plot 4, which lost a large number of trees.



Photograph 4.48 Trial to investigate the effect of retaining or removing prunings (Trial 1), showing the effect of competition for water being greater for pigeon pea (A) than for Sesbania (B) during January 2018, Wartburg.

Trial 2: Pigeon pea/P. maximum silvopostoral system testing hedgerow pruning

In the first season the pigeon pea hedgerows struggled to compete with the *P. maximum* grass which was very vigorous (Photograph 4.49).

Photograph 4.49 One of the pigeon pea-*Panicum maximum* alley cropping plots at Fountainhill, February 2017.

Trial 3: Maize/S. sesban alley cropping trial testing pruning heights

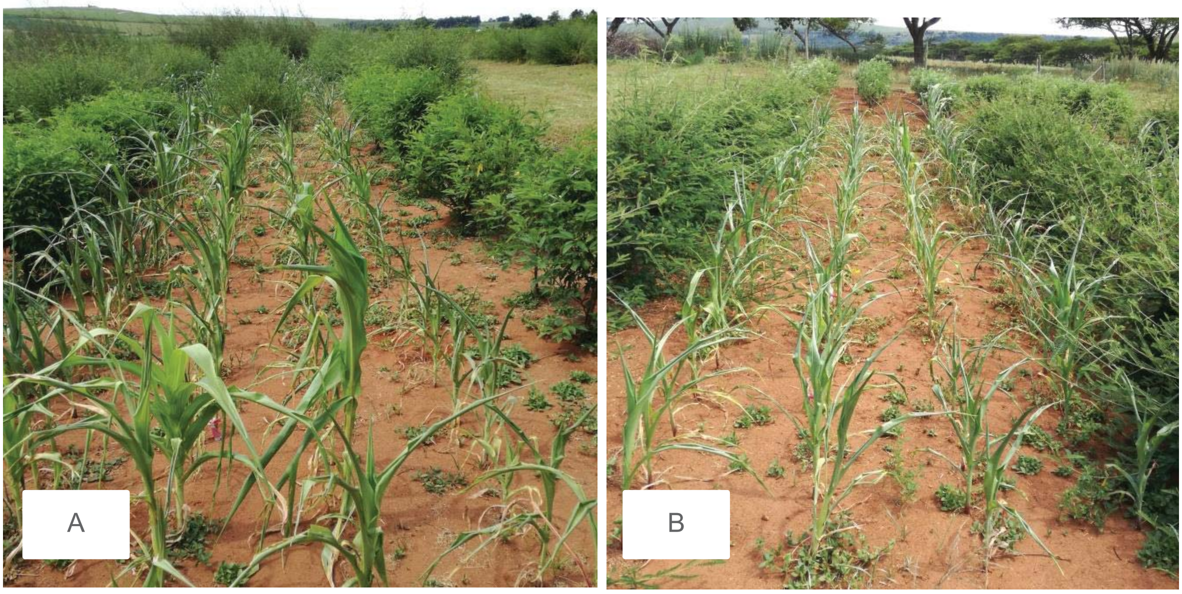
The uncut *S. sesban* hedgerows competed severely with the maize for available moisture (Photograph 4.50) and even when the hedgerows were cut back and the prunings used as much there was still evidence of competition for moisture (Photograph 4.51).

Photograph 4.50 Sesbania/maize trial (Trial 3) – The uncut hedgerow treatment, which only involved a single prune at maize planting, showing substantial growth and competition for light and water.

Photograph 4.51 The Sesbania/maize cutting height trial (Trial 3), with prunings being used to mulching the plot.

Trial 4: BNF trial that compared sole plots of S. sesban and pigeon pea with maize intercrops

In this trial the maize intercropped with pigeon pea looked better than the maize intercropped with pigeon pea because the Sesbania had grown very vigorously over summer (Photograph 4.52, Photograph 4.53).



Photograph 4.52 The BNF Trial (Trial 4) at Fountainhill, Wartburg showing that pigeon peas (A) compete less for water with maize than Sesbania (B), when the latter is actively growing. Note the Sesbania had already been pruned twice in the 2017/18 growing season.

Photograph 4.53 The BNF Trial (Trial 4) showing a maize/pigeon pea intercrop plot at Wartburg, January 2018.The pruning of pigeon pea hedgerows appears to have reduced the inter-specific competition for water.

4.5 Greenhouse trials

A set of trials were conducted under controlled conditions in greenhouses at University of KwaZulu-Natal to strengthen our understanding of *how S. sesban* plants respond to cutting height and frequency. Over time, a number of factors were identified in the field that also required deeper investigation.

4.5.1 Pot experiment 1: Evaluating the effects of pruning frequency of *S. sesban* on biomass productivity and nodulation

Introduction

Objective: To investigate the effect of pruning frequency on biomass productivity, total non-structural carbohydrates, nodulation and biological N_2 fixation by *Sesbania sesban*

The study was aimed to test the following hypotheses:

(i) Low and moderate pruning frequencies allows for plants to compensate for biomass productivity; but more frequently pruned plants are not able to compensate biomass productivity,

(ii) Low and moderate pruning frequency enhances nodulation and N_2 fixation capacity of plants, but high pruning frequency reduces nodulation and N_2 fixation, and

(iii) Total nonstructural carbohydrates in stems and roots decline with increasing pruning frequency due to continuous production of new leaves and branches.

We predicted reduced biomass production, nodulation, N_2 fixation and total nonstructural carbohydrates in plants subjected to high pruning frequency.

Methodology

Experimental site and plant culture

The experiment commenced on the 19th July 2016 and was carried out under controlled glasshouse conditions at the Department of Botany, University of KwaZulu-Natal, South Africa. Seeds of N_2-fixing woody legume *Sesbania sesban* (var. *nubica*) and non-N_2-fixing reference legume *Senna* were obtained from natural plantations in the KwaZulu-Natal Province. The seeds of both trees were surface scarified by immersing in boiled water for 10-15 minutes and cooled with five rinses of cool tap water. The seeds were then planted into 24-well plastic trays containing a mixture of the Umgeni River sand and seedling growth mix (Farmyard Organics). The seedling trays were placed in a glasshouse (temperature 21-32°C and relative humidity of 60-90%) and watered with fresh tap water once or twice a week, depending on the demand.

At 60 days after planting (DAP), healthy seedlings of both woody legumes were transplanted into 5 L free draining pots containing a 7: 1 kg mixture of local unsterilized Umgeni River sand and sterile vermiculite (Photograph 4.54). One seedling was transplanted per each pot. During the course of the trial, plants were fed with 1 L of modified 1/8 strength Hoagland N-free nutrient solution once a week and in some cases, particularly hot days, 1 L of water was used to supplement irrigation. Pesticides were used to control red spider mite.

Photograph 4.54 Sesbania seedlings planted out into pots for an investigation into the effects of cutting frequency.

Nodulation

To ensure the presence of compatible rhizobia essential for symbiotic N_2 fixation, rhizosphere soils of the *S. sesban* in the field were collected using shovels to prepare soil inoculum. About 700-800 g of soil from rhizospheres of *S. sesban* was collected in the 0.5-20 cm of the soil profile and stored in the freezer (-4^{o}C) prior to preparation of soil inoculum. The inoculum used to inoculate the potted seedlings was prepared by adding 1200 mL of sterile distilled water to 350 g of soil in a 2000 mL container. The contents were stirred for about 20 to 30 minutes and left to settle before applying the bacterial suspension to seedlings. To guarantee effective nodulation, the seedlings were inoculated immediately after transplanting and 14 days after transplanting at a rate of 15 mL per pot.

Pruning treatments

At approximately 100 days after transplanting (DAT) when the tree heights (measured from root collar to the terminal bud) and leaves attained an average of 98.4±2.9 cm (*n*= 16) and 87±12 number of leaves, respectively; the pruning treatments were applied to pots. Subsequent prunings were conducted at 6 and 9 months after the first pruning. The treatments included: a control (no pruning; PF0) and three cutting frequencies, i.e. removal of shoot biomass at 50% height at (i) 3 months only, (ii) 3 and 6 months, and (iii) 3, 6 and 9 months, subsequently referred to as PF1, PF2 and PF3, respectively. The experiment was laid out in a complete randomized design (CRD) with four replications. Control plants were allowed to grow for 10 months without any pruning manipulation.

Plant sampling and processing

After each pruning, the harvested biomass (prunings) was partitioned into stem, green leaves, twigs and branches. The plant components were put into brown perforated bags and weighed. Two samples of about 5 cm woody segments (woody stem or branch) were cut from the standing tree and put into small brown envelopes. The envelopes were inserted into zip lock bags and then kept in a cooler box containing crushed ice. All collected plant samples were oven-dried at 60°C for 72 hours (h) and weighed for determination of dry matter yield. The DM yield of prunings was later included in the shoot fraction of the corresponding plants at the final destructive harvest to determine cumulative shoot DM production.

At 4 weeks after the final pruning, plants were destructively harvested by decapitating at 2 cm above the soil line, and the aboveground biomass was partitioned into leaves, twigs, branches and main stem. Two woody samples of about 5 cm were cut from the upper and lower sections of the stems and were put into small brown envelopes. The envelopes were inserted into zip lock bags and then kept in a cooler box containing crushed ice. The roots were carefully recovered from pots, washed free of soil over a sieve and root length was measured using a ruler. A 5 cm sample was taken from the root and treated as with the stem samples. The nodules were detached from roots and counted. The plant samples were weighed, oven-dried at 60°C for 72 hours (h), weighed again for determination of dry matter yield. Samples were finely milled into powder for analysis of total nonstructural carbohydrates (TNC), total nitrogen (%N) and natural abundance $\delta^{15}N$.

Statistical analysis

For data analysis, two methods were used for assessing the effects of pruning frequency: a cumulative method which include DM yield of prunings harvested periodically during the course of the experiment, and a current approach of referring only to the final harvest. Analysis of variance (ANOVA) was done using the GenStat analytic software package (version 18.1; VSN International Ltd, UK). 1-Way ANOVA was carried out to compare treatment means and where significant differences were found, the Duncan Multiple Range Test was used to separate treatment means at $p \leq 0.5$.

Results and discussion

Aboveground dry matter (DM) production

Growth and dry matter production of 10-month-old *S. sesban* plants was significantly affected by the frequency of pruning. Total shoot DM yield of unpruned trees at final harvest were significantly higher than all the pruning treatments. Although PF2 and PF3 recorded statistically similar DM production, shoot DM of plants declined with increasing pruning frequency. In comparison with PF0 plants, total shoot DM production of PF1, PF2 and PF3 decreased by 27, 52 and 51%, respectively. Similarly, the amount of shoot removed by pruning and that recovered at the final harvest (together making up cumulative shoot DM production) was significantly greater in unpruned tree relative to all pruning treatments (Table 4.39). In comparison with the unpruned plants, cumulative shoot dry matter yield declined by 23, 42 and 17% for PF1, PF2 and PF3 treated plants, respectively. The results of this study clearly demonstrated that *S. sesban* plants could fully compensate for biomass removed under low pruning frequency. As was expected, the highest pruning frequencies (i.e. PF3 and PF2) were more detrimental and consequently plants were unable to compensate for biomass removed. This behavioral characteristic of *S. sesban* following increased pruning frequency implies that gradual depletion of reserve carbohydrates in the plants may have occurred in such a way that plants could no longer sustain vigorous growth. *Sesbania sesban* achieves rapid above-ground growth, but has been observed to lose vigor after severe cutting (Yamoah & Getahun, 1990).

In terms of cumulative ligneous (woody stem + branches) tissue, DM production of plants was significantly higher in PF0 followed by PF1 (Table 4.39). PF2 and PF3 treated plants achieved the lowest cumulative ligneous DM yield. In contrast, the most frequently pruned trees, PF3 followed by PF2, recorded the highest non-ligneous dry matter production as compared to PF1 and PF0 (Figure 4.48). The fact that frequently pruned plants yielded more cumulative non-ligneous DM indicates the advantage of green pruning for improving soil fertility and fodder productivity.

Table 4.39 Final harvest and cumulative total dry matter yield (g/plant) of *Sesbania sesban* var. nubica as affected by pruning frequency. Values (means) in columns followed by dissimilar letters are significantly different at $p \leq 0.001$* and $p \leq 0.01$**. NS= not significant.**

Treatment	Final harvest dry matter yield (g/plant)				
	Stem	Branch	Twig	Leaf	Total
PF0	57.82^{a}	35.90^{b}	0.87^{a}	9.83^{a}	104.42^{a}
PF1	16.56^{b}	49.50^{a}	0.70^{a}	9.33^{a}	76.10^{a}
PF2	13.20^{b}	15.17^{c}	1.83^{a}	6.50^{b}	49.90^{c}
PF3	17.88^{b}	8.00c	1.67^{a}	5.83^{b}	51.26^{c}
LSD $_{(0.05)}$	6.36	7.81	1.29	2.01	11.13
F-value	104.04***	56.36***	1.84NS	9.38**	88.24***
	[a] Cumulative dry matter yield (g)				
PF0	57.82^{a}	35.90^{b}	0.87^{b}	9.83^{c}	104.42^{a}
PF1	17.52^{b}	49.50^{a}	0.77^{b}	12.11^{b}	79.89^{b}
PF2	14.26^{b}	26.03^{c}	2.19^{ab}	17.66^{ab}	60.14^{c}
PF3	19.10^{b}	34.86^{b}	3.31^{a}	29.48^{a}	86.74^{b}
LSD $_{(0.05)}$	6.27	8.45	1.58	6.58	14.69
F-value	101.68***	12.48***	5.54**	16.89***	14.75***

PF0, PF1, PF2, PF3: unpruned, pruned once, pruned twice, pruned 3 times
[a] Including previous prunings

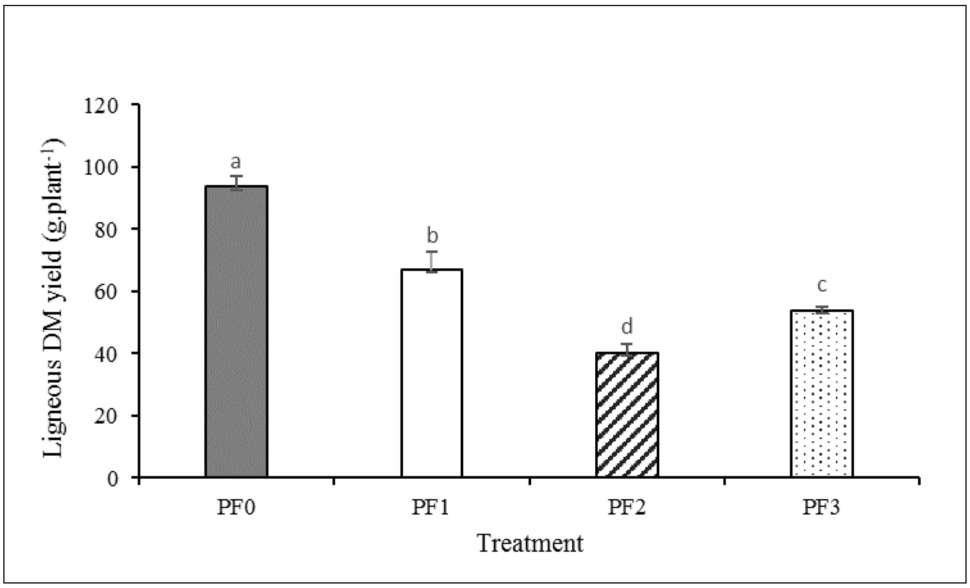


Figure 4.47 Cumulative ligneous (woody stems + branches) dry matter yield (g plant^{-1}) of *S. sesban* var. nubica as affected by pruning frequency. Vertical bars represent treatment means ± SE, *n*= 4.

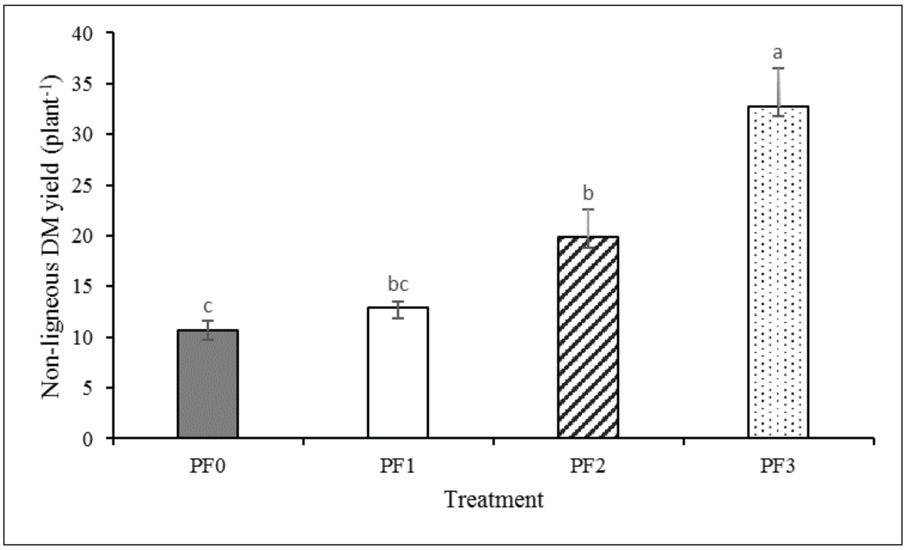


Figure 4.48 Cumulative non-ligneous (edible twigs + leaves) dry matter yield (g plant^{-1}) of *S. sesban* var. nubica as affected by pruning frequency. Vertical bars represent treatment means ± SE, *n*= 4.

Belowground DM production and nodulation

As with total shoot DM yield at final harvest, root dry weight was significantly reduced by increased pruning frequency (Table 4.40). In comparison with the unpruned plants, pruning reduced root DM yield by 22, 41 and 44% in PF1, PF2 and PF3, respectively. Similarly, root lengths of PF1, PF2 and PF3 were significantly reduced by 11, 18 and 23%, respectively. Nodule DM and nodule number of plants was significantly affected by pruning frequency, and this effect was only observed in PF3 plants. In comparison with PF0, the number of nodules in PF3 plants declined by as much as 82%. Nodule DM also significantly declined with increased pruning frequency. Nodule DM per plant was enhanced by PF0, PF1 and PF2 and was significantly reduced by PF3 (Table 4.40) These observations clearly demonstrate that trees pruned once or twice can renodulate and maintain N_2 fixation at levels similar to unpruned trees. The reductions in nodule weight and number of nodules per plant are likely to be due to shedding and decomposition of individual nodules and delay in the renodulation.

Table 4.40 Root dry matter yield (g plant^{-1}), root length (cm) nodule number (no. of nodules plant^{-1}) and nodule dry weight (mg plant^{-1}) of *S. sesban* subjected to three different pruning frequencies. Values (means) in columns followed by dissimilar letters are significantly different at *p*≤0.001* and *p*≤0.01**. NS= not significant.**

Treatment	**Final harvest**			
	Root		Nodulation	
	Dry weight	Length	Dry weight	Number
PF0	74.56^{a}	68.03^{a}	2.90^{a}	164.7^{a}
PF1	65.45^{a}	58.75^{a}	2.82^{a}	162.3^{a}
PF2	47.02^{b}	47.85^{b}	2.71^{a}	140.0^{a}
PF3	42.78^{b}	44.20^{b}	1.97^{b}	110.3^{b}
LSD $_{(0.05)}$	12.15	9.98	29.10	29.10
F-value	14.60***	11.17***	12.49**	7.15**

PF0, PF1, PF2, PF3: unpruned, pruned once, pruned twice, pruned 3 times

4.5.2 Pot experiment 2: Effect of cutting intensity on growth, recovery of plant biomass and nodulation of *S. sesban* following pruning

Introduction

Aim: To investigate effect of cutting intensity on recovery of biomass, non-structural carbohydrates, nodulation and N_2 fixation

Hypotheses:

(i) Higher levels of clipping intensity will lead to greater reduction in the NSC levels of the roots and stems, which will in turn reduce the rate of growth and biomass production

(ii) Low and moderately pruned trees will allow for nodulation and N_2 fixation recovery to a level of uncut trees within a short period of time; but severely pruned trees will take much longer to recover to uncut equilibrium

We predicted no recovery of biomass, non-structural carbohydrates, nodulation and N_2 fixation to a level of uncut trees in severely pruned trees.

Methodology

Experimental site and plant culture

The experiment was carried out under controlled glasshouse conditions at the Department of Botany, University of KwaZulu-Natal, South Africa. Seeds of N_2-fixing woody legume *Sesbania sesban* (var. *nubica*) and non-N_2-fixing reference legume *Senna* were obtained from natural plantations in the KwaZulu-Natal Province. The seeds of both trees were surface scarified by immersing in boiled water for 10-15 minutes and cooled with five rinses of cool tap water. The seeds were then planted into 24-well plastic trays containing a mixture of the Umgeni River sand and seedling growth mix (Farmyard Organics). The seedling trays were placed in a glasshouse (temperature 21-32°C and relative humidity of 60-90%) and watered with fresh tap water once or twice a week, depending on the demand.

At 60 days after planting (DAP), healthy seedlings of both woody legumes were transplanted into 5 L free draining pots containing a 7:1 kg mixture of local unsterilized Umgeni River sand and sterile vermiculite. One seedling was transplanted into each pot. During the course of the trial, plants were fed with 1 L of modified 1/8 strength Hoagland N-free nutrient solution once a week and in some cases, particularly on hot days, 1 L of water was used to irrigate all pots.

Nodulation

To ensure the presence of compatible rhizobia essential for symbiotic N_2 fixation, rhizosphere soils of the *S. sesban* in the field were collected using shovels to prepare soil inoculum. About 700-800 g of soil from rhizospheres of *S. sesban* was collected in the 0.5-20 cm of the soil profile and stored in the freezer (-4°C) prior to preparation of soil inoculum. The inoculum used to inoculate the potted seedlings was prepared by adding 1200 mL of sterile distilled water to 350 g of soil in a 2000 mL container. The contents were stirred for about 20 to 30 minutes and left to settle before applying the bacterial suspension to seedlings. To guarantee effective nodulation, the seedlings were inoculated immediately after transplanting and 14 days after transplanting at a rate of 15 mL per pot.

Pruning treatments

The effect of pruning intensity was analyzed following a factorial combination of four different cutting heights and four harvesting times. The experiment was arranged in a completely randomized design with four replicates. Prior to imposition of treatments it was generally assumed that all plants were similar in terms of tree height, number of leaves, biomass accumulation, nodulation, and N_2 fixation levels. Therefore, ten plants were harvested at pruning to characterize afore mentioned parameters. Height of plants was measured from soil level to the terminal bud using a ruler. Plants destructively harvested by decapitating at 2 cm above the soil line, and the aboveground biomass was partitioned into leaves, stems and twigs and weighed fresh. The plant components were oven-dried at 60°C for 72 hours (h), weighed for determination of dry matter yield and finely milled for determination of total N (%N) and natural abundance (^{15}N) using the isotope mass spectrometer.

The treatments included a control (unpruned, 0) and three pruning regimes: (i) removal of shoot biomass at 15 cm (cutting regime 1, CR1), (ii) removal of shoot biomass at 30 cm (cutting regime 2, CR2) and (iii) removal of shoot biomass at 45 cm (cutting regime 3, CR3) above the soil line. The pruning treatments were applied at 100 days after transplanting (DAT) when the tree heights (measured from root collar to the terminal bud) attained an average of 74.9 cm (n= 10). Control plants continued growth without any treatment manipulation.

Plant sampling and processing

Plants were destructively harvested at 4, 8, 12 and 16 weeks after pruning (WAP). At each harvest, plants were treated in a similar manner. The plants were destructively harvested by decapitating at 5 cm above the soil line, and the aboveground biomass was partitioned into leaves, stems and twigs. The roots were carefully recovered from pots, washed free of soil over a sieve; all nodules were detached from roots, and counted. The plant components were oven-dried at 60°C for 72 hours (h), weighed for determination of dry matter yield and finely milled for determination of total N (%N) and natural abundance (^{15}N).

Statistical analysis

Analysis of variance (ANOVA) was done using the GenStat software package (version 18.1; VSN International Ltd, UK). The effects of four pruning intensities (0, 45, 30 and 15 cm), sampling date (4, 8, 12 and 16 weeks after pruning (WAP) and their interactions on DM yield and nodulation of *S. sesban* were evaluated by a 2-Way ANOVA. The comparisons of parameters of the four treatments at the same harvesting time were conducted using a 1-Way ANOVA. Where significant differences were found, the Duncan Multiple Range Test was used to separate treatment means at $p \leq 0.05$ probability level.

Results and discussion

Aboveground dry matter (DM) production

The ANOVA of aboveground DM production showed a highly significant effect of pruning intensity and time of harvest on all measured parameters except for leaves (See Table 4.41). There was a significant interaction between the pruning intensity and time of harvest for all measured parameters so we explored the simple effects of pruning and time.

Table 4.41 A 2-Way ANOVA output for dry matter production and nodulation of *S. sesban* in response to pruning intensity treatments

Variables						
Dependent	Independent	Type III Sum of Squares	df	MS	F-ratio	*p*
Stem	Pruning intensity	8067.45	3	2689.15	219.88	<.001
	Time of harvest	1989.54	3	663.18	54.23	<.001
	Pruning intensity*Time of harvest	1604.08	9	178.23	14.57	<.001
	Error	587.00	48	12.23		
Branch + Twig	Pruning intensity	3543.34	3	1181.11	27.81	<.001
	Time of harvest	5679.38	3	1893.13	44.58	<.001
	Pruning intensity*Time of harvest	2138.62	9	237.62	5.60	<.001
	Error	2038.37	48	42.47		
Leaves	Pruning intensity	21.53	3	7.18	1.02	0.391
	Time of harvest	35.50	3	11.83	1.69	0.182
	Pruning intensity*Time of harvest	210.62	9	23.40	3.33	0.003
	Error	336.89	48	7.02		
Total shoot	Pruning intensity	1256.80	3	418.90	3.93	<.001
	Time of harvest	13229.30	3	4409.80	41.41	<.001
	Pruning intensity*Time of harvest	2510.90	9	279.00	2.62	<.001
	Error	5113.60	48	106.50		
Root DW	Pruning intensity	1822.73	3	607.58	16.69	<.001
	Time of harvest	2717.86	3	905.95	24.89	<.001
	Pruning intensity*Time of harvest	858.64	9	95.40	2.62	0.0150
	Error	1747.05	48	36.40		
Root length	Pruning intensity	1956.70	3	652.20	9.68	<.001
	Time of harvest	1446.90	3	482.30	7.16	<.001
	Pruning intensity*Time of harvest	1845.90	9	205.10	3.04	0.0059
	Error	3237.00	48	67.40		
Nodule DW	Pruning intensity	0.82	3	0.27	1.21	0.3162
	Time of harvest	23.74	3	7.91	34.91	<.001
	Pruning intensity*Time of harvest	6.15	9	0.68	3.02	0.0062
	Error	10.88	48	0.23		
Nodule no.	Pruning intensity	3822.06	3	1274.02	4.12	0.0112
	Time of harvest	51788.84	3	17262.95	55.81	<.001
	Pruning intensity*Time of harvest	30003.36	9	3333.71	10.78	<.001
	Error	14848.08	48	309.34		

Stem DM yield was consistently greater in uncut trees as compared with pruned trees throughout the experimental duration (Figure 4.49). There was no recovery of stem following pruning as shown in Figure 4.49. Irrespective of the pruning treatment, pruned trees had statistically similar stem DM yield throughout the duration of the experiment except at 16 WAP where the plants pruned at 45 cm height had significantly more stem than those pruned at 30 or 15 cm. In general, stem DM yield of all plants increased significantly with increasing time (Figure 4.49).

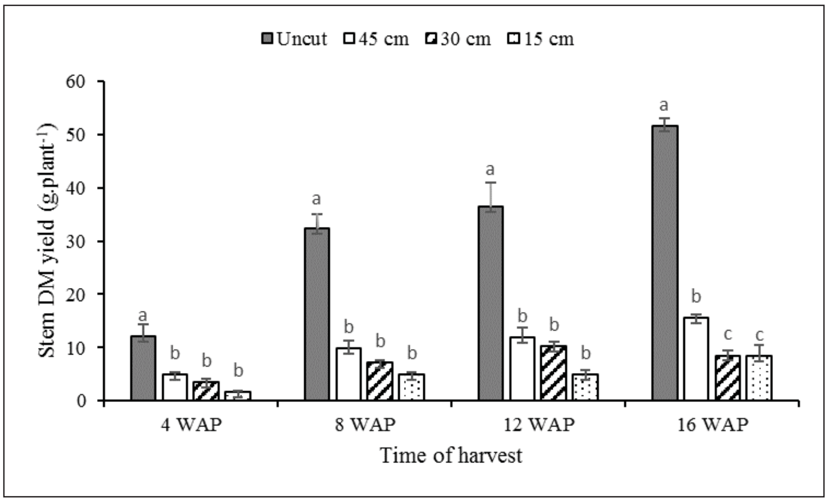


Figure 4.49 The effect of pruning intensity x time of harvest interaction on stem DM production of *S. sesban* subjected to four pruning intensities.

In terms of branches and twigs, the pruned treatments had significantly more dry matter yield than the uncut plants (Figure 4.50). This observation in this study supports the insertion that pruning induces lateral branching in *S. sesban.* Among the pruning treatments, trees cut at 30 and 15 cm height achieved the highest branch DM yield at 4, 8 and 12 WAP relative to those pruned at 45 cm height. However, at 16 WAP, trees pruned at 45 cm height recorded significantly higher branch DM yield relative to their pruned counterparts. Irrespective of the treatment, branch DM yield of plants tended to increase with increasing time (Figure 4.50).

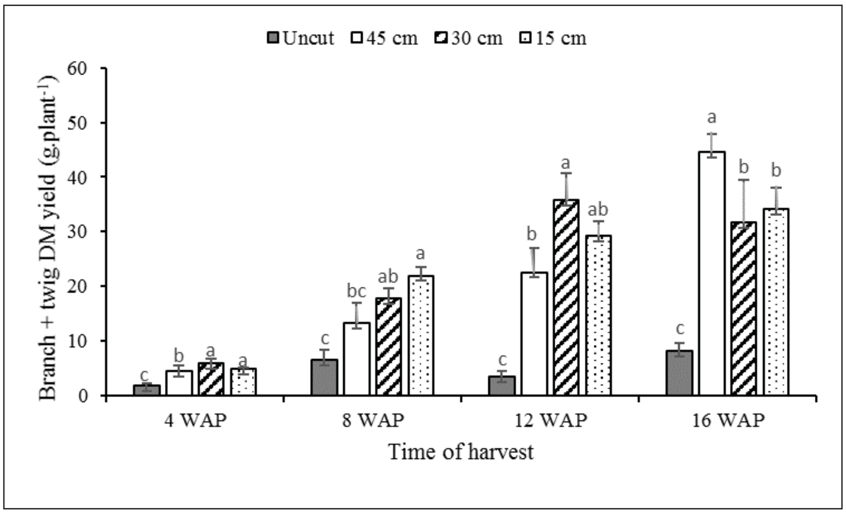


Figure 4.50 The effect of pruning intensity x time of harvest interaction on branch plus twig DM production of *S. sesban* subjected to four pruning intensities.

The effect of pruning treatment on leaf yield is very important particularly if one is considering fodder production as the primary objective. In terms of leaf DM production in this study, plants tended to display variable responses with time (Figure 4.51). For instance, at 4 and 8 WAP, leaf DM yield was significantly greater in uncut trees as compared with pruned trees. However, at 12 WAP all pruned trees achieved higher leaf DM yield as compared with uncut plants (Figure 4.51). At 16 WAP, trees that were pruned at 45 cm maintained greater leaf DM that was similar to the uncut trees. Trees pruned at 30 and 15 cm recorded the lowest DM yield at 16 WAP. Unlike stem and branch DM yield which increased with increasing time of growth, leaf DM yield of plants, irrespective of the treatment, tended to decline after attaining biomass ranging from 8.5-13 g per pot. Because trees that were pruned at 45 cm height accumulated leaf DM that was well below 8.5 g per pot, they were able to maintain similar leaf MD yield throughout the duration of the experiment (Figure 4.51). It is therefore suggested that this behavioural characteristic of *S. sesban* trees could be linked to moisture stress induced by high transpiration demand. This claim is supported by increased leaf observed in this experiment especially between 10 and 11 WAP.

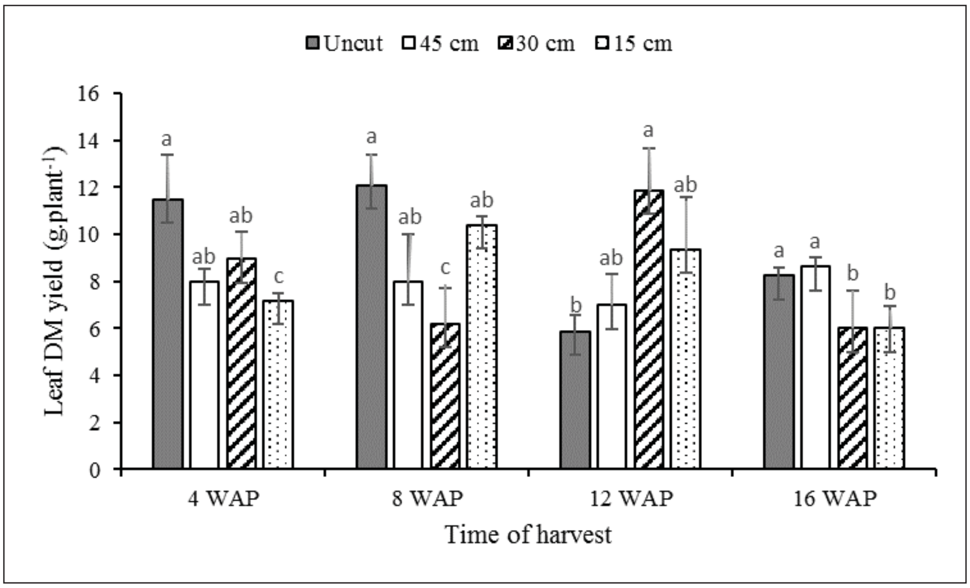


Figure 4.51 The effect of pruning intensity x time of harvest interaction on leaf DM production of *S. sesban* subjected to four pruning intensities.

Results for the total aboveground (total shoot) dry matter yield of study trees are presented in Figure 4.52. Although there were no significant differences at 12 WAP, shoot DM yield of uncut trees was significantly higher in uncut trees as compared with pruned trees. Plants pruned at 15 cm height recorded the least shoot DM yield at 4 WAP whilst those pruned at 45 and 30 cm recorded the lowest shoot DM yield 8 WAP. At 16 WAP, uncut plants and those pruned at 45 cm height recorded the highest shoot DM yield in comparison with plants pruned at 30 and 15 cm. In general, total shoot growth of plants in this experiment tended to increase with increasing time (Figure 4.52). However, a decline in shoot DM of uncut trees was observed at 12 WAP. Similarly, shoot DM yield of trees pruned at 30 cm declined at 16 WAP. The observed decline in shoot growth is mainly due to marked leaf fall because of moisture stress. Biomass recovery of *S. sesban* was apparent at 16 WAP but only for trees pruned at 45 cm height. This implies that cutting trees to lower heights may deplete greater carbohydrate reserved to an extent that plants cannot supply energy required for rapid regrowth.

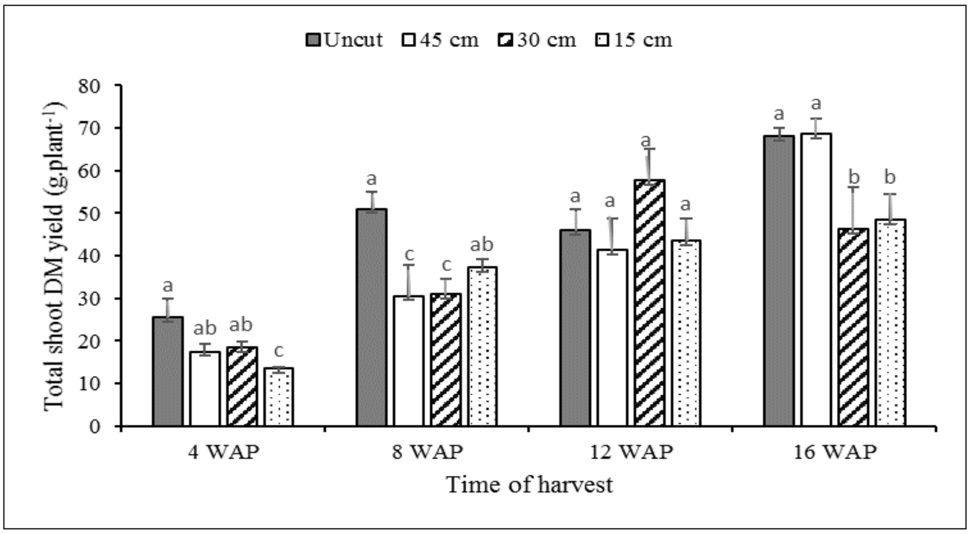


Figure 4.52 The effect of pruning intensity x time of harvest interaction on total DM production of *S. sesban* subjected to four pruning intensities.

Root DM yield was significantly affected by pruning (Figure 4.53). During the 4 and 8 WAP, root DM yield was significantly higher in uncut trees followed by moderately pruned trees. However, during this period, trees pruned at 30 and 15 cm height recorded the lowest root DM yield. At 12 WAP, root DM yield of uncut trees was significantly higher than all unpruned trees. Root dry matter recovery was observed at 16 WAP but only for lightly pruned trees. Trees pruned at 30 and 15 cm were unable to recover for root DM yield to a level of uncut trees (Figure 4.53). Root DM yield of all plants tended to increase throughout the recovery period. This observation suggests that severe pruning could potentially reduce competition for water between trees and the adjacent crop in an alley cropping system.

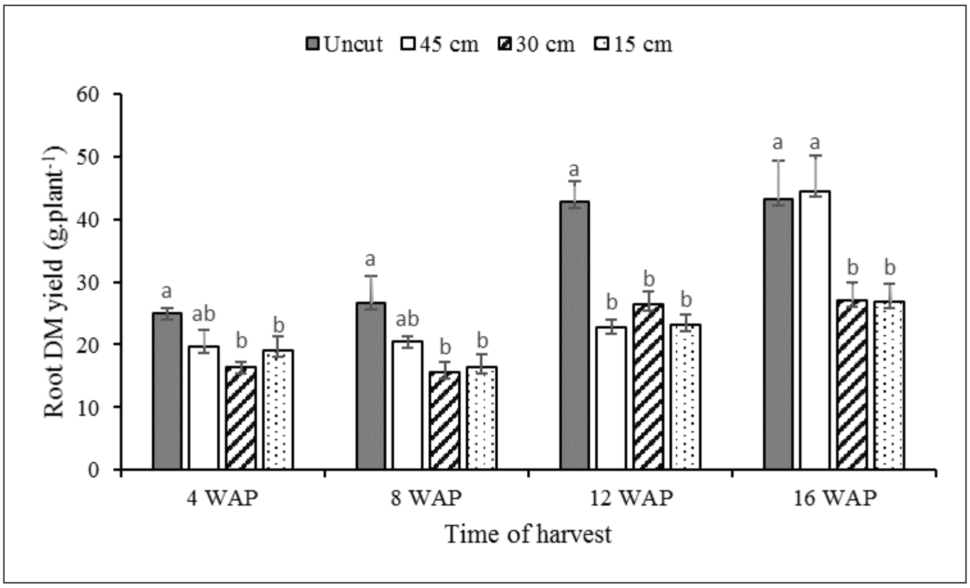


Figure 4.53 The effect of pruning intensity x time of harvest interaction on root DM production of *S. sesban* subjected to four pruning intensities.

Root length of *S. sesban* was significantly affected by pruning intensity (Figure 4.54). During the first four weeks following pruning, root length of uncut trees was significantly higher as compared to that of pruned trees. Among the pruned trees, pruning at 15 cm height resulted in lower root length as compared to their counterparts (below). Recovery in terms of root length was observed at 8 WAP for pruned trees except for trees pruned at 30 cm height. During the 12 and 16 WAP, root length of uncut trees and trees pruned at 45 and 30 cm height was statistically similar. In contrast, the most severely pruned trees recorded the lowest root length (Figure 4.54). Root length of all trees was similar throughout the recovery period except for uncut trees.

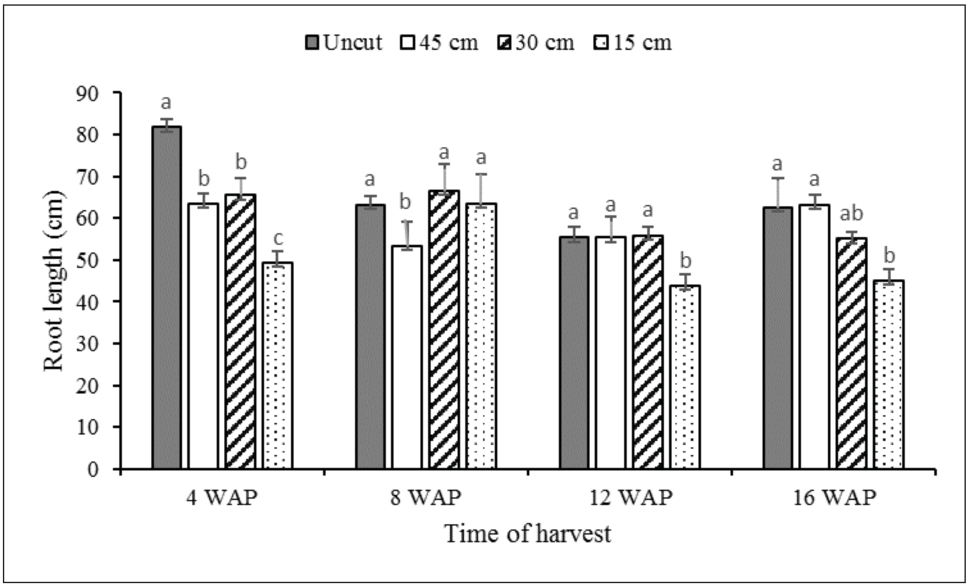


Figure 4.54 The effect of pruning intensity x time of harvest interaction on root length of *S. sesban* subjected to four pruning intensities.

Nodulated legumes are known to shed nodules following shoot pruning and renodulate during shoot regrowth. In this study, the response of nodulation, in terms on dry weight and number per plant, was investigated following tree pruning. At 4 WAP, nodule DM was similar for uncut trees and lightly (45 cm) and moderately (30 cm) trees, but the intense (15 cm) pruned trees recorded the lowest nodule DM yield (Figure 4.55). At 8 WAP, nodule DM was greater in uncut trees followed by trees pruned at 15 cm height whereas lower nodule DM yield was recorded for trees pruned at 45 and 30 cm height. There were no statistical differences among all treatments in terms of nodule DM yield at 12 WAP. Uncut trees and lightly pruned trees accumulated the highest nodule DM yield in comparison with trees that were pruned at 30 and 15 cm.

As with nodule DM, nodule number was significantly affected by tree pruning (Figure 4.56). Nodule number at 4, 8 and 12 was significantly higher in pruned trees than unpruned trees. Trees pruned at 15 cm height always recorded the lowest number of nodules numbers except for 8 WAP. At 16 WAP, number of nodules of uncut trees was similar to that of trees pruned at 45 cm height. In contrast, fewer nodule numbers were recorded for tree pruned at 30 and 15 cm at 16 WAP (Figure 4.56). Irrespective of the pruning treatment, number of nodules increased with tree growth between 4 and 8 WAP but declined markedly at 12 WAP followed by a significant recovery at 16 WAP. Taken together, the sharp decline in nodule DM and number at 12 WAP was mainly associated with loss of vegetative tissue induced by moisture stress. The subsequent profuse nodulation (nodule DM and numbers) observed in uncut and lightly pruned trees at 16 WAP was due to greater recovery of leaf growth as shown in Figure 4.51. The effects of pruning on nodulation show that pruning is likely to negatively affect the ability of the trees to fix nitrogen, but it also suggests that new nodules can be produced as long as the intensity is not too severe.

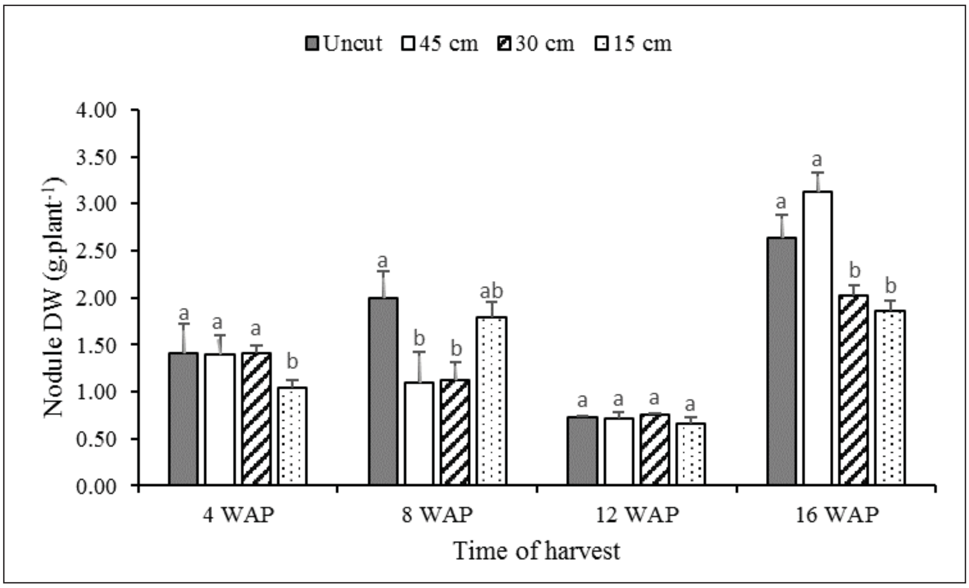


Figure 4.55 The effect of pruning intensity x time of harvest interaction on nodule DM production of *S. sesban* subjected to four pruning intensities.

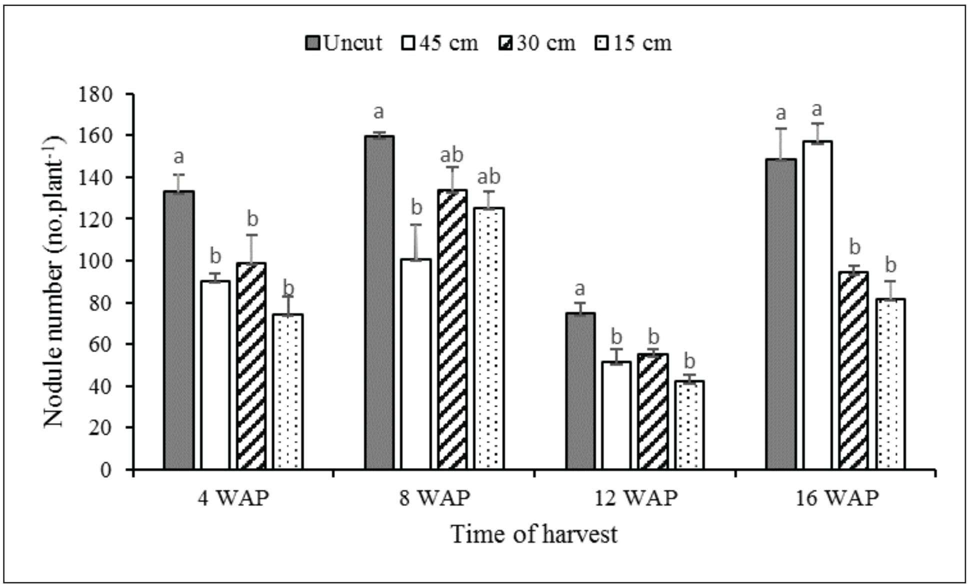


Figure 4.56 The effect of pruning intensity x time of harvest interaction on nodule number of *S. sesban* subjected to four pruning intensities.

4.5.3 Pot experiment 3: Effect of provenance and repeated cutting at different heights on biomass production

Introduction

Aim: To investigate differences between provenances in relation to their DM yields and their responses to different levels of pruning intensity.

The study was aimed to test the following hypotheses:

- There are differences between provenances in terms of their DM yields.
- There are differences between provenances in terms of their response to pruning intensity.
- Pruning will increase leaf production compared to unpruned trees.
- Increased pruning intensity will reduce leaf production.
- Increased pruning will reduce the concentration of NSCs in roots and stems.

Methodology

There were 5 provenances of *Sesbania sesban* tested, namely: BL100, BL101, BL102, BL103 and TM202. There were 3 cutting heights: T1 (45 cm from ground), T2 (30 cm from ground) and T3 (15 cm from ground) and an uncut control (T0).

After applying the initial treatments there were three harvesting events (January, February and March 2018) and then a final harvest in April 2018. After partitioning harvested material into (1) leaf, (2) stem and (3) twigs and branches, DM yield was determined for each harvesting event. Root and stem samples were taken at the final harvest to determine concentrations of non-structural carbohydrates comprising simple sugars and starch. Root DM was determined at final harvest, together with the diameter of the upper portion of the tap root.

Results and discussion

Effects on cumulative leaf DM yields

The effect of pruning intensity and provenance on cumulative leaf DM yield was investigated. Both were found to have a significant effect on leaf DM yield as shown in Table 4.42.

Table 4.42 Univariate general linear model for cumulative leaf DM yield (g/plant) of different provenances and under different pruning intensities

Source	Type III SS	df	Mean Square	F	Sig.
Corrected Model	587.759[a]	19	30.935	6.549	0.000
Intercept	8805.992	1	8805.992	1864.157	0.000
Provenance	187.566	4	46.891	9.927	0.000
Cutting Height	336.118	3	112.039	23.718	0.000
Provenance * Cutting Height	64.075	12	5.340	1.130	0.354
Error	283.431	60	4.724		
Total	9677.182	80			
Corrected Total	871.190	79			

a. R Squared = .675 (Adjusted R Squared = .572)

When the leaf DM yields were combined across the three pruning events for the different provenances, it would found that for BL100, BL101 and BL 103, there was a decline in yield with increasing pruning intensity. TM202 produced much lower leaf DM yields across all pruning intensities as shown in Figure 4.57.

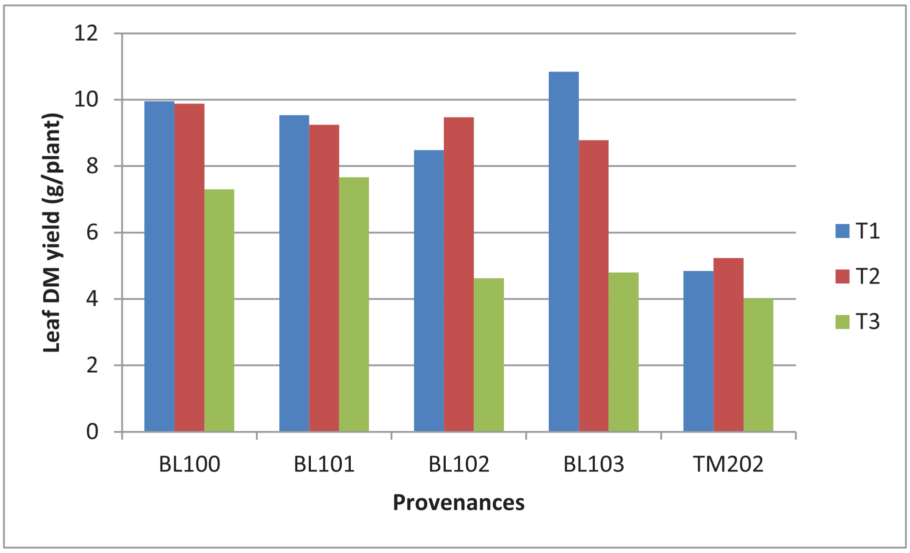


Figure 4.57 Effect of increased pruning intensity for cumulative leaf DM yield for the five provenances.

Table 4.43 shows that TM202 was significantly different from the other provenances when not considering the cutting intensity (as shown in Figure 4.58), while for cutting height treatment T0 resulted in greater leaf DM yield than T2 and T3, but was not significantly different from T1. T3 resulted in significantly lower leaf DM yield than all other treatments. There was no significant difference between T1 and T2.

Table 4.43 Mean cumulative leaf DM yield (g/plant) of *S. sesban* of different provenances subjected to different pruning intensities

Variables	Leaf DM yield (g/plant)
Provenance	
BL100	11.70[a]
BL101	11.07[a]
BL102	10.79[a]
BL103	11.41[a]
TM202	7.49[b]
Cutting height	
T0	12.28[a]
T1	11.91[ab]
T2	10.67[b]
T3	7.10[c]
2-way ANOVA	
	Probability
Provenance	0.000
Cutting height	0.000
Provenance X cutting height	0.354

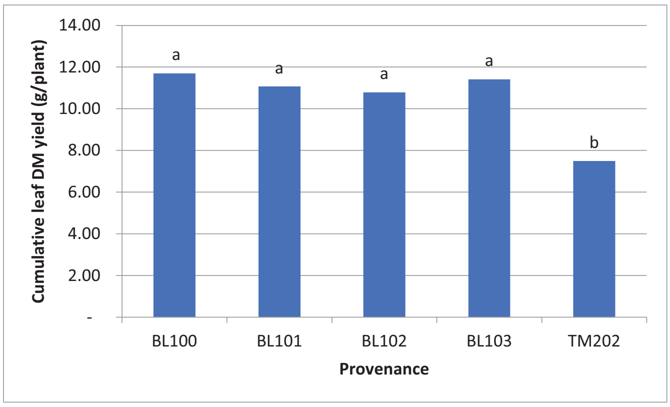


Figure 4.58 Cumulative leaf DM yield (g/plant) of different *S. sesban* provenances.

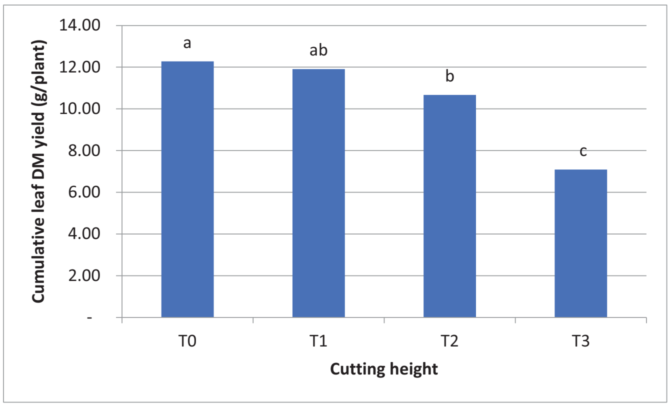


Figure 4.59 Effect of pruning intensity on the cumulative leaf DM yield (g/plant) of *S. sesban* plants subjected to different cutting height treatments.

This experiment suggests that pruning hedgerows to reduce the competition with the understorey crop can reduce the production of fodder by the trees if the cutting intensity is severe. It is also clear that there are no significant differences between the four provenances that were collected from road verges, but TM202, which was collected from a riparian area near Pongola, has lower potential to produce leaf DM yield.

Response of different S. sesban *provenances to consecutive harvesting events*

The ability of the different provenances cut at different heights (i.e. different pruning intensities) to tolerate repeated harvests was investigated.

From Figure 4.60 it can be seen that for BL100, BL101 and BL102 there was a decline in leaf DM with consecutive pruning events. This illustrates that their ability to regrow declined over time. In contrast, BL103 maintained better than the others and only declined at the third cut. It appears to be much more tolerant of pruning. TM202 had lower leaf DM yields than the other provenances and produced similar amounts of leaf material across the three pruning events.

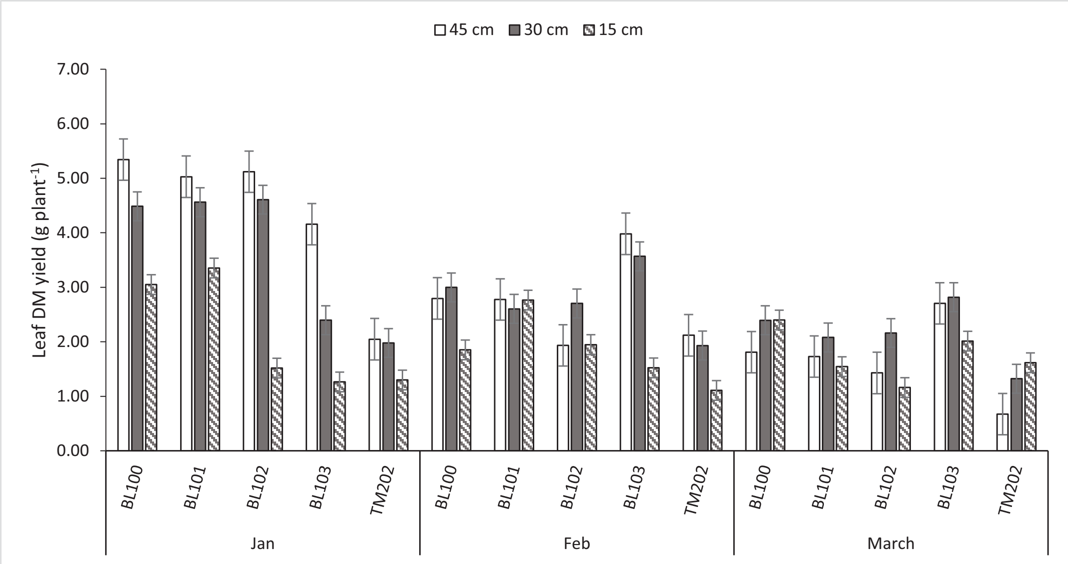


Figure 4.60 Leaf DM yields of different provenances at three consecutive harvesting events (January February and March) when subjected to different cutting height treatments.

When ranking the provenances in terms of leaf production at the first harvest (January), BL100 and BL101 were highest while TM202 was lowest. In February, BL103 had the highest leaf production showing the highest tolerance to pruning, while TM202 still showed lowest leaf biomass. By the third pruning event in March), BL103 still had the highest leaf DM production, although its ability to regrow had declined since the previous cut. In March, BL100 and TM202 showed increasing leaf yield with increasing pruning intensity (i.e. the seedlings cut lowest produced the most leaf). For BL101, BL102 and BL103, the 30 cm pruning height produced the highest leaf yield.

The effect of pruning intensity on roots

There was no significant interaction between provenance and cutting height and only cutting height had a significant effect on root DM yield as show in Table 4.44. This was the same for root diameter as shown in Table 4.45.

Table 4.44 Univariate general linear model for root DM yield (g/plant) of different provenances and under different pruning intensities

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5292.856[a]	19	278.571	20.490	.000
Intercept	14666.131	1	14666.131	1078.734	.000
Provenance	104.654	4	26.163	1.924	.118
CuttingH	4901.504	3	1633.835	120.173	.000
Provenance * CuttingH	286.697	12	23.891	1.757	.077
Error	815.741	60	13.596		
Total	20774.728	80			
Corrected Total	6108.597	79			

a. R Squared = .866 (Adjusted R Squared = .824)

Table 4.45 Univariate general linear model for root diameter (mm) of different provenances and under different pruning intensities

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	277.397[a]	19	14.600	15.585	.000
Intercept	7929.135	1	7929.135	8464.175	.000
Provenance	4.575	4	1.144	1.221	.311
CuttingH	252.498	3	84.166	89.845	.000
Provenance * CuttingH	20.324	12	1.694	1.808	.067
Error	56.207	60	.937		
Total	8262.739	80			
Corrected Total	333.604	79			

a. R Squared = .832 (Adjusted R Squared = .778)

Cutting height was found to have a significant effect on root mass and root diameter (p<0.005). The highest root mass and diameter were for T0 (uncut plants), while the lowest was for those cut at 15 cm (T3). Thus pruning intensity affects root development as shown in Figure 4.61 and Figure 4.62.

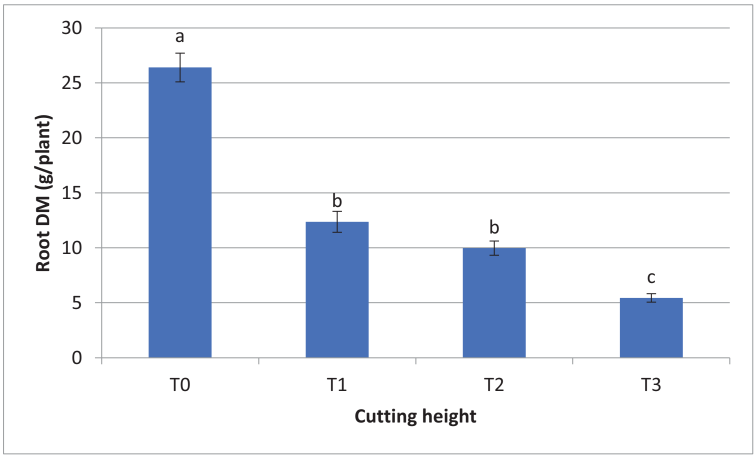


Figure 4.61 Effect of pruning intensity on the root DM yield of *S. sesban*.

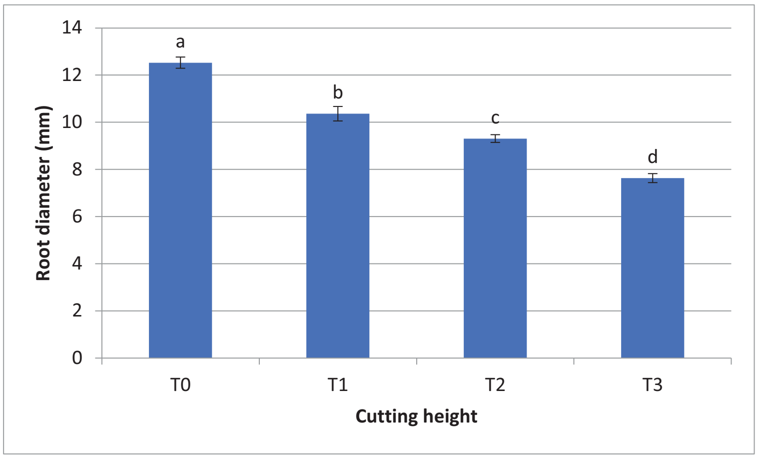


Figure 4.62 Effect of pruning intensity on the diameter of the tap root of *S. sesban*.

Table 4.46 Analysis of variance model output for DM yields as affected by provenance and cutting height

Variables	Final leaf DM (g/plant)	Cumulative leaf DM (g/plant)	Starch (mg/g)	Sugar (mg/g)
Provenance				
BL101	2.46[a]	10.96[a]	116.40[a]	89.61[a]
TM202	1.72[b]	6.33[b]	75.31[b]	45.54[b]
Cutting height				
T1	2.88[a]	9.80[a]	114.84[a]	74.01
T2	2.41[a]	9.36[a]	116.15[a]	62.58
T3	0.98[b]	6.78[b]	56.57[b]	66.12
2-way ANOVA				
F-Statistics				
Provenance	0.022	0.000	0.001	0.000
Cutting height	0.000	0.001	0.000	0.071NS
Provenance x cutting height	0.158NS	0.598NS	0.093NS	0.152NS

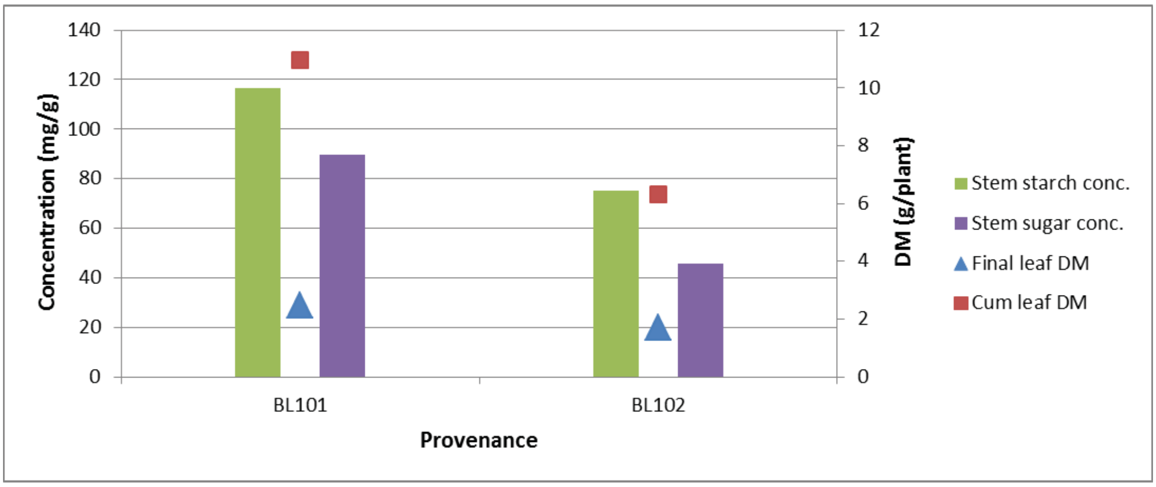


Figure 4.63 Effect of provenance on leaf DM yields and concentrations of non-structural carbohydrates in the stem.

From Figure 4.63 it is clear that TM202 starch and sugar concentrations were lower than those of BL101, and this correlates with final and cumulative leaf DM yields.

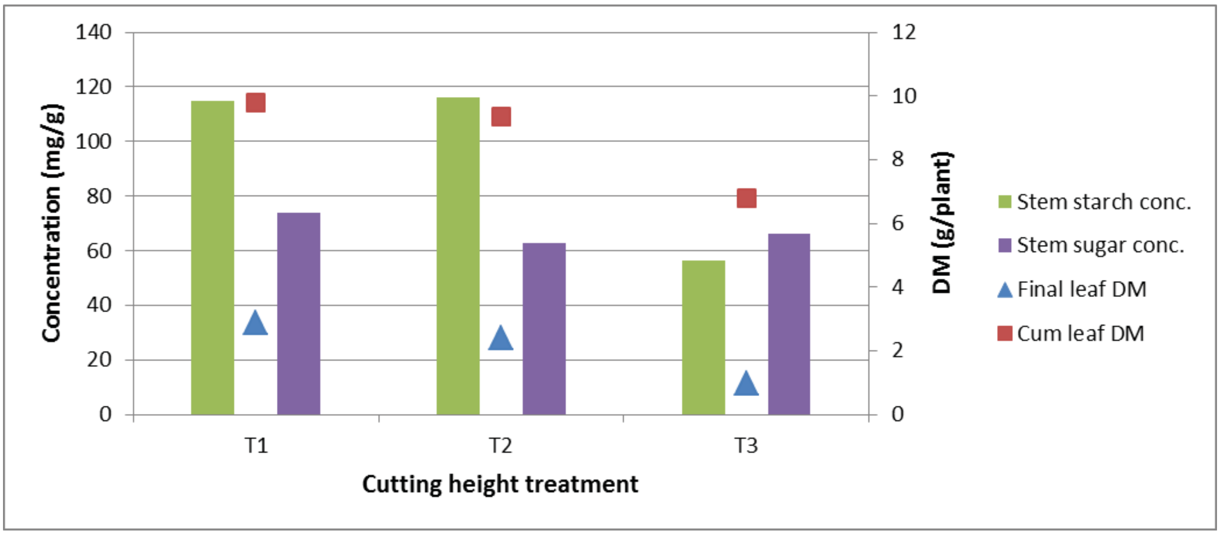


Figure 4.64 Effect of cutting height on leaf DM yields and concentrations of starch in the stem.

From Figure 4.64 it is clear that just as the final and cumulative leaf DM yields were lower for T3 than the other two cutting intensities.

4.5.4 Pot experiment 4: Effect of nutrient level and cutting frequency on *S. sesban*

Introduction

Due to high mortalities of S. sesban plants in some plots of the trial at Wartburg, a trial was designed to investigate the effects of nutrient levels as a possible explanation for what was seen in the field. The experiment sought to confirm whether nutrient availability affects plants response to pruning.

Aim: To determine the effect of nutrient level and cutting frequency on the DM yields of S. sesban.
Hypotheses:

- Increasing nutrient level will result in increased biomass production.
- Increased cutting frequency will lead to a reduction in biomass production.
- Increased cutting frequency will lead to reduction in the concentration of non-structural carbohydrates in roots and stems.

Methodology

A pot trial was carried out in the Grassland Science greenhouse at UKZN in 2018 to investigate the effects of nutrient levels and cutting frequency (CF) on *S. sesban*. There were 4 cutting frequency treatments: CF0 (the seedlings were left uncut until the time of harvest); CF1 (1 cut prior to the final harvest); CF2 (2 cuts prior to the final harvest) and CF 3 (4 cuts prior to the final harvest). There were 3 nutrient level treatments: N0 was water (0 nutrients), N1 was 50% strength solution and N2 was 100% strength of a Hoaglands solution. When separating plant material it was not possible to differentiate between twigs and branch due to the age and size of the plants.

Results and discussion

The findings from the trial are summarised in Table 4.47 and are presented in Figure 4.65 and Figure 4.66. For leaf DM production the interaction was not significant but nutrient level and cutting frequency had significant effects. For twig and branch DM, cutting frequency affected DM. Note that for the log of stem DM (g/plants) there was a significant interaction of nutrient level and cutting frequency.

Table 4.47 Summary of results from analysis of variance from trial investigating effects of cutting frequency and nutrient analysis

	DM yield (g/plant)		
Variables	**Leaf**	**Branch & twig**	**Log stem**
Cutting frequency			
CF0	6.69[b]	5.265[a]	1.053[a]
CF1	9.15[a]	4.634[a]	0.864[b]
CF2	8.93[a]	2.900[b]	0.640[c]
CF3	8.30[a]	3.631[b]	0.671[c]
Nutrients			
N0	6.79[b]	3.617[b]	0.789[a]
N1	9.00[a]	4.651[a]	0.802[a]
N2	9.02[a]	4.056[ab]	0.830[a]
2-way ANOVA			
F statistics			
Cutting frequency	0.003	0.000	0.000
Nutrients	0.000	0.032	0.422
CFxNutrient	0.747 NS	0.133 NS	0.051

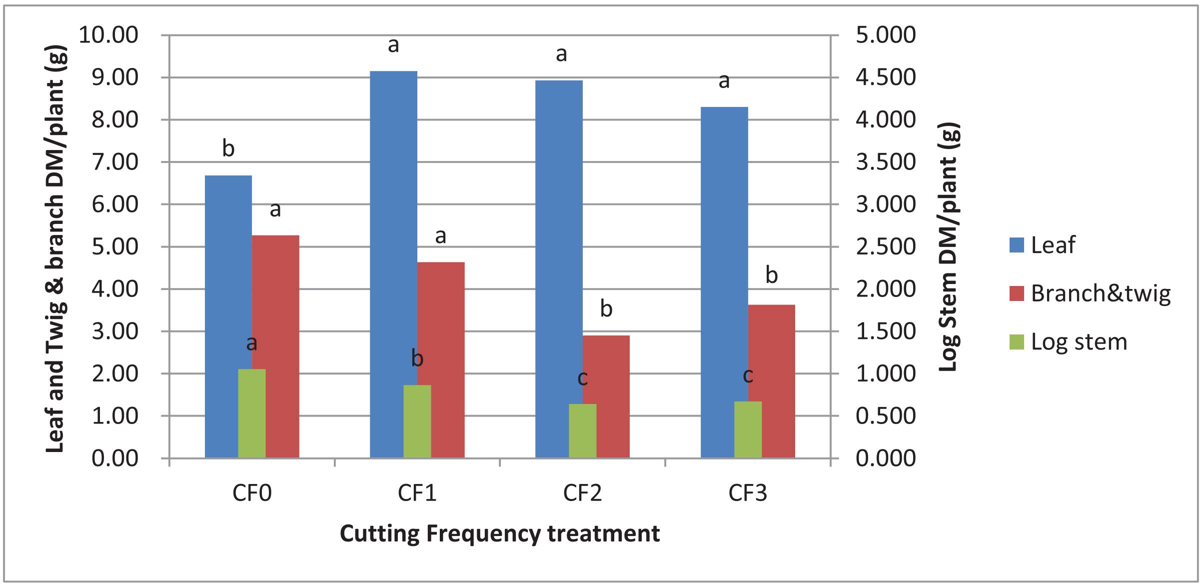


Figure 4.65 Effect of cutting frequency on DM production of leaf, twig & branch and log stem.

Leaf production was significantly lower for CF0 than for any of the other treatments. For branch & twig, CF0 was not significantly different from CF1, but the more frequently cut seedlings (CF2 and CF3) had significantly lower DM production.

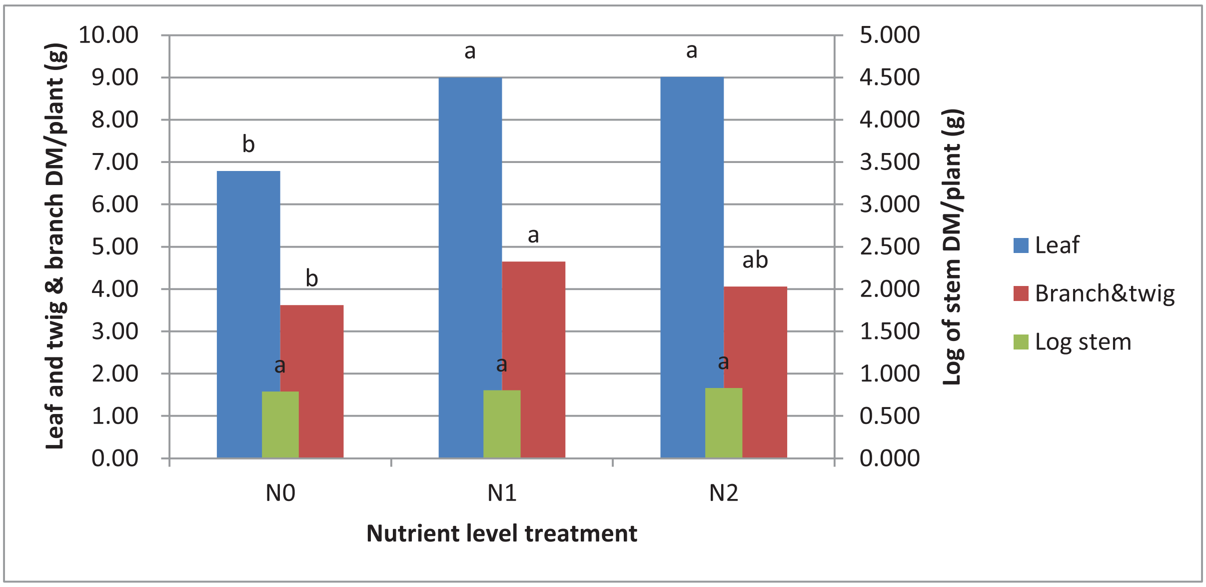


Figure 4.66 Effect of nutrient level on DM production of leaf, twig & branch and log stem.

Leaf and branch & twig production were significantly affected by nutrient level ($p<0.005$). For Leaf, the seedlings receiving no N had significantly lower DM production. There was no difference between N1 and N2 treatments. For branch & twig, N1 and N2 were not significantly different, and N2 was not different from N0, but N1 produced significantly more DM than N0. For stem (log stem), there was no significant difference across treatments ($p<0.005$).

In terms of practical application of these findings to an agroforestry system, cutting promotes the production of leaves, which is a source of fodder as well as a source of material for green manure, however there is no benefit in cutting frequently as this requires labour and does not yield significantly more leaf DM/plant.

4.6 Additional investigations

4.6.1 Palatability testing

In order to determine the palatability of *S. sesban*, several branches were fed to goats at OSCA, with the assistance of the farm manager, Francois du Toit. The goats had been confined for a number of days eating only hay, which may have affected the results but it appeared that the leaf material was highly palatable (Photograph 4.55). It is interesting that livestock do not voluntarily browse the *S. sesban* trees from which this material was harvested but do eat it when confined.

Photograph 4.55 *Sesbania sesban* offered to indigenous goats at OSCA showing the apparent palatability of the material (Source: Francois du Toit).

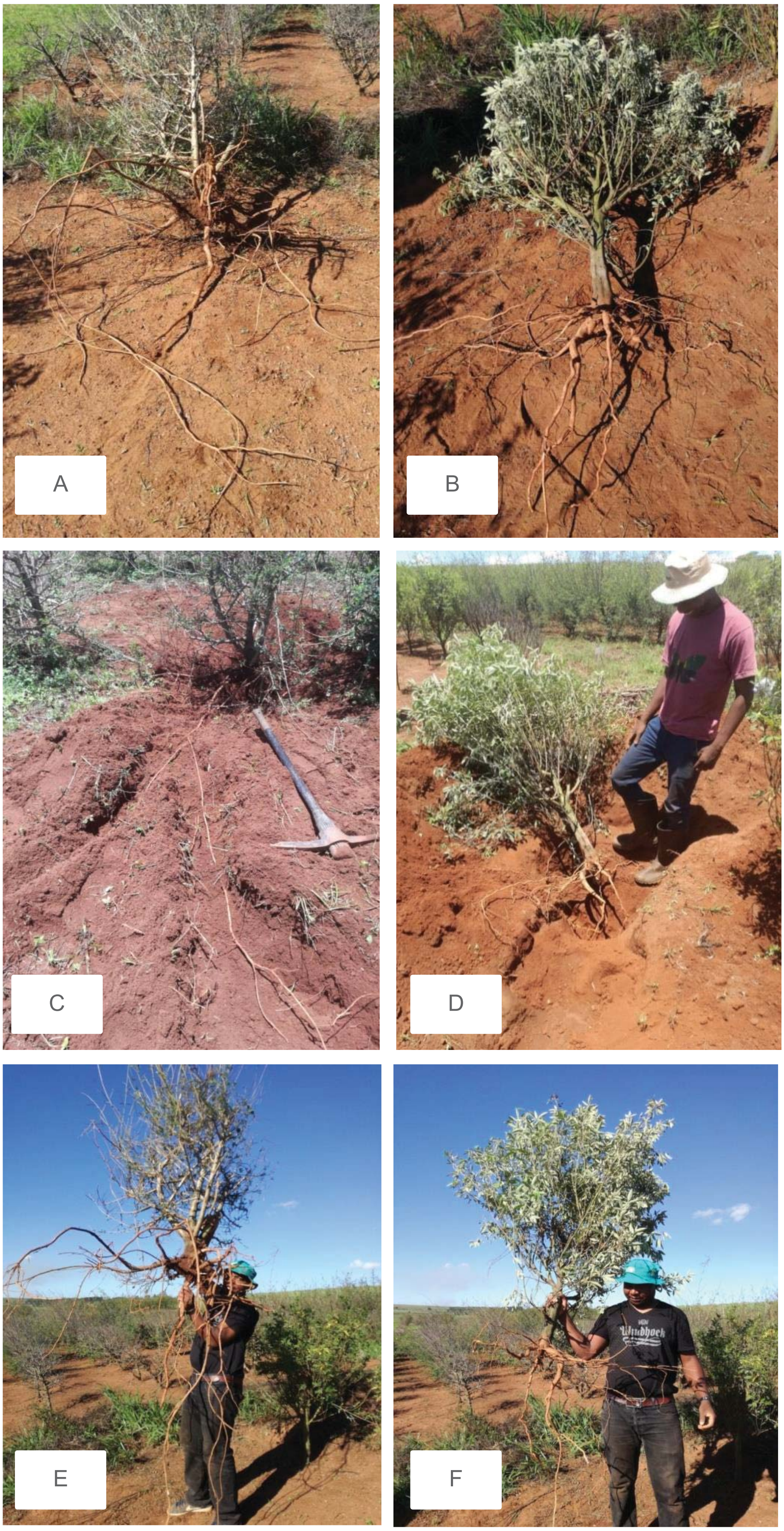
4.6.2 Investigation of the rooting depth and pattern of the trees

Alley cropping Trial 4 at Fountainhill Estate was also used to allow for excavation of a *S. sesban* tree and a pigeon pea tree to allow for comparison of the roots (**Table 4.48** and Photograph 4.56). This was done to try to explain the competitive effects that have been seen to date in the trial.

It was clear that the Sesbania tree had much longer lateral roots than the pigeon pea, and also a deeper taproot. This highlights that Sesbania is able to compete effectively with the understorey crop for soil water.

Table 4.48 Data collected from the trees that were excavated, December 2018

Measurements	*S. sesban*	Pigeon pea
Stem circumference (cm)	28	19.2
Stem diameter (cm)	5.97	4.94
Root number and size (estimated circumference in cm)		
Very small		4
Small	2	1
Medium	5	4
Big	5	1
Very big	1	
Taproot (very big)	1	2
Total number of roots	14	12
Percentage that were big or very big	50	25
Ratio of roots in top 30 cm : roots below 30 cm	70 : 30	60 : 40
Longest lateral root (cm)	270	125
Taproot depth (estimate for Sesbania)	223	93



Photograph 4.56 Visual comparison of the roots of the Sesbania (A, C, E) and pigeon pea (B, D, F) trees that were excavated. Note in the length of the lateral roots of Sesbania that cross from one plot towards the adjacent plot (C).

4.7 Conclusion

This section has covered three key agroforestry systems that offer opportunities for smallholder farmers in South Africa, namely improved fallows using woody legumes, alley cropping systems combining woody legumes and agronomic crops and silvopastoral systems that combined woody legumes and pastures.

Besides giving consideration to the choice of woody species and the challenges that may emerge as a result of competition between the woody component and the understorey crop, there are also management decisions that must be taken. Such decisions include the shoot pruning practices (cutting height and frequency), root pruning and residue management. Management decisions must take into account both the requirements of the crops as well as the needs of the farmer (e.g. prunings for fodder versus prunings to improve soil fertility).

4.8 References

Abraham, E.M., Kyriazopoulos, A.P., Arissi, Z.M., Ostopoulou P., Karatassiou, M., Anjalanidou, K. and Katsouta, C. 2014. Growth, dry matter production, phenotypic plasticity, and nutritive value of three natural populations of *Dactylis glomerata* L. under various shading treatments. Agroforestry Systems 88: 287-299.

Amusan, A.A., Shitu A.K., Makinde W.O., Orewole O. 2006. Assessment of changes in selected soil properties under different land use in Obafemi Awolowo University Community, ILE-IFE, Nigeria. Electronic Journal of Environment, Agriculture, Food and Chemistry 5: 1178-1184

Anderson, J.M. and Ingram J.S.I. 1993. Tropical soil biology and fertility: a handbook on methods. Wallingford (UK): CAB International.

Azam, M.G., Zoebisch, M.A., Wickramarachchi, K.S. 2008. Effects of cropping systems on selected soil structural properties and crops yields in the Lam phra phloeng watershed-northeast Thailand. Journal of Agronomy 7: 56-62.

Blanchart, E., Albrecht, A., Brown, G., Decaens T., Duboisset A., Lavelle, P., Mariani, L., Roose, E. 2004. Effects of tropical endogeic earthworms on soil erosion. Agriculture, Ecosystems and Environment 104: 303-315.

Bogdan A.V. 1977. Tropical pasture and fodder plants (grasses and legumes). Longman. ISBN 0582466768.

Bottinelli, N., Jouquet, P., Capowiez, Y., Podwojewski, P., Grimaldi, M., Peng, X. 2015. Why is the influence of soil macrofauna on soil structure only considered by soil ecologists? Soil Tillage Research 146: 118-124.

Brown, G.G., Barois, I., Lavelle, P. 2000. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. European Journal of Soil Biology 36: 177-198.

Chirwa, T.S., Mafongoya, P.L., Mbewe, D. N. M., Chishala, B.H. 2004. Changes in soil properties and their effects on maize productivity following *Sesbania sesban* and *Cajanus cajan* improved fallow systems in eastern Zambia. Biology and Fertility of Soils 40: 20-27.

Chirwa, P.W., Ong, C.K., Maghembe, J. and Black, C.R. 2007. Soil water dynamics in cropping systems containing *Gliricidia sepium*, pigeon pea and maize in southern Malawi. Agroforestry Systems 69: 29-43.

Dangerfield, J.M. 1997. Characterization of soil fauna communities. In: RAO, M.R., SCHOLES, R.J. (Eds.), Report on Characterization of Experimental Field in KARI Farm, Muguga, Kenya. ICRAF, Nairobi, Kenya.

De Bona, F.D. and Monteiro, F.A. 2010. The development and production of leaves and tillers by Marandu palisadegrass fertilised with nitrogen and sulphur. Tropical Grasslands 44: 192-201.

Dhima, K.V., Lithourgidis, A.A., Vasilakoglou, I.B. and Dordas, C.A. 2007. Competition Indices of Common Vetch and Cereal Intercrops in Two Seeding Ratio. Field Crops Research 100: 249-256.

Giller, K.E., Beare, M.H., Lavelle, P., Izac A.M.N. and Swift, M.J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. Applied Soil Ecology 6: 3-16.

Hluyako, L.L., Odindo, A., Mafongoya, P., Sithole, N. and Magwaza, L. 2017. Characterisation of pigeon pea (*Cajanus cajan*) landraces grown in two climatic zones in KwaZulu-Natal province, South Africa. South African Journal of Plant and Soil 34 (3): 191-199.

Kamanga, B.C.G., Kanyama-Phiri, G. and Minae, S. 1998. Assessment of resource requirement and output potential of soil management technologies in Zomba, Malawi. Agris

Kostiakov, A.N. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity of studying it from a dynamic point of view for purposes of amelioration. Transactions of the sixth committee International Society of Soil Science, Russian Part A.

Lavelle, P. 1997. Faunal activities and soil process: In: Begon, M., Fitter, A.H. (Eds.), adaptive strategies that determine ecosystem function. Advances in Ecological Research. Academic Press., New York, pp. 93-132.

Kaushal, P., Agrawal, A., Malaviya, D.R., Siddiqui and Roy, A.K. Ploidy manipulation in guinea grass (*Panicum maximum* Jacq., Poaceae) utilizing a Hybridization supplemented Apomixis components Partitioning Approach (HAPA). Plant Breeding 128 (3).

Kwesiga, F., Phiri, D.M., Simwanza, C.P. and Mwanza, S. 1993. Zambia/ICRAF Agroforestry Research Project, 1993 Annual report. AFREMA Report No. 71.

Kwesiga, F. and Coe, R. 1994. The effect of short rotation Sesbania sesban planted fallows on maize yield. Forest Ecology and Management 64: 199-208.

Kwesiga, F.R., Franzel, S., Place, F., Phiri, D. and Simwanza, C.P. 1999. Sesbania sesban improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm. Agroforestry Systems 47: 49-66.

Kyriazopoulos, A.P., Abraham, E.M., P Arissi, Z.M., K Oukoura, Z. and Nastis, A.S. 2012. Forage production and nutritive value of *Dactylis glomerata* and *Trifolium* subterraneum mixtures under different shading treatments. Grass and Forage Science 68: 72-82.

Lavelle, P., Senapati, B., Barros, E., 2003. Soil macrofauna. In: Scroth, G., Sinclair, F. L. (Eds.), Trees, Crops and Soil Fertility: Concepts and Research Methods. CAB International, Wallingford, UK

Liu, D.W., Wang, Z.M., Zhang, B., Song, K.S., Li, X.Y., Li, J.P., Li, F. and Duan, H.T. 2006. Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region, Northeast China. Agr. Ecosystems and Environment. 113: 73-81.

Mando, A. and Miedema, R., 1997. Termites induced change in soil structure after mulching degraded (crusted) soil in the Sahel. Applied Soil Ecology 6: 241-249.

Mapa, R.B., Gunasena, H.P.M. 1995. Effect of alley cropping on soil aggregate stability of a tropical Alfisol. Agroforestry Systems 32: 237-245.

Maroko, J., Buresh, R.J. and Smithson, P.C. 1997. Soil phosphorus pools in unfertilized fallow-maize systems and relationships to maize yield. Soil Science Society of America Journal. (Submitted.)

Mathews, C., Jones, R.B. and Saxena, K.B. 2001. Maize and Pigeonpea Intercropping Systems in Mpumalanga, South Africa. International Chickpea and Pigeonpea Newsletter 8.

McCarty, L.B., Hubbard, L.R.J and Quisenberry, V.L. 2016. Applied soil physical properties drainage and irrigation strategies. Springer International Publishing Switzerland.

Moço, M.K.S., Gama-Rodrigues, E.F., Gama-Rodrigues, A.C., Machado, R.C.R., Baligar, V.C. 2009. Soil and litter fauna of cacao agroforestry systems in Bahia, Brazil. Agroforestry Systems. 76(1): 127-138.

Musokwa, M., Mafongoya, P. and Lorentz, S. 2019. Evaluation of agroforestry systems for maize (*Zea mays*) productivity in South Africa. South African Journal of Plant and Soil 36 (1): 65-67.

Muthuri, C.W., Ong, C.K., Black C.R., Ngumi, V.W. and Mati, B.M. 2005. Tree and crop productivity in Grevillea, Alnus and Paulownia-based agroforestry systems in semi-arid Kenya. *Forest Ecology and Management* 212: 23-39.

Nambiar, E.K.S. and Sands, R. 1992. Effects of compaction and simulated root channels in the subsoil on root development, water uptake and growth of radiata pine. Tree Physiology 10: 297-306.

Nyamadzawo, G., Chikowa, R., Nyamugafata, P., Nyamangara, J. and Giller, K.E. 2008. Soil organic carbon dynamics of improved fallow-maize rotation systems under conventional and no-tillage in Central Zimbabwe. Nutrient Cycling in Agroecosystems. 81: 85-93.

Ofori, F. and Stern, W.R. 1987. Cereal-Legume Intercropping Systems. Advances in Agronomy 41: 41-90.

Oyenuga, V.A. 1960. Effect of stage of growth and frequency of cutting on the yield and chemical composition of some fodder grasses in Nigeria (*Pennisetum purpureum* schum). Journal of Agricultural Science 53: 25.

Paciullo, D.S.C., Pires, M.F.A., Aroeira, L.J.M., Morenz, M.J.F., Mauricio, R.M. and Gomide, C.A.M. 2014. Sward characteristics and performance of dairy cows in organic grass-legume pastures shaded by tropical trees. Animal 8: 1264-1271.

Phiri, E., Verplancke, H., Kwesiga, F., Mafongoya, P. 2003. Water balance and maize yield following improved sesbania fallow in eastern Zambia. Agroforestry Systems 59: 197-205.

Rahman, P.M., Varma, R.V. and Sileshi, G.W. 2012. Abundance and diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats, India. Agroforestry Systems 85:165-177.

Ren, Z.P., Zhang, G.H., Wang, B. and Shi, Y.Y. 2012. Effects of double-ring diameter on soil infiltration rate. Journal of Soil and Water Conservation 26: 94-103.

Rossi, J.P., and Blanchart, E. 2005. Seasonal and land-use induced variations of soil macrofauna composition in the Western Ghats, southern India. Soil Biology and Biochemistry 37: 1093-1104.

Rowell, D.L., 1994. Soil science: Methods & Applications. Addison Wesley Longman Singapore Publishers (Pte) Ltd., England, UK. 350 p.

Sanchez, P.A. 1976. Properties and management of soils in the tropics. New York: John Wiley and Sons Inc.

Santiago-Hernandez, F., Lopez-Ortiz, S., Avila-Resendiz, C., Jarillo-Rodriguez, J., Perez-Hernandez, P. and Guerrero-Rodriguez, J da D. 2016. Physiological and production responses of four grasses from the genera *Urochloa* and *Megathyrsus* to shade from *Melia azedarach* L. Agroforestry Systems 90: 339-349.

Shaver, T.M., Peterson, G.A., Ahuja, L.R., Westfall, D.G., Sherrod, L.A. and Dunn, G., 2002. Surface soil physical properties after 12 years of dryland no-till management. Soil Science Society of America Journal 66: 1296-1303.

Sheoran, V., Sheoran, A.S. and Poonia, P. 2010. Soil Reclamation of Abandoned Mine Land by Revegetation: A Review. International Journal of Soil, Sediment and Water 3(2).

Shukla, M.K., Lal, R. and Ebinger, M. 2004. Principal component analysis for predicting corn biomass and grain yields. Soil Science 169: 215-224.

Sileshi, G. and Mafongoya, P.L., 2006. Variation in macrofaunal communities under contrasting land use system in eastern Zambia. Applied Soil Ecology 33: 49-60.

Sileshi, G.W., Akinnifesi, F.K., Ajayi, O.C. and Muys, B. 2011. Integration of legume trees in maize-based cropping systems improves rain use efficiency and yield stability under rain-fed agriculture. Agricultural Water Management 98: 1364-1372.

Singh, D., Sharma, A. and Saini, G.K. 2013. Biochemical and molecular characterisation of the bacterial endophytes from native sugarcane varieties of Himalayan region. Biotechechnology 3(3): 205-212.

Six, J., Bossuyt, H., Degryze, S., Denef, K. 2004. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Research 79: 7-31.

Strauss, P., Dannhauser, C.S., Van Pletsen, W. and Venter, W.D. 2010. Seed testing – The Chaffy Grasses. The Grassland Society of Southern Africa | Grassroots. https://grassland.org.za/publications/grassroots/issues/february-2010/5%20201002%20Strauss.pdf (Downloaded 27/02/2020)

Susilo, F.X., Nuetal, A.M., Noordwijk, M., Hairiah, K., Brown, G., Swift, M.J. 2004. Soil Biodiversity and Food webs, Below-ground Interactions in Tropical Agro ecosystems. CAB International, Wallingford, UK.

Tolk, J.A. 2003. Plant Available Soil Water. United States Department of Agriculture (USDA), Bushland, Texas, U.S.A. Encyclopedia of Water Science. Marcel Dekker, Inc. 669-672.

Torquebiau, E.F. and Kwesiga, F. 1996. Root development in a Sesbania sesban fallow-maize system in Eastern Zambia. Agroforestry Systems 34: 193-211.

Tripathi, G., Ram, S., Sharma, B.M, Singh, G. 2005. Soil faunal biodiversity and nutrient status in silvopastoral systems of Indian desert. Environment and Conservation 32: 178-188.

Udawatta, R.P., Kremer, R.J., Adamson, B.W., Anderson, S.H. 2008. Variations in soil aggregate stability and enzyme activities in a temperate agroforestry practice. Applied Soil Ecology 39:153-160.

Valenzuela, H. and Smith, J. 2002. Sorghum-Sudan grass Hybrids. Sustainable Agriculture Green Manure Crops. https://scholarspace.manoa.hawaii.edu/bitstream/10125/12740/SA-GM-10.pdf (Downloaded 27/02/2020)

Van Bavel, C.H.M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Science Society of America Proceedings 14: 20-23.

Van Bavel, C.H.M. 1952. Gaseous diffusion and porous media. Soil Science. 73: 91-104.

Wandera, J.L., Munyekho, F.N., Mbugua, D.M. and Kiruiro, E.M. 2000. Effects of intercropping herbacious legumes and napier on forage dry matter production in the high rainfall highlands of Kenya. In: Mureithi J.G. et al. (eds) Participatory Technology Development by Smallholders in Kenya. Special Publication of Soil Management and Legume Research Network Projects. Kenya Agricultural Research Institute, Nairobi, pp. 101-107.

Workayehu, T. 2014. Legume-based cropping for sustainable production, economic benefit and reducing climate change impacts in southern Ethiopia. Journal of Agricultural and Crop Research 2(1): 11-21.

Yamoah, C.F. and Getahun, A. 1990. Alley cropping and crop yield enhancement with Sesbania species. In Perennial Sesbania species in agroforestry systems (Editors B Macklin and DO Evans. Proceedings of a workshop held at ICRAF, Nairobi, Kenya, 27-31 March 1989. NFTA, USA.

Yoder, R.E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Journal of the American Society of Agronomy 28: 337-351.

5 WATER USE OF AGROFORESTRY SYSTEMS

5.1 Introduction

This chapter covers the water use aspects of the study. It considers both the effect of the agroforestry systems of the soil water status as well as the water use of the different systems.

5.2 Methodology (for both Fountainhill Estate and OSCA)

The investigation of water use of agroforestry systems involved a number of different procedures. Firstly, geophysical surveys and characterisation of the soils was conducted at the research sites. Secondly instrumentation to measure soil water was installed. The information from these two elements were then used to determine soil water tension and volumetric water content of soils associated with the different components of the agroforestry systems.

5.2.1 Geophysical survey

Geo Hydraulic and Environmental Technology (Pty) Ltd (GET) undertook a geophysical investigation as part of agroforestry study at the Fountainhill Estate and OSCA research sites (Photograph 5.1 and Photograph 5.2). The underlying rock formations (Figure 5.1) were also considered in interpreting the results.

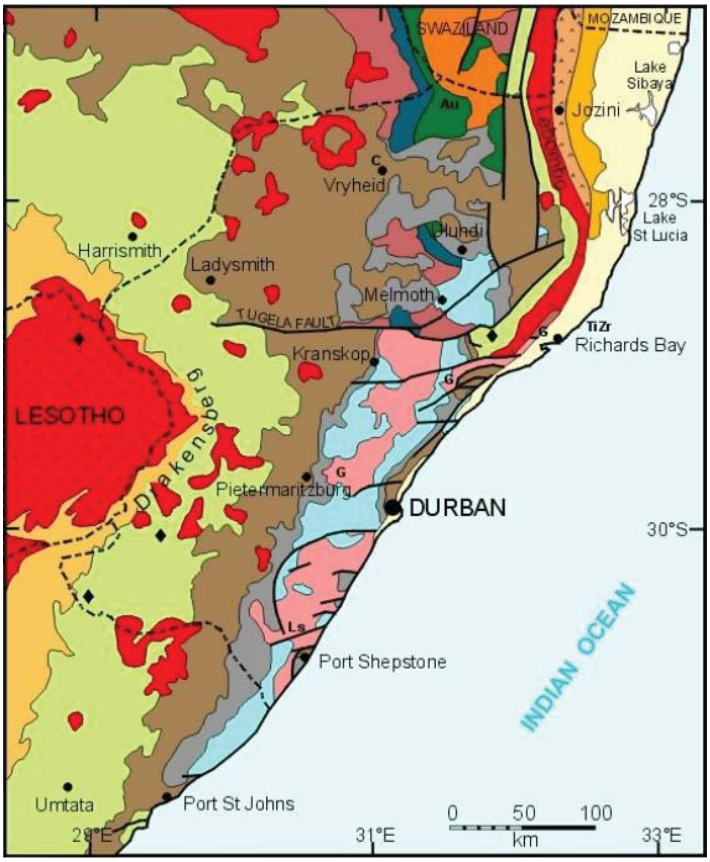


Figure 5.1 Underlying geology of KwaZulu-Natal – Simplified and modified from 1:1 000 000 scale geological map sheets (Geological Survey, 1984, Pretoria, Government Printer, NE & SE sheets).

2D electrical resistivity tomography (ERT) surveys were performed in October 2015 and in July 2016 by GET to determine subsurface water distribution at research trials. The survey in October was undertaken prior to trial establishment and can be seen as the start of the rainy season. The survey undertaken in July 2016, was supposed to represent the dry season, but at Empangeni, however out of season winter rainfall was received and this compromised the outcomes of the survey, meaning that the results obtained were not typical of mid-winter dry soils.

The objectives of using the ERT technique at the agroforestry trial sites were as follows:

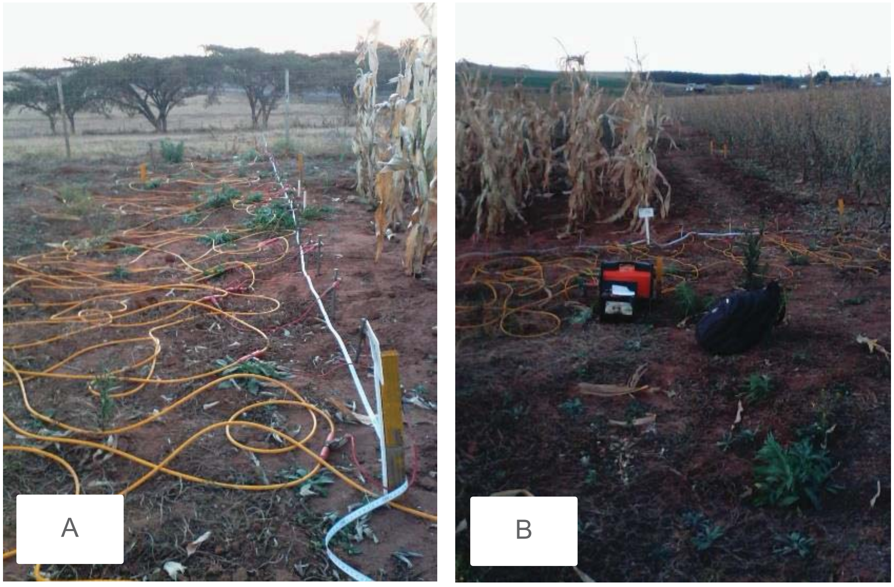
- To set up a series of water distribution transects in time in order to learn about the seepage, uptake and lateral flow characteristics of water during the trial.
- For bi-annual soil moisture monitoring in the field in order to reveal contrasting water depletion patterns under intercropping systems.
- To characterise site litho-stratigraphy (soil and bed rock interface).

To get a more detailed understanding of the water dynamic in the root zone and/or vadose zone (the non-saturated soil zone above the water table), spatially resolved monitoring of soil water contents is necessary. It is anticipated that a substantial spatial variability of water content is to be expected within intercropping systems, therefore point measurements of water content may not be sufficient. ERT is potentially a valuable technique to solve this problem and to monitor changes in soil moisture in space and time by providing an overview of the distribution of soil water over a larger area.

The principle of the ERT survey is based on the understanding of the relationship between electrical currents applied to the soil and displacement of ions in soil pore water. The electrical current in soils is therefore a function of the water content in pores and the presence of dissolved salts. It has been established from laboratory experiments that electrical resistivity deceases when water content increases.

For the October 2015 survey, the ERT surveys were carried out using the ABEM Lund Imaging System together with a Terrameter SAS 1000 for data acquisition. The Lund system consists of a basic charging unit, Electrode Selector ES464; four Lund spread cables of 3 m takeout spacing which were connected to 21 electrodes each using cable jumpers as shown in Photograph 5.2. By selecting Wenner (Long and Short) protocol (array), automatic sequential measurements were achieved in order to obtain a 2D resistivity distribution.

Photograph 5.1 John Kalala (GET) laying out the cables at the Wartburg site.



Photograph 5.2 ABEM LUND Imaging System with Terrameter SAS 1000.

Data acquisition was repeated using 5 transects of differing lengths at each of the sites.

5.2.2 Soil characteristics

Prior to cultivation and planting, soil surveys were undertaken at both sites (OSCA and Fountainhill Estate). The survey procedure was uniform across both sites, where seven 1.2 m deep pits were prepared as shown in Photograph 5.3. The position of the soil pits relative to each trial site is shown in Figure 5.2.

Photograph 5.3 Soil pits were used to determine the physical characteristics of the soil.

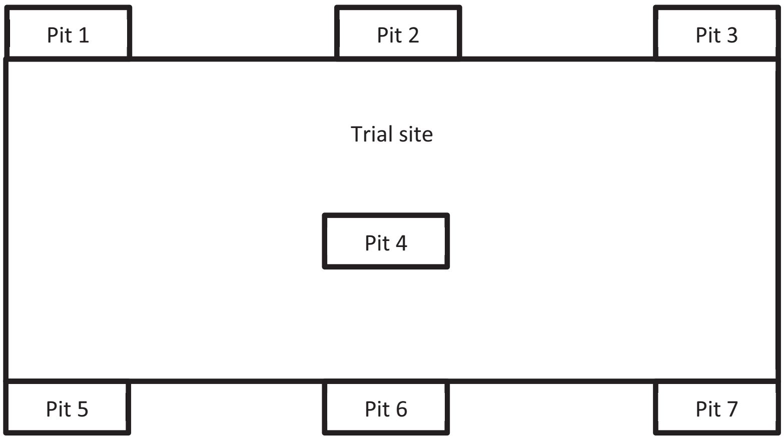


Figure 5.2 Positions of the soil pits relative to the trial site.

A visual description of the soil was compiled, inducing the following:

- Determination of number of horizons in the whole profile
- Identification of the limiting horizon (for effective rooting depth)
- Identification of the total soil depth in the profile
- Effective rooting depth
- Classification of soil form and family.

In addition to this samples were taken for further analysis as follows:

- At each of the 7 soil pits, sampling was done at five different depths (0 mm, 15 cm, 30 cm, 60 cm and 90 mm). Three fraction and organic carbon analysis were performed using disturbed soil samples sampled at these depths.'
- In addition to 7 pits that were used for soil physical determination, 8 composite 20 cm depth soil samples were collected from the trial site and were sent to Cedara for chemical analysis.

Furthermore, two survey pits (1 and 7) were selected on the basis that they are most representative of the whole experimental field, to determine hydraulic conductivity and infiltration rate using the Double ring infiltrometer and Guelph permeameter.

The following laboratory analyses were conducted:

- Soil physical characteristics:
  - Retentivity curves
- Soil chemical characteristics
  - Ph (KCl)
  - Essential macronutrients (N, P and K)
  - Micronutrients (Cu, Mg and Mn)
  - Presence of cations.
  - Carbon:nitrogen ratio

Due to the lack of available laboratory equipment which resulted in delays, the Fountainhill samples were prioritised. OSCA is currently of secondary importance due to the drought that was experienced in 2015/2016. Laboratory analysis will be ongoing until all relevant data has been obtained.

Hydraulic conductivity

Guelph permeameters and a double ring infiltrometer were used to measure soil hydraulic conductivity, soil sorptivity, matrix flux potential and soil infiltration rates.

A double ring infiltrometer was used to determine soil infiltration rates and saturated hydraulic conductivity (Ksat). The double-ring infiltrometer consists of two concentric metal cylinders that are pushed a small distance into the soil. The inner small ring had the following dimensions, 10 cm diameter and 7 cm depth the bigger ring had 22 cm and 7 cm diameter and depth, respectively. The rings were filled with water, and the infiltration rate was determined until a constant value was reached in the inner ring. As the head of water ponded on the soil surface affects the infiltration rate, a constant water level was maintained in the cylinder. To prevent leakage between the cylinders, equal water levels were maintained in both cylinders. Measurement of water depletion was confined to the inner ring to, minimise errors due to non-vertical flow (i.e. lateral seepage) at the edge of the cylinder (Zhang et al., 1998).

The Guelph permeameter was used to measure saturated hydraulic conductivity below the soil surface (Photograph 5.4). Ksat was measured a three depths by augering to depths of -= 200, 500 and 1200 mm at each sampling point. The depth and radius of each augured hole was measured to determine volume. The hole was scarified and all loose materials were removed from the base. A constant head level in the hole was established and maintained at the level of the bottom of the air tube by regulating the position of the bottom of the air tube, which was in the centre of the permeameter. A mark was inserted on the permeameter at ground level. The permeameter tube was opened and filled with water and kept sealed until inserted back into the hole to the mark that indicates ground level and tied up so that it hung freely from the support arm. The stopper was released from the air breather tube and the stop watch was started. As the water level reached the markers on the manometer, time was recorded. At various intervals, the depth of water in the hole was checked to ensure it remained constant. Once a steady state was reached, four more readings were recorded and the permeameter was disassembled.

Photograph 5.4 Readings being taken using a Guelph permeameter to determine saturated hydraulic conductivity.

Soil chemical properties

Soil samples were taken to Cedara Soil Laboratory for analyses to determine the chemical characteristics of the soil. In addition, organic carbon and total nitrogen were determined for the disturbed soil samples that were taken from the soil pits at the two sites.

Soil water retentivity curves

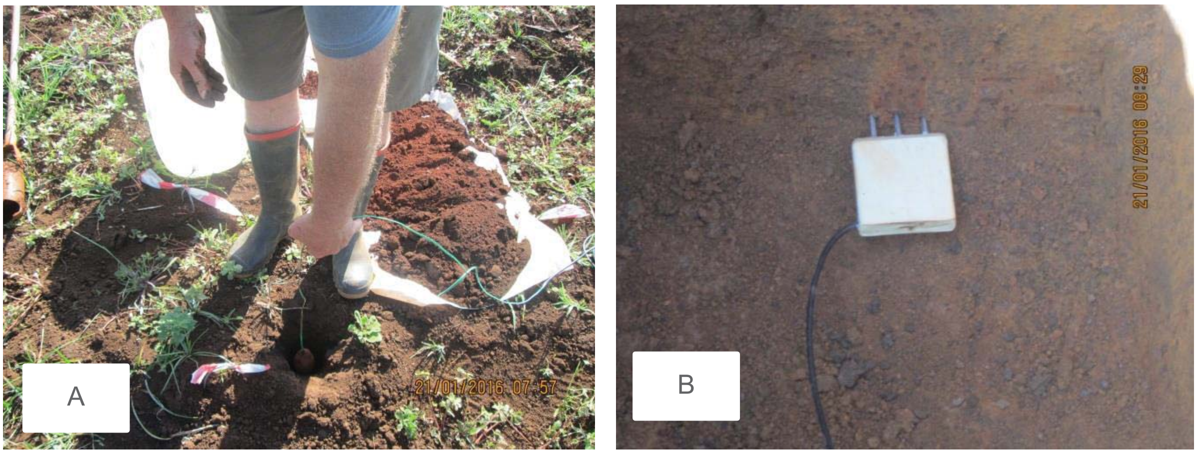
A moisture release curve was constructed through laboratory analysis to establish soil moisture content at field capacity (FC), permanent wilting point (PWP) and intermediate values. Undisturbed soil samples were connected to pF rings to determine retentivity at the 0 cm, 15 cm, 30 cm, 60 cm and 90 cm depths from two representative positions at the research sites. These were placed in a pressure membrane chamber and completely wetted before being subjected to tensions of 0-90 cm to span the range between FC and PWP; samples were equilibrated for 4-5 days before completing the measurement. Volumetric water content (VWC) was determined for each soil sample for all tensions applied; mean VWC values for each soil depth were plotted against the corresponding TDR probe water content reading to determine the moisture release curve.

5.2.3 Instrumentation

A combination of Watermark sensors and time domain reflectometry (TDR) probes at depth intervals of 200 mm, 500 mm and 1200 mm below ground level were used to monitor soil water tension and volumetric soil water content, respectively (Photograph 5.5). These depths as they provide good indication of soil water status (and changes thereof) within the crop root zone for most agronomic crops. The instruments were installed across 8 plots that made up one replication in the middle of in the randomised complete block trial.

To avoid crop damage, installations of instruments was done prior to planting. This allowed time for the watermark sensors to equilibrate with the water in the surrounding soil.

Data was collected hourly using a logger for all the Watermark sensors. For the TDR probes, some were connected to the logger while others at Fountainhill Estate were read manually on a weekly basis.



Photograph 5.5 Installation of Watermark sensors (A) and TDR sensors (B) at OSCA, Empangeni.

Watermark sensors operate on the same principles as other electrical resistance sensors. Water conditions inside the Watermark sensor change with corresponding variations in water conditions in the soil. These changes within the sensor are reflected by differences in electrical resistance between two electrodes attached in the sensor. Resistance between the electrodes decreases with increasing soil water. The Watermark sensor contains a transmission material of a consistency close to that of fine sand protected in a porous membrane. The transmission material was designed to respond more quickly to soil wetting and drying cycles. This report only presents the values obtained from the Watermark sensors because some of the TDR cables were damaged during weeding.

5.3 Results for the improved fallow trial at Fountainhill Estate, Wartburg

5.3.1 Geophysical survey

The findings of the geophysical survey are detailed below.

Underlying rock

According to groundwater levels map of South Africa (DWA 2007), the depth to water level varies from 5 metres below ground level (mbgl) to 20 mbgl in the Wartburg area. From an aquifer classification map of South Africa (DWA 1999), the Wartburg site is underlain by a moderate-yielding aquifer system of variable water quality.

It is anticipated that groundwater preferential flow pathways are weathered zones and sandstone (bedrock) interfaces as well as connected fractures zones. Soil water within the soil profile (sandy material zone) and groundwater occurrence in the weathered media below the soil and their fluctuations due to rainwater infiltration imply that water is available for agroforestry activities on site.

ERT results

Two surveys were conducted for the ERT surveys, a wet season survey (October 2015) and a dry season survey (July 2016). For both the dry-season and wet season surveys, the following transect were applied at Fountainhill:

- AFWB1: a single 240 m long transect to characterise deep geology and hydrogeology along the site hillslope (runs west-east)
- AFWB2: a single 80 m long transect to depict changes across the hillslope (north-south)
- AFWBs1, 2 and 3 transects of 40 m to depict shallow vadose zone setting across the trial (runs west-east).

The transects are shown in Figure 5.3. The outcomes of the dry-season survey are provided in this section. The resistivity model section AFWB1, which is shown in Figure 5.4, runs from the west to east but the trial site is located right on the far west of the transect, at the lower end of the slope. The section reveals the following resistivity contrasts across the hillslope:

- The first shallow layer of approximately 5 m thickness from ground surface, with resistivity ranging from 300 Ωm to 3500 Ωm consists of dry sandy materials (Red layer).
- The second layer of approximately 25 m thickness from ground surface, with resistivity ranging from 30 Ωm to 300 Ωm consists probably of wet sandy material and/or weathered zone overlaying the bedrock. This layer is likely to be a water-bearing formation.
- The third layer with high resistivity range of 600 Ωm to 3500 Ωm consists probably of a consolidated sedimentary rock such as sandstone or an igneous rock.
- In general groundwater flow direction mimics the topography of a site. It is therefore understood that the shallow groundwater level at the trial location is an indication of groundwater movement down the gradient.

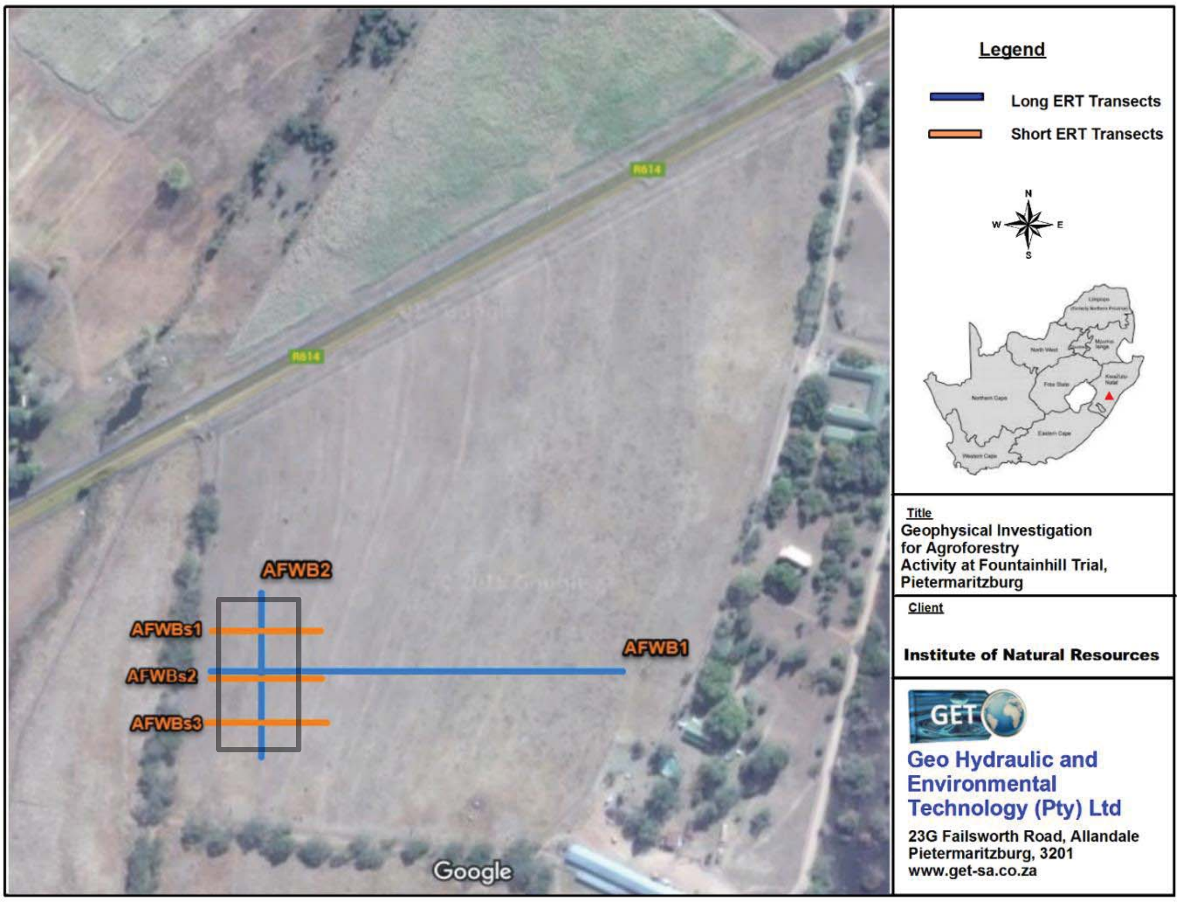


Figure 5.3 Location of the ERT transects relative to the trial site at Fountainhill Estate, Wartburg.

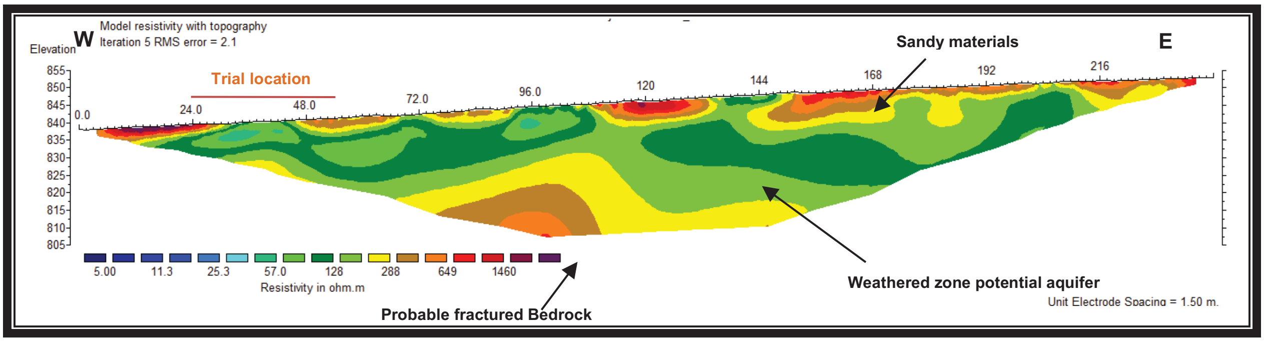


Figure 5.4 Transect AFWB 1 showing the location of the trial site.

Figure 5.5 shows transect AFWB2. This transect shows higher water content in the centre of the transect, with drier areas in the north and south. The resistivity at different depths all indicated that the northen part of the trial block has lower moisture compared with the southern part. It is observed that soil moisture varies laterally in the root zone across the Fountainhill trial as indicated by green curve in Figure 5.5.

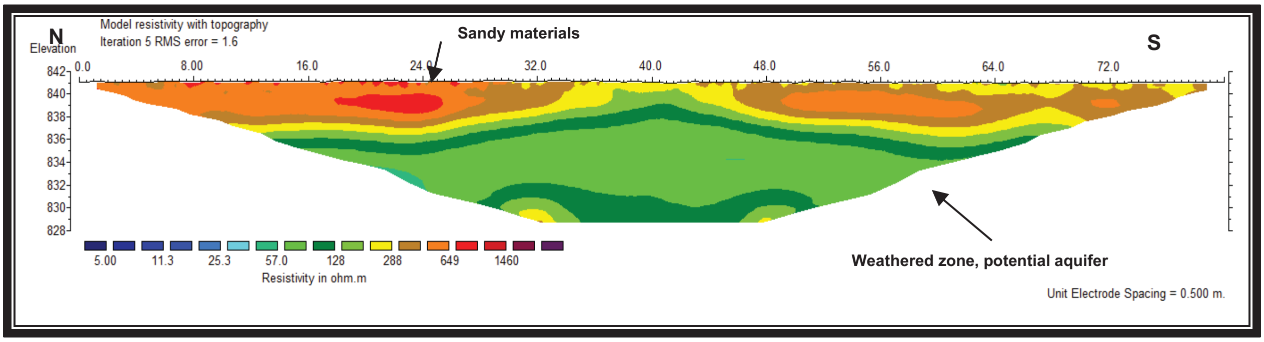


Figure 5.5 Transect AFWB 2 which runs down the length of the trial site at Fountainhill Estate, Wartburg.

Figure 5.6 shows the lateral and vertical variations of soil moisture in the three short east-west transects AFWBs 1, 2 and 3. Figure 5.6 bears out the observations from AFWB2, in that northern transect (AFWBs1) is drier, the centre (AFWBs2) shows the most moisture content near to the surface and the southern transect (AFWBs3) is intermediate in terms of moisture content.

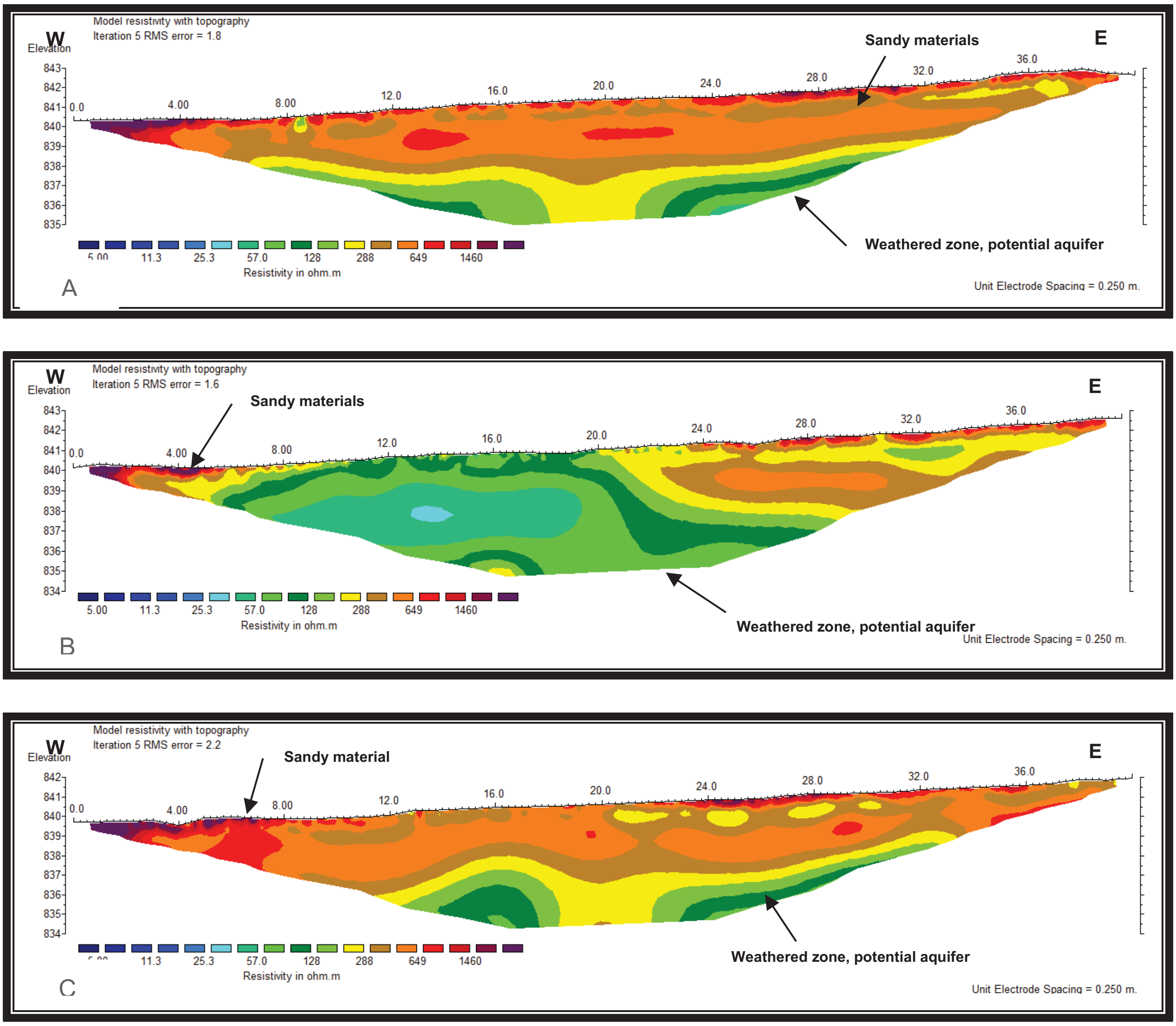


Figure 5.6 Transect AFWBs 1 (A), 2 (B) and 3 (C).

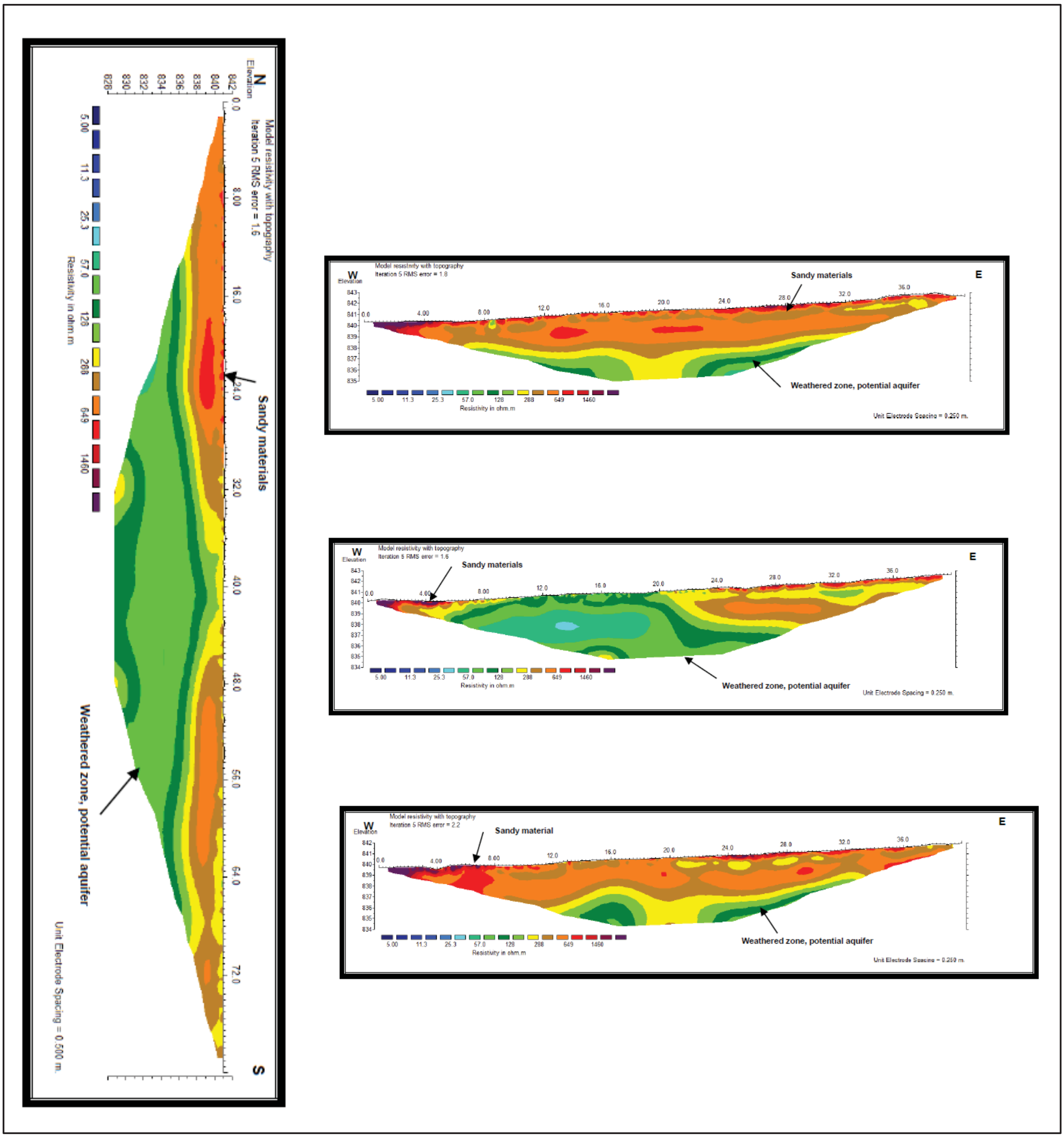


Figure 5.7 Composite of transects showing relative position of short transects and long transect running down the length of the trial site at Fountainhill Estate in July 2016.

Figure 5.7 provides a composite showing the relative positions of AFWB2 and AFWBs1, 2 and 3. It is clear from this assessment that there is substantial variation in soil water content across the trial site and at different soil depths. The northern parts of the site are drier, with the north-eastern corner being the driest (plots 1 and 9 especially). The soil water content is highest in the centre of the trial, becoming drier to the south. The trends in soil water content are corroborated by the short transects which correspond with the findings from AFWB2.

Time-lapse resistivity method

In studying the changes of the subsurface resistivity with time, two dimensional resistivity imaging surveys are often repeated over the same line at different times. The change of resistivity is evaluated using time-lapse inversion technique. Such technique is widely applied in studies including the flow of water through the vadose zone, changes in the water table due to water extraction (Barker and Moore 1998), flow of chemical pollutants and leakage from dams. In order to evaluate the change in water content over time within the vadose zones at the Fountainhill trail, resistivity model results obtained from the survey conducted in October 2015 are compared with results from the survey conducted in July 2016. Comparing the two resistivity model sections for all 5 transects, it appears that there is substantial change in resistivity distribution within the vadose zone, even though the October survey at the onset of the wet season. It is observed that the resistivity values increased within the saturated zone from the October 2015 survey to the July 2016 survey.

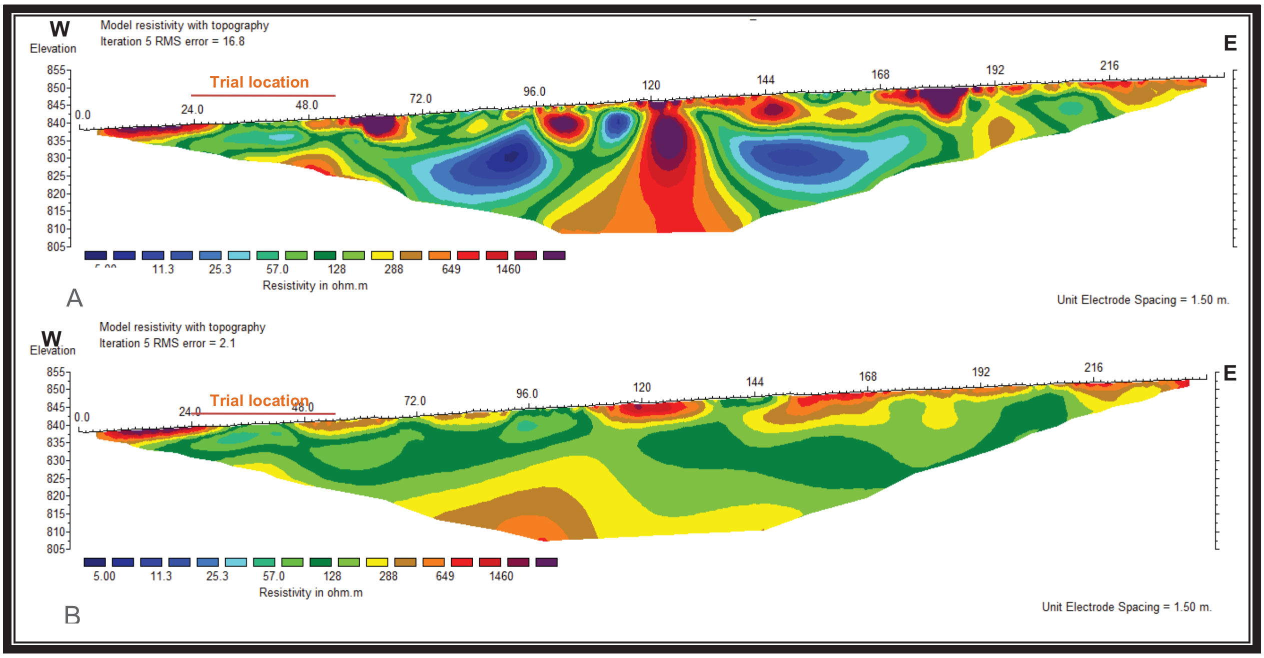


Figure 5.8 October 2015 (top) and July 2016 (B) results on Transect AFWB1.

Note: The red intrusion obtained in October 2015 (at the centre of the top AFWB1 section) is not a real geological formation but is due to discrepancies of data recorded. The second conductive layer (blue) on each side of the intrusion is probably a continuous section across the centre of this transect. This is borne out by the observations of the resistivity sections obtained in July 2016, which shows no such anomaly and is confirmed by the RMS error difference between the two resistivity sections.

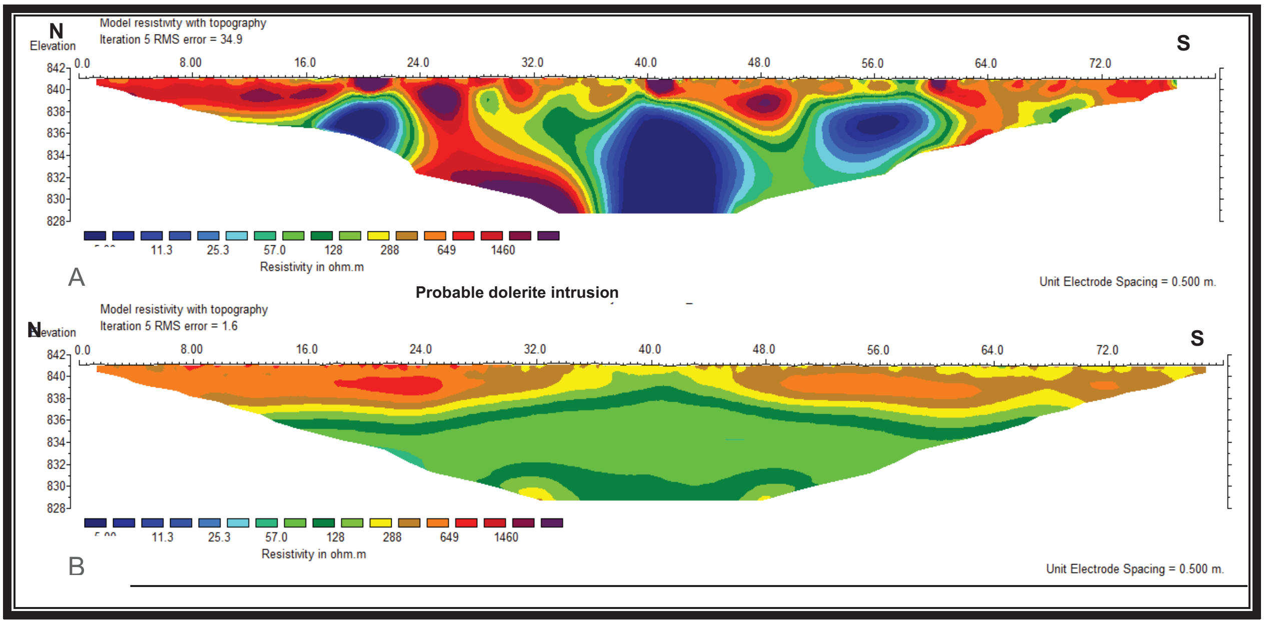


Figure 5.9 October 2015 (A) and July 2016 (B) results on Transect AFWB2.

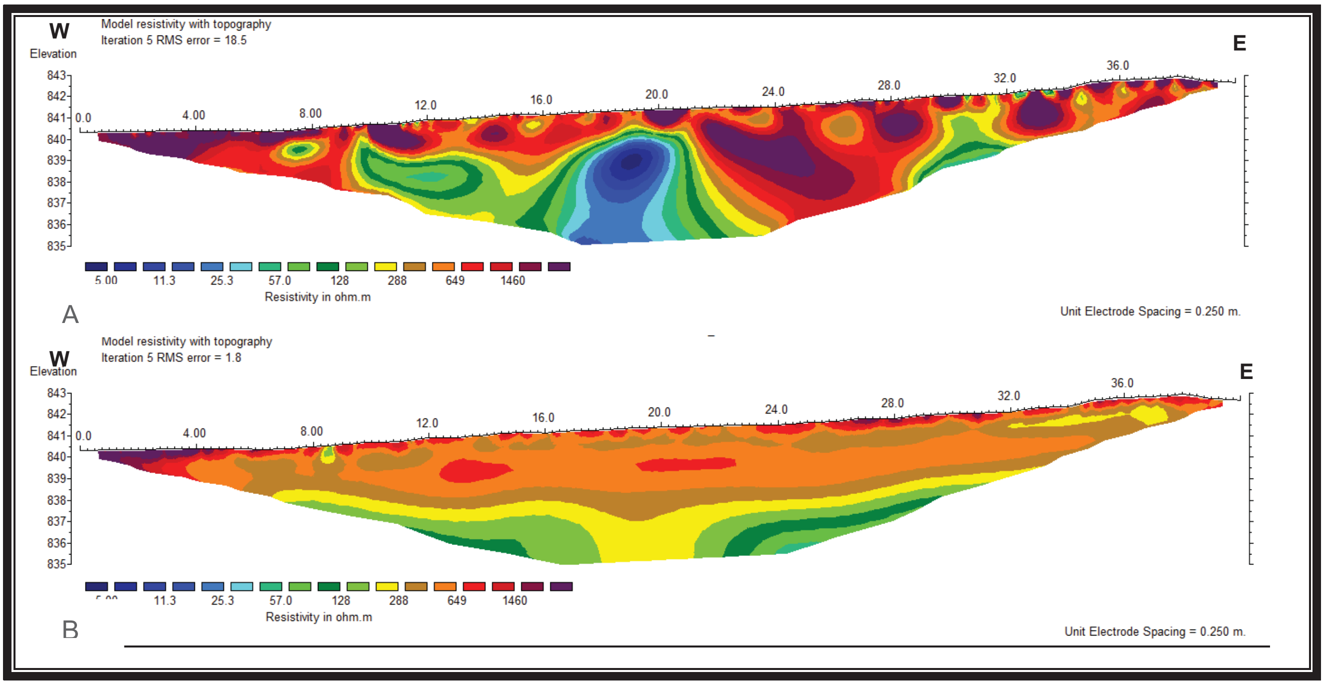


Figure 5.10 October 2015 (A) and July 2016 (B) results on Transect AFWBs 1.

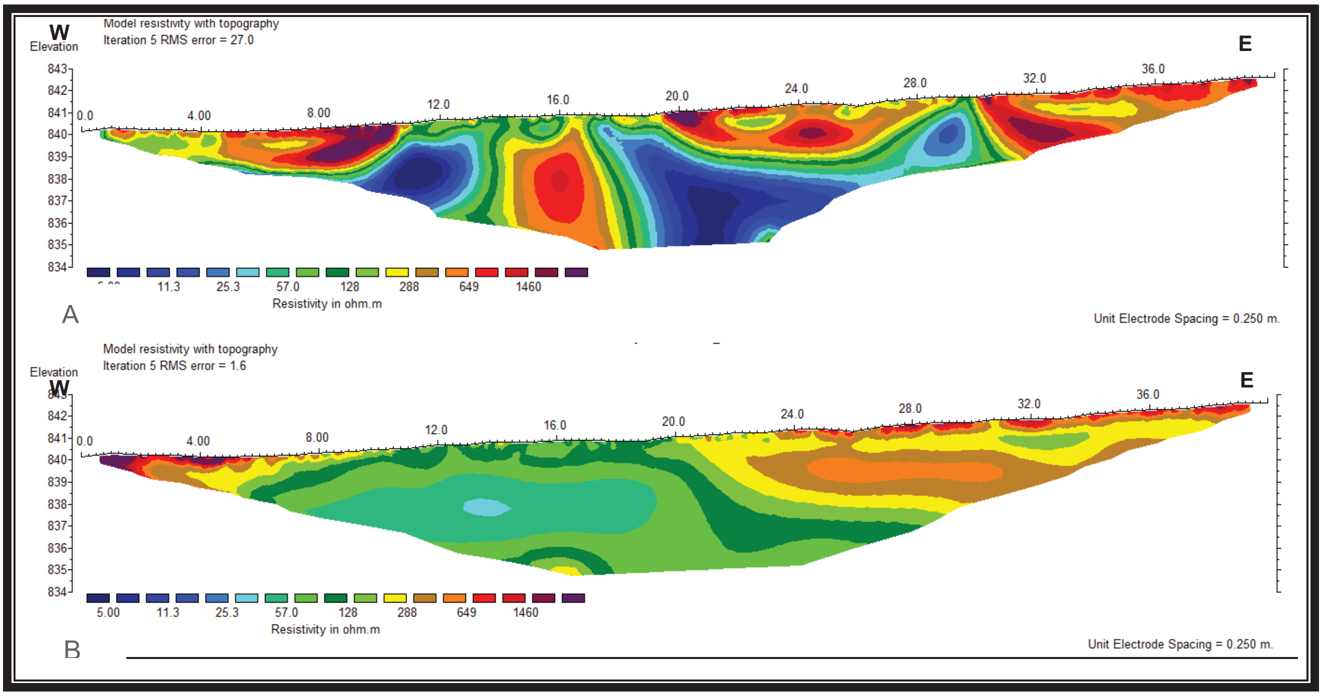


Figure 5.11 October 2015 (A) and July 2016 (B) results on Transect AFWBs 2.

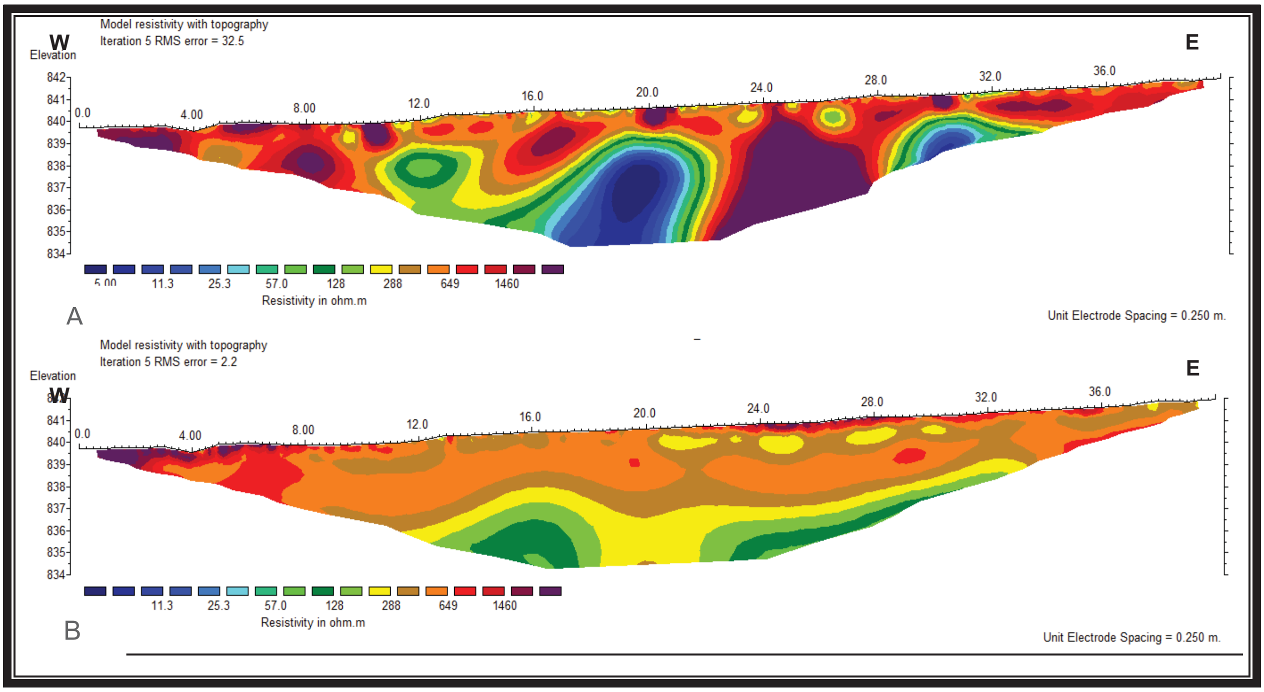


Figure 5.12 October 2015 (A) and July 2016 (B) season results on Transect AFWBs 3.

In theory since the inversion of each data set is carried out independently, there is no guarantee that the differences in the resistivity values are only due to actual changes in the subsurface resistivity with time. Comparing the RMS error percentage between the two set of data (October 2015 and July 2016), it appears that the data set recorded in July using Terrameter LS reveals a very higher quality data (error range from 1 to 2) than the set of data recorded in October 2015 using Terrameter SAS 1000 (error range from 15 to 37). Because of this discrepancy of data between the two seasons, time-lapse inversion could not be used at this stage to assess accurately the change percentage between the two sets of resistivity data. Nevertheless, the data indicates that there tends to be a higher water content in the wet season compared with the dry season, which is to be expected.

5.3.2 Soil physical and chemical characteristics

The site at Fountainhill Estate is located at the mid to foot slope terrain unit. The slope class was estimated to range from 3 to 8. Prior to establishing the trial, 7 soil pits were dug to allow sampling at five different depths (0 mm, 15 cm, 30 cm, 60 cm and 90 mm. In addition to 7 pits that were used for soil physical determination, 8 composite 20 cm depth soil samples were collected from the trial site and were sent to Cedara for chemical analysis.

Soil profile description

The soils in this site are deep, exceeding two metres. While the parent material was never reached due to the depth of the soil, based on the texture of the overlying horizon, the parent was believed to be sand stone. In addition there were patches of feroxides and sesquioxides observed throughout the horizon. This is associated with the hydration of iron and aluminium which results in the formation of sesquioxides, which indicates variations in water content (drying and wetting cycles). The topsoil in all soil pits was classified as Orthic A. The thickness of this horizon was 60 cm with light brown as a general colour for this horizon. The B horizon was classified as Red Apedal B. The thickness of the B horizon was greater than 100 cm. The process of cheluviation (the movement of smaller particles down the soil horizon) was found to occur in all pits described. This was witnessed by the stronger structures that were found with increasing depth of the horizon. However, those structures were not sufficiently developed to qualify the horizon as a red structured B horizon. Due to these characteristics, the soil form was found to Hutton (Hu1200). The pits were more or less the same since they were on the same contour line and showed similar characteristics.

Soil physical characteristics

Soil physical characteristics for the site at Fountainhill Estate are presented below.

Soil texture

The outcomes of the soil texture analysis are presented in Figure 5.13. Generally, the top 15 cm of the soils at the experimental site are comprised of loamy sand (Pits 1, 5 and 7) and sandy loam (Pits 2, 3 and 6). A notable difference is on the survey pit at the centre (Pit 4) top horizon is characterised by sandy clay loam.

At 15 cm depth, the dominant texture is a loamy sand. Most of the survey points show an increase in clay across all pits, with the centre pit being the only one which consistently has a sandy clay loam throughout the profile. This bears out the findings of the ERT survey which shows a higher water content in the centre of the experimental plots.

Soil water retentivity curves

Water retentivity curves were determined for survey pits 1, 4 and 7 in order to characterise the trial site and are shown in Figure 5.14. Retentivity was evaluated at depth of 0 cm, 30 cm, 60 cm and 90 cm depth at each of these three pits. A water retention curve is the relationship between the volumetric water content, θ, and the matric pressure head or soil water potential, ψ. Soil water retentivity is used to predict the soil water storage, water supply to the plants (field capacity), wilting point (Unavailable water to plants) and soil aggregate stability. The data will be used again to calculate water use efficiency and productivity within the treatments. Generally the retention curves indicate that as the matric pressure head increases, low water content is retained. For example, at 0 cm the soils retained 0.3-0.5 water content.

Depth (cm)	% clay	% silt	% sand	Texture
0	7	2	88	Loamy sand
15	11	4	81	Loamy sand
30	14	2	86	Loamy sand
60	34	5	65	Sandy clay
90	28	4	70	Sandy clay loam

1

Depth (cm)	% clay	% silt	% sand	Texture
0			81	Sandy loam
15	11	2	89	Loamy sand
30	13	2	86	Loamy sand
60	19	4	78	sandy loam
90	24	4	75	Sandy clay loam

2

Depth (cm)	% clay	% silt	% sand	Texture
0	18	7	79	Sandy loam
15	13	2	84	Loamy sand
60	22	2	75	Sandy clay loam
90	23	6	70	Sandy clay loam

3

depth (cm)	% clay	% silt	% sand	Texture
0	24	4	70	Sandy clay loam
15	25	2	73	Sandy clay loam
30	24	4	74	Sandy clay loam
90	28	4	70	Sandy clay loam

4

Depth (cm)	% clay	% silt	% sand	Texture
0	6	2	93	Loamy sand
15	11	2	88	Loamy sand
30	7	4	88	Loamy sand
60	31	2	66	Sandy clay loam
90	34	5	63	Sandy clay loam

5

Depth (cm)	% clay	% silt	% sand	Texture
0	17	2	83	Sandy loam
30	14	2	84	Loamy sand
60	22	5	74	Sandy clay loam
90	24	9	64	Sandy clay loam

6

Depth (cm)	% clay	% silt	% sand	Texture
0	9	2	86	Loamy sand
30	18	2	81	sandy loam
60	18	7	75	sandy loam
90	36	2	59	Sandy clay

7

Figure 5.13 Soil texture for different depths at Fountainhill Estate.

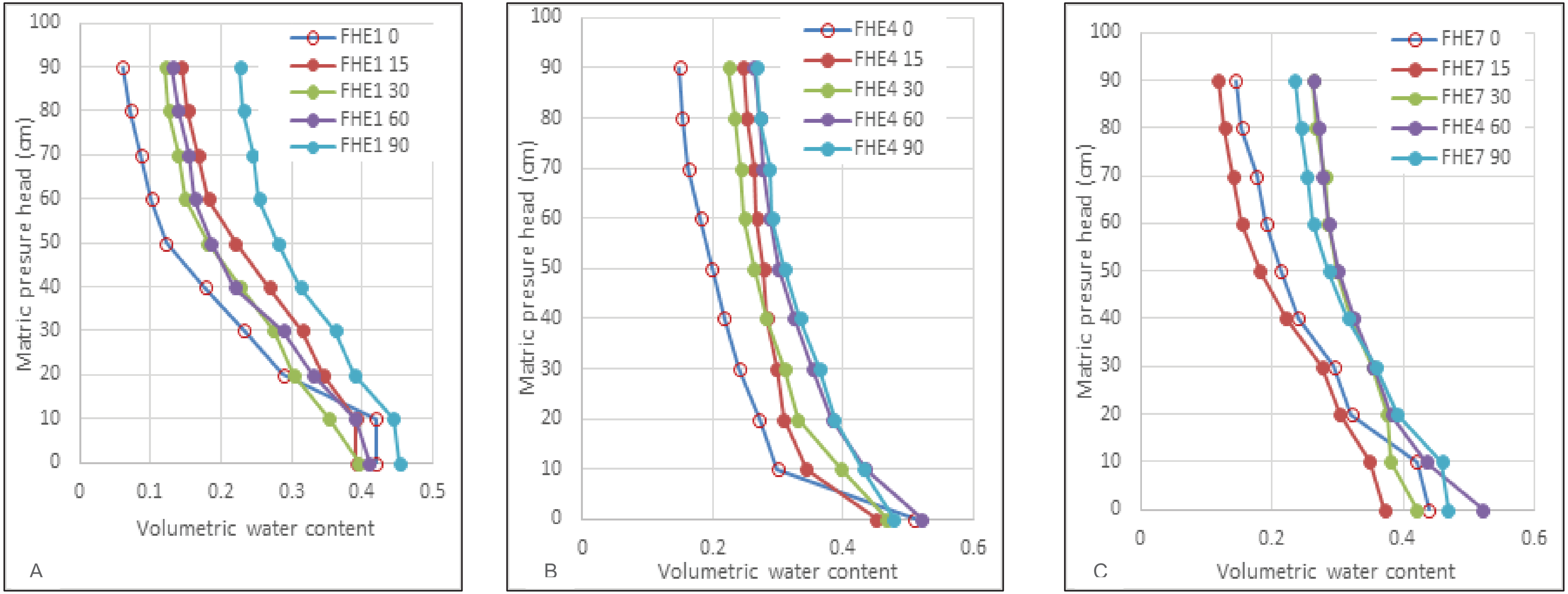


Figure 5.14 Soil water retention curve for FHE 1 (A), FHE 4 (B) and FHE 7 (C).

Soil chemical characteristics

Composite samples were taken across the trial site as shown in Figure 5.15. The results of the analysis, which was done by Cedara Soil Science Laboratory are presented in Table 5.1.

FHE8	FHE7	FHE6	FHE5	FHE4	FHE3	FHE2	FHE1
1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24

Figure 5.15 Sampling procedure at Fountainhill for determining soil chemical properties.

The analysis shows that the experimental site has a relatively low pH, but is consistent with soils that are generally encountered in this area. Plant growth and most soil processes, including nutrient availability and microbial activity, are favoured by a soil pH range of 5.5-8. Acid soil, particularly in the subsurface, will also restrict root access to water and nutrients. The optimum pH (KCl) for maize is 5.0-5.5, pigeon pea is 5-7 (KCl) and *S. bispinosa* is 5.8-7.5. The results of analysis clearly indicates that the pH was not within the range which supports the growth of both tree species (pigeon pea & *S.bispinosa*) and maize. In terms of the main nutrients (N, P and K), only potassium was adequate while phosphorus and nitrogen levels were low. The plots relating to FHE 1 showed better results in terms of growth as compared to those that were within FHE 8. Slightly higher concentration of cations (Calcium in particular) might have caused this, as is shown in Table 5.1.

Table 5.1 Chemical properties being determined at Fountainhill Estate, Wartburg

ID	N%	P mg/L	K mg/L	Ca mg/L	Mg mg/L	Cu mg/L	Exch Acidity cmol/L	pH (KCL)	O.C	Clay %
FHE1	0.06	19	124	518	89	2.9	0.05	4.61	<0.5	15
FHE2	0.05	24	123	519	92	2.9	0.06	4.33	0.8	17
FHE3	0.06	24	121	518	94	2.7	0.09	4.32	0.5	15
FHE4	<0.05	17	100	415	102	3.3	0.14	4.23	<0.5	19
FHE5	<0.05	18	103	470	101	3.1	0.06	4.36	<0.5	14
FHE6	<0.05	30	117	333	63	2.4	0.17	4.11	<0.5	15
FHE7	<0.05	19	94	352	68	1.8	0.14	4.23	<0.5	15
FHE8	0.5	22	81	369	76	1.8	0.14	4.23	0.5	16

Source: Cedara soil laboratory

5.3.3 Instrumentation at Fountainhill Estate

Fountainhill Estate (latitude 29°27'2" S; longitude 30°32'42" E and altitude 853 m above sea level) is located within in the uMshwathi Local Municipality, near Wartburg approximately 30 km northeast of Pietermaritzburg in KwaZulu-Natal, South Africa. The site has a mean annual precipitation of 805 mm per annum. The mean minimum temperature is 3.3°C and the maximum is 37.4°C.

The experiment that was established during the 2015/16 summer season had five treatments (1) sole maize, (2) sole pigeon pea (*Cajanus cajan*), (3) sole *Sesbania. bispinosa* (4) maize + *S. bispinosa,* (5) maize + pigeon pea. The experiment was laid out in a randomised complete block design (RCBD) replicated three times.

The layout of the trial is shown in Figure 5.16, where PP is pigeon pea, Mz is maize, Sb is *Sesbania bispinosa* and PM is *Panicum maximum*.

1 Mz_Sb	2 Mz_PP	3 PP	4 Mz	5 Sb	6 PM_PP	7 PM_Sb	8 PM
9 Mz_PP	10 PM_Sb	11 PP	12 PM_PP	13 Mz	14 PM	15 Mz_Sb	16 Sb
17 PM_PP	18 Mz_Sb	19 PP	20 Mz	21 PM	22 Mz_PP	23 PM_Sb	24 Sb

Figure 5.16 Layout of the agroforestry trial at Wartburg in the 2015/16 cropping season (The instruments were placed in the shaded plots).

The two tree species (pigeon pea and *S. bispinosa*) were planted at 1 m inter-row and 1 m intra-row spacing, while the mixed crop of trees and maize had 1 m inter-row and 0.4 m intra row spacing for the maize. Sole maize had 0.8 m inter-row and 0.5 m intra-row spacing with 120 plants per plot such that the same maize plant population as the mixed plots was maintained (i.e. 25 000 plants/hectare). Each treatment was replicated three times.

The *S. bispinosa* is an annual species and thus it died within 2016. The pigeon pea never established properly and was also excluded. The two-year fallow therefore only made use of pigeon pea and the plots with *S. bispinosa* or *P. maximum* are excluded from this discussion. Thus the treatments considered were:

- Sole maize
- Sole pigeon pea
- Pigeon pea/maize intercrop

5.3.4 Weather conditions

The following climatic variables were recorded from an automatic weather station in the immediate vicinity of the experimental plots (Table 5.2): dry and wet bulb temperature, humidity, incoming short-wave radiation, wind speed and rainfall. Measurements were taken at as hourly means. These values were used to compute daily values of potential evapotranspiration using Penman's formula (Penman, 1948).

Table 5.2 Climatic data recorded for the period 16 Jan-12 Aug 2016 at Fountainhill Estate

Month	January	February	March	April	May	June	July	August
Rainfall (mm)	122	52	116	28.6	23.3	4.6	73.7	47.9
Max T (°C)	27	28	27	27	24	22	19	22
Min T (°C)	16	16	14	11	7	4	4	3
Max RH	80	81	83	86	86	81	80	77
Min RH	64	61	56	48	40	40	49	33
Solar Radiation	18	16	18	13	12	10	11	14
Wind	136	143	123	103	84	91	115	106
ETo	7.6	8.9	9	9.8	8.8	8.2	6.6	9.1

A description of the instruments that have been installed in the various plots is provided below in Figure 5.17.

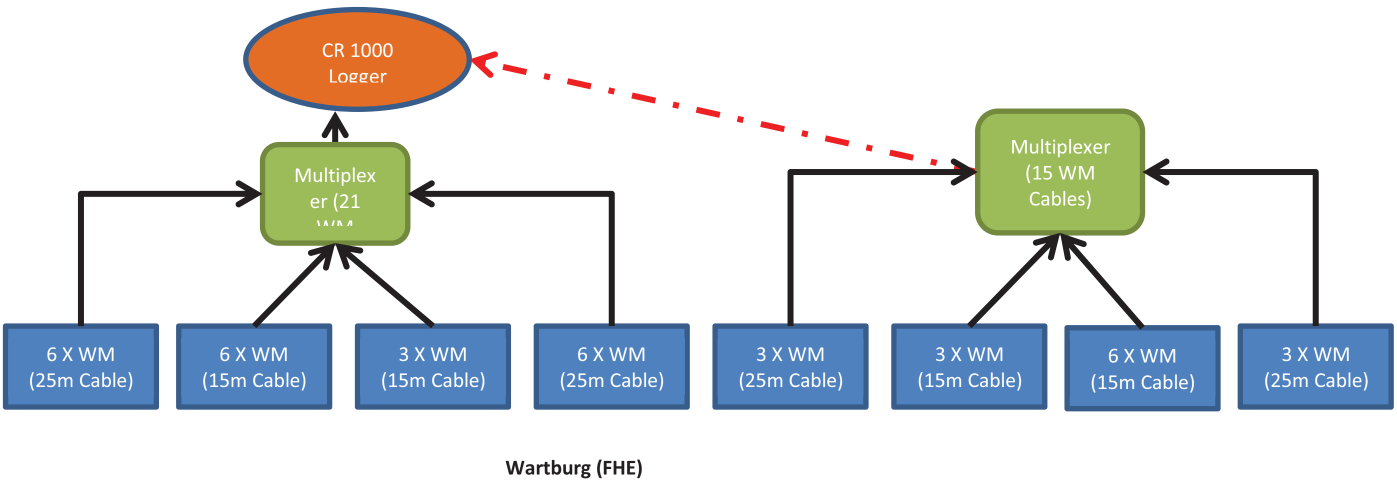


Figure 5.17 Instrumentation arrangement for Fountain Hill Estate, Wartburg, showing the positions of Watermark sensors (WM) and TDR probes in plots 9-16.

5.3.5 Results of the study

The study considers two different periods, firstly the water use during the two-year fallow period and secondly the water use of the maize in the year after the fallow period.

Rainfall received during the fallow period

The total rainfall received from fallow establishment in January 2016 to fallow termination in November 2017 was 1552.6 mm, which was spread as shown in Figure 5-18. During the entire pigeon pea fallow phase, the lowest monthly rainfall was received in July 2016, June 2017 and July 2017, which was 4.6 mm, 1.8 mm and 0.4 mm respectively, while 156.4 mm was the highest monthly amount received, being in February 2017.

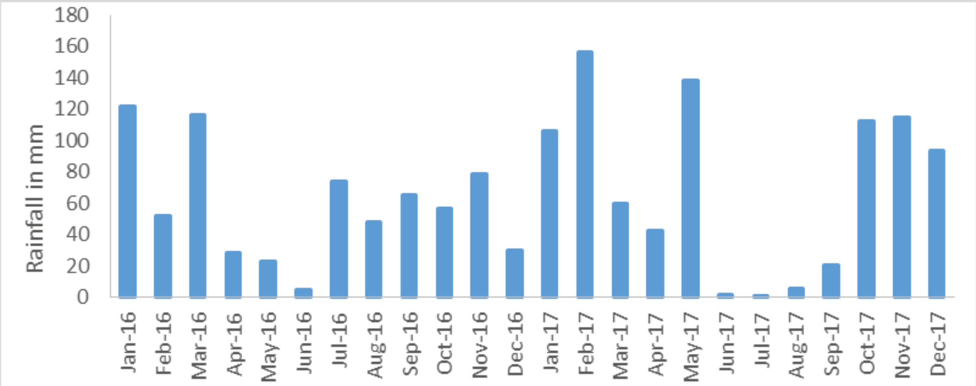


Figure 5.18 Rainfall received over the period January 2016 to December 2017 at Fountainhill Estate, Wartburg

Soil water distribution within soil profiles

Figure 5.19 shows the time courses of soil water content for three depths (200 mm, 500 mm and 1200 mm) examined during the two year pigeon pea fallow phase.

Note: The equation used to calculate the soil water content from the soil water tension values for the 500 mm sensors appeared to inflate the values relative to the other two depths. As a result it is not possible to compare values across depths, but it is still possible to compare values for different treatments at each of the depths.

The pigeon pea trees were established in January 2016 and were actively growing until they were cut back in November 2017 to allow for planting of maize. During this time there was die-back in June 2016 due to frost but the trees resprouted from their base in September 2017. All treatments showed a dip in soil water content associated with the low rainfall received in December 2017 and for the period June-August 2017. The only treatments that showed differences were the lower soil water content for the maize treatment around March 2017 and from August 2017 onwards. There was no maize crop growing from August to November 2017, so the lower soil water content may have been due to reduced infiltration on the maize plants compared with those that had pigeon pea trees.

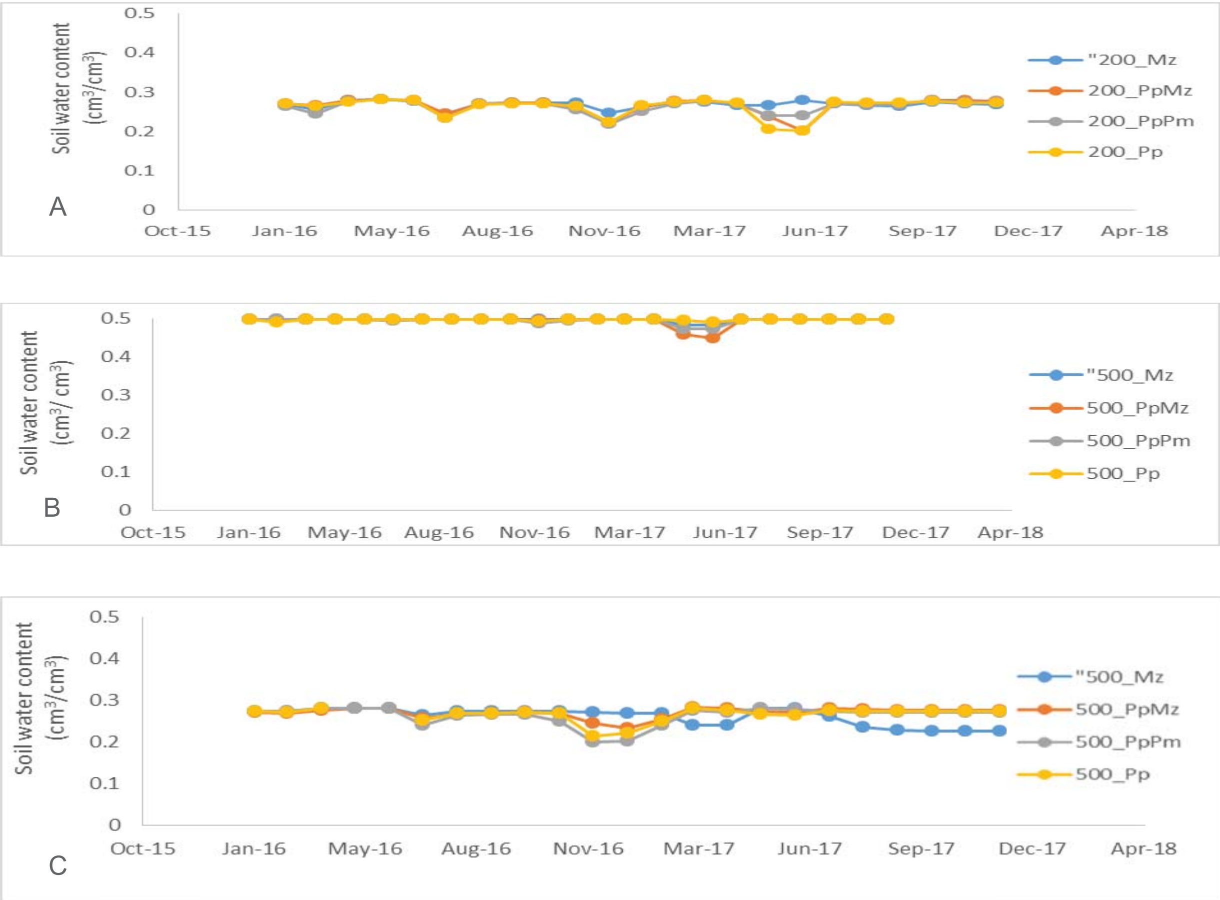


Figure 5.19 Soil water content for three depths (A: 200 mm, B: 500 mm and C: 1200 mm) during 2 years of the improved fallow comparing maize, pigeon pea/maize intercrop, pigeon pea/*P. maximum* intercrop and sole pigeon pea

5.3.6 Post-fallow water use

Methodology

The four treatments that were compared after termination of the two year fallow were.

- T1 Continuous unfertilised maize (control)
- T2 Natural fallow – then maize (control)
- T3 Pigeon pea intercropped with grass (1st year) – then pigeon pea (2nd year) – then maize (3rd year).
- T4 Two-year pigeon pea fallow – then maize.

Weather data

The following climatic variables were recorded from an automatic weather station in the immediate vicinity of the experimental plots: maximum and minimum temperature and rainfall. The annual rainfall during the 2017/18 summer cropping season was 672.2 mm, with January 2018 being the driest month (Figure 5.20).

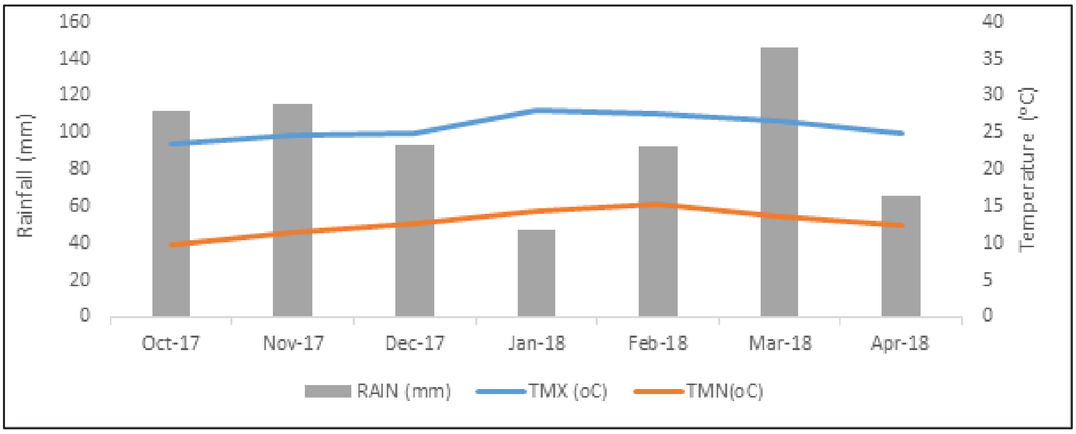


Figure 5.20 Fountainhill weather during the study period of 2017-2018 summer cropping season.

Soil water content distribution

Soil water tension within the soil profile was monitored in situ using a set of Watermark sensors, installed at 200, 500 and 1200 mm depths in each plot. For the determination of soil-water content (SWC), soil water retention curves developed from the experimental field were used to transform the daily soil water data. The soil water retention curves were obtained from undisturbed soil cores (0.05 m height and 0.05 m diameter) by desorption using standard techniques (Klute, 1986) and analysed in terms of the empirical retention model of Van Genuchten (1980) using non-linear parameter optimisation programme RETC (Van Genuchten et al., 1991). The soil water content in the total 1200 mm soil profile for each plot was then calculated as the total soil water storage.

Profiles of soil water content for the treatments at each of three depths are shown in Figure 5.21. Given that the equation for calculating SWC at 500 mm depth seemed to inflate the values it is not possible to compare values across profiles, but it is possible to compare treatments within each soil depth. Overall, the soil water content was much more variable for the 200 mm depth than for the 500 mm or 1200 mm depths. At 200 mm depth, T1 (continuous maize) and T3 (maize after two years of pigeon pea) did not respond to the rainfall events in the same way as the other two treatments. With T1 it could be that there was run-off rather than infiltration occurring. It is unclear why this would have been the case for T3.

At 500 and 1200 mm depths there was almost no differences between the treatments across the growing season, although 500 mm SWC was marginally lower for T4 in late January 2018 and 1200 mm SWC was slightly lower between late January and early 2018 for T4 where there was maize growing after a two-year pigeon pea fallow. This could be related to the vigorous growth of the maize under this treatment.

Note: Instruments were only placed in one plot for each treatment so we cannot be sure that the differences are due to treatments and not due to soil differences or errors with the instruments. For examples at 200 mm: T1 and T3 seem to have lower soil water content that T2 and T4. This makes sense for T1 (continuous maize) but not for T3.

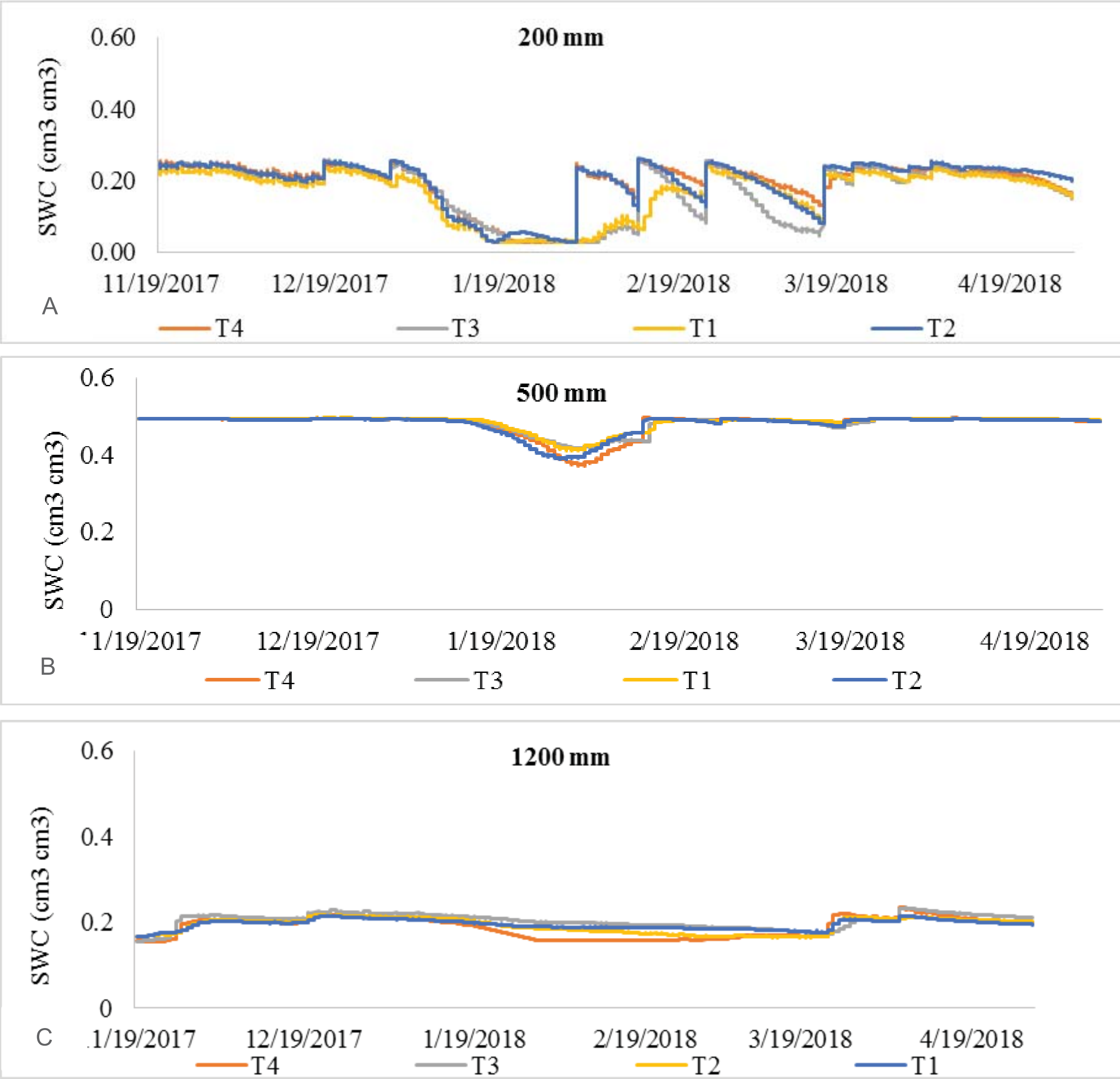


Figure 5.21 Soil water distribution within different soil depths (A: 200 mm, B: 500 mm, C: 1200 mm) and treatments [T1 Continuous unfertilized maize (control); T2 Natural fallow – then maize; T3 Pigeon pea intercropped with grass in (1st year) – then pigeon pea (2nd year) – then maize (3rd year); T4 Two-year pigeon pea fallow – then maize].

5.3.7 Validation and modelling the effect of maize grown after fallow on soil water content

Introduction

The objectives of this study were (i) to calibrate and validate the HYDRUS (2D/3D) model using the experimental data (ii) to determine the water content of soil after rainfall events where maize is planted after an improved pigeon pea fallows as compared to soil under continuous maize.

Materials and methods

Daily minimum, mean and maximum temperature, relative humidity, mean wind speed, precipitation solar radiation, net radiation, dry and wet temperature, soil temperature in three depths, humidity, wind speed, wind direction and precipitation were monitored by an automated station _Didcot UK_ on at least hourly interval. Soil water tension within the soil profile was monitored in situ using a set of Watermark sensors that were installed at 20, 50, and 120 cm depths in each plot. Readings were logged automatically recording hourly. The soil water tension measurements were recorded daily throughout the experiment.

HYDRUS 2D/3D was used to simulate the soil water dynamics considering the plant water uptake. Water flow in Hydrus-2D is a two/three-dimensional isothermal Darcian flow in a variably saturated medium, and it is assumed that the air phase plays an insignificant role. The governing flow equation is given by the modified Richard's equation, wherein the root water uptake is specified as a sink term (Simunek et al. 1999). The soil water retention characteristics are summarised in Table 5.3.

Table 5.3 Soil water retention characteristics

Texture class	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α (cm^{-1})	*n (-)*	*Ks (cm day^{-1})*	*l (-)*
Sandy clay loam	0.0555	0.4037	0.025	1.28	14.3	0.5

θ_r is residual volumetric soil water content; θ_s is the saturated volumetric soil water content Ks is saturated hydraulic conductivity, the others are constants used in the Van Genuchten model.

The plant water uptake is taken into account by the incorporation of the sink term following the empirical model developed by Feddes *et al.* (1978). The sink term (*S*), is the amount of water extracted from the soil per unit time (Šimůnek et al., 2006).

Feddes Plant water uptake (Sink term-S) equation:

$$\boldsymbol{S(h) = \alpha(h)S_p}$$

Where *α (h)* is the dimensionless water stress function which varies from zero to one, S_p is the potential water uptake (T^{-1}).

The potential root water uptake have a close similarity with the potential evapotranspiration and thereby affected by climatic parameters (Šimůnek and Hopmans, 2009). Root water uptake can simulate as compensated or uncompensated where the latter allows for water extraction in lower layers by water-stressed plants. However, in this study, compensated root water uptake was not considered. The model uses the two dimensional functions described in Vrugt et al. (2001). Root water uptake parameters for corn, were adopted from the HYDRUS 2D/3D database. This included critical pressure heads; P_O (pressure head below which plant roots begin water extraction), P_{Opt} which is the pressure head below which the plant roots begin water extraction at maximum possible rate, P_{2H} and P_{2L} being the high and low pressure heads respectively below which the maximum root water extraction is no longer possible, and P_3 which is the pressure head corresponding to wilting point (Li et al., 2015). The root water distribution was assumed to vary linearly with depth. The HYDRUS 2D/3D water uptake and root parameters used in the study are indicated in Table 5.4.

The 2-D soil profile created had four external boundaries, which were the soil surface, the left side, the right side and the bottom. The soil surface used an atmospheric boundary, which processed daily atmospheric inputs of precipitation, evaporation and transpiration. The left and right sides of the domain had no-flux boundary condition. The lower boundary was free drainage while the other remaining boundaries were assigned no flux BC. The moisture content at planting was the initial conditions in the model. The simulation domain was 90 cm by 200 cm.

Table 5.4 Root water uptake parameters

Parameter	Value
Root water uptake	
Root water uptake model	Feddes
Critical pressure heads (cm)	P_O = -15, P_{Opt} = -30, P_{2H} = -325, P_{2L} = -600, P_3 = -8000
Limiting potential transpiration rates	r_{2H} = 0.499999 cm day^{-1}, r_{2L} = 0.1 cm day^{-1}
Root distribution	
Maximum rooting depth, Z_m (cm)	80
Depth with maximum root density (cm)	40
Maximum rooting radius, r (cm)	40
Radius of maximum root density (cm)	30
Empirical parameters	Pz = Px = 1

HYDRUS 2D/3D requires input of separate values of potential soil evaporation and transpiration. Therefore, evapotranspiration (ET) was split into potential transpiration (Tp) and evaporation (Ep) using the Beer's law represented by Equations 4.2 and 4.3 (Šimůnek et al., 2013).

Split Potential Transpiration using the Beer`s law

$$\boldsymbol{T_p = ET_c \times \left[1 - e^{(-k \times LAI)}\right]}$$

Split Potential Evaporation using the Beer`s law

$$\boldsymbol{E_p = ET_c \times e^{(-k \times LAI)}}$$

Where ET_c = potential crop evapotranspiration, k = light extinction coefficient and LAI = leaf area index

Evapotranspiration using FAO Penman-Monteith method

$$\boldsymbol{ET_c = ET_0 \times K_c}$$

Where ET_o = reference crop evapotranspiration K_c = crop coefficients

The ET_o values were computed using FAO Penman-Monteith method described in Allen et al. (1998) using daily weather data. Leaf area index (LAI) was monitored along the cropping cycle, measurements being done approximately each week using the Ceptometer.

Initial conditions The HYDRUS (2D/3D) provided an option of setting the initial conditions in terms of pressure head or water content. In the present study, observed volumetric soil water content determined at the various depths at the beginning of the experimental period in the field was used as the initial condition in the model domain. Maize was planted on 22 November 2017 and matured on 11 April 2018. For calibration purposes simulations were done during that period (140 days). Observation nodes were set at 20, 50 and 120 cm depth as for these depths water contents were measured. At observation nodes simulated water content per time step is given out by Hydrus-2D.

The model performance was evaluated using the root mean square error (RMSE) (Kandelous et al., 2011) and the coefficient of determination (R^2) (Moriasi et al., 2007). After model calibration and validation, the model was used to determine soil water content on maize planted on improved pigeon pea fallows and continuous maize on 48 hours on DOY 122 and 123 where there was high rainfall intensity. The objective was to compare how soil water will be retained for maize grown after two year improved fallow compared with continuous unfertilized maize.This was obtained by simulating the soil water dynamics under three depths of 20 cm, 50 cm and 120 cm on sandy clay loam soil described in Table 5.3. The root distribution parameters were the same as in Table 5.4. The infiltration rate (cm/day) was the only parameter which was changed in the model: T4 (71.54), T3 (50.38), T2 (45.86), T1 (25.87) after it was measured at fallow termination.

<u>Results</u>

Model calibration

The average data were used to calibrate the soil hydraulic parameters (Table 5.3), and average soil water from data were used to validate the model. Since relatively similar trends in SWCs were obtained from the four treatments, only the results for the 200 mm and 500 mm (validation) are presented in Figure 5.22 and Figure 5.23. The results indicate that the model was satisfactory ($R^2 \geq 0.73$ and RMSE ≤ 0.054 cm^3 cm^{-3}) in simulating the soil water contents at 200 m depth. Similarly, the simulated water contents over the growing period closely matched ($R^2 \geq 0.60$ and RMSE ≤ 0.084 cm^3 cm^{-3}) the observed values under 500 mm indicating satisfactory model performance. Overall, temporal changes or high fluctuations in SWCs in the upper soil layers (200 mm) was larger than at 500 mm and at the deeper layer (1200 mm), since that profile was more directly affected by precipitation, evaporation, and transpiration root water uptake. After all rainfall events, SWCs increased quickly in the upper soil layer, especially in the very top layer (200 mm). In general, the errors in the simulated soil water contents were less than 10%. The simulated and observed soil water contents on 1200 mm were not satisfactory (not shown) as the model overestimated soil water content.

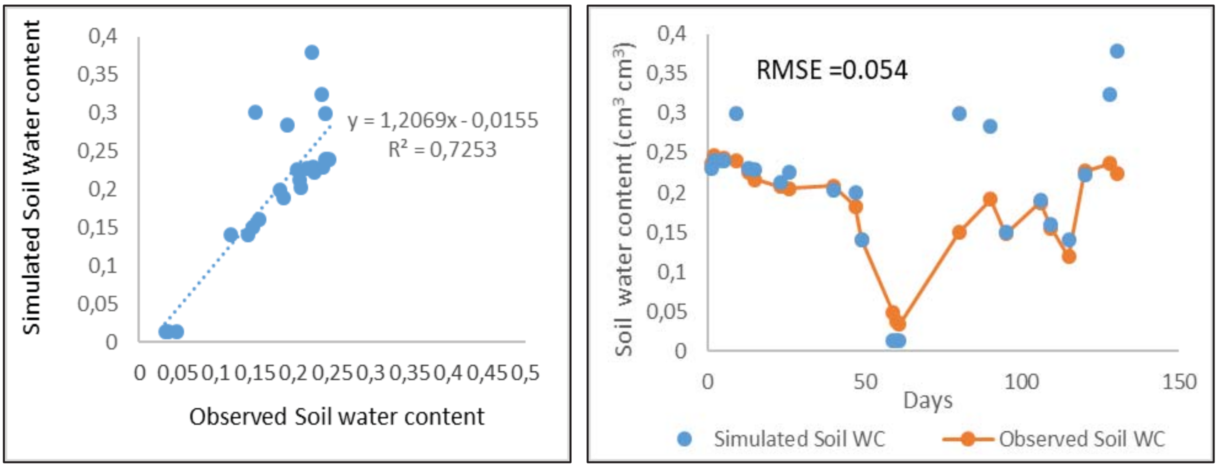


Figure 5.22 Observed and simulated soil water content at 20 cm.

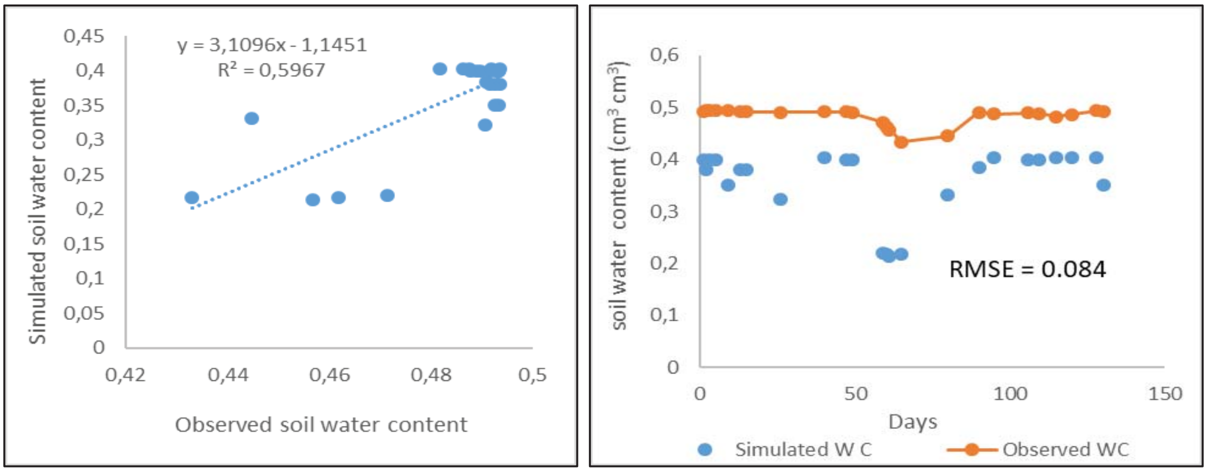


Figure 5.23 Observed and simulated soil water content at 50 cm.

Soil water content

The soil water retained by the different treatments can be described by the following order T4 > T2 ≥ T3 > T1. Maize grown after two-year improved fallow had higher soil water content at the top surface after rainfall events as compared to unfertilized continuous maize as shown in Figure 5.24.

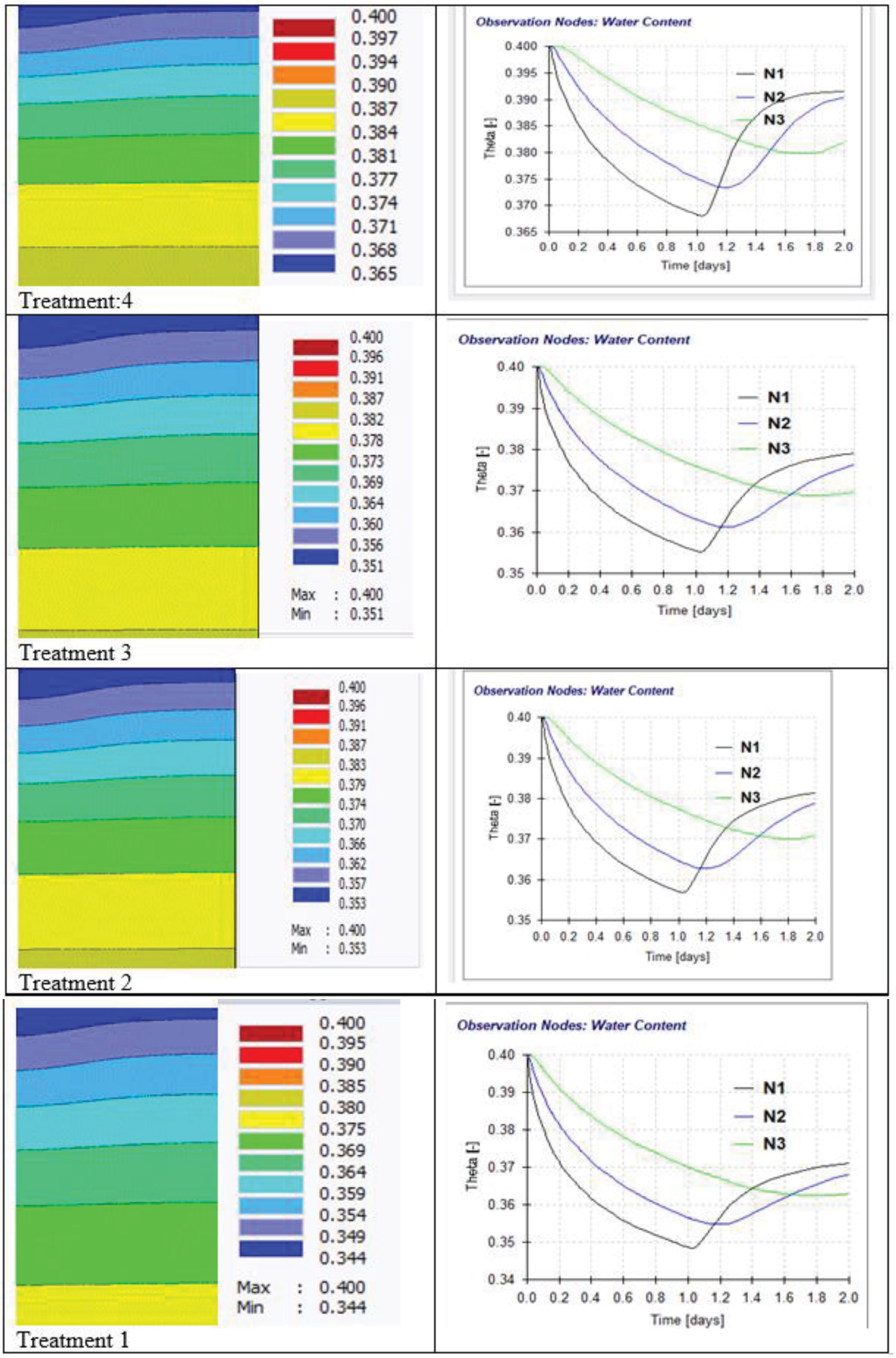


Figure 5.24 Soil water content of different treatments (N1 = 20 cm depth, N2 = 50 cm depth, N3 = 30 cm depth).

Discussion

Model calibration

These results indicate that HYDRUS 2D/3D can be used in simulating the soil water dynamics of maize grown under two-year improved fallows and continuous maize without fertilizer. Values of R^2 range from 0.0 to 1.0 with values greater than 0.5, indicating acceptable model performance (Moriasi et al., 2007). The correlation between the simulated and observed results was strong for 20 and 50 cm depth for both calibrations and the model accounted for 73% to 60% of the variation in the observed data, which is an acceptable performance of the model (Moriasi et al., 2007). The simulated and observed soil water contents at 120 cm were not satisfactory as the model overestimated soil water content. The probable reason might be the presence of an impermeable layer within the soil profile. In terms of water table, it could be that the impermeable soil layer observed at depths around 50 cm restricted water movement down the soil profile resulting in saturated soils and a temporary water table. Conversely, the higher SWC observed at depths of 50 cm across all the treatments could suggest the impermeable layer was higher resulting in a higher temporary water table. However, this will be given further attention to confirm the probable cause.

Soil water content

Moisture stress is not only a function of low and erratic precipitation but also of the ability of the soil to hold and release moisture. Soil that cannot hold water has a particularly negative impact on crop yields as farmers face climate change, with its associated increased incidence of drought, intense rainfall, and disruptions in rainfall patterns. Depending on the quantity and distribution of rainfall, crop yield losses can range widely from a small percentage to almost total crop failure. In our study maize planted on two-year pigeon pea fallow retained more water as compared to continuous maize at the surface (Figure 5.24). The probable reason is the presence of organic matter through pigeon pea leaf litter fall as the presence of trees improves water holding capacity of the soil with addition of organic material through litter fall (Komicha et al., 2017). A main target of agricultural management is to ensure a high volume of stored soil water available for plant uptake. Commonly, an important role in water storage has been attributed to soil organic matter (Hudson 1994) so interventions should aim at increasing soil organic matter content, infiltration and water storage (Sun et al., 2008). This might be the reason more water was retained with maize planted after the two-year improved fallow.

Conclusions

The HYDRUS (2D/3D) model was parameterised and calibrated to simulate the soil water movement in a maize grown after two-year improved pigeon pea fallows and continuous maize without fertilizer. Simulated SWCs at observation points at two soil depths (20 and 50 cm) were found to be in good agreement with experimental data. The average errors were all lower than 10%, while the average root mean square were 0.73 and 0.60 the average RMSEs were 0.054 and 0.084 $cm^3\ cm^{-3}$ for 20 and 50 cm, respectively. SWCs were significantly affected by rainfall amounts, and significant differences in SWCs were observed between different soil depths. The HYDRUS-2D model performed reasonably well in predicting soil water content. The numerical model HYDRUS (2D/3D) proved to be a powerful tool for investigating dynamics of soil water in agroforestry systems such as improved fallows. A fully calibrated model could be used to quickly evaluate different soil water management strategies without the need for laborious field work. Additional modifications of HYDRUS (2D/3D), such as considerations of crop yield; the surface energy balance; and coupled movement of water, vapor, and energy, would also be greatly beneficial for such analysis.

5.4 Results for the improved fallow trial at OSCA, Empangeni

A similar procedure was followed at OSCA, however the poor germination and survival of the crops due to the low rainfall required that the trial be re-established in the 2016/17 cropping season.

5.4.1 Geophysical survey

ERT surveys were conducted at OSCA in October 2015 and July 2016. The transects used for the surveys are shown in Figure 5.25. Since the July surveys were conducted a short time after a rainfall event and thus did not differ substantially from the October 2015 profiles, only these profiles are presented here. In addition, the equipment used for the 2016 surveys was better than that used previously.

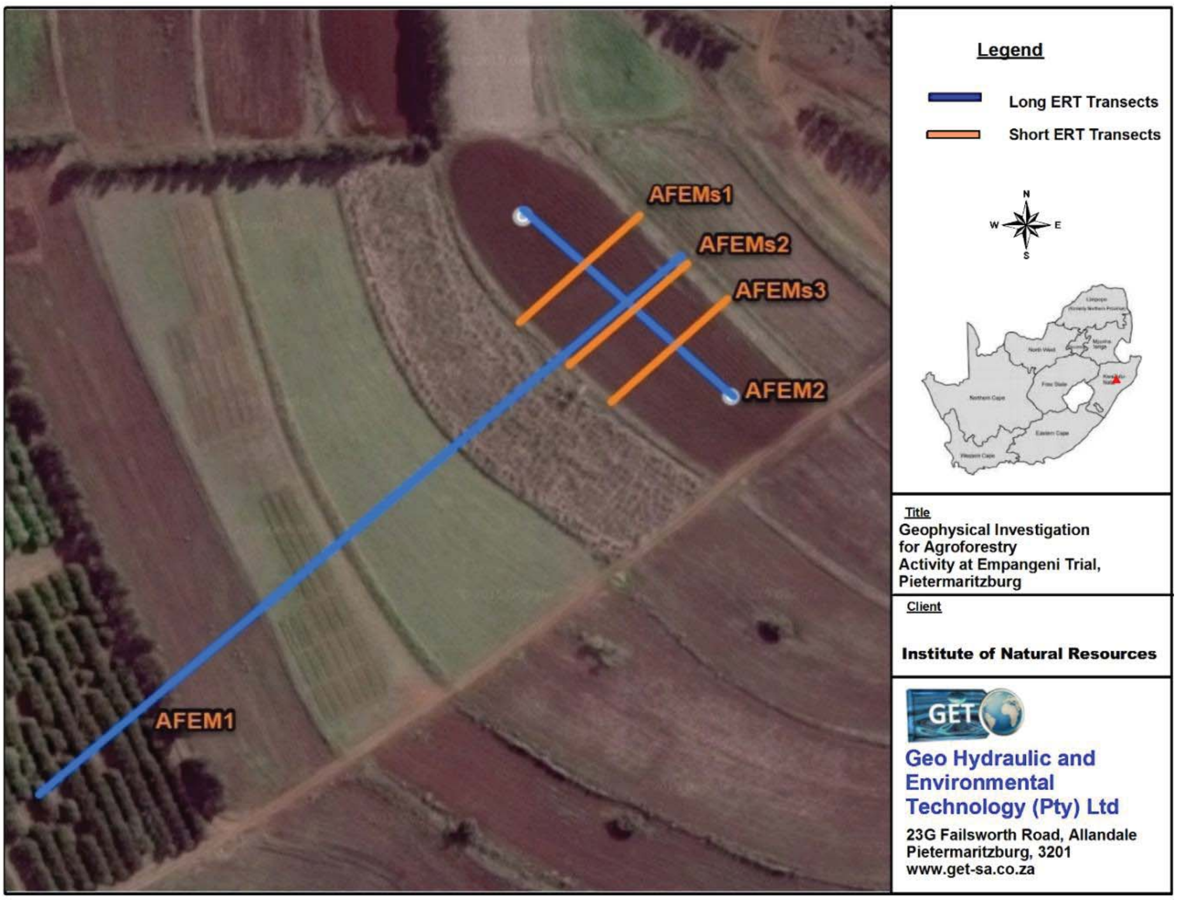


Figure 5.25 ERT transects at the OSCA trial site.

The resistivity model section AFEM 1 (Figure 5.26) reveals the following resistivity contrasts:

- A first layer approximately 10 m thick and with resistivity values ranging from 5 Ωm to 50 Ωm consists probably of sandy clay material.
- A second layer approximately 11 m thick and with resistivity values ranging from 50 Ωm to 150 Ωm consists probably of a weathered zone or a sedimentary rock such as sandstone. This layer is likely to be an aquifer.
- A deepest layer with resistivity > 1000Ω m consists of consolidated bedrock probably a basalt as indicated by the regional geology map shown above in Figure 5.1. This bedrock is fractured at approximately 120 m location.

Figure 5.26 also provides an indication of the geophysical characteristics of the site. A composite of the three short transects that run across the site is shown in Figure 5.28. There appears to be less variation across the OSCA trial site than across the Fountainhill Estate site.

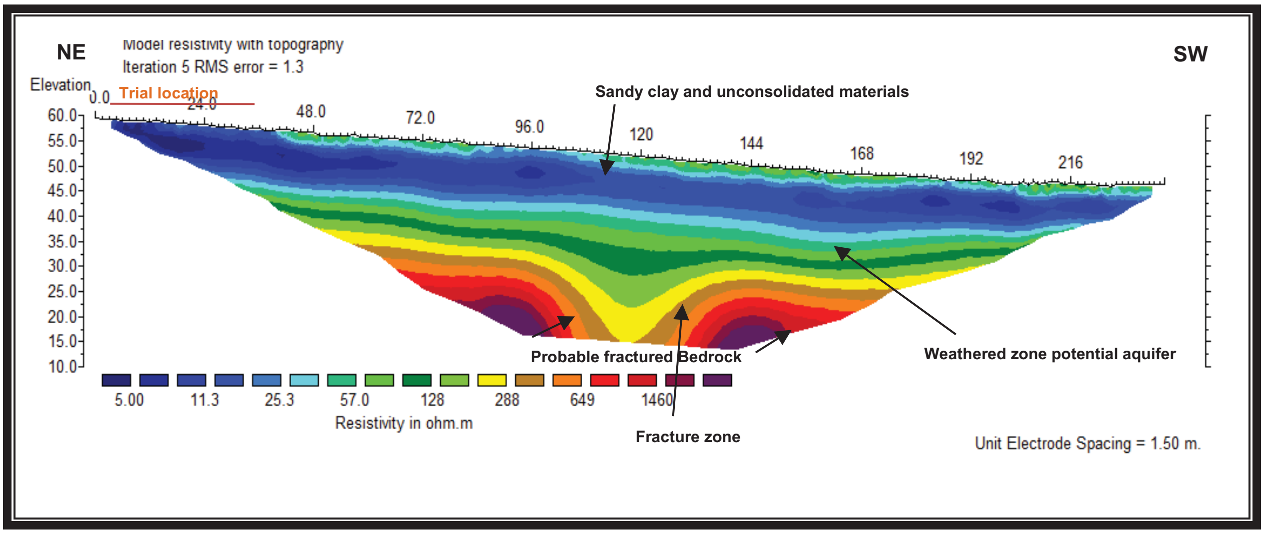


Figure 5.26 Transect AFEM 1 at OSCA, Empangeni showing the location of the trial, July 2016.

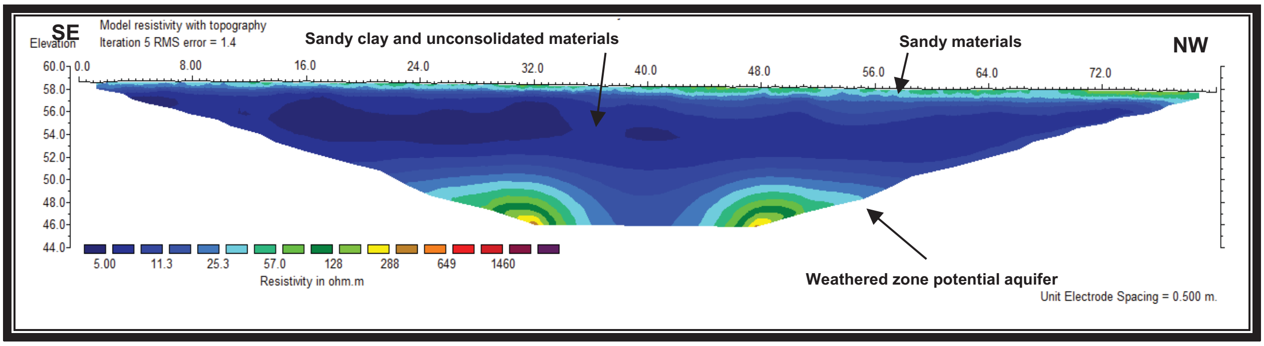


Figure 5.27 Transect AFEM 2 at OSCA, Empangeni, July 2016.

The timelapse resistivity method which was used at Fountainhill was applied at OSCA did not produce meaningful results because there was rain in July prior to the survey meaning the contrast between wet and dry season readings was limited and thus the profiles obtained were very similar to those from the October survey.

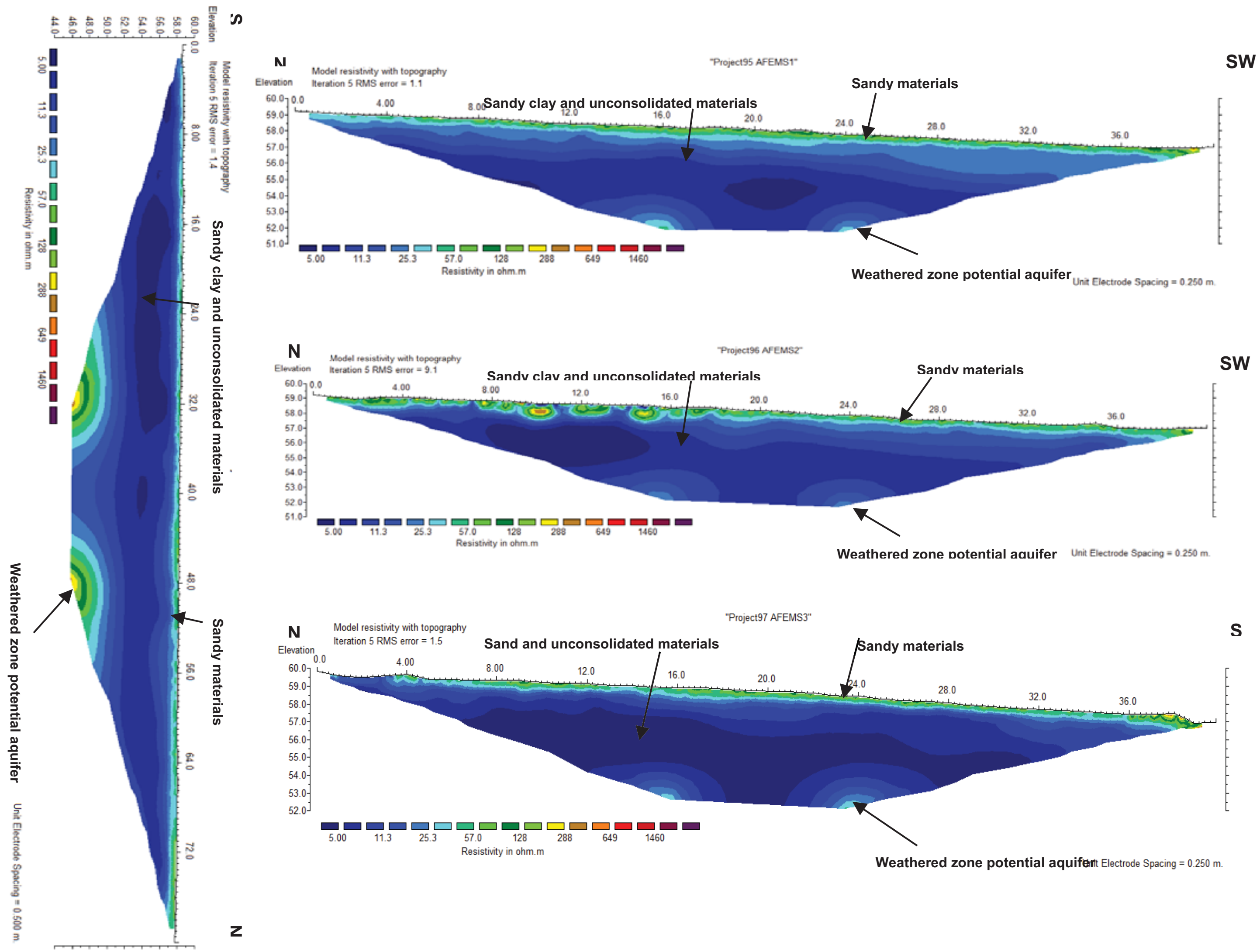


Figure 5.28 Composite of transects across the OSCA trial site in July 2016.

From the ERT survey undertaken during this assessment it can be concluded that the OSCA trial site is probably underlain by a confined aquifer associated with the weathered material overlying the bedrock. Within the vadose zone there is does not appear to be significant lateral variability of soil moisture distribution across the site, however there are vertical changes. Notably the resistivity is substantially higher compared to Fountainhill. This suggests that there is a higher water content in this vadose zone. This can be attributed to the high clay and silt contents of these soils. The clayey materials are also potentially be less permeable and thus retaining water within the crop root zone, which can enhance crop growth.

5.4.2 Soil characteristics

This site is located at mid to foot slope with deep soils as result of material deposition from the upper slope. The dominating soil form was found to be Sepane (Se1100). The depth for the Orthic A horizon was found to be 50 cm with effective rooting depth greater than 50 cm. The Pedocutanic B horizon was found to have the depth greater than 50 cm. The soil depth was limited to 100 cm and the parent material was an unconsolidated material with signs of wetness. No limiting horizons (e.g. E Horizon or stone lines) were observed. One of the pits displayed characteristics of Westleigh soil form which has horizon sequence of Orthic A horizon over soft plinthic B.

Further detail pertaining to the soil characteristics of the site will be included in the next deliverable that documents the research findings at OSCA from the 2016/17 season.

5.4.3 Investigation of effect on soil water status (with *S. bispinosa*)

<u>*Materials and methods*</u>

At OSCA the maize was unsuccessful over the years and for the 2018/19 growing season, all the treatments involving maize was discontinued and the plan for the last year of the trial was amended to allow for a focus on silvo-pastoral systems as shown in Table 5.5.

Table 5.5 Replacement of current cropping mixes at OSCA, Empangeni for 2018/19 season

Treatments	**Pigeon pea improved fallow**	***Sesbania sesban* Improved fallow**	**Continuous *P. maximum***	**Pigeon pea silvopostoral system**	***S. sesban* silvopastoral system**
2017/18	Pigeon pea	*S. sesban*	*P. maximum*	*Pigeon pea /P. maximum*	*S. sesban/P. maximum*
2018/19	*P. Maximum* (after 2-yr fallow)	*P Maximum* (after 2-yr fallow)	*P. maximum*	*Pruned pigeon pea/P. Maximum*	Pruned *S. sesban/P. maximum*

The initial plan for instrumentation for the trial (

Figure 5.29) was adapted to allow for measurement of soil water status of the trial as it was implemented over the 2017/18 and 2018/19 growing seasons.

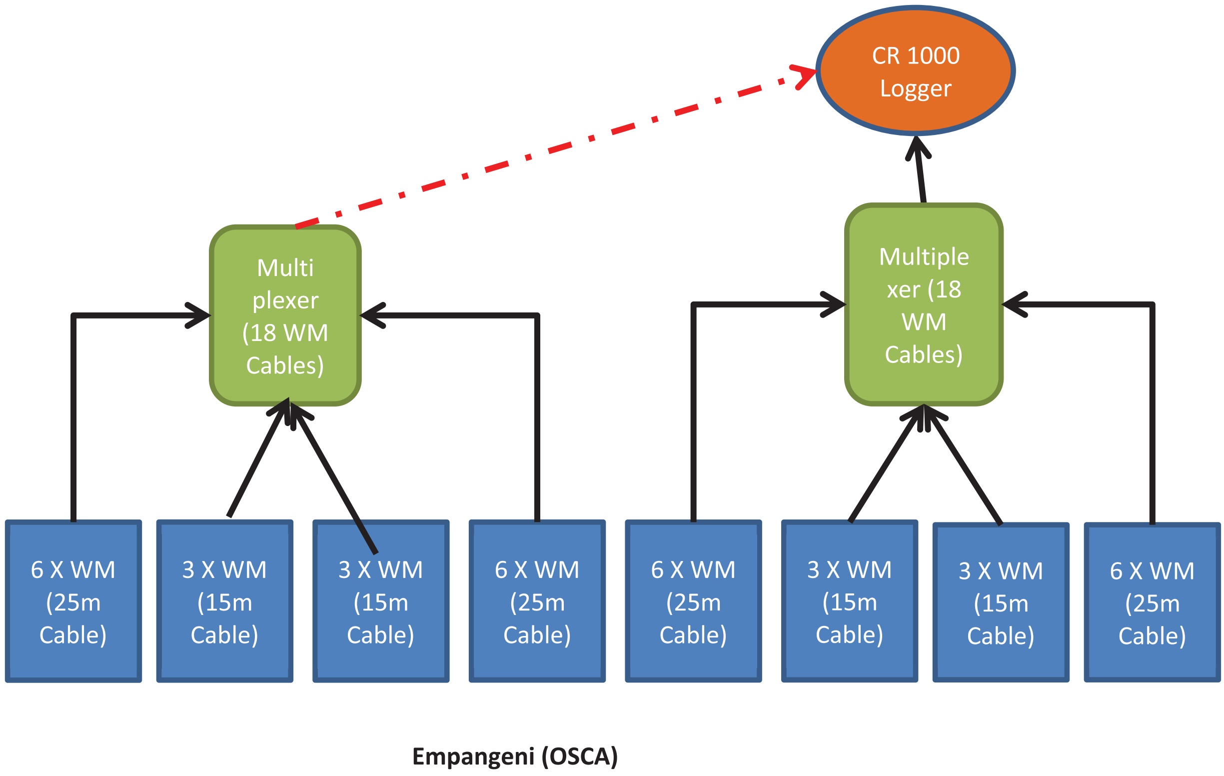


Figure 5.29 Instrumentation arrangement for OSCA, Empangeni, showing the positions of Watermark sensors (WM) and TDR probes in plots 9-16.

Results (2017/18 and 2018/19 growing seasons)

The figures below show soil water tension values from sensors placed at three depths (200, 500 and 1200 mm) across eight plots. The sensors are named according to the depth and the plot (for example the label 1200 PmPP_16 indicates that the sensor is placed in plot 16 at 1200 mm below *P.maximum* in a plot that also has pigeon peas).

Overall, the effects of rainfall events shown in Figure 5.30 were apparent across all treatments, but there were differences in the soil water tension values (reflecting soil moisture) at the three depths across the treatments.

For the sensors associated with *S. sesban* trees in the *S. sesban*/*P. maximum* plot (SSPm_9) as shown in Figure 5.36 the 1200 mm depth remained dry except when there were substantial rainfall events. There were clear fluctuations for 200 and 500 mm sensors. For the sensors associated with *P. maximum* trees in the *S. sesban*/*P. maximum* plot (PmSS_9) as shown in Figure 5.33, the 1200 mm sensor showed extreme dryness which could have be due to the roots from the Sesbania trees, but could also have been a problem with the functioning of the sensor.

For the sensors associated with *S. sesban* trees in the sole *S. sesban* plot (SS_10) shown in Figure 5.37, there *was an error with the 500 mm sensor so it is excluded from the graph.* Generally the 1200 mm sensor for the SS plot recorded lower values than for the sensor associated with the *S. sesban* in the *S. Sesban*/*P. maximum* intercrop, indicating that the water use was higher for the intercropped Sesbania trees. It is unclear why the presence of grass appears to have increased water use at the 1200 mm depth. This might be because when the trees encountered competition in the surface layers they responded by drawing more on water in the deeper layers. For the sensors associated with the pigeon pea trees in the pigeon pea/*P. maximum* plot (PPPm_16) as shown in Figure 5.35, there were clear fluctuations associated with rainfall events for the 200 and 500 mm sensors. The 500 mm sensor showed that soils remained generally wetter than under the Sesbania tree in Plot 9 – indicating the pigeon pea trees used less water than Sesbania.

For the sensors associated with the *P. maximum* in the pigeon pea/*P. maximum* plot (PmPP_16) shown in Figure 5.31 there were also clear fluctuations similar to PmSS for 200 and 500 mm, though the soils at 500 mm depth appeared slightly wetter than for the *P. maximum* intercropped with Sesbania, and the soils at 1200 mm were much wetter. The 200 and 500 mm sensors showed that surface layers were drier under the *P. maximum* between the trees than under the pigeon pea trees (PPPm – Figure 5.35). The values for the 1200 mm sensors were similar between and under the pigeon pea trees.

For the sensors under the pigeon pea trees in the sole pigeon pea treatment (PP_15) as shown in Figure 5.34, there was very little difference for 1200 mm when comparing the sole pigeon pea with the pigeon pea intercropped with *P. maximum* (PPPm_16 – shown in Figure 5.35) but the 500 mm sensor recorded slightly higher tensions (i.e. soils were slightly drier). For the sensors under the *P. maximum* in the sole *P. maximum* treatment there was a fault with the 200 mm sensor so it is not included in Figure 5.32. Comparing with the sensors under the P. maximum in plot 16 (Figure 5.31) that is intercropped with pigeon pea, both the 500 mm and 1200 mm sensors gave lower water tension readings, indicating that the soils were wetter. This demonstrates that the trees were pulling out water at 1200 mm and 500 mm depths. In summary, the soil water tension values obtained from this study indicate that trees increase soil water tension compared with a sole pasture treatment and furthermore Sesbania sesban had a greater effect on soil water tension values than did pigeon pea. This has implications for the understorey crop, which must compete with the trees' water needs.

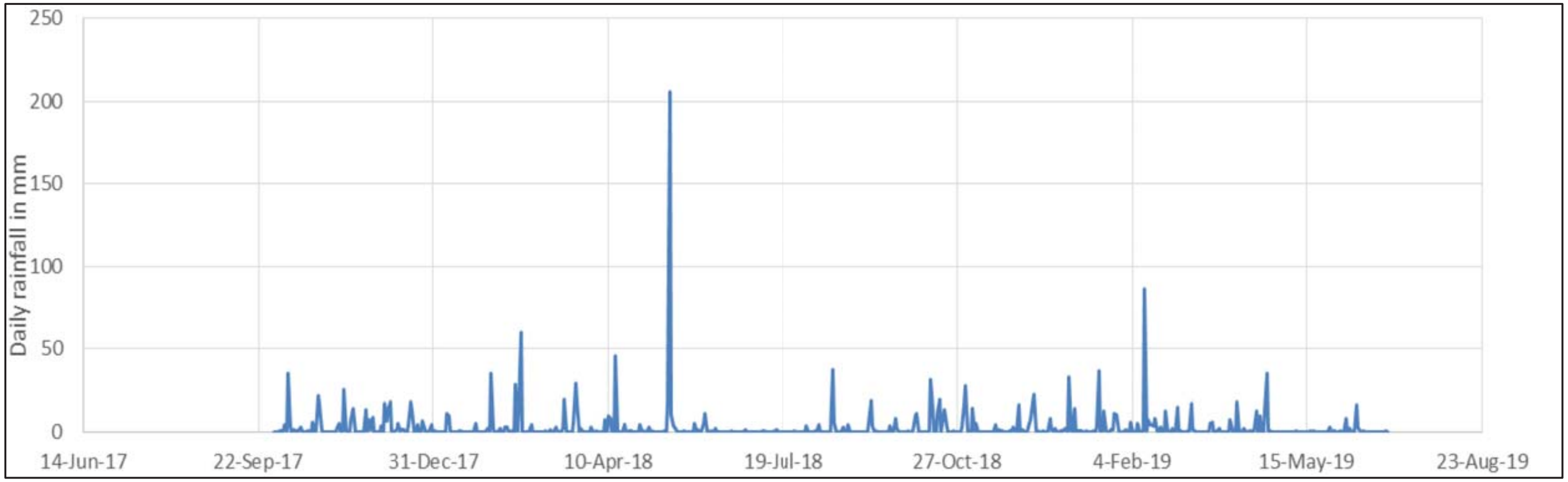


Figure 5.30 Rainfall occurring between September 2017 and August 2019 at OSCA

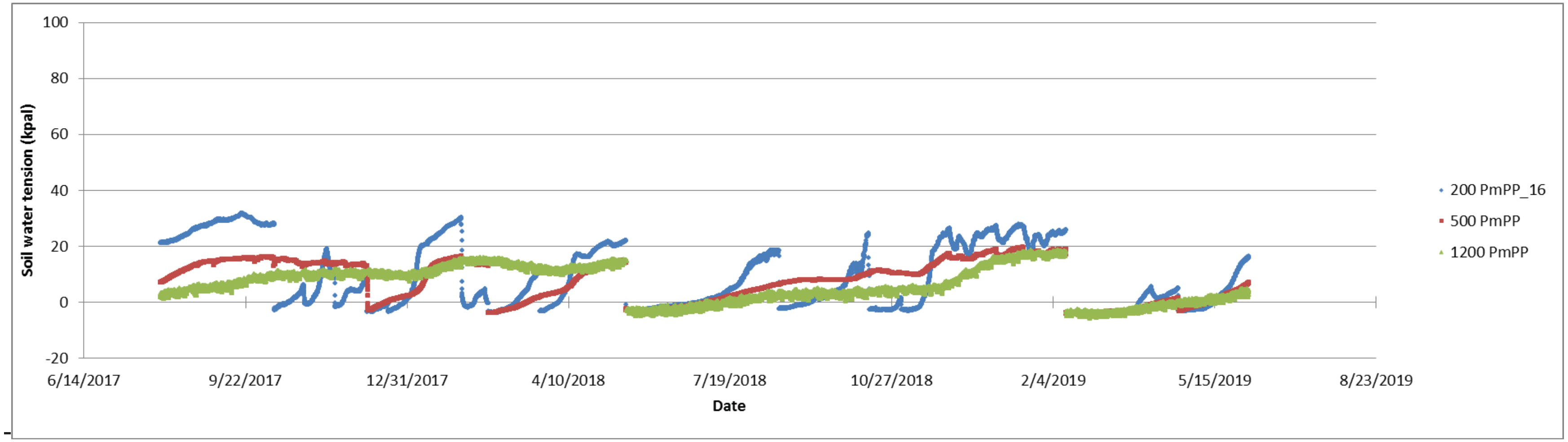


Figure 5.31 Soil water tension values for the sensors placed under *P. maximum* in the plot with *Panicum maximum*/pigeon pea intercrop (Note the legend indicates the plot number, sensor depth and intercrop. PmPP is the sensor under the *P. maximum* intercropped with pigeon pea)

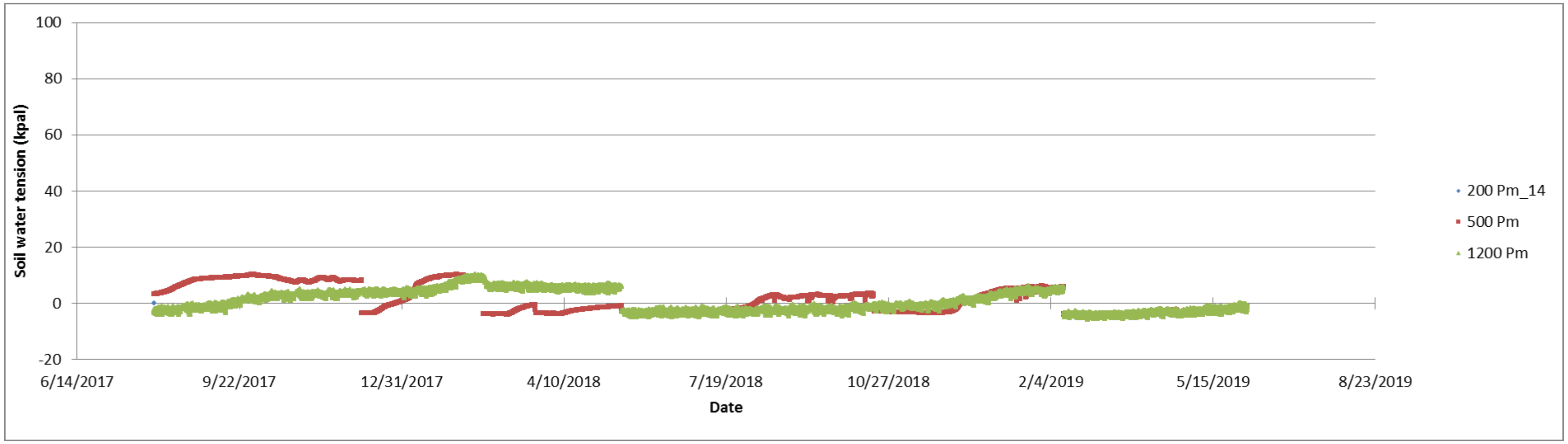


Figure 5.32 Soil water tension values for the sensors placed under *P. maximum* in a sole *P. maximum* plot, (Note the legend indicates the plot number, sensor depth and crop. Pm is the sensor under sole *P. maximum*)

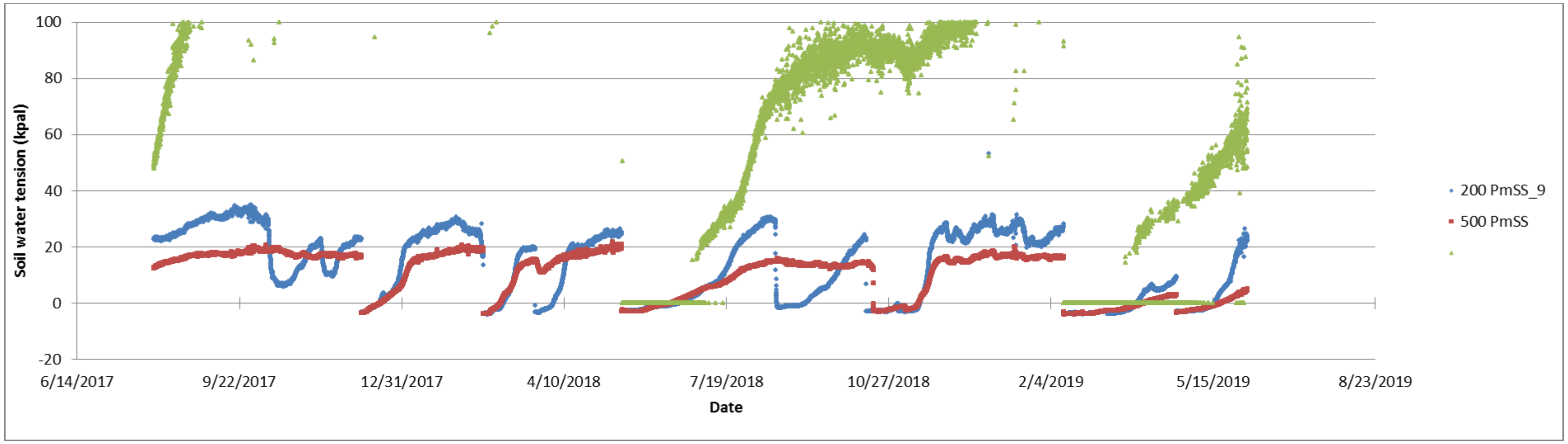


Figure 5.33 Soil water tension values for the sensors placed under *P. maximum* in the plot with *Panicum maximum/Sesbania sesban* intercrop. (Note the legend indicates the plot number, sensor depth and intercrop. PmSS is the sensor under the *P. maximum* intercropped with *S. sesban*)

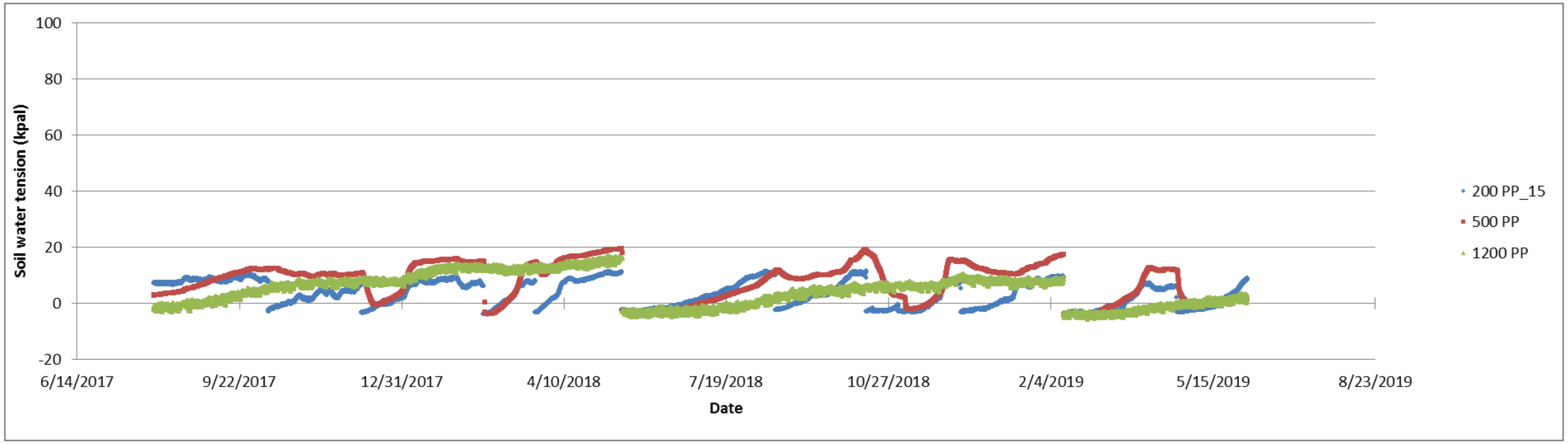


Figure 5.34 Soil water tension values for the sensors placed under pigeon pea in a sole pigeon pea plot (Note the legend indicates the plot number, sensor depth and crop. PP is the sensor under the pigeon pea)

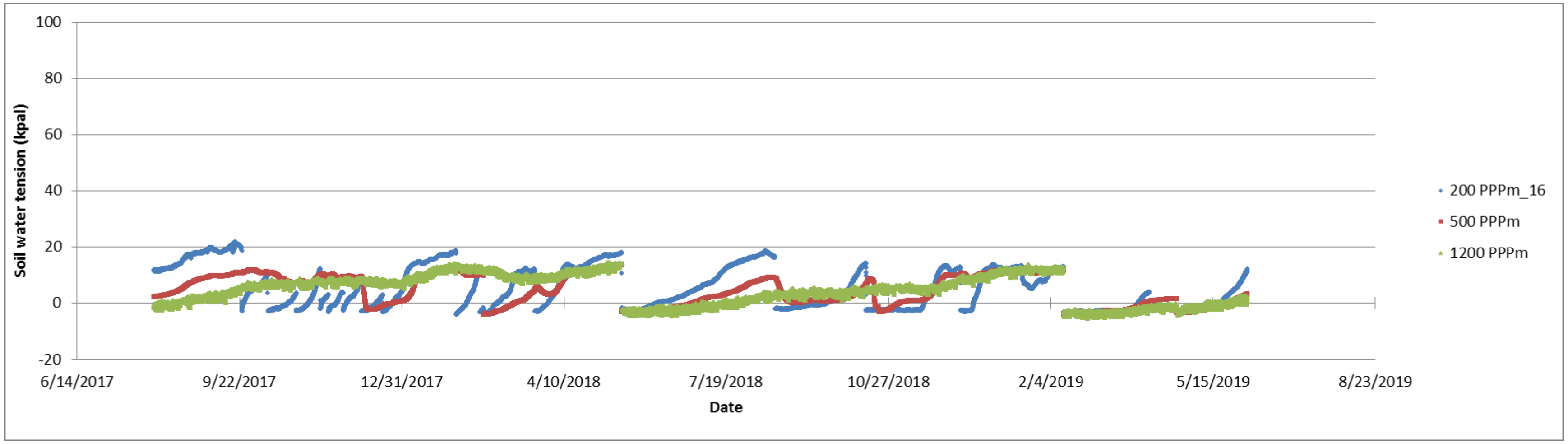


Figure 5.35 Soil water tension values for the sensors placed under pigeon pea in the plot with *Panicum maximum*/pigeon pea intercrop. (Note the legend indicates the plot number, sensor depth and crop. PP is the sensor under the pigeon pea)

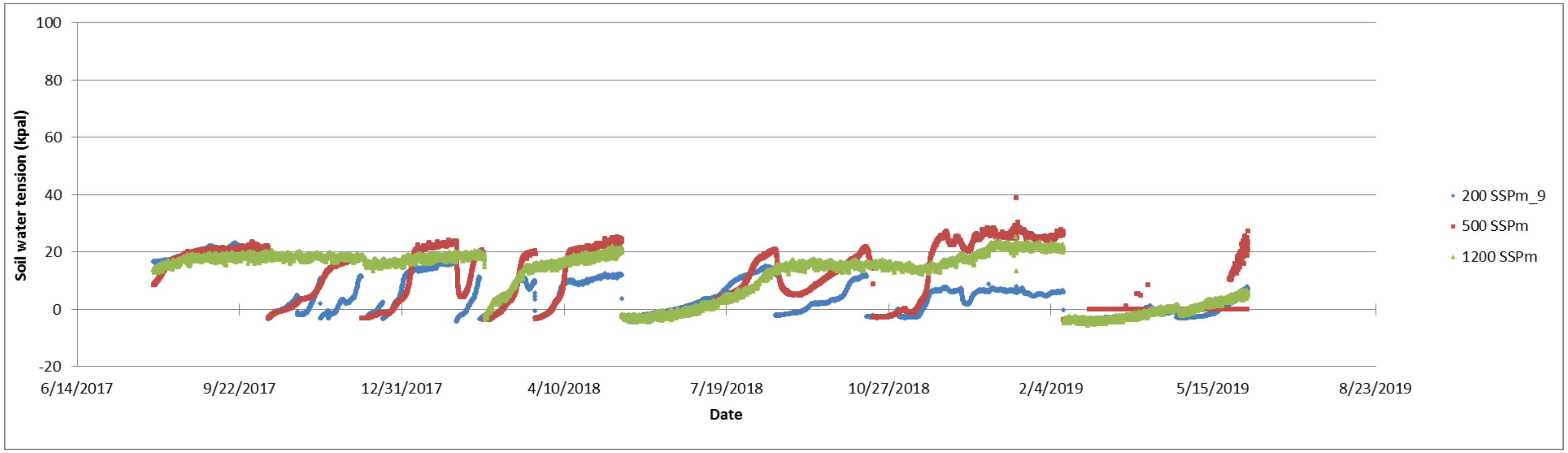


Figure 5.36 Soil water tension values for the sensors placed under *Sesbania sesban* in the plot with *Panicum maximum*/*Sesbania sesban* intercrop

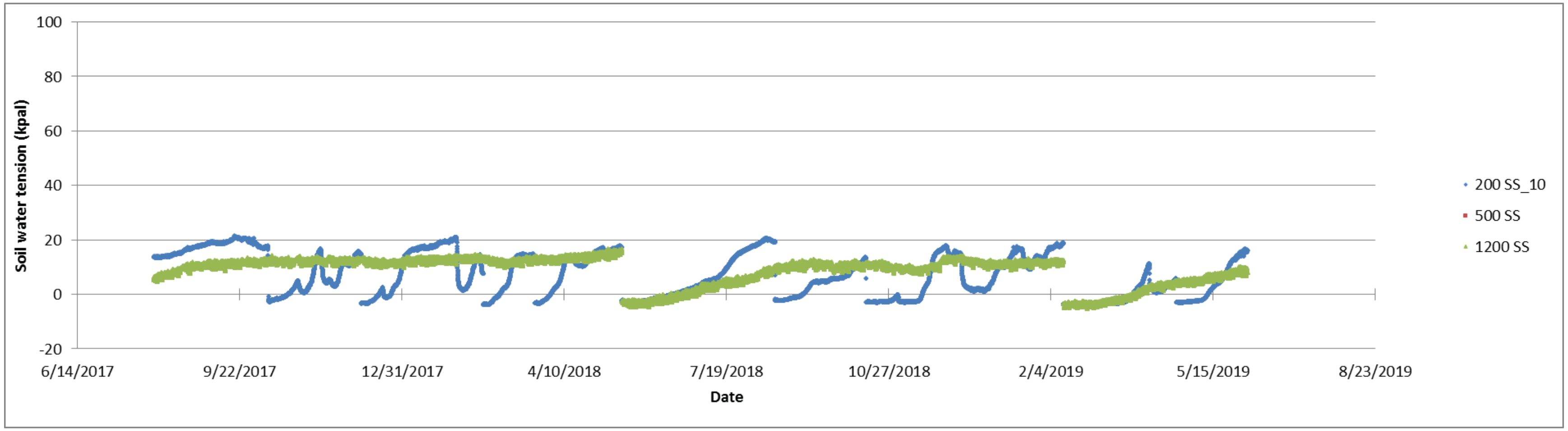


Figure 5.37 Soil water tension values for the sensors placed under *Sesbania sesban* in a sole *Sesbania sesban* plot

5.5 Intrinsic water use efficiency of legume species

5.5.1 Introduction

Within the alley cropping system, tree pruning is a compulsory management practice to avoid shading of associate crops and enhancing nutrient cycling. This practice appears to increase water use of trees by reducing leaf area and therefore transpiration. Also, there are different options for managing the prunings that are removed – they can either be retained as mulch or removed to use as livestock feed. In addition to improved soil N fertility, retaining pruning residues promotes microbial activity and also reduces water loss by transpiration and evaporation, ameliorates soil temperature, improves soil water infiltration and retention, thus resulting in improved water use efficiency (WUE) (Kang, 1997; Singh et al., 2007; Peng et al., 2015).

Moreover, it has been shown that leaf carbon isotopic ratios ($\delta^{13}C$) of pruned trees are low as compared to unpruned trees, reflecting their greater stomatal conductance and suggesting that pruned trees could have greater drought stress resistance. Detailed information on gas exchange and $\delta^{13}C$ of agroforestry tree components is essential to improve our understanding of their photosynthetic activity and productivity, particularly the impact of water stress on carbon assimilation and water use efficiency (WUE). Although retention of prunings as mulch is a common practice in alley cropping, the effects of pruning residue retention on WUE by hedgerows are poorly understood. Accordingly, such information will be of great importance, particularly in arid areas such as parts of South Africa where water is one of the main limiting resources for plant growth and productivity.

Hence, the objective of this study was to assess the influence of pruning residue management on carbon (C) accumulation and WUE in *S. sesban* and pigeon pea (*Cajanus cajan*). It was hypothesised that retention of prunings would decrease foliar $\delta^{13}C$ isotopic composition (i.e. which is related to low water use efficiency).

5.5.2 Methodology

The study was conducted between November 2016 and February 2018 at Fountainhill Estate. The alley cropping experiment commenced in November 2016. The alley width was 3 m and the legume plants were spaced at 0.75 m within rows, giving a density of 3 900 trees ha^{-1}. Four maize (OPV Border king) rows were planted between the alleys, at 0.3 m within and 0.5 m between rows giving a population of 38, 095 plants ha^{-1}. The study was set up in a 2 x 2 x 2 factorial experiment and the treatments were arranged in a randomised complete block design (RCBD) with 3 replicates. The combination of treatment factors were:

- Factor A: Two woody legume species: *S. sesban* and pigeon pea.
- Factor B: Two methods of residue management: surface retention (retain) vs. complete removal from plots (remove).
- Factor C: Two dates of sampling, i.e. November 2017 and February 2018.

The first pruning was conducted in April 2017; subsequent prunings were conducted in November 2017 and February 2018. At pruning, trees were cut back to 75 cm height using secateurs. For the purpose of comparing the effects of retaining (for soil fertility improvement) versus removing (for livestock fodder), prunings (twigs and leaves) were evenly spread in the 'retain' plots as mulch whereas in the 'remove' plots these biomass components were completely removed.

Shoots of non-fixing reference plants, but only leaves of legume trees were finely ground (0.45 mm) into powder for the determination of $\delta^{13}C$.

$^{13}C/^{12}C$ isotopic analysis

To analyse for $^{13}C/^{12}C$ ratios, aliquots of 1.1 to 1.2 mg subsamples of finely ground plant samples were weighed into Al tin capsules and run on the mass spectrometer as described for $^{15}N/^{14}N$ ratio. The ratio of $^{13}C/^{12}C$ in each sample was used to calculate the ^{13}C natural abundance, or $\delta^{13}C$ (‰):

$$\delta^{13}\mathrm{C} = \frac{(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{sample}} - (^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{standard}}}{(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{standard}}} \mathrm{x}\ 1000$$

where $^{13}C/^{12}C$ sample is the isotopic ratio of the sample, and $^{13}C/^{12}C$ is the isotopic ratio of PDB, a universally accepted standard from belemnite Pee Dee limestone formation (Craig, 1957).

5.5.3 Results

The soil properties are presented in Table 5.6. Additional results are provided below.

Table 5.6 Properties of soil along the profile wall before the initiation of the alley cropping experiment at Fountainhill Estate, Wartburg.

Soil properties	Unit	Depth (cm)			
		0-20	20-40	40-60	60-80
Clay	%	21.75	21.75	27.25	30.5
pH (KCl)	KCl	4.24	4.31	4.4825	4.49
Organic Carbon	%	0.80	0.50	0.5	0.5
N	%	0.07	<0.05	<0.05	<0.05
P	mg/L	15.75	9.50	4	4
K	mg/L	82.75	44.75	43.5	42.75
Ca	mg/L	419.25	371.5	495.25	498
Mg	mg/L	101.5	106.5	150.5	185.75
Total cations	cmol/L	3.51	3.29	3.965	4.27
Exch. Acidity	cmol/L	0.37	0.45	0.155	0.15
Zn	mg/L	3.85	2.625	0.825	0.625
Mn	mg/L	46.75	50.00	26.75	21.25
Cu	mg/L	2.95	3.00	2.53	2.36

Pre-treatment symbiotic performance, C accumulation and $\delta^{13}C$

A 2-Way ANOVA revealed no significant interaction between species and residue management plots for %C and $\delta^{13}C$ of test legume species (Table 5.7). Similarly, the main effect of residue management plots on measured variables was not significant indicating that soil conditions of the study site were uniform prior to assessing the effects of residue management. However, the main effect of species was significant for all measured variables. Pigeon pea exhibited significantly higher foliar C concentration and $\delta^{13}C$ as compared with *S. sesban* (Table 5.7).

Effects of residue retention on symbiotic performance, C accumulation and $\delta^{13}C$

A 3-Way ANOVA revealed no significant interactions between species, residue management and pruning date for %C and $\delta^{13}C$. However, there was a significant interaction between species and pruning date as well as residue management and pruning date for $\delta^{13}C$. (Table 5.8).

Table 5.7 A 2-Way ANOVA for δ^{13}C of pigeon pea and *S. sesban* trees prior to mulching with their respective tree prunings

Treatment	δ^{13}C (‰)
Tree species	
Pigeon pea	-28.4±0.1^{b}
S. sesban	-28.8±0.2^{a}
Residue management	
Mulch	-28.6±0.3^{a}
Control	-28.6±0.3^{a}
F-statistics	
Species	4.6*
Residue management	0.1NS
Species*Residue management	0.1NS

Table 5.8 Summary of a 3-Way ANOVA F-statistics on δ^{13}C of pigeon pea and *S. sesban* plants as affected by mulching with their respective prunings in an alley cropping system

Source of variation	df	*δ*^{13}C (‰)
Main effects		
Species	1	29.70***
RM	1	0.20NS
Pruning date	1	14.60***
2-Way interactions		
Species*RM	1	0.00NS
Species*Pruning date	1	9.70**
RM*Pruning date	1	5.50*
3-Way interactions		
Species*RM*Pruning date	1	3.10NS

RM, residue management (mulch/no mulch)

Effects of mulching on C concentration and δ^{13}C

The main effects of species and time for foliar C concentrations of pigeon pea and *S. sesban* are shown in Figure 7A and B. Averaged across the two species, C concentration of plants was greatest (46.2%) in February and lowest (44.2%) in November (Figure 5.38 A). Pigeon pea accumulated about 4% higher C concentration as compared with *S. sesban* (Figure 5.38 B). Analysis of ^{13}C/^{12}C showed that pigeon pea exhibited similar foliar δ^{13}C isotope signals across the pruning dates (Figure 5.39). The δ^{13}C of *S. sesban* varied between the pruning dates, and was greatest (-27.5‰) in November and lowest (-28.1‰) in February pruning. *S. sesban* consistently had higher δ^{13}C values as compared with pigeon pea across the pruning dates. Retention of tree prunings affected δ^{13}C values in two contrasting patterns between the pruning dates (Figure 5.40). For instance, retaining prunings increased δ^{13}C of plants in November. However, in February the foliar δ^{13}C composition was increased by removal of prunings.

Generally, C3 plants comprise a wide range of C isotope compositions ranging from -20 to -37‰ (Farquhar et al., 1989). Foliar δ^{13}C values of pigeon pea (-27 to -29‰) and *S. sesban* (-27 to -30‰) obtained in this study were within this range thus indicating that the δ^{13}C values can be used as reliable indices for comparisons of long-term WUE of test legume trees as influenced by pruning residue management and pruning date (Table 5.7).

The results showed that leaf C concentration varied remarkably between the species with mean values of 46 and 44% for pigeon pea and *S. sesban*, respectively (Figure 5.38 A). The values were slightly lower as compared with 47-52% reported for *Cyclopia* and *Aspalathus* species (Maseko and Dakora, 2015) and 50-55% for *Chamaecrista* and *Stryphnodendron* species (Sprent et al., 1996). The variation in foliar C concentration among the species could be associated with differences in composition of organic compounds that have different C concentrations (Niinemets et al., 2002), particularly lipid content (Yoneyama et al., 1993). Generally, higher %C of plants has been associated with lipid content in leaves as lipids are usually depleted in $\delta^{13}C$ as compared to other plant tissues (Farquhar et al., 1989; Yoneyama et al., 1993; Sprent et al., 1996). The finding that pigeon pea exhibited greater %C and more negative $\delta^{13}C$ is consistent with previous findings that plants with higher %C tend to have more negative $\delta^{13}C$ values (Yoneyama et al., 1993; Sprent et al., 1996). While C concentration in plants indicates photosynthetic transfers of C from CO_2, environmental factors such as temperature and rainfall can have significant influences on plant metabolism and functioning (Kaiser et al., 2014). This might in part explain the lower C concentration of plants in the dry season as compared with the rainy season pruning (Figure 5.38 B).

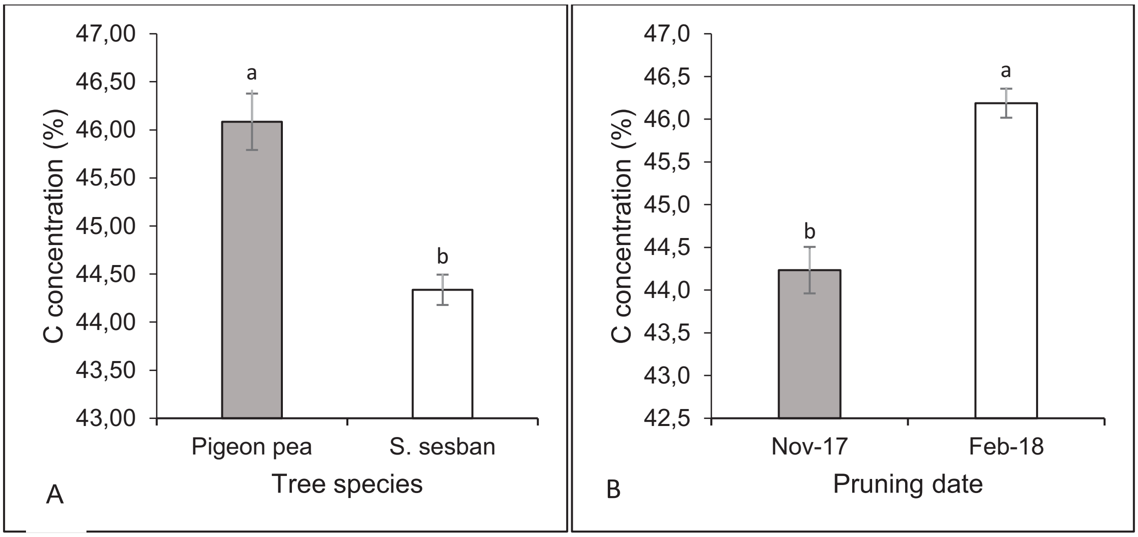


Figure 5.38 Foliar C concentration (%C) of (A) pigeon pea and *S. sesban* and of (B) both species assessed in November and February

The natural abundance of foliar $\delta^{13}C$ is a primary means for assessing the impact of environmental variability on metabolism and long-term WUE of higher plants (Farquhar et al., 1989; Dawson et al., 2002) and has been used widely in agroecosystems (Condon et al., 2004; Maseko and Dakora, 2015). In C3 plants, the reduction in diffusive rates of CO_2 into the leaf subsequent to partial stomatal closure during drier seasons results in lower discrimination against ^{13}C (Wu et al., 2015). Consequently, the lower $\delta^{13}C$ discrimination (high A/T or increased $\delta^{13}C$) in plants indicates a conservative trait in relation to their water use (Condon et al., 2004). In this study, across both pruning dates, the mean $\delta^{13}C$ of S. sesban was consistently higher compared to that of pigeon pea which suggests that the former species was more water use efficient during photosynthesis as compared with the latter.

Pigeon pea discriminated highly against the heavier ^{13}C isotope (i.e. low WUE) during photosynthesis and exhibited a strong $\delta^{13}C$ stability despite the fact that seasonal variability in temperature and soil moisture affects $\delta^{13}C$ (Farquhar et al., 1989). Less negative foliar $\delta^{13}C$ of S. sesban during the dry season as compared with the rainy season is an indication of higher stomatal conductance and hence high WUE (Farquhar et al., 1989; Dawson et al., 2002). As compared with removal of prunings, retention of prunings increased WUE ($\delta^{13}C$) of species during the dry season (November). However, during the rainy season (February) retention of prunings decreased WUE of plants as compared with removal of prunings. Regardless of the residue management, higher WUE or higher foliar $\delta^{13}C$ in November as compared to February could be explained by stomatal closure at low soil moisture levels. For instance, it was shown that the $\delta^{13}C$ value of three dominant C3 species correlated negatively with the amount of precipitation (Ma et al., 2012).

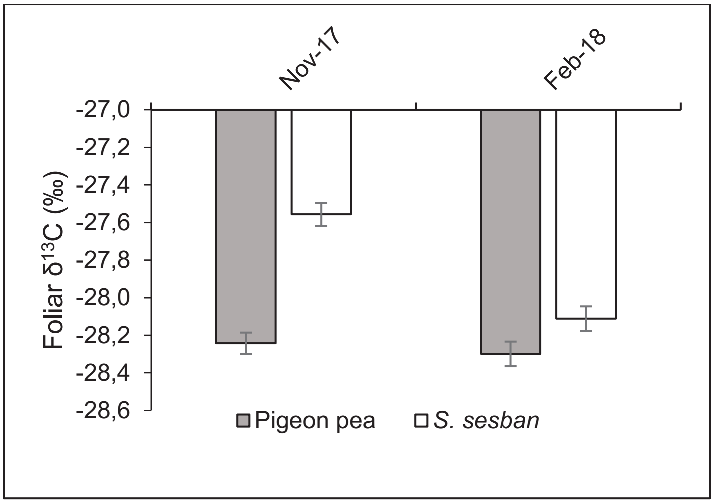


Figure 5.39 The interaction between tree species and pruning date on foliar $\delta^{13}C$ isotopic composition

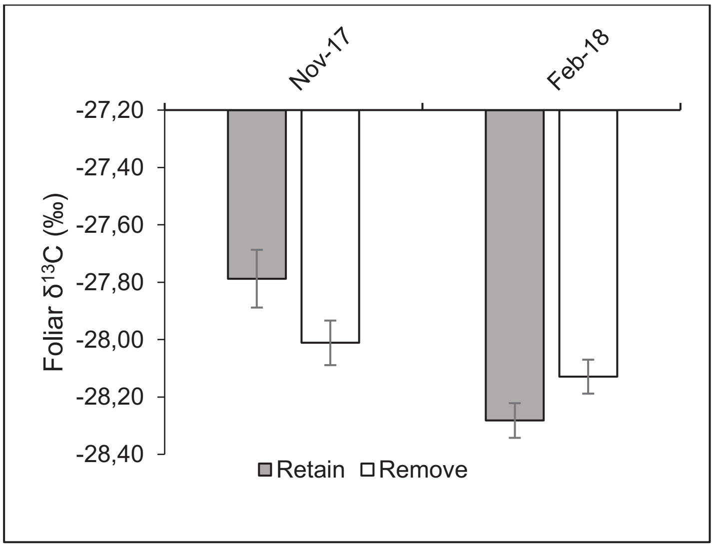


Figure 5.40 The interaction between residue management and pruning date on foliar $\delta^{13}C$ isotopic composition

It was concluded that retaining tree prunings enhances symbiotic performance and WUE of pigeon pea and *S. sesban* through the improvement of soil physical, chemical and biological properties associated with soil fertility.

5.6 Effect of mulching on soil water dynamics

Two alley cropping systems were investigated, namely maize/*Sesbania sesban* and maize/pigeon pea. The trees were pruned to reduce competition with the understorey crop. Prunings can either be removed to feed livestock, or can be retained to improve soil fertility. The hypothesis was that the retention of prunings would not only improve soil fertility, but would also increase the water holding capacity of the surface layer of the soil.

5.6.1 Methodology

The pruning treatments were as follows:

(i) Pruning with prunings removed (P)

(ii) Pruning with prunings applied as green manure.

For manuring purposes, the leafy biomass (leaves and twigs) will be slightly chopped and spread evenly onto plots. These treatments will be laid out in a randomised complete block design (RCBD) with three replicates.

Table 5.9: Species, management and treatments

Cropping system	Management	Treatments	Replicates	Trial design
Alley cropping	Pruning at 75 cm height at 3 month intervals	SS+Mz Remove	3	Randomized complete block design
		SS+Mz Retain	3	
		Pp+Mz Remove	3	
		Pp+Mz Retain	3	

Note that SS: Sesbania sesban, PP: Pigeon pea, Mz: Maize

To determine the effect of tree prunings removal and pruning application on soil moisture content, the volumetric water content of soil will be measured in the 20 cm profile using a portable Hydrosense devise (Photograph 5.6).

Photograph 5.6 Hydrosense device used for measuring volumetric water content in the upper soil layer.

5.6.2 Results

Effect of treatment and species on VWC

The VWC figures were not normal so were log transformed before an ANOVA was applied. The ANOVA showed no significant effect of species, residue management or the species x residue management interaction on the VWC of the plots (Table 5.10). It is likely that this is because the conditions of the plots prior to the experiment were already highly variable.

Table 5.10 Analysis of variance output for the effect of species and treatment on $\log_{10}$ mean VWC

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Species ignoring Residue	1	0.000015	0.000015	0.00	0.966
Species eliminating Residue	1	0.000498	0.000498	0.06	0.805
Residue ignoring Species	1	0.023307	0.023307	2.89	0.094
Residue eliminating Species	1	0.023790	0.023790	2.95	0.091
Species. Residue	1	0.013106	0.013106	1.62	0.207
Residual	68	0.548909	0.008072		
Total	71	0.585819	0.008251		

Effect of VWC on status of the trees

When VWC of the top 20 cm of the plots was investigated, it was noted that the Sesbania plots with consistently low VWC showed high tree mortality levels and this was investigated further.

From the statistical analysis, it was clear that soil VWC was positively correlated with the health status of the Sesbania trees (i.e. % healthy trees in the plot), but this was not the case for the pigeon pea plots. Sesbania plots with low VWC generally had lower percentages of healthy trees as shown in Figure 5.41.

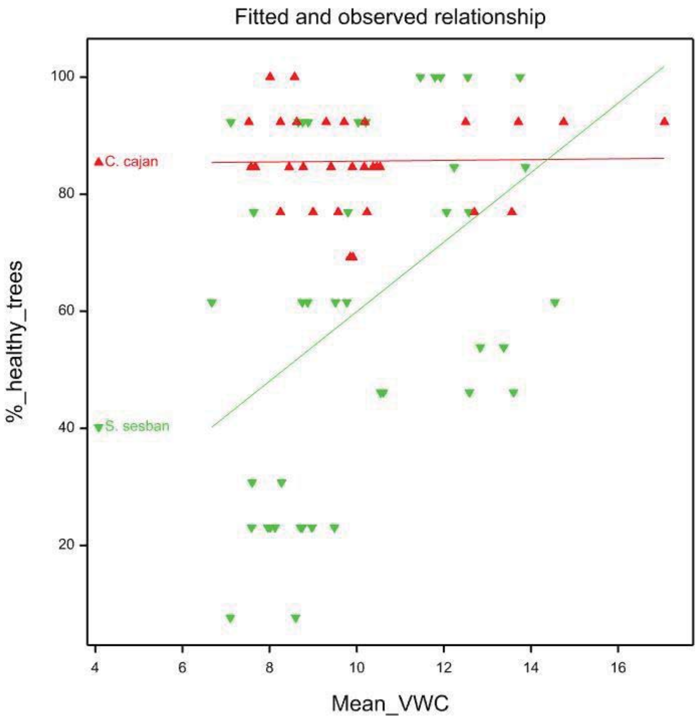


Figure 5.41 Correlation between VWC of top 20 cm of plots on the survival of the pigeon pea (*C. cajan*) and Sesbania (*S. sesban*) trees (Genstat output).

The variable ‘percentage healthy trees’ was not normally distributed and transforming the data did not improve normality. A Kruskal-Wallis one way ANOVA that was conducted indicated that there was a significant difference between species for the % healthy trees, with pigeon pea having higher percentage healthy trees than did Sesbania.

Table 5.11 Kruskal-Wallis one-way analysis of variance

Variate: %_healthy_trees
Group factor: Species
Value of H = 9.652
Adjusted for ties = 9.866

Sample	Size	Mean rank
Group C. cajan	30	45.57
Group S. sesban	42	30.02

Degrees of freedom = 1
Chi-square probability = 0.002

Table 5.12 Regression analysis for % healthy trees against mean VWC, with species as a grouping factor

Response variate: %_healthy_trees
Fitted terms: Constant + Mean_VWC + Species + Mean_VWC.Species

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	3	17753.	5917.8	12.56	<.001
Residual	68	32039.	471.2		
Total	71	49793.	701.3		
Change	-1	-2933.	2933.4	6.23	0.015

Percentage variance accounted for 32.8
Standard error of observations is estimated to be 21.7.

When regression analyses were carried out between & healthy trees and mean VWC for pigeon pea plots and Sesbania plots separately, it was clear that there was a relationship for Sesbania but not for pigeon pea as shown below in Table 5.13 and Table 5.14.

Table 5.13 Regression analysis for % healthy trees against mean VWC (*Sesbania sesban*)

Response variate: %_healthy_trees
Fitted terms: Constant, Mean_VWC

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	6959.	6959.0	9.22	0.004
Residual	40	30178.	754.5		
Total	41	37137.	905.8		

Percentage variance accounted for 16.7
Standard error of observations is estimated to be 27.5.

Table 5.14 Regression analysis for % healthy trees against mean VWC (for pigeon pea)

Response variate: %_healthy_trees
Fitted terms: Constant, Mean_VWC

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	1.	0.70	0.01	0.919
Residual	28	1861.	66.47		
Total	29	1862.	64.20		

Residual variance exceeds variance of response variate.
Standard error of observations is estimated to be 8.15.

5.7 Relationship between soil texture and volumetric water content for Trial 1

Soil texture analysis was conducted by Soil Science Laboratory at Cedara and showed the variation between sandy loam and sandy clay loam soils (Table 5.15). This was undertaken for the first and third blocks of the trial as samples from the second block were used for additional analyses.

Table 5.15 Results of particle size analysis for top 40 cm (according to: Soil Classification, A Taxonomic System for South Africa 1991), April 2019

Laboratory Number	**Sample ID**	**Clay % (<0.002 mm)**	**Fine Silt % (0.02-0.002 mm)**	**Coarse Silt & Sand % (0.02-2 mm)**	**Texture Class**
FS55	T1 – P1	15	4	81	Sandy Loam
FS56	T1 – P2	25	4	71	Sandy Clay Loam
FS57	T1 – P3	27	6	67	Sandy Clay Loam
FS58	T1 – P4	13	4	83	Sandy Loam
FS59	T1 – P9	13	4	83	Sandy Loam
FS60	T1 – P10	15	5	80	Sandy Loam
FS61	T1 – P11	14	5	81	Sandy Loam
FS62	T1 – P12	22	5	73	Sandy Clay Loam

The soil texture analysis showed that the sandy loam plots had relatively lower volumetric water content (Table 5.16). Further to this, there seemed to be a relationship between mortality rates of *S. sesban* and soil texture, with 100% mortality on two plots classified as sandy loam, and slightly lower mortality rates on the plots classified as sandy clay loam. The same relationship was less clear for the pigeon peas, which suggests that they were less sensitive to soil moisture conditions.

Table 5.16 Relationship between soil texture, mean volumetric water content and mortality rates of *Sesbania sesban* (SS) and pigeon pea (PP) in Trial 1

Plot	Soil text	VWC	Species	% Mort	Plot	Soil text	VWC	Species	% Mort
1	Sandy loam	9.85	PP	79	9	Sandy loam	8.81	PP	61
2	Sandy clay loam	14.05	PP	66	10	Sandy loam	11.98	SS	100
3	Sandy clay loam	13	SS	89	11	Sandy loam	9.94	PP	92
4	Sandy loam	7.93	SS	100	12	Sandy clay loam	11.98	SS	84

There was no significant relationship between VWC and soil bulk density readings as shown in Figure 5.42.

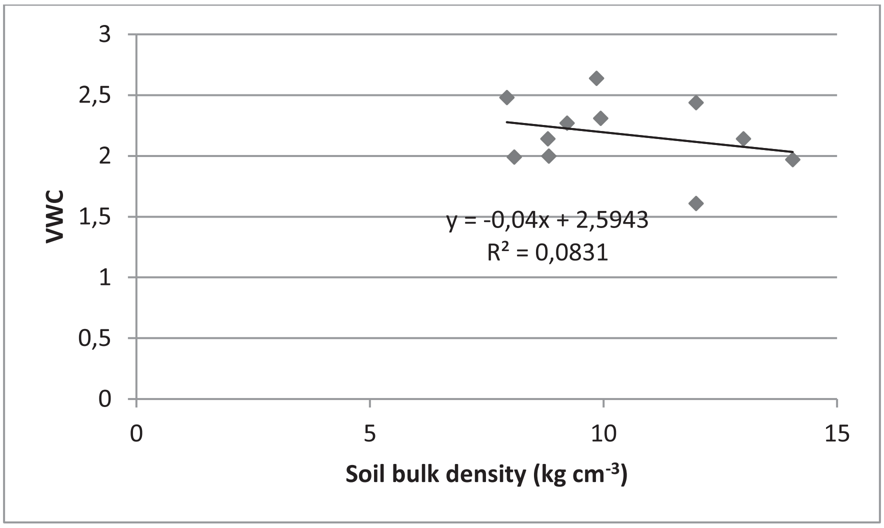


Figure 5.42 Graphical representation of VWC against soil bulk density of plots in Trial 1

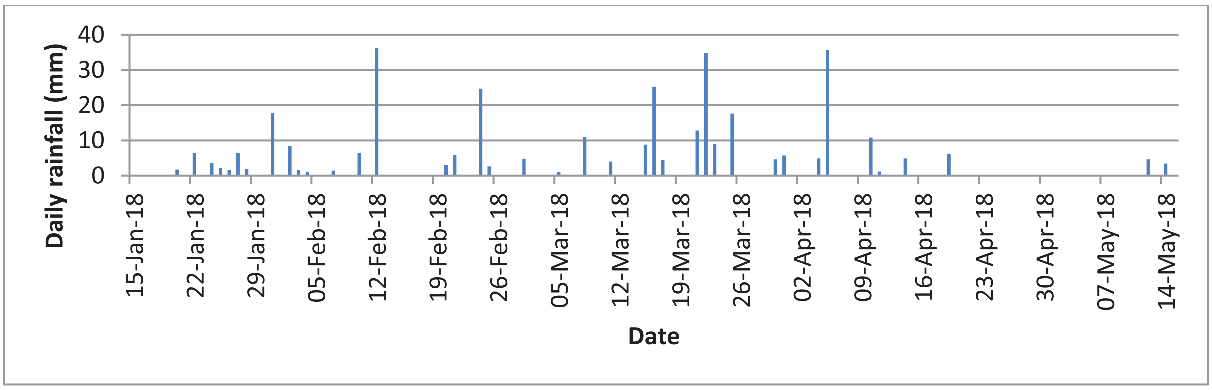


Figure 5.43 Daily rainfall events (≥ 1 mm day-1) for the period 15 January 2018 to 15 May 2018 at Fountainhill Estate, Wartburg (Source: SASRI Weatherweb)

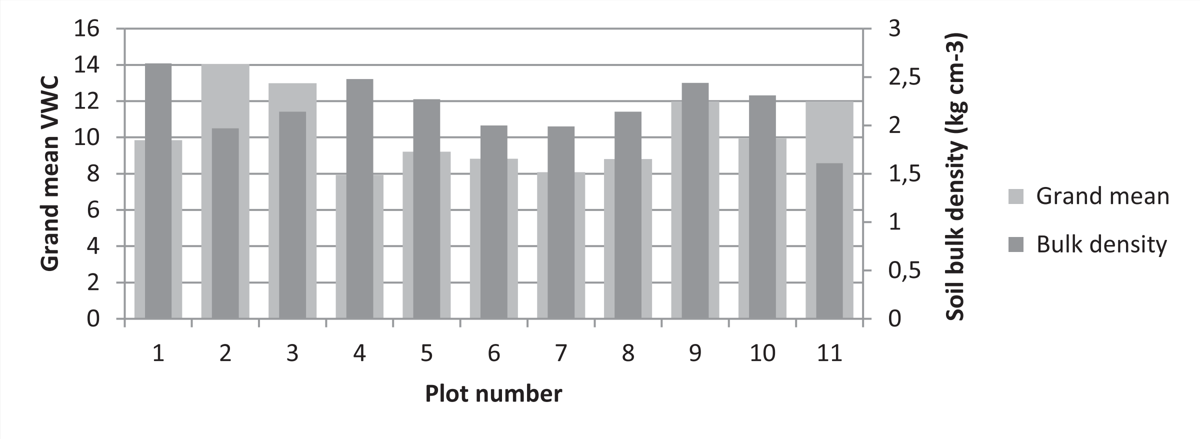


Figure 5.44 Relationship between grand mean VWC and soil bulk density of plots in Trial 1, Fountainhill Estate, Wartburg.

Table 5.17 Summary of mean volumetric water contents at two weekly intervals from January 2018 to May 2018 and the soil bulk density values (kg cm^{-3}) as of April 2019

Plot	mean vwc1	mean vwc2	mean vwc3	mean vwc4	mean vwc5	mean vwc6	mean vwc7	mean vwc8	Grand mean	Bulk density
Date	220118	070218	210218	070302	260318	040418	180418	040518		
1	2.58	7.72	5.90	6.48	18.65	13.72	14.98	8.73	9.85	2.64
2	4.75	12.35	8.23	8.58	25.87	21.28	21.93	9.38	14.05	1.97
3	3.85	8.55	7.02	8.38	26.73	21.42	18.13	9.92	13.00	2.14
4	2.08	6.92	3.42	4.53	16.38	12.13	12.12	5.82	7.93	2.48
5	3.72	6.65	5.02	6.32	17.03	14.52	12.58	7.95	9.22	2.27
6	3.43	5.85	4.48	4.62	17.47	12.85	13.55	8.37	8.83	2.00
8	2.65	5.75	3.52	4.53	15.85	13.08	12.63	6.68	8.09	1.99
9	3.12	7.32	4.77	2.85	17.90	12.95	12.22	9.35	8.81	2.14
10	4.60	7.58	6.58	6.13	22.18	18.22	18.50	12.07	11.98	2.44
11	3.33	5.13	5.83	5.25	19.05	15.87	15.43	9.65	9.94	2.31
12	4.70	7.60	6.40	7.72	22.93	16.58	16.73	13.18	11.98	1.61

5.8 Soil water dynamics in alley cropping systems

5.8.1 Introduction

While the tree and understorey components of an alley cropping system compete for water, light and nutrients, the extent to which their water use patterns can be complementary is not well understood. The purpose of the study was to use Watermark sensors to investigate the soil water tension of the soil within the alley cropping system, which is an indication of availability of water in the soil for use by plants.

5.8.2 Methodology

Watermark sensors were placed at depths of 200 mm, 500 mm and 1200 mm below the soil surface and placed at 3 positions across the alley from the central hedgerow and into the alley where the understorey crop is grown as shown in Figure 5.45. The sensors are connected to a logger so that hourly readings can be recorded.

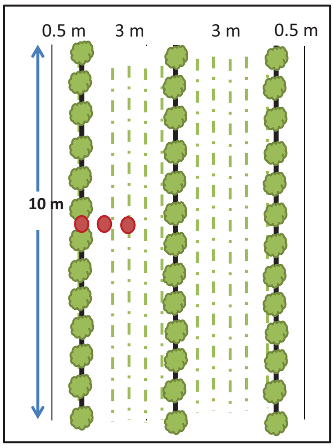


Figure 5.45 Alley cropping plot showing the positions of the Watermark sensors that have been installed in two alley cropping plots at Fountainhill Estate, Wartburg.

5.8.3 Results

This section presents a series of three graphs that provide a comparison of the soil water content at 200 and 1200 mm depths across the Sesbania/maize and the pigeon pea/*P. maximum* plots, as well as two graphs that allows for comparing 1200 mm soil water content for the three points for each of the plots.

Note: The equation used to calculate the soil water content from the soil water tension values provided inflated values for the 500 mm sensor so these values have been omitted from the graphs and discussions below.

Differences within the Sesbania/maize plot

Soil water content

When comparing the readings across the sensors from the tree line to the alley centre of the Sesbania/maize plot (Figure 5.46), the following points can be noted:

- The 200 mm SWC readings declined across all points from June to September 2017, which is the dry season, but were lowest in the alley centre, which may have been due to evaporation as well as water use by shallow lateral roots of the Sesbania. From April to July 2018 the 200 mm SWC was lowest at the point between the treeline and the alley centre. At this time the maize had died off so it is likely that this decline in SWC was due to water use by the Sesbania combined with evaporation.

- The 1200 mm readings were similar across the three points showing that there was very little difference across the alley in terms of the water content of the deeper soil layers. This suggests that that even at 1.5 m from the Sesbania, they were affecting the SWC, which is an indication of their ability to compete with the understorey crop for water.

From this it can be concluded that the trees would have competed with the maize for water, with more obvious signs of differences being for the 200 mm soil water tension readings for the treeline and the alley centre. **The roots of the Sesbania were still actively competing at a distance of 1.5 m from the treeline (given that the pigeon pea/*P. maximum* graphs in Figure 5.49 suggest what the soil water content can potentially be).**

Comparison across plot for SWC at 1200 mm

Figure 5.46 shows the SWC at a depth of 1200 mm (which we assume reflects water use by the Sesbania) across the plot. Changes occur across the growing season, but generally the midway point has highest SWC during the off season and the lowest SWC over the growing season. The treeline SWC is higher than midway over the growing season. The alley centre has the highest water content early in the growing season but it falls below the treeline SWC in the later part of the growing season.

Soil water storage

A comparison of SWS at the treeline and in the alley centre for the Sesbania/maize plot (Figure 5.48) shows that the treeline had lower SWS over the period May to September (dry season) – when there was no active maize crop – but higher SWS over the growing season when both the Sesbania and the maize were actively growing.

.

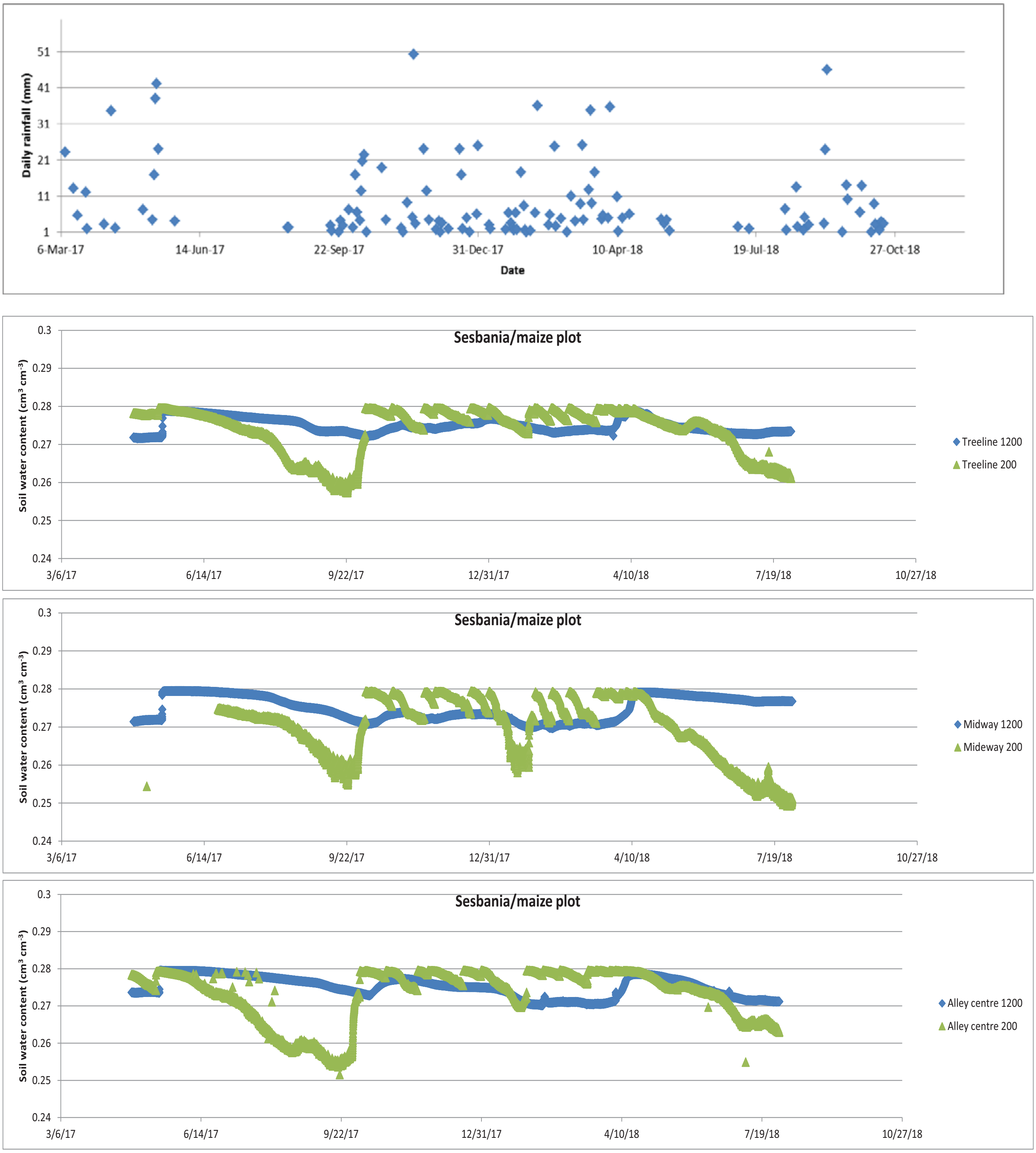


Figure 5.46 Comparison of soil water content at two depths (200 mm and 1200 mm) at three points in a *Sesbania sesban*/maize plot

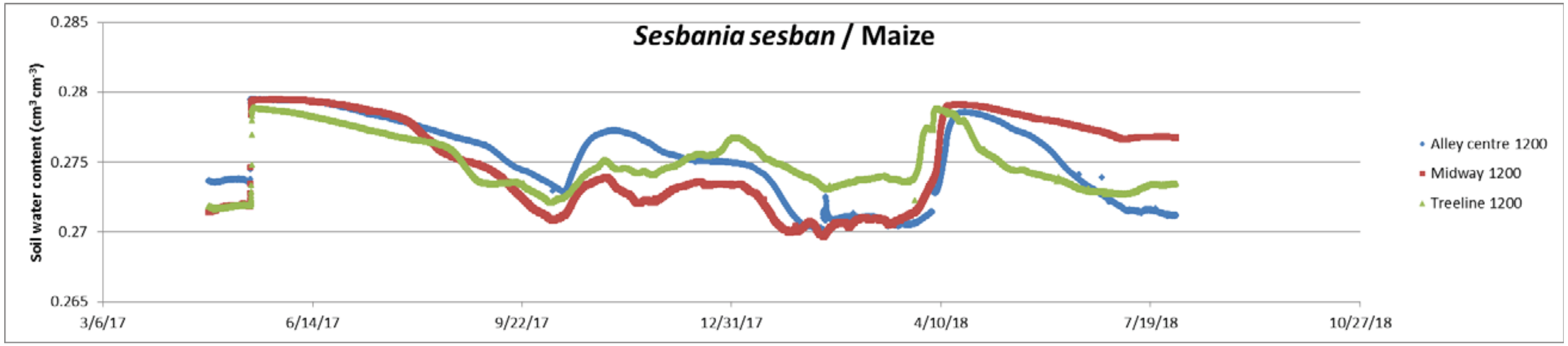


Figure 5.47 Soil water content at 1200 mm depth at the treeline, midway and alley centre of the S. sesban/maize plot

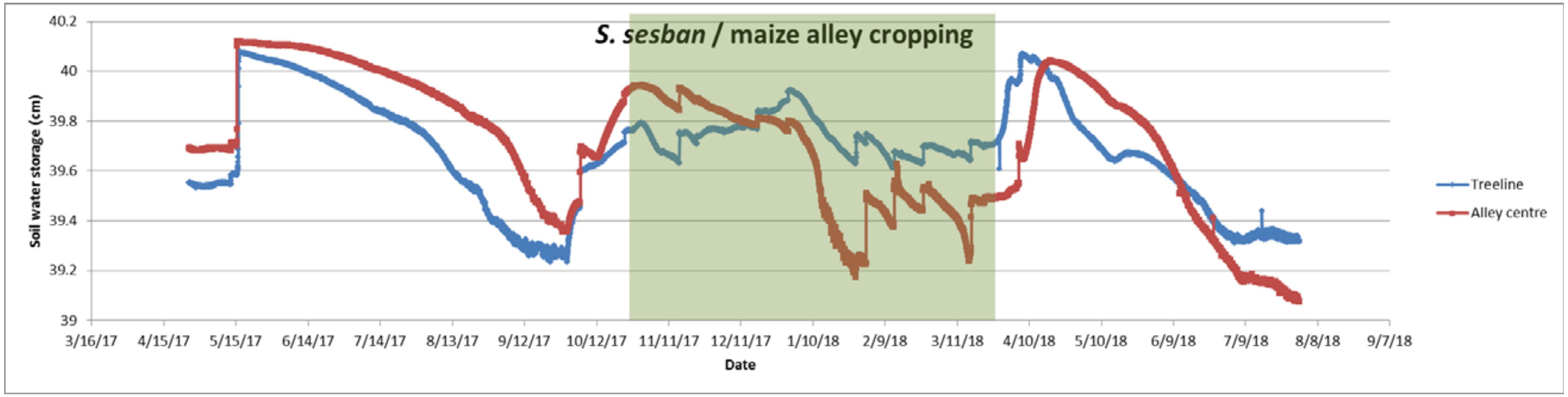


Figure 5.48 Comparison of soil water storage in the top 1200 mm profile at the treeline and alley centre of the S. sesban/maize plot

<u>Differences within the pigeon pea/</u><u>Panicum maximum</u> *<u>plot</u>*

Soil water content

- In the period June to September 2017, there was little rain and the 200 mm sensor in the treeline gave readings similar to those midway, but there was a marked decrease in SWC at the alley centre, indicating that it was drier (Figure 5.49).
- At 1200 mm the SWC was high both in the tree line and the alley centre, but lower at the midway point. The decline in SWC for the midway point was from June 2017 to April 2018, which was the growing season when both the trees and the grass component were actively growing. Given that the 1200 mm SWC in the alley centre was higher than at midway, we can assume that the pigeon pea trees were responsible for the reduced SWC at 1200 mm.
- In June 2018 there are again signs that the SWC at 1200 mm was starting to decline for the midway point. **This suggests that the pigeon pea roots are most competitive at a distance of approximately 75 cm from the treeline**.

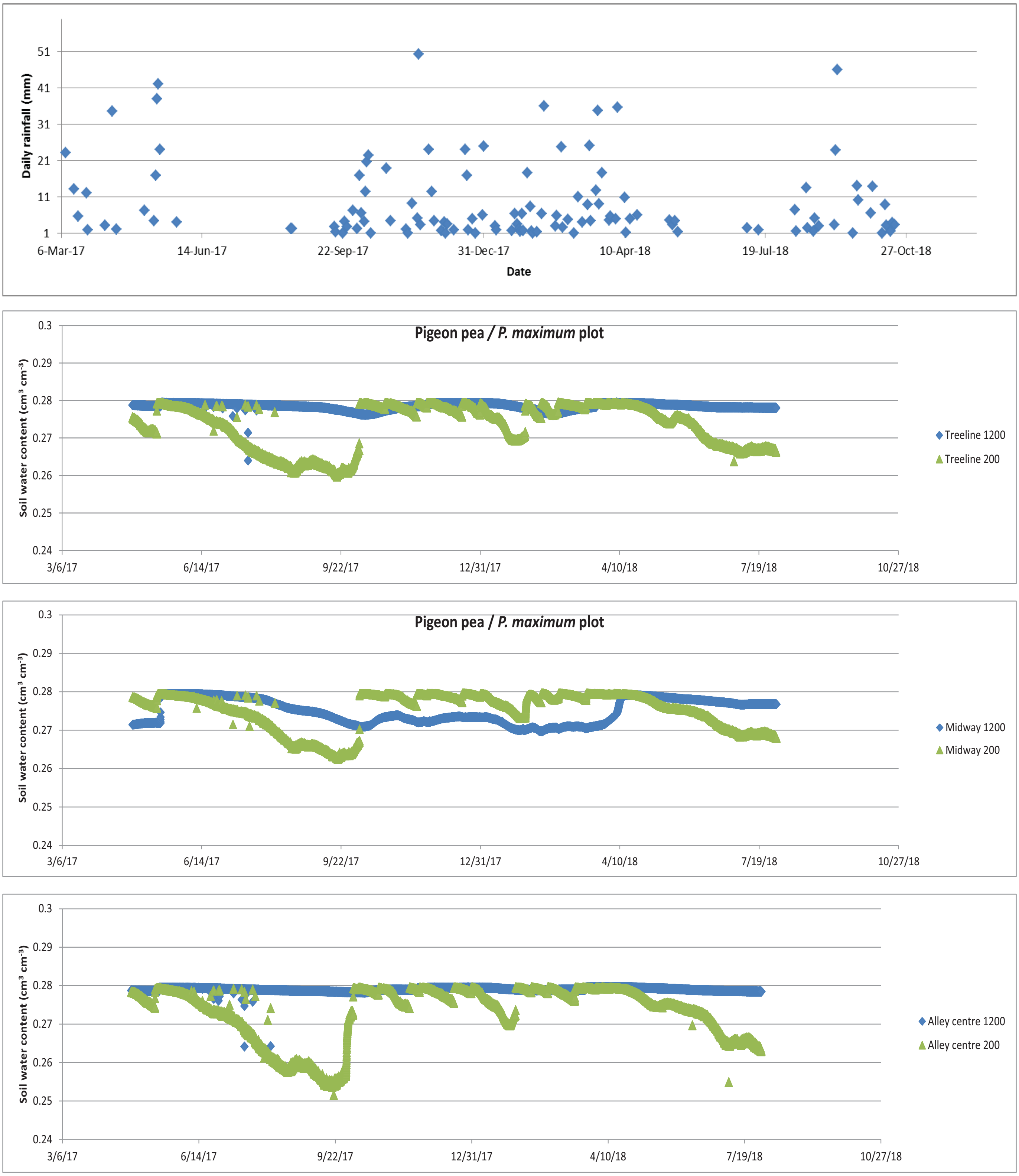


Figure 5.49 Soil water content at two depths (200 mm and 1200 mm) at three points in a pigeon pea/*Panicum maximum* plot.

Comparison across plot for SWC at 1200 mm

When considering the SWC at 1200 mm across the pigeon pea/*P. maximum* plot, the treeline generally showed the lowest soil water content, especially in October 2017 and in February 2018. October is the end of the dry season, which explains the dip in the soil water storage value, while the dip in February 2018 may have been due to active growing of the trees at that time.

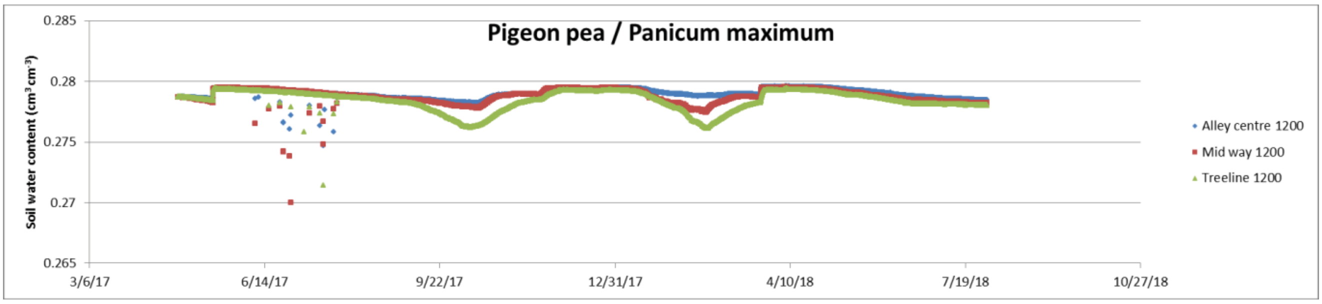


Figure 5.50 Soil water content at 1200 mm at three points across a pigeon pea/*P. maximum* plot

Soil water storage

Comparing the total soil water storage in the top 1200 mm at the treeline and alley centre within the pigeon pea/*P. maximum* plot (Figure 5.51, there was much less variation between them through the study period than can be seen for the Sesbania/maize plot (Figure 5.48).

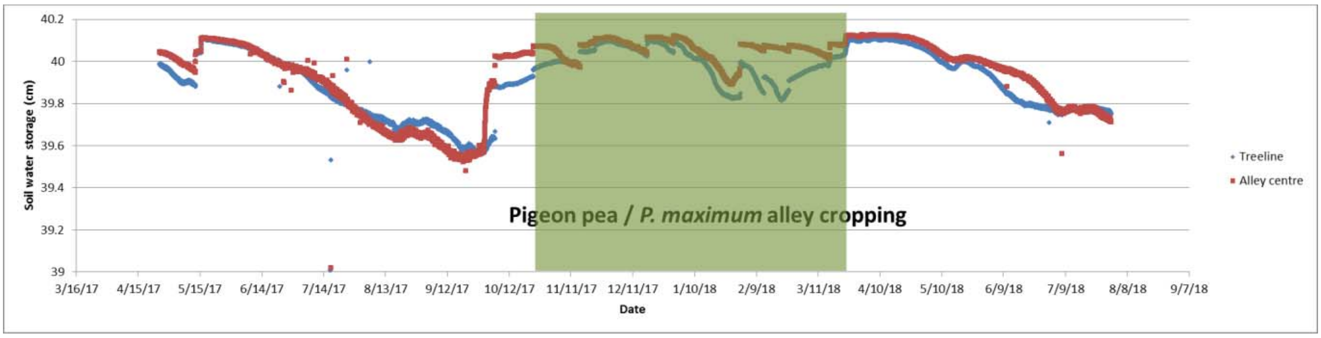


Figure 5.51 Comparison of soil water storage in the top 1200 mm profile at the treeline and alley centre of the pigeon pea /*P. maximum* plot

<u>*Comparing SWC at Sesbania and pigeon pea treelines*</u>

When comparing the SWC values for the two extreme points (treeline and alley centre) at 1200 mm in the Sesbania/maize plot and the pigeon pea/*P.* maximum plots, there are a number of factors to take into account:

- The Sesbania trees were cut at 75 cm above ground level and the pigeon peas were cut at 60 cm above ground.
- The Sesbania trees had much more biomass than the pigeon peas.
- The maize is an annual crop that is planted in November and harvested in April, while the *P. maximum* is a perennial pasture.

While it is difficult to draw meaningful comparisons due to the differences in the species combinations and their growth habits, the data do suggest that Sesbania uses more water than does pigeon pea, which is very clear from the sensors at 1200 mm below soil surface. The surface layers show a somewhat different picture, showing that within the alley centre the pigeon pea plot was drier in

September 2018, which could have been due to water use by the *P. maximum* grass already actively growing at this point.

It was also clear that the soil water storage (SWS) at the treeline was generally lower for the Sesbania than for the pigeon pea (Figure 5.52)

Figure 5.52 Soil water content for the two plots comparing sensors placed at 1.2 m depth

5.8.4 Water use and water use efficiency

Water used by plants is also known as evapo-transpiration (ET).

Crop water use (ET) = R +SI±ΔS-DP-RO

Where RF is rainfall (mm), SI is supplemental irrigation (mm), ΔS is the change in soil moisture storage (mm), DP is deep percolation (mm) and RO is runoff (mm) (Weldelassie et al., 2016). If DP and Ro are assumed to be zero because the storm rainfall never exceeded the available water storage capacity of the root zone (Weldelassie et al. (2016), and there is no supplementary irrigation then:

ET = R ±ΔS.

This was the basis for using the difference in soil moisture storage over the growing season and the rainfall obtained over the same period to obtain a measure of ET for the two components of each of the agroforestry systems (namely silvopastoral system comprising pigeon pea and *P. maximum*; alley cropping system comprising *S. sesban* and maize; and the two sole crops (maize and *P. maximum*).

The water use of the two alley cropping systems was then calculated based on the assumption that the treeline value reflected a 1.5 m strip and the alley centre value reflected a 2.5 m strip that was then repeated across a one hectare area.

What was clear from this calculation was that the crude method used to estimate water use showed very little difference between the components of each system, and between the intercrops and the sole crops. The treeline and alley centre water use values are presented in Figure 5.53.

The DM production of the two alley cropping systems and the sole understorey plots for the 2017/18 growing season is summarised in Table 5.18.

Table 5.18 DM production of different plant components of the S. sesban/maize, sole maize, pigeon pea/P. maximum and sole P. maximum over the 2017/18 growing season

DM (kg/ha)	SSMz	Sole maize	PPPM	Sole PM
Leaf	2844	0	2585	0
Twig	1207	0	783	0
Stover	1672	2487	-	-
Grain	3014	5019	-	-
Grass	-	-	6200	5781
Total	10835	7506	9568	5781

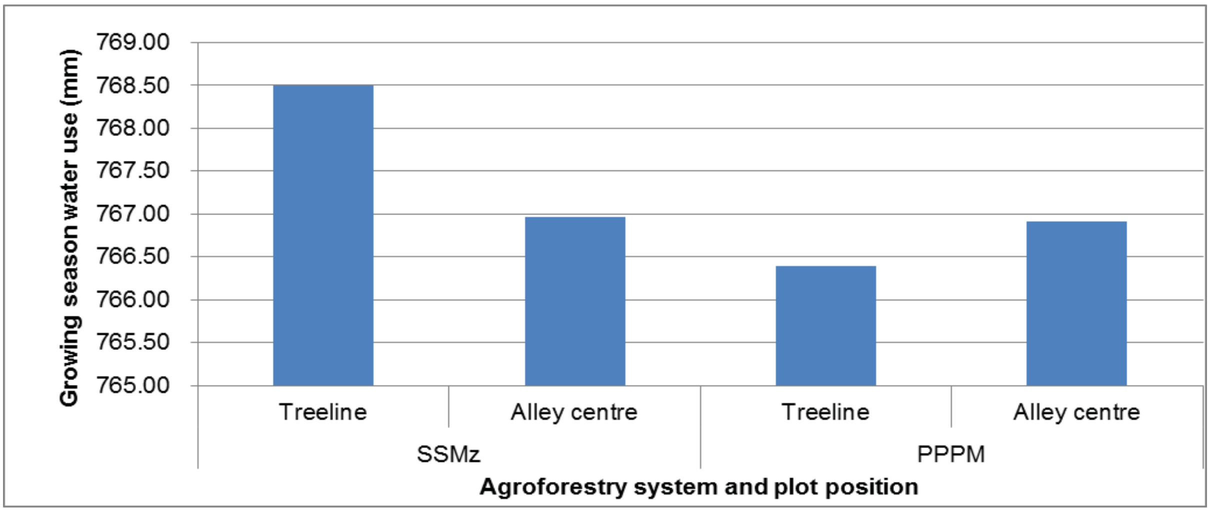


Figure 5.53 Water use over the growing season for treelines and alley centres of a *S. sesban*/maize (SSMz) and pigeon pea/*P. maximum* alley cropping systems.

Water use efficiency is generally defined as the amount of biomass or grain produced per unit of water used by the crop (Hatfield and Dold, 2019). Some organisations such as the Food and Agriculture Organisation (FAO) are however preferring to use the term <u>water productivity</u> to refer to the ratio of net benefits from an agricultural system relative to the water used to produce those benefits (Sadras et al., undated). They also distinguish between <u>physical water productivity</u> (biomass/water use) and <u>economic water productivity</u> (e.g. nutrition produced/water used). The FAO also refers to Crop Water Productivity (CWP), stating that it is a measure of the economic or biophysical gain from the use of a unit of water consumed in crop production (FAO).

The water use values have also been used to estimate the water productivity of the different components of the alley cropping systems so that a comparison of the two alley cropping systems can be made as well as a comparison against the sole understorey crop. The findings are summarised in Figure 5.45. Note: The water use values from the alley centres was used as a proxy for the sole plots given that there was very different between any of the values as a result of the method used.

System	ET (mm)	WUE (kg/mm)	WP_CP (kg/mm)
SSMZ	767.54	11.38	1.65
Sole Mz	766.96	9.79	0.88
PPPM	766.72	12.48	1.23
Sole PM	766.92	7.54	0.44

Figure 5.54 Evapotranspiration, water use efficiency and water productivity in terms of crude protein supply (WP_CP) of *S. sesban*/maize, sole maize, pigeon pea/*P. maximum* and sole *P. maximum*

From Figure 5.54 it is clear that while the water use does not appear to differ substantially, there is definitely a benefit of including a woody species into the system as a source of fodder – especially in terms of water productivity (calculated as kg CP/mm ET).

5.9 Conclusion

This study has demonstrated that the choice of species as well as the spatial arrangement is important to avoid competition between the woody component and the understorey crop or it may lead to poor yields and even crop failure.

The rooting structure of the woody species as well as its potential growth rate both appear to affect its water use patterns and ability to compete. It is clear that under some conditions the woody component and the understorey crop compete for water rather than accessing different layers of the profile.

In arid areas where competition for limited water is likely to occur, it would be recommended that alley cropping systems be avoided or the alley be widened considerably. The alternative is to consider systems that make use of biomass transfer between stands of trees and agronomic cropping areas.

The decisions taken by farmers regarding the design and management of their agroforestry systems will depend on their existing farming systems, their priorities, their resources and the climatic conditions under which they farm.

5.10 References

Abunyewa, A. A., Karbo, K. N., 2005. Improved fallow with pigeon pea for soil fertility improvement and to increase maize production in smallholder crop-livestock farming system in the sub humid zone of Ghana. Land Degradation Development 16: 447-454

Ajayi, O.C., Place, F., Kwesiga, F., Mafongoya, P., 2007. Impacts of improved tree fallow technology in Zambia. In International Research on Natural Resource Management: Advances in Impact Assessment; CABI: Wallingford, UK; Science Council/CGIAR: Rome, Italy, pp. 147-168

Akinnifesi, F.K., Chirwa, P.W., Ajayi O.C., Sileshi G., Matakala P., Kwesiga F.R., Harawa H., Makumba W., 2008. Contributions of agroforestry research to livelihood of smallholder farmers in Southern Africa: 1. Taking stock of the adaptation, adoption and impact of fertilizer tree options, Agriculture. Journal. 3, 58-75

Allen, R., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration guidelines for computing crop requirements. FAO Irrigation and Drainage Paper No. 56, FAO, Rome

Alliance for a Green Revolution in Africa (AGRA). 2016. Africa Agricultural Status Report: Progress Towards Agriculture Transformation in Sub-Saharan Africa. Nairobi. Kenya. Issue No.4

Amarteifio, J. O., Munthali, D. C., Karikari, S. K., Morake, T. K., 2002. The composition of pigeon pea [Cajanus cajan (L.) Millsp.] grown in Botswana. Plant Foods Human Nutrition., 57, 173-177

Blanchart, E., Albrecht, A., Brown, G., Decaens, T., Duboisset, A., Lavelle, P., Mariani, L., Roose, E., 2004. Effects of tropical endogeic earthworms on soil erosion. Agricultural Ecosystems Environment 104: 303-315.

Bullied, W.J., Martin H.E., 1999. Soil water dynamics after alfalfa as influenced by crop termination technique. Agronomy J., 91, 294-305.

Chirwa T.S., Mafongoya, P.L., Chintu, R., 2003. Mixed planted fallows using coppicing and non-coppicing tree species for degraded Acrisols in eastern Zambia. Agroforestry Systems.

Chirwa, P.W., Ong, C.K., Maghembe, J., Black., C.R., 2007. Soil water dynamics in intercropping systems containing *Gliricidia sepium*, pigeon pea and maize in southern Malawi. Agroforestry Systems 69:29-43

Connolly, R, D., Freebairn, D, M., Bridge, B, J., 1997. Change in infiltration characteristics associated with cultivation history of soils in south-eastern Queensland. Australian Journal of Soil Research 35(6):1341-1358

Cooper, P.J.M., Gregory, P.J., Keatinge J.D.H., Brown, S.C., 1987. Effect of fertilizer variety and location on barley production under rainfed conditions in northern Syria. Field Crops Res., 16, 67-84

El Chami, D., El Moujabber, M., 2016. Drought climate change and sustainability of water in agriculture: A roadmap towards the NWRS2. South African Journal of Science 112:9-10

Everson, C., Ghehezi, S., Everson, T.M., Annandale, J., 2011. Agroforestry systems for improved food production through the efficient use of water. Final report for WRC Project No. K5/1480, presented at WRC Reference Group Meeting, 16 November 2011. Water Research Commission, Pretoria, South Africa

Feddes, R., Kowalik, P., Zaradny, H., 1978. Simulation of field water use and crop yield. Wiley, New York

Fisher T.A. and Turner N.C., 1978. Plant productivity in the arid and semiarid zones. Plant Physiol., 297-317.

Food and Agriculture Organization (FAO). 2012. Coping with Water Scarcity – An Action Framework for Agriculture and Food Security. FAO Water Reports No. 38 Rome: Food and Agriculture Organisation of the United Nations.

Food and Agriculture Organization (FAO), 2017. Emerging practices from Agricultural Water Management in Africa and the Near East. Theme 1 Water productivity. http://www.fao.org/fileadmin/user_upload/agwa/docs/bari2017/Session1/Productivity_introduction_I.pdf

Hatfield, J. L., Sauer, T. J., Prueger, J. H., 2001. Managing soils to achieve greater water use efficiency. Agronomy Journal 93:271-280

Hensley, D., Deputy, J., 1999. Using Tensiometers for measuring soil water and scheduling irrigation. CTAHR Cooperative Extension Service, Landscape L-10 http://www.ctahr.hawaii.edu/publications

Hillel, D., 1998. Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations. Academic press

Hudson, B.D., 1994. Soil organic matter and available water capacity. J Soil Water Conserv 49:189-194

Hunderkar, S.T., Badanur, V.P., Saranagamath, P.A., 1999. Effect of crop residues in combination with fertilizers on soil properties and sorghum yield. Fertilizer News, 44, 59-63

Hunt, J., Kirkegaard, J., 2012. A guide to consistent and meaningful benchmarking of yield and reporting of water-use efficiency. Sustainable Agriculture. http://www.csiro.au

Kadigi, R.M., Tesfay, G., Bizoza, A., Zinabou, G., 2012. Irrigation and water use efficiency in Sub-Saharan Africa. In Policy Research Paper: Supporting Policy Research to Inform Agricultural Policy in Sub-Saharan Africa and South Asia; GDN: New Delhi, India

Kandelous, M.M., Kamai, T., Vrugt, J.A., Šimůnek, J., Hanson, B., Hopmans, J.W., 2012. Evaluation of subsurface drip irrigation design and management parameters for alfalfa. Agricultural Water Management 109, 81-93.

Klute, A., 1986. Water retention: Laboratory Methods. In: Klute A. (ed.), Methods of Soil Analysis: Physical and Mineralogical Methods, Part 1, (2nd ed.), Agronomy Monograph No. 9. American Society of Agronomy, Madison, WI, pp. 635-662.

Komicha, N.D., Lisanenwork, N., Muktar, M., 2017. Physico-chemical properties of soil under the canopies of *Faidherbia albida* (Delile) A. Chev and *Acacia tortilis* (Forssk.) Hayen in park land agroforestry system in Central Rift Valley, Ethiopia. Journal of Horticulture and Forestry Vol 10(1):1-4

Kwena, K.M., Ayuke F.O., Karuku G.N., Esilaba. 2018. No rain but bumper harvest: the magic of pigeon pea in semi-arid Kenya, International Journal of Agricultural Resources, Governance and Ecology. 14 (2): 181-203

Kwesiga FR, Franzel S, Place F, Phiri D and Simwanza CP. 1999. Sesbania sesban improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm. Agroforestry Systems 47: 49-66.

Liu S, Yang JY, Zhang XY, Drury CF, Reynolds, Hoogenboom G. 2013. Modelling crop yield, soil water content and soil temperature for a soybean-maize rotation under conventional and conservation tillage systems in Northeast China Agric. Water Manage., 123: 32-44

Lubana, S.P.P., Narda, N. K., 2001. Modelling Soil Water Dynamics under Trickle Emitters – A review. Review J. agric. Engng Res. 78 (3), 217-232

Ludlow M.M. and Muchow R.C. 1990. A critical evaluation of traits for improving crop yields in water-limited environments. Advances in agronomy, vol. 43 107-153.

Mafongoya, P.L., Dzowela, B.H., 1999. Biomass production of tree fallows and their residual effect on maize in Zimbabwe. Agroforestry Systems 47: 139-151

Mafongoya, P.L., Kuntashula, E., Sileshi, G., 2006. Managing soil fertility and nutrient through fertilizer trees in southern Africa. In: Uphoff N, Ball AS, Fernandes E. et al. (ed.), Biological Approaches to Sustainable Soil Systems. Taylor & Francis. pp 273-289

Mbow, M., Smith, P., Skole, D., Duguma, L., Bustamante, M., 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Curr. Opin. Environ. Sustain. 6 8-14. http://dx.doi.org/10.1016/j. cosust.2013.09.002

Meena, B.L., Singh, A.K., Phogat, B.S., Sharma, H.B., 2013. Effects of nutrient management and planting systems on root phenology and grain yield of wheat. Indian Journal of Agricultural Sciences. 83(6): 627632.

Michot, D., Benderitter, Y., Dorigny, A., Nicoullaud, B., King, D. and Tabbagh, A. 2003. Spatial and temporal monitoring of soil water content with an irrigated corn crop cover using electrical resistivity tomography. In: Samoueliana, A., Cousina, I., Tabbaghc, A., Bruandd, A. and Richarde G. 2005. Electrical resistivity survey in soil science: a review. Soil & Tillage Research 83:173-193.

Molden, D., Oweis T., Steduto, P., Bindraban, P., Hanjra, M.A., Kijne, J., 2010. Improving agricultural water productivity: Between optimism and caution. Agric. Water Manage. 97 528-535.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R. D., Veith, T. L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50(3): 885-900

Mula, M.G., Saxena, K.B., 2010. Lifting the Level of Awareness on Pigeon pea – A Global Perspective. Patancheru 502-324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 540 pp. ISBN: 978-92-9066-535-9.

Musokwa, M., Mafongoya, P., Lorentz, S., 2018. Evaluation of agroforestry systems for maize (Zea mays) productivity in South Africa, South African Journal of Plant and Soil, DOI: 10.1080/02571862.2018.1459898

Neuman, S.P., Feddes, R.A., Bresler, E., 1974. Finite element simulation of flow in saturated-unsaturated soils considering water uptake by plants, Third Annual Report, Project No. A10-SWC-77, Hydraulic Engineering Lab., Technion, Haifa, Israel

Nyamadzawo, G., Nyamugafata, P., Chikowo, R., Giller, K, E., 2007.Improved legume tree fallows and tillage effects on structural stability and infiltration rates of kaolinitic sandy soil from central Zimbabwe. Soil and Tillage Research 96: 182-194

Phiri, E., Verplancke, H., Kwesiga, F., Mafongoya, P., 2003. "Water balance and maize yield following improved sesbania fallow in eastern Zambia." Agroforestry Systems 59: 197-205

Ren, X., Zhang, P., Liu, X., Ali, S., Chen, X., Jia, Z., 2017. Impacts of different mulching patterns in rainfall-harvesting planting on soil water and spring corn growth development in semihumid regions of China. Soil Res. 55, 285-295

Rockström, J., Karlberg, L., Wani, S.P.S., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., Qiang, Z., 2010. Managing water in rainfed agriculture – The need for a paradigm shift. Agric. Water Manag. 97, 543-550

Sadras, V.O., Grassini, P. and Steduto, P. XXX. Status of water use efficiency of main crops. SOLAW Background Thematic Report, FAO.
– TR07. http://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_07_web.pdf

Šimůnek J, Van Genuchten, M.T., Šejna, M., 2006. The HYDRUS software package for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably saturated media, Technical manual, version 1.0, PC Progress, Prague, Czech Republic, p 241

Šimůnek, J., Sejna, M., Saito, H. Sakai, M., Van Genuchten, M.T., 2009. The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media: Version 4.08. University of California Riverside. Riverside, CA.

Šimůnek J., Van Genuchten M.T., Sejna, M., 2012 (a). HYDRUS technical manual: The HYDRUS software package for simulating the two- and three-dimensional movement of water, heat and multiple solutes in variably-saturated porous media. Technical manual version. 2.0.

Šimůnek, J., Van Genuchten, M.T., Šejna, M., 2012 (b). HYDRUS: Model use, calibration, and validation. Transactions of the ASABE 55(4): 1261-1274.

Sun, H., Tang, Y., Xie, J., 2008. Contour hedgerow intercropping in the mountains of China: a review. Agrofor Syst 73:65-76

Tijani, F.O., Oyedele, D.J., Aina, P. O., 2008. Soil moisture storage and water-use efficiency of maize planted in succession to different fallow treatments. Int. Agrophysics, 22: 81-87

Van Genuchten, M. Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal 44: 892-898.

Van Genuchten, M. Th., Leij E.J., Yates, S.R., 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. United States Salinity Laboratory, CA, 85 pp

Vereecken, H., Weynants, M., Javaux, M., Pachepshy, Y., Schaap, M.G., Van Genuchten, M.T., 2010. Using pedotransfer functions to estimate the Van Genuchten-Mualem soil hydraulic properties: a review. Vadose Zone J. 9 (4), 795-820.

Vrugt, J.A., Hopmans, J.W., Simunek, J., 2001. Calibration of a two-dimensional root water uptake model. Soil Sci. Soc. Am. J. 65, 1027-1037

Wallace, J.S., 1996. The water balance of mixed tree-crop systems. In: Ong CK, Huxley PA (eds) Tree-crop interactions: a physiological approach. CAB International, Wallingford, pp 189-233

Wu, Y., Huang, F., Jia, Z., Ren, X., Cai, T., 2017. Response of soil water temperature, and maize (Zea may L.) production to different plastic film mulching patterns in semi-arid areas of northwest. China. Soil Till. Res. 166, 113-121

Yu, L., Zeng, Y., Su, Z., Cai, H., Zheng., 12016. The effect of different evapotranspiration methods on portraying soil water dynamics and ET partitioning in a semi-arid environment in Northwest China. Hydrol. Earth Syst. Sci., 20, 975-990,

Zhang, Z.F., P.H. Groenevelt, and G.W. Parkin. 1998. The well shape-factor for the measurement of soil hydraulic properties using the Guelph Permeameter. Soil Tillage Res. 49:219-221.

6 FARMER EXPERIENCES WITH AGROFORESTRY

6.1 Introduction

The involvement of farmers in testing and evaluating agroforestry systems was seen as very important to add value to the controlled trials conducted at Empangeni and Wartburg.

6.2 On-farm participatory action research

6.2.1 Ixopo/Highflats

Joint experimentation has been conducted with a number of farmers in the Ixopo/Highflats area to introduce the new agroforestry species and systems for evaluation by farmers (Photograph 6.1).

Context

Ixopo is situated on a tributary of the Mkhomazi River in the midlands of KwaZulu-Natal and forms part of an important sugar farming and forestry area under Ubuhlebezwe Local Municipality. Ixopo is located approximately 85 km south east of Pietermaritzburg, capital of KwaZulu-Natal, and is strategically located at the intersection of four major provincial routes leading to Pietermaritzburg, the Drakensberg, the Eastern Cape and the South Coast. The area is under the leadership of Amazizi K and B, Emawusheni and Majikane Traditional Authorities.

The ten farmers interested in participating in the agroforestry project were located in eight sub-villages of the four Traditional Authorities in the Ixopo/Highflats area. The local farming system is characterised by maize, vegetable and potato production, with land sizes of approximately 0.5-2 ha. Peach trees are also popular within the respective households.

Agroforestry was a new concept to most farmers. They were a bit concerned about planting trees within commercial crops. The main concern was management of the root system and water use of the agroforestry trees. They were concerned that the trees will consume more water and nutrients in the soil leaving minimal for the companion crops. Presentation of other agroforestry projects in different sites and its advantages alleviated some of the farmers' concerns. Farmers were also concerned about the use of tractors in the intercrops involving trees. Alley planting could address the issue of using equipment in the field. The farmers were uneasy about the growth habit of Faidherbia, which appears to be similar to that of acacia tree. Their main worry about acacia was that it leads to bush encroachment hence causing problems in the grazing veld, rather than providing an alternative feed source for livestock. Reassurance was provided to farmers that Faidherbia has a hard seed coat and require scarification such as boiling water for the seeds to germinate. Farmers queried about the duration it takes for legumes to initiate soil fertility. Agroforestry is a long term cultivating process. Generally, changes in soil properties are observed in a period of 5-10 years. Farmers queried about the types of trees to be used in agroforestry, their management and benefit to livestock. Their main concern was the growth height of trees and feeding it to the livestock. Normally for the trees used in the trials (faidherbia and Sesbania) it is recommended to cut the leaves and pods and feed the animals rather than direct grazing on the trees. Most farmers showed interest towards pigeon pea and F*aidherbia* trees. Pigeon pea was more favourable because of its multipurpose use for instance as fodder and for human consumption.

Joint experimentation activities

The wet season (November 2015 to March 2016) experimentation started with 5 farmers situated in Emazabekweni, Nokweja and Mhlabashane villages. Farmers allocated 10 x 5 m pieces of land for experimentation. Two farmers' (Mr Mtshali and Mrs Joyce Dlamini) land was not fenced. Farmers were therefore provided with fencing material for the plot before planting.

The Chairperson of the Ubuhlebezwe Livestock Association gave progress reports during the association meetings to keep the members informed of experimentation being hosted by the 5 farmers from the 3 villages.

Photograph 6.1 Site selection at Ixopo, and discussions with farmers about their specific interests.

The experimentation conducted at each of the homesteads over the course of the project is summarised below.

Inkosi TP Dlamini (Emazabekweni)

Inkosi Dlamini had allocated a bigger piece of land for experimentation which allowed for the planting of 6 Faiderbia trees, 8 *Sesbania sesban*, and pigeon pea intercropped with maize (Photograph 6.2). He planted maize in the first week of November 2015, the Faiderbia trees and pigeon peas were planted on 24 November 2015, and the maize had germinated. *Sesbania sesban* was planted on 21 December 2015. The pigeon pea only started to germinate mid-January 2016. He was advised not to apply any form of weed herbicides in the experimental plot as it would interfere with the growth of trees. Chief Dlamini had been growing pasture species, i.e. rye grass for his cattle and sheep; he was further given cocksfoot seed to grow on a separate garden in addition to the other pasture species that he was planting.

At the garden of Chief Dlamini, a similar trial to that at MamJoyce Dlamini's home was established. The harvesting of maize and biomass transfer took place end of May 2017. The Sesbania trees were cut at 75 cm and material applied on top of the surface of the maize plots. The highest maize yield was obtained in the maize + fertilizer plot (the farmer's normal practice) at 2.8 kg from a 4 m^2 plot. The biomass transfer at the Chief's garden was done with Sesbania material only and applied in the 3 maize plots. Again the timing of the biomass transfer did not support the maize crop but it was hoped that the effect would be seen in the next season.

Chief Dlamini started to harvest pigeon pea seeds to expand the planting areas, and was not very keen on the harvesting of pigeon pea material for biomass transfer. An idea of propagating trees locally was discussed and was accepted by all trial farmers. The Sesbania trees were to be propagated at the Chief's garden at the beginning of September 2017. Through learning and observation on the Sesbania cutting regime for biomass transfer, Chief Dlamini initiated his own experiment of cutting the five pigeon pea trees planted in 2016 to see how their growth would be affected.

Photograph 6.2 *Sesbania sesban* (A) and pigeon pea (B) planted at the homestead of Chief Dlamini, Highflats, July 2017.

During the 2017/18 season, at Chief Dlamini's trial, the highest maize yield was obtained in the maize + fertilizer plot at 5 kg in 4 m^2 plot followed by maize + *Sesbania* biomass transfer plot at 3 kg (Photograph 6.3, Photograph 6.4 and Photograph 6.5). The lowest maize yield was obtained in the maize + pigeon pea and *S. sesban* intercrop plots at 1.5 kg. This was even less than the maize control plot due to the competition between the trees and the maize. He decided to plant *Sesbania* trees along the fence to provide a source of fodder while not impacting on his maize crop.

Photograph 6.3 Pigeon pea and cut *Sesbania* trees at Chief Dlamini's trial in June 2018.

Photograph 6.4 Mulching maize plot with Sesbania leaves (A) and maize mulched and intercropped with Sesbania in January 2018.

Photograph 6.5 Chief Dlamini's sole pigeon pea plot at Highflats, January 2018.

Mrs Joyce Dlamini (Emazabekweni)

At the beginning of the project Mam Joyce selected the trial site within her homestead. During the initial engagements about her farming practice, she mentioned that she had stopped planting on the one part of her cropping area because she was not harvesting any crop. She recommended that trees be planted on the same area that had not been giving her any yields with the view to improve soils. A 10 x 5 m garden was fenced. She planted 2 faiderbia trees and 4 *Sesbania sesban* intercropped with yellow maize and sugar beans. Faidebia trees were planted on the 24 November and 21 December 2015 while sesbania, maize and beans were planted on 10 January 2016.

In the 2016/17 season, MamJoyce Dlamini planted a number of sole plots of trees for biotransfer to sole maize plots and some alley cropping plots (maize and *Sesbania sesban*). The performance of maize in all plots was poor, and no yield was recorded. Only 3 cobs were harvested from the maize and pigeon pea intercrop. In the sole pigeon pea and the maize + pigeon pea there was poor germination of pigeon pea, and there was no material to harvest for biomass transfer. The biomass transfer was done at two different maize growing stages (after weeding in January 2017 and at the maize tasselling stage). In

January the procedure involved harvesting of Sesbania leaves and burying them in between the maize in the sole maize and the maize + *S. sesban* intercrop plots. The second biomass transfer was done in April 2017. The trees were cut at 75 cm and material applied on top of the surface of the maize plots. Mam Joyce reported that even though there was no yield obtained from all plots, she observed that the soil from the sole *S. sesban* plot had turned darker in colour which is a sign of soil fertility improvement. It is clear that biomass transfer does not have the intended benefits in the first year as the amount of material is insufficient and the timing is too late to support the maize crop.

During maize harvesting in May 2017, the performance of maize in all plots was poor, and no significant yield was recorded. The pigeon pea in her plot had not been doing well, and did not give material to prune for biomass transfer into the maize plot. Maize was planted in November 2017 in the intercrop and sole maize plots. Pigeon pea was also re-planted in the gaps where there was no germination. Mam Joyce's maize was not looking good from all plots, and she decided to plant dry beans end of January 2018. Some photographs taken over the course of her trials are presented below, together with a photograph of her minimum tillage maize field (Photograph 6.6, Photograph 6.7 and Photograph 6.8).

Photograph 6.6 The research site of MamJoyce Dlamini at Highflats, July 2017.

Photograph 6.7 Mam Joyce in her garden at Highflats, January 2018.

Photograph 6.8 Minimum tillage fertilised maize production of Mam Joyce at Highflats, January 2017.

Mr N.F Dlamini (Emazabekweni)

The farmer was provided with 3 *Faidherbia* trees planted along the fence of his garden, and 3 rows of pigeon pea intercropped with yellow maize. The planting took place on 21 December 2015. Pigeon pea has not germinated, and the farmer has been advised to re-plant the remaining pigeon pea seeds.

Mr T.V Dlamini (Mhlabashane)

The farmer had planted vegetable crops in his garden, and very little piece of land was left for experimentation. He was provided with 6 *Sesbania sesban* and pigeon pea planted on the 21 December 2015. Maize and pigeon pea has germinated. He has planted cocksfoot in a separate garden. After attending the farmers day in May 2017, Mr Dlamini went back and tried biomass transfer with Sesbania on his own where he had harvested potatoes, and is due to re-plant potatoes by end of August 2017 in the same plot without applying chemical fertilizer. In 2017/18 at TV Dlamini's garden, it was impossible to design the little trial because he has already planted vegetables (potatoes, beans, carrots and there are fruit trees in the garden – this can be seen as traditional agroforestry being practiced by the farmer.

In the small space available, 5 Sesbania trees were planted in a 3 m row. He had 3 pigeon pea trees that survived in 2015. More pigeon pea seeds were planted in between the existing trees, and this increased the number of pigeon pea rows to 4 in total. He fed harvested leaf material for his sheep, and found that they liked green Sesbania leaves the most. He however mentioned that birds had been nesting in the Sesbania trees and had been eating his vegetables (Photograph 6.9).

Photograph 6.9 The garden of Mr TP Dlamini which contains Sesbania sesban plants in a multi-species system.

Mr Mkhize

Pigeon pea and Sesbania trees were planted along the rainwater harvesting contours in the maize field (Two rows of pigeon pea and one row of Sesbania trees). Mr Mkhize wanted to harvest the tree material to add soil fertility in his big maize field next to Umkhomazi River for 2017/18 season (Photograph 6.10). He also planned to harvest seeds to start another trial in the home garden. Mr Mkhize pruning the trees to feed his goats, and harvested the seeds but he is getting discouraged to continue growing maize in his fields due to the problem of warthogs eating the maize.

Photograph 6.10 The fields of Mr Mkhize at Nokweja, Highflats, July 2017.

Mr S Mtshali (Nokweja)

Sesbania and pigeon pea trees were introduced into existing kikuyu grass in 2015. The pigeon pea germination was poor, and was re-planted. In 2016/17 more trees were planted and grew well (Photograph 6.11). In April 2017 Mr Mtshali allowed his goats into the trial to graze on kikuyu and browse on trees. From the farmers observation the goats liked Sesbania more than pigeon pea tree leaves. He further cut kikuyu grass that had grown at 35 cm and fed to his cattle.

Photograph 6.11 The fenced area of kikuyu where pigeon pea and Sesbania sesban has been established at the homestead of Mr Mtshali, Highflats, July 2017.

Mr Mtshali harvested kikuyu and leaf material to feed his cows. The cows later made a forced entry into the garden and ate the trees, and kikuyu. However the trees recovered during the rainy season since they were not completely grazed by the cows (Photograph 6.12). He went on to plant some maize within the fenced area (Photograph 6.13).

Photograph 6.12 Kikuyu and fodder trees (Sesbania and pigeon pea) after being eaten by cattle in October 2017 (A) and after recovery from grazing in January 2018 (B).

Photograph 6.13 Rows of maize planted into the kikuyu and trees by Mr Mtshali at Highflats, January 2018.

Phumelele Shezi (Emazabekweni)

Ms Shezi also had her own trial at home (Photograph 6.14 and Photograph 6.15). The trial had 2 sole *S. sesban* plots, sole pigeon pea, maize + pigeon pea intercrop, maize and *S. sesban* intercrop, Pigeon pea and *S. sesban* biomass transfer, and maize with kraal manure. Phumelela did not practice biomass transfer in 2017 as she only started her experiment in November 2017. She obtained Sesbania trees from the nursery she is managing, and pigeon pea seeds from Chief Dlamini. While her trees were still small, she harvested leaves from Mam Joyce and Chief Dlamini for biomass transfer. Lungelo Ngcobo, Phumelela's neighbour also tried an experiment with pigeon pea and maize with assistance from Phumelela, but due to poor fencing it was all destroyed by cattle.

Photograph 6.14 Pigeon pea sole plot at Phumelela's trial, January 2018.

Photograph 6.15 Phumelela's pigeon pea growth in June 2018 (A) and her Sesbania growth in June 2018 (B).

Emazabekweni primary school activities

Through Phumelela's initiative, a trial was initiated at the local school (Photograph 6.16). In January 2018, school children participated in the practical demonstration of sowing *Sesbania* trees at school (Photograph 6.17). However, the germination of trees was poor, and more trees will be sown in spring for the purpose of planting in the school garden, and for children and educators who might be keen in planting trees at home. Two grade 6 learners and their Life Science educator also participated in the farmer's day held in March 2018 at Wartburg research station.

Photograph 6.16 Trial at Emazabekweni School, Highflats, January 2018.

Photograph 6.17 eMazabekweni grade 6 school children sowing *Sesbania* trees with Phumelela Shezi.

General comments

During harvesting of maize in June 2018, farmers were upfront in saying that the maize planted with conventional fertilizer and kraal manure, which is their normal practice gave better yields with bigger cobs and stover than the biomass transfer plots. They have learnt that the effects of intercropping and biomass transfer on soil properties are slow and that the trees can affect the adjacent crop if not managed correctly. However, they have seen benefits of planting these trees, namely the production of fodder for their livestock. While the initial results of maize yield were disappointing, farmers continued to harvest leaf material to mulch their sole maize plots with the hope of seeing improvements for 2018/19 season. All experimenting farmers in Ixopo have adopted the practice of feeding leaf material to livestock, they have seen that leaf material can be fed green, dried and or mixed with maize. Farmers were able to harvest seeds from pigeon pea and *Sesbania* trees which allowed them to expand the cultivated area, and also to share seeds with the local school. Seeds harvested were also shared with other interested farmers to try in their homestead gardens.

Use of Sesbania for firewood

The harvested material that is not used for mulching is being used as firewood (Photograph 6.18).

Photograph 6.18 Sesbania trees cut for firewood at Chief Dlamini's trial (A) and dried Sesbania branches being kept for firewood (B).

Nursery establishment at eMazabekweni, Highflats

In September 2017, a nursery was set up for *Sesbania sesban* tree propagation (Photograph 6.19). The recommendation had been made by farmers who participated in the farmer field day held in May 2017 at FHE. The farmers were interested to know if the seeds will germinate under local conditions. The small nursery was set up at Emazabekweni Chief Dlamini's homestead. The seed sowing took place on the 12 September 2017 with four farmers participating. A total of 185 trees were sown using different soil fertility treatments such as mixture of soil and kraal manure, mixture of soil and sand, kraal manure only, and soil only. The nursey is managed by Phumelela a community based field assistant and collecting data with regards to germination rate. The seedlings only started to emerge in the kraal manure treatment mid November 2017. Phumelela and Chief Dlamini took a decision of taking out the other treatments and added kraal manure and soil and re-planted the seeds. The sand only treatment was a complete failure as no germination took place, and had to be replaced with the mixture of soil and kraal manure. The trees that have germinated have been planted in the two new trials of Emazabekweni School and Phumelela. The Chief transplanted some of the trees along the fence to provide additional fodder and support the fence. The lesson learnt from this level of experimentation is that the types of trees are not easy to establish, looking at the period of sowing to germination. The seeds used to propagate the trees were harvested from the trees at the Chief's trial.

Photograph 6.19 Trees germinating in the nursery in December 2017 and Phumelela Shezi with trees ready for transplanting

Alternative pigeon pea intercropping system

Following a discussion renowned agroforestry expert Ken Giller at a conference in Stuttgart in May 2018, the team decided to test a pigeon pea based intercroppping system that he is promoting in East Africa. New experiments were initiated in November-December 2018 in which maize was intercropped with pigeon pea as an annual crop, was established with four experimenting farmers (Mr Ngcobo, TV Dlamini, Phumelela Shezi and Chief Dlamini) (Photograph 6.20). One of the challenges is that this system of planting on mounds is not practiced in South Africa and experience thus needs to be developed as the mounds collapsed due to rainfall. The benefit of the system is that the pigeon pea is slow to establish and does not impact on the maize yield. At the end of the season, once the trees have been harvested, they are removed and the system is re-established the following growing season.

Photograph 6.20 INR intern, Thembani Nxumalo assisting Phumelela Shezi with planting the trial at Mr Ngcobo in November 2018 (A) and Mr Ngcobo weeding the 3 maize/3 pigeon pea trial established in December 2018 at Ixopo (B).

6.2.2 Zwelisha, Bergville

Work was initiated at Mr Mbele's farm where previous agroforestry work was done and later expanded to other households in the vicinity.

Mr Mbele's site

This site is located in the communal area of Zwelisha village in Bergville under Okhahlamba Local Municipality. The Zwelisha village falls under Amangwane Traditional Authority. The name of a farmer visited is Mr Simon Mbhele a smallholder dairy and beef cattle farmer. In the period of 2005-2009 the farmer was involved in another WRC-funded agroforestry project where different fodder production systems were tested on his farm. The farmer was identified through interaction with the researchers who were involved in the previous research. The total area of the field available for the agroforestry trial was approximately 0.6 ha.

Experimentation activities

The provisional experimental design was discussed with the farmer, especially in terms of what could possibly be planted in the 2015 growing season. One of the species identified by Mr Mbhele was *Sericea lespedeza* also known as poor man's lucerne. The team together with the farmer initially agreed that planting would start mid October 2015, but that was not possible due to drought. The planting date was therefore moved to beginning of December 2015 after some rain had been received. The prepared land was demarcated into 9 plots of 5 x 5 m, as per layout.

The planting took place from 30 November to 1 December 2015. Although some rain had been received before and after planting, there was still no germination by the end of December 2015. Further engagements were held with the farmer to discuss possibilities of re-planting in January 2016. The second planting took place on 5 January 2016 as well as fencing of the site (Photograph 6.21).

Photograph 6.21 Repairing the fence at the Bergville site.

Table 6.1 Trial layout of crops planted during the wet season (November 2016 to February 2017) and dry season (March 2017 to June 2017) at Zwelisha site

<table>
<tr><th>Block One</th><th colspan="2">Block Two</th><th>Block Three (Control)</th></tr>
<tr><td>Current: Row of pigeon pea (permanent)</td><td rowspan="2">Summer : Maize

Winter: Oats</td><td rowspan="2">Summer : Lespedeza

Winter: Cover crop mix</td><td>Summer : Maize

Winter : Oats</td></tr>
<tr><td>Summer: Cocksfoot

Winter: Japanese radish</td><td>Summer : Lespedeza

Winter: Cover crop mix</td></tr>
<tr><td>Summer : Lespedeza

Winter: Cover crop mix</td><td>Summer : Cocksfoot

Winter: Japanese radish</td><td>Summer : Maize

Winter: Oats</td><td>Summer : Cocksfoot

Winter: Japanese radish</td></tr>
</table>

The pastures planted in pasture and maize did not germinate after replanting twice November 2016 and January 2017 (Photograph 6.22).

Photograph 6.22 Replanting of the plots at the Bergville site in January 2016.

Germination was first observed on the 20 January 2016 in all plots. Data collection and monitoring was done twice a week by a local person, Mr Thabo Bocibo, and Mr Mbhele when he was available. The cocksfoot plot was growing well compared to lespedeza which was a bit slow. There has been flooding experienced in the area since the date of germination, and the plan was to reshape the contour to harvest water and minimise erosion to the site. Areas of improvement were discussed by the team and Mr Mbhele, and those recommendations were applied in preparation for the dry season such as:

- Use of weed herbicide to control weeds
- Establishment of swales to control run-off.

In the winter season the yellow maize plots, after removal of the maize for silage production, were planted with oats (*Avena sativa*). The oats was planted on 4 May 2016. Two more farmers (Mrs Ndawo and Mrs Bocibo) also planted in their vegetable gardens. Originally the plan was to oversow the standing maize with oats after harvest of the cobs as shown in Photograph 6.23, but this was not practical for his dairy system.

Photograph 6.23 Maize oversown with oats as was proposed for the site[2].

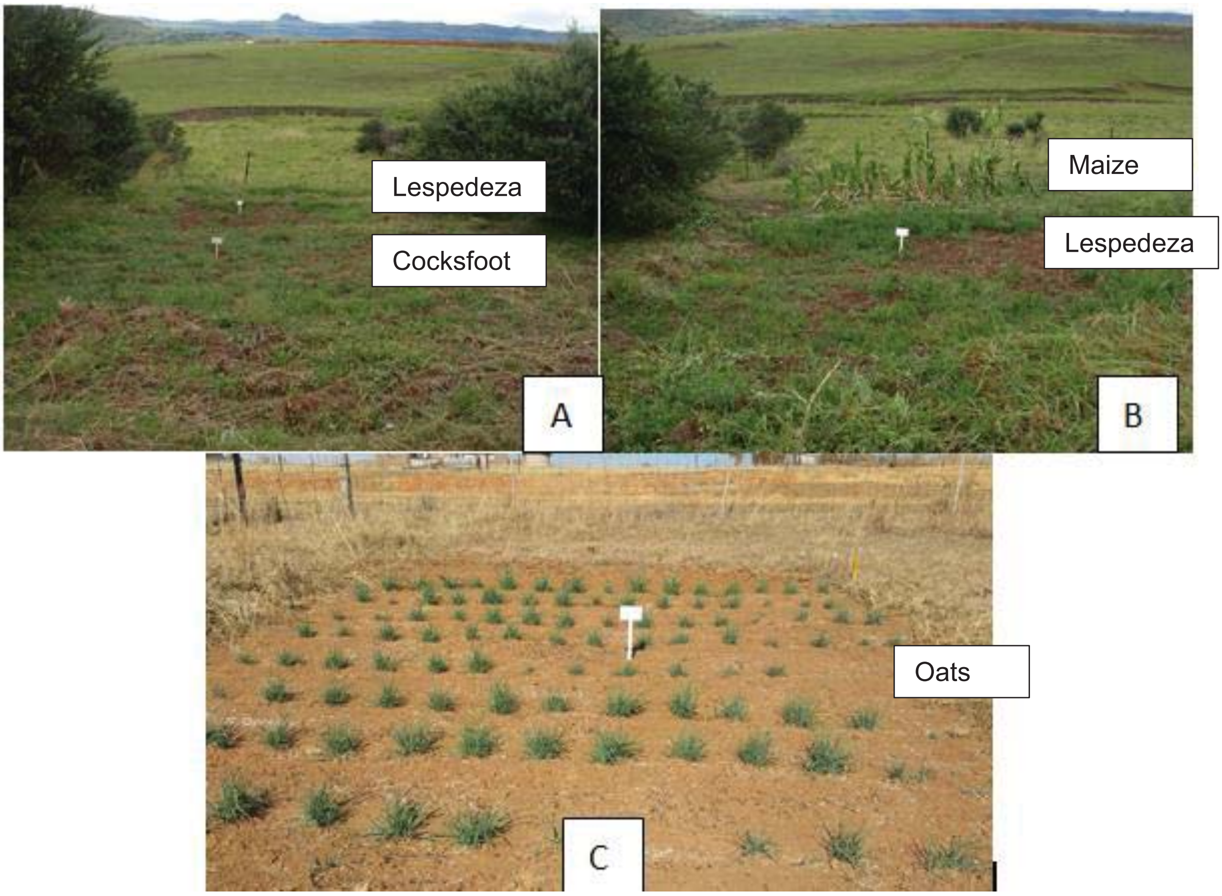
From visual observations in this demonstration the interaction between the *Vachellia* trees and the various understorey crops (cocksfoot, lespedeza and maize) was negative. The emergence of the fodder crops were poor hence growth on the plots was very patchy (Photo A and C in Photograph 6.24). The worst affected plots were those shown in Photo A, as there were rows of trees adjacent to both sides of the plot. The plots shown in Photo B only had trees on one side and appeared to do slightly

[2] Caspers-Simmet, J. 2013. Farmers are cover crop believers | Agrinews | PostBulletin.com

better. In contrast the control treatment of the same crops (planted on a more level slope 5 m away from the trees) had better germination and stand establishment.

The cocksfoot plot shown in Photograph 6.25 was a plot that was actually extended beyond the rows of trees and had little competition. This could be the key reason for the good cover and biomass production that was achieved. Germination and growth of oats sown during winter on plots that were previously planted with maize was good, especially given the fact that it was grown under rain fed conditions and rainfall was very limited during this period (Photo C). From these observations it could be deduced that: a) slope led to seeds being washed to the bottom of the plot during heavy rains; b) *Vachellia* tress were more aggressive in competing for nutrients and water. The swales were dug on the contour and filled with branches and grass to trap run-off and hold moisture that is then available to the crops. The swales were very successful in reducing surface run-off that had previously interfered with efforts to establish crops as shown in Photograph 6.26.

Pigeon pea was also introduced on the experimental site and with another farmer (Mrs Ndlovu) to test its survival and performance under local conditions. This was a medium duration variety as opposed to a long season variety as has been planted at the other trial sites. The reason for this is that the cold temperatures at Bergville are likely to result in leaf fall in winter and thus the crop needs to be ready by the onset of winter. Short-season pigeon pea varieties are also being tested at Ukulinga Research Farm and these will also be introduced to farmers once the seed has been bulked (Photograph 6.27). At the farmers' day there was much interest in the pigeon pea, with some farmers having eaten it but very few farmers having any experience with growing it.



Photograph 6.24 Performance of cocksfoot, lespedeza, maize (A & B) and oats (C).

Photograph 6.25 Cocksfoot plot some distance from trees that had good cover.

Photograph 6.26 Swales used in the trial site at Zwelisha to control soil wash, May 2017.

Photograph 6.27 Short duration pigeon pea varieties being tested at Ukulinga Research Farm, June 2017.

The winter crops, which included a commercial cover crop mix (jap radish, oats and stooling rye), oats and Japanese radishes were established. A farmers' day was held in May 2017. The status of the trial at that stage is shown over page in Figure 6.1. The effect of the trees competing with the understorey crops was very clear.

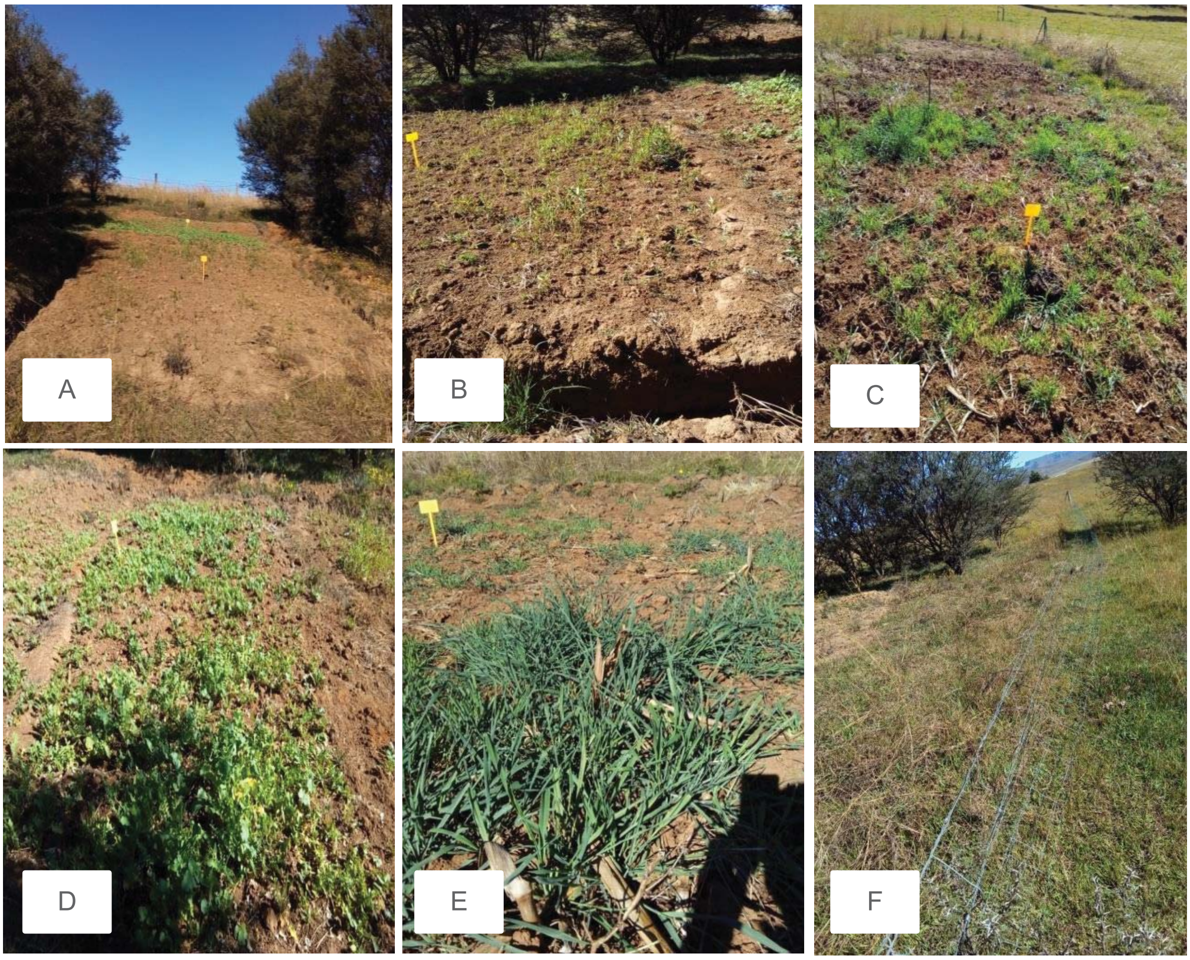
Poor germination and uneven growth of understorey crops had been experienced since the start of the trial with Mr Mbhele in Bergville, especially for the plots that were bound by tree hedgerows on both edges of the plots. There was a clear difference with the crops growing without and with competition from adjacent Vachellia trees in Zwelisha since the start of the trial in 2015. One factor that has been suggested as contributing to this challenge has been the possibility of Vachellia trees competing with the crops for water and nutrients. Root pruning was undertaken to address this. Narrow trenches were dug along the edges of the pasture plots in October 2017. After the digging was completed, summer understorey crops were planted (cocksfoot, lespedeza and maize). In March 2018, winter understory crops were also planted (oats, cover crop mix and Jap radish).

This page provides a visual assessment of the performance of the crops within the trial site. The green cells depict the hedgerows.

- Plots 1-3 are control plots with no competition from the tree lines. Plot 1: Oats, Plot 2: Jap radish, Plot 3: Cover crop
- Plots 4-7 had intermediate competition. With trees only along one edge of each plot. Plot 4: Oats, Plot 5: Jap radish, Plot 6: cover crop, Plot 7: Oats
- Plots 8-9 had the most severe competition from the treelines on either side of the plots. Plot 8: Jap radishes, Plot 9: Cover crop.
- All plots were planted on the same day
- Note the gradients in plant height across Plots 5-7.

Figure 6.1 Status of the trial at Zwelisha, Bergville in May 2017.

Before the end of winter pasture growing season, Mr Mbhele’s dairy cows got into the trial site and grazed on the pastures. The lower part of the fence had been lying down because supporting standards had been stolen. The challenge of the fence disappearing had been ongoing since 2016 at the trial site, and Mr Mbhele was engaged about the ongoing challenges. He acknowledged that there is a serious problem with the fence being stolen, not only on the trial site, but across his farm. The general consensus between Mr Mbhele and the project team was to discontinue the trial due to ongoing challenges. However, there were some interesting lessons learnt from Mr Mbhele’s trial (Photograph 6.28).



Photograph 6.28 Photographs of the Bergville trial in June 2018: Trenches on either side of block (A), Pasture remaining after grazing (B), Maize oversown with oats – after being grazed (C), Jap radish after grazing (D), Maize oversown with oats in the control (E), and Fence on the ground after the theft of standards (F).

Management of competition for water

Poor germination and uneven growth of understorey crops have been experienced since the start of the trial with Mr Mbhele in Bergville, especially for the plots that are bound by tree hedgerows on both edges as seen in Photograph 6.29. One factor that has been suggested as contributing to this challenge has been the possibility of *Vachellia* trees competing with the crops for water (Photograph 6.29).

Photograph 6.29 Crops growing without (A) and with competition (B) from adjacent Vachellia trees at Zwelisha, Bergville.

The recommendation of cutting the branching fibrous roots of the *Vachellia* trees (i.e. practicing root pruning) has been tested at the site. This was discussed with farmers at the farmer's day held in May 2017 and the plan was to implement the intervention ahead of the summer growing season.

Block 3: Control No competition from trees			**Block 2** Intermediate competition from trees			**Block 1** Severe Competition from trees	
Plot 1							
Plot 2			Plot 4	Plot 6		Plot 8	
Plot 3			Plot 5	Plot 7		Plot 9	

Figure 6.2 Layout of the trial in Zwelisha, Bergville (green cells depict hedgerows).

The cutting of the branching roots was implemented by digging narrow trenches along the edges of the pasture plots in Block 1 and 2 (Figure 6.2). The activity of digging trenches took place in October 2017 before the planting of summer understorey crops (cocksfoot, lespedeza and maize). The trenches were dug at a width of 30 cm, knee height depth, and 5 meter length, at a distance of 1.5 m away from the trees. To prevent run-off and erosion, the trenches were staggered on either side of the plots so that there was not a long distance over which water can pick up velocity. The process and outcomes are captured in Photograph 6.30 to Photograph 6.33.

After the digging of tranches, it was observed that the understorey crops planted in summer were starting to grow even on the edges of the plots next to the trees, which had been a challenge since the start of the trial. At planting November 2017, a 4 m long root that had been cut emerged in the cocksfoot plot when the land was being worked. This was a clear indication that the roots had encroached into the plots before the trial started. They had grown thick enough to compete with the pastures for nutrients and water. There were no roots found below 15 cm when digging the trenches.

The planting of summer crops took place on 8 November 2017. The performance of the crops will be assessed through a participatory process with the farmers to determine whether the root pruning has been effective in reducing the obvious differences in performance of the crops across the three blocks.

Photograph 6.30 Trench digging depth, roots emerging in the upper layer of the soil and roots grew into the adjacent plots at Bergville.

Photograph 6.31 Roots branching from Vachellia trees to plots at Bergville.

Photograph 6.32 Planting in November 2017 (A) after digging the trench (B).

Photograph 6.33 Maize production adjacent to the trenches, growing similarly to the control plots, which suggests that the competition for water has been addressed.

6.2.3 Nutritional content of forage vs commercial feed products

Part of the work at Bergville involved nutrient comparison of commercial feed and fodder crops produced on farm. Destructive leaf sampling of *Vachellia* trees, cocksfoot and lespedeza was performed and samples were sent to the lab for nutrient content analysis. The findings were presented to the Bergville farmers during farmer field days.

Table 6.2 Nutrient content of commercial feed vs own produced feed

	Commercial Feed		Own Production		
Nutrients (g/kg)	**Meadow Multilak**	**Meadow TMR**	**Lespedeza**	**Cocksfoot**	***Vachellia* leaves**
CP	160	150	319.81	378.55	119.90
ADF	120	135	340.57	379.83	271.00
NDF	200	280	410.40	592.02	348.80
Ca	15	9.5	6.67	3.01	16.70
P		3	3.27	4.01	1.20

The *Vachellia* leaves were found to have a comparable crude protein (CP) content compared to the commercial products. Crude protein content of *Vachellia* leaves was 20-25% lower compared to the commercial products. The crude protein found in lespedeza and cocksfoot leaves was remarkably high when compared to the commercial products. The disadvantage with these home produced forage were the high levels of Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF). These are not particularly desirable in animal feed as they affect the digestibility of the forage/feed. Further work will be looking at creating a *Vachellia* tree feed ration and this should also look into exploring ingredients that would reduce the ADF and NDF to make the feed more digestible.

A recipe for a dairy ration using Vachellia leaves was obtained from Cedara and efforts were made to harvest and dry leaf material so that the recipe could be tested with the farmers. While the matter was discussed with farmers at the farmers' day, there was insufficient material to allow for the ration to actually be formulated.

Table 6.3 Acacia leaf dairy ration

	Chemical/nutrient composition (g/kg or MJ/kg)							Quantity	kg	Nutients fed (total kg or MJ)					
Ingredient	DM	CP	ADF	NDF	ME	Ca	P	as fed	DM	CP	ADF	NDF	ME	Ca	P
HPC	900	380	0	0	10	33	16	**20**	18	7.6	0	0	0.2	0.66	0.32
Maize Grain	880	80	26	80	12.4	0.4	2.6	**65**	57.2	5.2	1.69	5.2	0.806	0.026	0.169
Acacia leaves	955	200	169	195	9	6.1	1.8	**15**	14.7	3	2.535	2.925	0.135	0.0915	0.027
P12	980					240	120	**1**	1	0	0	0	0	0.24	0.12
salt	1000							**1**	1	0	0	0	0	0	0
								0	0	0	0	0	0	0	0
								0	0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
									0	0	0	0	0	0	0
Total kg/MJ nutrients in mix								**102**	91.9	15.8	4.225	8.125	1.141	1.0175	0.636
						Final mix g/kg nutrient DM				**172**	**46**	**88**	**12**	**11**	**7**
							Requirements								
							Difference								

6.2.4 Mrs Ndlovu's experimentation with pigeon pea

Mrs Ndlovu, who lives in Zwelisha, planted pigeon pea in October 2016 in her backyard garden. She was provided with seeds during a farmers' day. The pigeon pea did well in 2016/17 growing season even though it got frosted in winter 2017, regrowing in the spring after the first rains, and she managed to collect seeds from the plants to increase the planting area and to share with other women also working on Extended Public Works Programme (EPWP). However, the original plants were frosted again in winter 2018 and most did not survive. This confirms that medium duration (perennial) varieties are not suited to areas that experience severe frost. One option would be to try short duration varieties as an annual crop.

Photograph 6.34 Mrs Ndlovu's garden with pigeon pea.

6.2.5 Other research and extension activities

Testing of forage with farmers

Given that we are using multi-purpose legume trees that play a role as providing a source of high value fodder, it has been necessary to test the palatability of the material with farmers.

Highflats

Leaf material collected from pigeon pea and Sesbania sesban was tested as a winter feed supplement with Mr Mtshali at Highflats (Photograph 6.35). It was mixed with crushed maize and some water and offered to cattle. Ms Shezi tried feeding goats with green pigeon pea and dried Sesbania mixed with crushed yellow maize (Photograph 6.36).

Photograph 6.35 Grinding maize, mixing with dried leaf and feeding cattle to test usefulness of forage from Sesbania sesban and pigeon pea.

Photograph 6.36 Fresh pigeon pea leaves (A) and dried Sesbania leaves being tested with goats (B, C, D).

Swayimane

Fresh material removed from the hedgerows of the trial at Fountainhill was transported by vehicle to a group of smallholder farmers at Swayimane, which is approximately 20 km from the trial site (Photograph 6.37). The purpose of the activity was to test the palatability of the material and to create awareness about agroforestry and multi-purpose legume trees as a source of fodder.

Photograph 6.37 Material loaded at Fountainhill and fed to cattle at Swayimane, May 2017.

Testing pigeon pea as a foodstuff

A number of farmers have tested the acceptability and ease of preparation of pigeon pea. This is important as the labour required for harvesting and shelling the peas, is substantial and may preclude formal market chain access.

The pigeon peas are washed and soaked overnight before cooking. The use of a "wonderbag" was found to reduce the cooking time substantially and produce a softer product (Photograph 6.38). The pea can be used as a replacement for beans or lentils in soups, stews and curries.

Photograph 6.38 Pigeon peas can be prepared by washing, soaking and cooking. A "wonderbag" reduces cooking time substantially.

Sappi experience

Some pigeon pea was established at the Sappi nursery in Richmond in 2018. The staff at the centre were not familiar with pigeon pea but have been very happy with the performance of the trees and the good yields that they have obtained (Photograph 6.39). They have also cooked the grain and are happy with the results too. Mr Khubeka, who works with the Sappi Khulisa Programme sees opportunities to introduce pigeon pea as a way of diversifying small growers' farming systems in areas that do not experience frost.

Photograph 6.39 Sappi staff, Mrs Sithole and Mr Khubeka, with some of the harvested pigeon pea seed

Rabbits as a part of an integrated farming system

Efforts have been made through the on-farm work to promote rabbit keeping as an enterprise with potential to generate income and improve food security for rural women. We have also developed local skills in cage making. There are real opportunities to introduce rabbits into agroforestry systems, especially systems that use pigeon pea as the leaves, twigs and green pods have proved to be very palatable and provide a highly nutritious source of fodder for growing rabbits (Photograph 6.40).

Photograph 6.40 New Zealand Whites being supplemented with pigeon pea leaf and green pods (A) and local cage making skills being developed (B).

6.3 Farmer days

A number of field days have been held over the course of the project to share findings with farmers and get their feedback about what seems to offer opportunities for integration into their farming systems.

6.3.1 Bergville

Mr Mbhele is a mentor to other smallholder farmers from his village through the Grain SA program. The plan was to organize a field day through his group to share the lessons emerging from the site. An evaluation session was also held to inform what was to be planted in winter.

Two field days were organised by the INR team in 2016 for the purpose of sharing information on agroforestry to the community/farmers of Bergville. The first field day was held just before the end of the summer season (Photograph 6.41) and the second one was held in winter (Photograph 6.43). A presentation of the agroforestry concept was given to the farmers using posters and later there was a walk around the demonstration site to allow for discussion.

2016 summer event

Farmers showed great interest in agroforestry especially during this period of drought when there was limited food for livestock. The farmers were interested in knowing more about the fodder crops in terms of the how to acquire seeds, the agronomic practices associated with them and the right growth stage suitable for feeding livestock. It was further discussed that maybe it would be interesting to sample lespedeza at different growth stages and analyse for nutrients to see if quality of the fodder changes as the crop matures.

Photograph 6.41 Field day at the end of summer season (4 April 2016).

The farmers were surprised to discover that thorny trees like *Vachellia* were suitable for livestock feed. They however, enquired the method of preparing the feed since the leaves cannot be given to livestock with thorns. The method was discussed; Mr Bocibo (local field assistant) explained the harvesting and drying of the leaves and removal of thorns until the material is ready for consumption (Photograph 6.42). Mr Mbhele also added that he tried feeding his dairy cows, but it was a time consuming for him because it requires harvesting, drying and mixing. Mr Mbhele was interested in upscaling and planting lespedeza on a 2 ha piece of land.

The farmers were concerned by the poor growth of the fodder crops in the first plot (closely associated with the tree rows). They raised the issue of competition between the fodder crops and *V. karroo* trees as a possible reason of poor growth. Initially famers showed less interest in lespedeza as it was a new unknown crop. After explanations and demonstration, they showed interest in lespedeza and cocksfoot. Weed infestation was high in lespedeza plot. There was a concern about weeds outcompeting the fodder and the management. It was suggested that lespedeza seeds be planted in rows at a narrow spacing to facilitate hand weeding, rather than broadcasting. Though competition is an issue in agroforestry, proper management practices is the key to successful cropping system.

Photograph 6.42 Dried *Vachellia* leaves ready to be eaten by livestock.

Another interesting point to note is that one the farmers, when asked about the perceived benefits of agroforestry systems highlighted that the trees provide habitat for birds. This was clear from the large number of weaver bird nests hanging from the branches.

Weed control on the cocksfoot and lespedeza plots proved to be difficult due to the fact that cocksfoot is a grass species. When other types of grasses grow amongst the cocksfoot, it is not easy to differentiate for weeding purposes. Broadcasting the seeds at planting also contributed to difficulties of weed control. It was suggested that in future these crops should be planted in rows in order to improve the ease of weeding. This will however differ if the farmer were to grow fodder on a larger scale or if it were to oversown into maize.

2016 winter event

The winter field day was organised in collaboration with Farmer Support Group, outreach arm of UKZN, and this significantly improved the information dissemination because FSG works with many farmers in Bergville. The presentation of the agroforestry concept was an eye opener to many of the livestock farmers that were present. The farmers enquired about the ease of establishing trees such Acacia or *Vachellia* since they mostly grow naturally in the wild. It was clarified that, agroforestry is not only about *Vachellia* tree, they can explore other leguminous shrubs which grow fast and easy to establish. Ms Bhambabele (Currently doing MSc on agroforestry) was given a chance to talk about pigeon pea and other related shrubs. Farmers were eager to hear more about where they can get some oat seeds and any other fodder crop seeds.

The information sharing extended to the other village at Obonjaneni where FSG was hosting the rest of the farmers collaborating with other NGOs including Philakahle, Lima and World Vision (Photograph 6.44). Again the INR team gave a presentation on agroforestry and farmers suggested that this information would be very relevant to the Okhahlamba Livestock Association and recommended that such projects should be presented in such platforms. The event was attended by 60 farmers from Amangwane and Amazizi communities and other local NGO’s (World Vision, Philakahle and LIMA).

Photograph 6.43 Field day held in winter on the 6 July 2016

Photograph 6.44 Feedback about the trial at the Obonjaneni hall, part of a broader event.

2017 event

The farmers’ day was held on 25 May 2017, attended by 22 farmers and 2 extension officers from the Bergville office of KZN Department of Agriculture and Rural Development (Photograph 6.45). The day started with the introduction and background to the project, and challenges that have been experienced since the start of the trial in 2015. Photographic images of agroforestry systems were presented showing other project research sites such as Fountainhill Estate and Ixopo. Farmers were given an opportunity to walk about the trial site to capture their observations and thoughts of the performance of pastures planted in between Vachellia Karroo trees.

Photograph 6.45 Farmers visiting the trial site at Zwelisha, Bergville in May 2017.

Block 3 (Control)	**Block 2 Intermediate competition from trees**		**Block 1 Severe competition from trees**
Plot 1			
Plot 2	Plot 4	Plot 6	Plot 8
Plot 3	Plot 5	Plot 7	Plot 9

Figure 6.3 Layout of the trial at Zwelisha, Bergville.

Observations, comments and discussion points:

- Soils: Farmers observed that soils in the trial are different – for instance in block 1 and 3 (control). The slow growth of pastures in block 1 could somehow be attributed to this factor.
- Growth of pastures in block 1 & 2: Farmers noted the difference between the two treatments that the pastures that are closer to the trees are not performing well compared to the middle of the plots. They could clearly see this difference in the 2 oats plots planted in block 2.
- When farmers got to block 3 (control) – they noticed a big difference in that the soils wee different and the pastures were growing much quicker compared to blocks 1 & 2. It was clarified that all plots were planted on the same day 29 March 2017. It was also explained that since block 3 is a control, pastures were planted at 8 m away from the trees to prevent competition. Farmers including Mr Mbhele emphasised that the trees do have a negative effect in the growth of trees due to the root system that is spreading, given that the trees had been there for more than ten years. Mr Mbhele further highlighted to farmers that *Vachellia Karroo* is not invasive – the natural grass continues to grow underneath the trees. If it were invasive there will be little or no grass growing under the trees. The control looks impressive and farmers could observe a clear difference between the 2 treatments and control.
- Fertility: Farmers also advised that fertilizer should be added when planting pastures, it seems like there is no fertility in the soil. The team further explained that the idea with agroforestry is to minimise the use of chemical fertiliser but rely on species that are able to fix nitrogen in the soil.
- Weed control methods: The team explained to farmers that the natural grass had out-competing the planted species. Pre-emergence herbicide has been used to control weeds – the spraying happened in February 2017 before planting at end of March 2017.

- Erosion control: Farmers wanted to know why there were swales in the trial. The team explained that since 2015 when the trial started, seeds had been washed from top to bottom of each plot. As a result summer pastures (cocksfoot and lespedeza) planted in November 2016 were a complete failure. The swales were a measure to minimise run-off and a technology used as in-field rainwater harvesting tried in Msinga and Eastern Cape. They has made a difference and germination has improved.

6.3.2 Ixopo

A farmers' day was held on 14 April 2016 at Emazabekweni village, Ixopo (Photograph 6.45). The event was attended by fifteen farmers who are members of Ubuhlebezwe Livestock Association. The main purpose of the event was to visit the experimental trials being conducted at five farms, which are situated at Nokweja, Mhlabashane and Emazabekweni villages. The purpose of the field day was to inform farmers about agroforestry and show them the trials that are being conducted with five farmers actively involved in experimentation. Farmers' questions were mainly based on the benefits of agroforestry with regards to livestock production. The five farmers involved in experimentation presented progress in their respective trials. Two sites (Chief Dlamini and Mr Mtshali) were later visited to observe the trials. Farmers whose sites were not visited had taken pictures and shared them during presentations; this is one method of farmer-led documentation that farmers have started to use.

The trial of Mr Mtshali consists of intercropping kikuyu with pigeon pea, at Mr Mtshali's the farmers observed the five month recovery of kikuyu in the trial, which points out the significance of resting pastures. However the kikuyu has recovered and growing faster than pigeon pea. The issue of competition between pigeon pea and the kikuyu was observed by farmers. If allowed to grow bigger, the kikuyu could pose more competition to the pigeon pea. Therefore a decision was made to cut the kikuyu grass and feed it to livestock. This would reduce competition and allow the pigeon pea to grow adequately. It was observed that the Sesbania trees were shedding leaves. At the time of the farmers day the INR team was not yet aware that the species planted was *S. bispinosa* and not *S. sesban* and thus the drying off was as a result of it being an annual rather than a perennial species. During discussion in mid-winter farmers shared that the trees planted and pigeon peas had not been affected by frost, which was promising for the adoption of agroforestry in the longer term.

Photograph 6.46 Farmers at Chief Dlamini observing the growth of faidherbia tree in the maize field.

The experimental trials conducted with farmers have so far been doing well and encouraging farmers. They were confident that by the end of three years they would have benefited from new knowledge about agroforestry.

6.3.3 Wartburg

2017 event

The farmer's day was held on 3 May 2017 at Fountainhill Estate and farmers from Ixopo in Highflats and KwaSwayimane were invited to take part in the day (Photograph 6.47). The trials were visited where most of the discussion took place. The students working on the project presented their work, sharing with the farmers what their trials were all about. Farmers were showed around the trials, explaining the systems they are testing and the tree species used. After the field visit, there was a short session back at the conference room to reflect back on what was presented and getting farmers thoughts on the different systems at Fountainhill comparing with their experiences on farm.

Farmers perceived agroforestry as a great intervention as it provides multiple benefits such as:

- Soil improvements
- Livestock fodder.

The day was beneficial in expanding farmers' knowledge about agroforestry. Mr Khuzwayo from Swayimane mentioned that he saw the fallow systems relevant especially during this critical time of climate change and over-usage of soil which leads to soil degradation. He added that natural fallow has been the only systems they knew and it takes a long time, this was a good alternative to him. MamJoyce Dlamini added that although she is one of the experimenting farmers, she got more insight on the benefits and options available. One of the farmers (Mr Khuboni) mentioned that the project should investigate ways of linking agroforestry into a value chain. Farmers emphasised that what is being done here was under controlled conditions, and questioned its feasibility in an open access area. The issue of fencing as a pre-requisite for adoption as well as access to planting material was highlighted by all farmers in attendance.

Photograph 6.47 Farmers visiting the trial site at Fountainhill Estate in May 2017.

Questions about what is required to sustain agroforestry were discussed as follows:

- Value chain analysis and market availability of tree bi-products was raised as something that farmers would want to learn about.
- The farmers also mentioned that fact that they see the need to organise themselves as farmers in the community in order to ensure self-sustainability even when the project support is not there. There needs to be strengthening of institutional arrangements.
- Mr Khuboni suggested that going forward they should come up with a plan that will detail how they want to take things forward as farmers. So they needed to know what resources are

available, what type of capacity building they need and where they want to see agroforestry going forward at a given time frame.

- The project team suggested that farmers should organise themselves into an “interest group” with lead farmers to facilitate what Mr Khuboni was suggesting and also facilitate knowledge transfer to the broader community going forward. It was also added that it is important to clarify with farmers that some of the issues of adoption of research cannot be addressed within the timeframe of the project, but discussions on issues such as availability of planting material to farmers can be facilitated.
- Miss Joyce Dlamini also highlighted that since the seeds of these tree species are not readily available, local farmers should be trained on how to establish seedling nurseries.

2018 event

In March 2018, famers from Ixopo and Swayimane participated in the farmer’s day held in Wartburg at the research site at Fountainhill Estate (Photograph 6.48). The event was also attended by two extension officers of the uMngeni Resilience Project implemented by University of KwaZulu-Natal with Swayimane farmers. Farmers gave feedback to the research team comparing the different systems, and their practices. The research team explained the different systems to farmers and farmers were able to understand the difference between the biomass transfer being practiced on-farm and the improved fallow system in Wartburg. Farmers made their observation based on the growth of maize in the improved fallow that it is quite clear that the trees have restored fertility to better support the maize.

Photograph 6.48 Farmer field day at Wartburg in March 2018 (A) and Mr Mkhize sharing his knowledge at farmers day (B).

6.3.4 UKZN honours students 2019

Two students from University of KwaZulu-Natal, supervised by Karen Caister, undertook some field work in Ixopo/Highflats towards their Honours degrees in Agricultural Extension Practice. The two students Snegugu Mvelase and Mthobi Zulu were introduced to the farmers by Zanele Shezi who works for INR, and were assisted in the field by Ms Phumele Shezi, who has been working informally with us on the project for some time. The inputs from their reports will also contribute to the extension guidelines being prepared through this project because they discussed farmers’ experiences with the agroforestry on-farm research that has been implemented.

6.4 Conclusion

The work with smallholder farmers at Zwelisha near Bergville and at Ixopo/Highflats provided a lot of useful lessons that complemented the formal research trials and Empangeni and Wartburg. Making use of the old agroforestry research trial at Zwelisha was an opportunity for us to learn how to manage the competition that established trees (in this case *Vachellia karroo*) can exert on the understorey crop. However, the experimentation was a challenge because the farmer who owned the site was not always in Zwelisha and his staff sometimes allowed his cattle to access the trial site. Furthermore he was facing problems with theft of fencing, which also affected the trial and finally led to our decision to terminate activities.

The work with the group of farmers at Highflats was an opportunity to address new woody species and new cropping systems to farmers. They had never heard of the concept of agroforestry. Quite quickly we all became aware of the highly competitive nature of *S. sesban* and realised that it could not be effectively grown with maize. Some farmers saw the soil improvement that resulted from the S. sesban and others saw the value of the multi-purpose species for fodder production. The testing of dried leaf material for feeding livestock looked promising but farmers do not yet have enough trees to be able to harvest substantial volumes, however a number of livestock owners were feeding fresh material to their livestock.

The farmers' days at Fountainhill Estate provided an opportunity for farmers to see what we were doing, to make suggestions about how the crops could have been managed differently. The farmers days at the sites where we were engaged in participatory action research allowed for much discussion and sharing of information.

While we cannot yet be sure whether farmers will continue to plant and use these new tree species in the future, there certainly seems to be interest though in some cases the local climatic conditions have proved unsuitable for species that are not frost tolerant. One of the valuable outcomes of the WRC project is that the INR has been able to establish a relationship with farmers at Highflats/Ixopo and if it is possible to maintain this relationship, then it will also be possible to see how the integration of agroforestry species persists.

7 COST BENEFIT OF ANALYSES OF VARIOUS AGROFORESTRY SYSTEMS

7.1 Introduction

Agroforestry systems have been recognised as sustainable land-use management practices with the potential to provide environmental and socioeconomic benefits (Alavalapati et al., 2004). In addition, agroforestry systems have been shown to be financially viable and attractive at the household/farmer scale (Alavalapati and Mecer, 2004). A key factor influencing the adoption of agroforestry systems are their relative profitability compared to alternative production systems at the household level (Alavalapati et al., 2004). Assessing the benefits and costs of agroforestry systems compared to monocrop systems from a household or farmer perspective is important for providing information that can be incorporated into practical guidelines for extension officers to advise farmers on appropriate agroforestry practices. Farmers adopting agroforestry systems obtain increased financial benefits, relative to monocrop practices, largely through increased biophysical productivity or through reduced input costs. As part of this research project, technical elements, biophysical outcomes, financial information and social factors related to agroforestry systems are being assessed through several research trials and farmer engagement activities. This component of the research contributes to the overall aims of the WRC project, specifically:

- To determine economic and social benefits and costs of the agroforestry systems, and
- To develop guidelines for extension on agroforestry systems.

For agroforestry to achieve its full potential in South Africa, adequate information on both technical and financial aspects needs to be provided. The aim of this component of the project was to generate information on the relative financial costs and benefits of agroforestry systems compared to monocrop systems that can be incorporated into practical guidelines for extension officers to advise farmers in selecting appropriate agroforestry systems and practices. The specific objectives of the study were to:

1) Assess the financial costs and benefits at the household/farmer scale of several agroforestry systems relative to monocrop systems, based on the research trials;
2) Integrate the financial information generated from assessing the research trials into practical guidelines for extension officers to advise farmers in selecting appropriate agroforestry systems and practices.

The project team recognises that this approach addresses only the financial aspect of agroforestry systems, whereas agroforestry systems also have the potential to provide significant ecological and socio-economic benefits. To better address these additional benefits, the first stage of this component of the research was to compile and interrogate a suite of potential benefits that included ecological, social, and financial dimensions.

7.2 Costs and benefits of agroforestry systems

A list of some costs and benefits of agroforestry systems was developed drawing from the literature. These included financial, ecological/ecosystem and social benefits and costs (Table 7.1 and Table 7.2). These are some of the aspects that were given consideration when undertaking the cost benefit analysis above. Anyone encouraging the adoption of agroforestry systems should be aware of the information contained in the tables below.

Table 7.1: Potential benefits of agroforestry systems in general (extracted from the literature)

Attribute	Physical benefit	Financial benefit (farmer)	Financial benefit – measure/indicator	Ecological benefit	Social benefit	Examples of trees
Nitrogen fixation	Improved soil fertility	Reduced production costs Increased income	Fertilizer use Yields	No/reduced inorganic fertilizer reduces nutrient loads to aquatic ecosystem	Improved food availability Improved livelihoods	Any legumes (i.e. pigeon pea, Sesbania, Acacia)
Nutrient inputs from the fallow (mulch)	Improved soil fertility	Reduced production costs Increased income	Total biomass P, K, Ca, Mg added	No/reduced inorganic fertilizer reduces nutrient loads to aquatic ecosystem	Improved food availability Improved livelihoods	
Ability of trees to extract deep water	Improve use of available water below root zone of understory crop	Reduce irrigation need (enables production in drier areas/during dry spells)	Water use Yields	Water conservation	Improved production – fuel, nutrients, or fodder	Deep rooted trees (e.g. *Faidherbia albida*, *Sesbania sesban*)
Shading	Reduce evaporative losses	Reduce irrigation need	Water use	Water conservation	Reduced labour/financial cost of irrigation	Pigeon peas
Nutrient cycling (root mass, leaf litter)	Increase the water holding capacity of the soil through increased organic matter content. Improved soil fertility	Reduce irrigation need Reduce fertilizer cost Higher yields (income)	Water use Fertilizer use Yields	Water conservation Soil conservation	Food security Improved livelihoods	*F. albida* , pigeon pea
Fodder for livestock	Fodder/grass Improved manure production	Improved livestock condition & productivity Yields of milk, meat, manure	Nutrient content Yields of milk, meat, manure	Improved manure production	Food security Improved livelihoods	Pigeon pea, Sesbania

Attribute	Physical benefit	Financial benefit (farmer)	Financial benefit – measure/indicator	Ecological benefit	Social benefit	Examples of trees
Food for humans (e.g. fruit trees)	Fruit	Sale of products (fruits, nuts & seeds)	Yields of fruits, nuts and seeds		Food security Improved livelihoods Nutritional benefits, e.g. pigeon pea	Fruit trees [exotic (e.g. oranges) or indigenous (marula)], nuts (e.g. almond), seeds (e.g. pigeon pea)
Medicinal benefits	Insect repellents, Snake repellents	Sale of products (medicinal plants & extracts)	Yields of medicinal plants	Reduced wild harvesting	Cultural benefits Health benefits	Moringa, F. albida, Indigenous woody species (e.g. Lippia javanica, umhlonyane – Artemisia afra, rooi bos)
Fuel (biofuels and fuelwood)	Fuel	Fuel for sale and/or home use (income and/or reduced costs)	Yields	Reduce pressure on natural forests	Access to energy (security)	Gums, pine trees, Sesbania, Jatropha, Acacia
Hardwood		Planks for furniture, carving	Quantity/yield	Reduce harvesting from natural forests and woodland Long-term soil stabilisation	Improved livelihoods	Gum, pines, oak, Deodar Indigenous trees (some require permits)
Soil cover & roots	Reduced soil erosion Improved soil microbial content Improved soil physical and chemical properties Improved soil moisture	Higher production	Yield	Soil conservation, reduce downstream impacts, Long-term soil stabilization		All
Barriers around croplands that prevent livestock damage	Allow for retention of crop residues	Reduce crop/yield losses Reduced fencing costs	Yields 'saved' Spending on fencing	Improved soil and water conservation	Reduce livestock damage and related conflict	Kei apple (Dovyalis caffra), aloes, Num Nums (Carissa macrocarpa)

Attribute	Physical benefit	Financial benefit (farmer)	Financial benefit – measure/indicator	Ecological benefit	Social benefit	Examples of trees
(Agro)-Biodiversity	Improved insect diversity (e.g. pollination) Biocontrol of pests and diseases Habitat for birds	Reduce crop/yield losses (buffer mechanism against harvest failure) Improved yields Reduced costs (labour and production)	Yields Cost savings	Promote biodiversity Reduced pesticide use	Livelihood security Risk reduction Improved health Improved aesthetics	A variety of species
Climate change mitigation	Carbon sequestration	Carbon credits	t C per hectare	Build ecological resilience		Spekboom (Portulacaria afra)
Climate change adaptation	Through other services (soil and water conservation; species diversity; soil fertility, etc.)	More stable yields	Yields over time		Build household resilience	
Market niche		Price premium for organic /LEISA produce	Price premium	Reduced use of chemicals	Improved livelihoods	
Availability of germplasm/planting material		Sale of seedlings Reduced cost of purchasing	Number of seedlings produced per unit area	Improved planting of trees	Local knowledge Improved livelihoods	

Table 7.2: Potential costs associated with agroforestry systems (extracted from the literature)

Attribute	Financial cost	Financial cost-measure/indicator	Ecological cost	Social costs
Direct costs				
Opportunity cost of alternative agricultural systems			None	
Inputs (especially planting material	Cost of purchasing or propagating	Shadow pricing	Use of invasive species can lead to degradation	May require good relations with neighbours that have trees
Labour	Financial cost/time commitment	Local rate	None	Potentially dependence on family for labour
Indirect costs				
Transaction costs for setting up the system – access to extension services, access to tree/shrub seed(lings)	Transaction costs			Public sector support/subsidies
Management and planning of system (to avoid negative combinations)	Time cost (research, planning harvests, etc.)	Rate 1 to 5 relative to monocrop/traditional system	None	Change in mind set Rate 1 to 5 relative to monocrop/traditional system
Competition between species (light, water, nutrients)	Reduced yields Reduced income	Yields	None	Negative impact on food security
Acceptability (e.g. fear of snakes, perceptions of fallows being waste, introduction of new weeds)	Costs of adoption	Scale (rate)	None	Conflicts with neighbours Family unwilling to work in fields Legalities

7.3 Cost-benefit analysis approach

A cost-benefit assessment of several agroforestry production systems compared to their conventional alternative production systems was undertaken using a partial farm budget (gross margin) approach considering only the costs and benefits associated with each production system (e.g. only variable costs were considered). The Net Present Value (NPV) and Benefit-Cost (B-C) ratio appraisal indicators were used to compare the two systems. The data and values used in the cost-benefit assessment were based on the results of the trials from the project and converted to R/ha. Market/farm gate prices were used.

The net present value is the difference between the present value of cash inflows (benefits) and the present value of cash outflows (costs) over a period of time. A positive net present value indicates that the projected earnings generated by the production system over the cycle exceed the anticipated costs. The costs and benefits associated with the production systems accrue at different points in time; discounting is used to bring future benefits and costs to equivalent 'present' values so that they may be compared. Following Mullins et al. (2014) an 8% discount rate was used in calculating the net present values. The discount rate can have a significant impact of the net present values and therefore the decision outcomes. A sensitivity analysis was performed using discount rates of 6% and 10.5% (the SA lending rate for 2018). The timeframe used were based on the cropping cycle of the systems. Variation in labour intensity across the different production systems is of particular interest and labour costs were reflected as a separate cost component. A rate of R100/day was used to reflect the labour cost because this is the rate paid by members of rural communities; however this is lower than the present minimum wage. The effect of changing labour rates was investigated as a sensitivity analysis: a lower rate (R50/day) reflects the rate paid locally in some rural communities while the higher rate (R160/day) reflects current minimum wage.

"Taking into account the international discount rate benchmarks and the marginal return on capital approach, the current "official" **8 percent discount rate** applicable in South Africa still seems to be reasonably applicable for both inter and intra-generational discounting" (Mullins et al., 2014).

The benefit-cost ratio is an indicator showing the relationship between the relative costs and benefits of the production system, expressed in monetary terms. If a project has a B-C ratio greater than 1.0, the system is expected to deliver a positive net present value to the farmer (i.e. the benefits exceed the costs over the timeframe considered). If the B-C ratio is less than 1.0, the system's costs exceed the benefits over the timeframe (production cycle).

7.4 Results

7.4.1 Silvopastoral system

A cost-benefit assessment of a silvopastoral production system (*P. maximum* and pigeon pea) and the alternative, a conventional pasture system (*P. maximum*) was undertaken. A five-year timeframe was used, based on the cropping cycle of the silvopastoral system, and an 8% discount rate. Sensitivity analyses were performed to investigate the effect of varying the discount rate (10.5% and 6%) and the labour rate (R50/day and R160/day).

The results of the cost-benefit analysis are presented in Table 7.3 and the appraisal indicators are summarised in Table 7.4. Key findings are highlighted in the points below.

- The NPV is positive for both production systems, indicating that the benefits are greater than the costs for each system over the 5-year cycle.

- The NPV is higher for the silvopastoral system than for the conventional pasture system, indicating that the silvopastoral system generates greater earnings per ha under production than the conventional system over the 5-year cycle. This is due to the additional fodder (tree biomass) and grain benefits produced in the silvopastoral system.
- For the silvopastoral system, the cash flow for the first year is negative, indicating that the expected costs (cash outflows) exceed expected benefits (cash inflows) for the first year. For the conventional system, the cash flow across all years is positive.
- The B-C ratio is greater than 1.0 for both systems indicating that the benefits exceed the costs across the 5-year period for both systems.
- The B-C ratio for the conventional pasture system is higher than for the silvopastoral system, indicating that a greater benefit is generated per unit cost in the conventional system than in the silvopastoral system. The silvopastoral system has higher variable costs than the conventional pasture system, however, it also generates a higher cash flow (gross margin per ha) than the conventional system.
- Even at a higher discount rate (10.5%), the NPV for both the production systems remains positive over the 5-year period.
- The labour expense is the main driver of cost in the silvopastoral system (and primary reason for the difference in cost for the two systems); factors affecting the labour rate and labour availability are important considerations in comparing the two production systems. The sensitivity analysis of the labour rate confirms the effect of the labour cost on the financial profitability of the system. A lower rate of R50/day improves the negative cash flow in the first year of the silvopastoral system to a positive cash flow and improves the B-C ratio. Under a lower labour rate, the B-C ratios indicate that a greater benefit is generated per unit cost in the silvopastoral system than in the conventional system.

Table 7.3 Comparison of the costs and benefits of the silvopastoral and conventional pasture production systems (R/ha, 2018)

SILVOPASTORAL SYSTEM AND CONVENTIONAL PASTURE SYSTEM (R/ha, 2018)										
Costs and benefits	SILVOPASTORAL SYSTEM					CONVENTIONAL SYSTEM				
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	**6,094.39**	**7,532.74**	**7,532.74**	**7,532.74**	**8,693.45**	**4,033.30**	**1,372.02**	**1,372.02**	**1,372.02**	**1,372.02**
Cash expenses	2,493.20	955.36	955.36	955.36	955.36	2,485.68	955.36	955.36	955.36	955.36
Land preparation (contractor)	1,000.00	0.00	0.00	0.00	0.00	1,000.00	0.00	0.00	0.00	0.00
Grass seed (P. maximum)	1,008.00	0.00	0.00	0.00	0.00	1,008.00	0.00	0.00	0.00	0.00
Tree seed (pigeon pea)	7.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mower hire & fuel (grass cutting)	477.68	955.36	955.36	955.36	955.36	477.68	955.36	955.36	955.36	955.36
Labour costs	3,601.19	6,577.38	6,577.38	6,577.38	7,738.10	1,547.62	416.67	416.67	416.67	416.67
Plant trees (pigeon pea)	892.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant grass (P. maximum)	446.43	0.00	0.00	0.00	0.00	446.43	0.00	0.00	0.00	0.00
Weed	892.86	0.00	0.00	0.00	0.00	892.86	0.00	0.00	0.00	0.00
Cut grass - 1st cutting (Nov)	0.00	208.33	208.33	208.33	208.33	0.00	208.33	208.33	208.33	208.33
Cut grass - 2cd cutting (April)	208.33	208.33	208.33	208.33	208.33	208.33	208.33	208.33	208.33	208.33
Prune trees - 1st (Nov)	0.00	1,160.71	1,160.71	1,160.71	1,160.71	0.00	0.00	0.00	0.00	0.00
Prune trees - 2st (Feb)	0.00	1,160.71	1,160.71	1,160.71	1,160.71	0.00	0.00	0.00	0.00	0.00
Prune trees - 3rd (May/Jun)	1,160.71	1,160.71	1,160.71	1,160.71	0.00	0.00	0.00	0.00	0.00	0.00
Harvest grain (Nov)	0.00	2,678.57	2,678.57	2,678.57	2,678.57	0.00	0.00	0.00	0.00	0.00
Cut trees (May/Jun)	0.00	0.00	0.00	0.00	2,321.43	0.00	0.00	0.00	0.00	0.00
BENEFITS	**5,899.02**	**18,180.37**	**16,400.00**	**15,375.00**	**21,050.00**	**5,268.89**	**5,902.78**	**5,500.00**	**4,800.00**	**4,000.00**
Fodder - hay (Nov)	0.00	3,777.78	3,700.00	3,600.00	3,500.00	0.00	3,627.78	3,500.00	3,000.00	2,500.00
Fodder - hay (April)	3,511.67	2,766.67	2,500.00	2,300.00	2,200.00	5,268.89	2,275.00	2,000.00	1,800.00	1,500.00
Fodder - tree biomass (Nov)	0.00	1,189.96	1,100.00	1,000.00	900.00	0.00	0.00	0.00	0.00	0.00
Fodder - tree biomass (Feb)	0.00	3,894.43	3,600.00	3,400.00	3,200.00	0.00	0.00	0.00	0.00	0.00
Fodder - tree biomass (May/Jun)	2,387.36	3,066.61	2,800.00	2,600.00	9,000.00	0.00	0.00	0.00	0.00	0.00
Grain - tree seed (Nov)	0.00	3,484.93	2,700.00	2,475.00	2,250.00	0.00	0.00	0.00	0.00	0.00
Cash flow	(195.37)	10,647.63	8,867.26	7,842.26	12,356.55	1,235.59	4,530.75	4,127.98	3,427.98	2,627.98

Table 7.4 Summary of appraisal indicators for the silvopastoral and conventional pasture production systems at varying discount rates (6%, 8% and 10.5%), across a 5-year time frame

Tillage system	Indicator	6%	8%	10.5%
	Net present value	34,113	32,574	30,803
Silvopastoral system	Benefit-cost ratio	2.03	2.02	2.01
	Net present value	14,144	13,623	13,020
Conventional pasture	Benefit-cost ratio	2.61	2.59	2.56

The effect of changing labour rates was investigated as a sensitivity analysis and the comparison is provided in Table 7.5. The lower rates reflect the rates paid locally in rural communities while the rate of R160/day reflects current minimum wage.

Table 7.5 Sensitivity analysis for silvopastoral and conventional pasture considering labour rates of R50/day, R100/day and R160/day

Labour rate R50/day											
Costs and benefits	SILVOPASTORAL SYSTEM						CONVENTIONAL SYSTEM				
	Year 0	Year 1	Year 2	Year 3	Year 4		Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	4,294	4,244	4,244	4,244	4,824		3,259	1,164	1,164	1,164	1,164
Cash expenses	2,493	955	955	955	955		2,486	955	955	955	955
Labour costs	1,801	3,289	3,289	3,289	3,869		774	208	208	208	208
BENEFITS	5,899	18,180	16,400	15,375	21,050		5,269	5,903	5,500	4,800	4,000
Cash flow	**1,605**	**13,936**	**12,156**	**11,131**	**16,226**		**2,009**	**4,739**	**4,336**	**3,636**	**2,836**
Labour rate R100/day											
Costs and benefits	SILVOPASTORAL SYSTEM						CONVENTIONAL SYSTEM				
	Year 0	Year 1	Year 2	Year 3	Year 4		Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	6,094	7,533	7,533	7,533	8,693		4,033	1,372	1,372	1,372	1,372
Cash expenses	2,493	955	955	955	955		2,486	955	955	955	955
Labour costs	3,601	6,577	6,577	6,577	7,738		1,548	417	417	417	417
BENEFITS	5,899	18,180	16,400	15,375	21,050		5,269	5,903	5,500	4,800	4,000
Cash flow	**(195)**	**10,648**	**8,867**	**7,842**	**12,357**		**1,236**	**4,531**	**4,128**	**3,428**	**2,628**
Labour rate R160/day											
Costs and benefits	SILVOPASTORAL SYSTEM						CONVENTIONAL SYSTEM				
	Year 0	Year 1	Year 2	Year 3	Year 4		Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	8,255	11,479	11,479	11,479	13,336		4,962	1,622	1,622	1,622	1,622
Cash expenses	2,493	955	955	955	955		2,486	955	955	955	955
Labour costs	5,762	10,524	10,524	10,524	12,381		2,476	667	667	667	667
BENEFITS	5,899	18,180	16,400	15,375	21,050		5,269	5,903	5,500	4,800	4,000
Cash flow	**(2,356)**	**6,701**	**4,921**	**3,896**	**7,714**		**307**	**4,281**	**3,878**	**3,178**	**2,378**

Note: Negative cash flows shown in red

7.4.2 Improved fallow system

A cost-benefit assessment of an improved fallow production system (pigeon pea and maize) and the alternative, a conventional sole maize system was undertaken. A four-year timeframe was used, based on the cropping cycle of the improved fallow system, and an 8% discount rate. Sensitivity analyses were performed to investigate the effect of varying the discount rate (10.5% and 6%) and the labour rate R50/day and R160/day).

The results of the cost-benefit analysis are presented in Table 7.6 and the appraisal indicators are summarized in Table 7.7. Key findings are highlighted in the points below:

- The NPV is negative for both production systems, indicating that the costs exceed the benefits for each system over the 4-year cycle. The NPVs remain negative under both a lower (6%) and higher (10.5%) discount rate.
- The NPV is higher for the improved fallow system than for the conventional maize system, indicating that the improved fallow system generates greater earnings per ha than the conventional system over the 4-year cycle. This is due to higher maize grain and stover yields under the improved fallow system as well as the additional benefits of the pigeon pea seed grain and fuel wood.
- For the improved fallow system, the present values of the cash flows for the second two seasons are positive, but the increase in benefits (cash inflows) is insufficient to offset the losses in the first two seasons.
- For the sole maize system, the benefits (cash inflows) decline over the four years due to declining maize yields. Cash flows are negative for all four periods.
- The B-C ratio is less than 1.0 for both systems indicating that the costs exceed the benefits across the 4-year period for both systems.
- The B-C ratio for the improved fallow system is 0.94, indicating that the costs only just exceed the benefits and the production system almost breaks even. The B-C ratio for the sole maize system is much lower (0.56) and indicates that the costs are almost double the benefits.
- The costs (present value) of the two systems are very similar; the benefits (present value) of the improved fallow system are greater than the benefits of the sole maize system. The present value of the benefits of the improved fallow system exceed that of the sole maize system by R19 382/ha.
- For the improved fallow systems, cash inflows are the lowest in the first year; while for the sole maize system cash flows are lowest in the last year.

Table 7.6 Comparison of the costs and benefits of the improved fallow and sole maize production systems (R/ha, 2018)

IMPROVED FALLOW AND SOLE MAIZE SYSTEMS (R/ha, 2018)								
Costs and benefits	IMPROVED FALLOW				SOLE MAIZE			
	Year 0	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2	Year 3
COSTS (variable costs)	**18,492.34**	**11,458.33**	**13,823.79**	**13,823.79**	**15,823.79**	**13,823.79**	**13,823.79**	**13,823.79**
Cash expenses	2,067.50	0.00	550.00	550.00	2,550.00	550.00	550.00	550.00
Land preparation (contractor)	2,000.00	0.00	0.00	0.00	2,000.00	0.00	0.00	0.00
Pigeonpea seed	67.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maize seed	0.00	0.00	550.00	550.00	550.00	550.00	550.00	550.00
Labour costs	16,424.84	11,458.33	13,273.79	13,273.79	13,273.79	13,273.79	13,273.79	13,273.79
Plant pigeon pea	651.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weed	4,761.90	0.00	4,761.90	4,761.90	4,761.90	4,761.90	4,761.90	4,761.90
Weed	4,761.90	0.00	4,761.90	4,761.90	4,761.90	4,761.90	4,761.90	4,761.90
Harvest pigeon pea	4,464.29	4,464.29	0.00	0.00	0.00	0.00	0.00	0.00
Shell pigeon pea	1,785.71	1,785.71	0.00	0.00	0.00	0.00	0.00	0.00
Pigeonpea fallow termination	0.00	5,208.33	0.00	0.00	0.00	0.00	0.00	0.00
Plant maize	0.00	0.00	892.86	892.86	892.86	892.86	892.86	892.86
Harvest maize - grain	0.00	0.00	535.71	535.71	535.71	535.71	535.71	535.71
Harvest maize - stover	0.00	0.00	535.71	535.71	535.71	535.71	535.71	535.71
Harvest maize - shell	0.00	0.00	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71
BENEFITS	**4,828.50**	**12,100.00**	**20,621.65**	**18,559.48**	**14,392.86**	**16,828.57**	**9,740.71**	**7,305.54**
Pigeonpea seed grain	4,828.50	7,425.00	-	-	0.00	0.00	0.00	0.00
Pigeonpea fuel wood	-	4,675.00	-	-	0.00	0.00	0.00	0.00
Maize grain	-	-	15,942.86	14,348.57	14,392.86	13,285.71	7,683.57	5,762.68
Maize stover	-	-	4,678.79	4,210.91	3.828.57	3,542.86	2,057.14	1,542.86
Cash flow	(13,663.84)	641.67	6,797.86	4,735.69	(1,430.93)	3,004.78	(4,083.08)	(6,518.25)

Table 7.7 Summary of appraisal indicators for the improved fallow and sole maize production systems at varying discount rates (6%, 8% and 10.5%), across a 4-year time frame

Tillage system	Indicator	6%	8%	11%
Improved fallow	Net present value	(3,032)	(3,482)	(4,006)
	Benefit-cost ratio	0.94	0.93	0.92
Sole maize	Net present value	(7,703)	(7,324)	(6,887)
	Benefit-cost ratio	0.85	0.86	0.86

The effect of changing the labour rate was investigated and was found to have a large effect on the viability of the different systems. The rates paid locally for hired help will thus affect farmers' choice to adopt agroforestry systems. At the rate set by government as minimum wage, neither system is viable.

Table 7.8 Sensitivity analysis for improved fallow and sole maize considering labour rates of R50/day, R100/day and R160/day

Labour rate R50/day								
Costs and benefits	**IMPROVED FALLOW**				**SOLE MAIZE**			
	Year 0	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2	Year 3
COSTS (variable costs)	10,280	5,729	7,187	7,187	9,187	7,187	7,187	7,187
Cash expenses	2,068	-	550	550	2,550	550	550	550
Labour costs	8,212	5,729	6,637	6,637	6,637	6,637	6,637	6,637
BENEFITS	4,829	12,100	20,622	18,559	14,393	16,829	9,741	7,306
Cash flow	**(5451.42)**	**6370.83**	**13434.74**	**11372.57**	**5205.95**	**9641.66**	**2553.80**	**118.63**
Labour rate R100/day								
Costs and benefits	**IMPROVED FALLOW**				**SOLE MAIZE**			
	Year 0	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2	Year 3
COSTS (variable costs)	18,492	11,458	13,824	13,824	15,824	13,824	13,824	13,824
Cash expenses	2,068	-	550	550	2,550	550	550	550
Labour costs	16,425	11,458	13,274	13,274	13,274	13,274	13,274	13,274
BENEFITS	4,829	12,100	20,622	18,559	14,393	16,829	9,741	7,306
Cash flow	**(13663.84)**	**641.67**	**6797.86**	**4735.69**	**(1430.93)**	**3004.78**	**(4083.08)**	**(6518.25)**
Labour rate R160/day								
Costs and benefits	**IMPROVED FALLOW**				**SOLE MAIZE**			
	Year 0	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2	Year 3
COSTS (variable costs)	28,347	18,333	21,788	21,788	23,788	21,788	21,788	21,788
Cash expenses	2,068	-	550	550	2,550	550	550	550
Labour costs	26,280	18,333	21,238	21,238	21,238	21,238	21,238	21,238
BENEFITS	4,829	12,100	20,622	18,559	14,393	16,829	9,741	7,306
Cash flow	**(23518.77)**	**(6233.33)**	**(1166.44)**	**(3228.61)**	**(9395.23)**	**(4959.52)**	**(12047.38)**	**(14482.55)**

7.4.3 Alley cropping system

A cost-benefit assessment of an alley cropping production system (Sesbania and maize) and the alternative, a conventional sole maize system was undertaken. A five-year timeframe was used, based on the cropping cycle of the alley cropping system, and an 8% discount rate. A sensitivity analysis was performed using 10.5% and 6% discount rates. An additional sensitivity analysis was conducted to explore the impact of reducing the labour costs associated with pruning the trees in the alley cropping system.

The results of the cost-benefit analysis are presented in Table 7.9 and the appraisal indicators are summarised in Table 7.10. Key findings are highlighted in the points below:

- The NPV is negative for the alley cropping system indicating that the costs exceed the benefits for over the 5-year cycle. The NPVs remain negative under both a lower (6%) and higher (10.5%) discount rate. The cash flows are negative for all 5 years, driven by sesbania seedling propagation costs in the first year and pruning and weeding costs for all years.
- The NPV is positive for the sole maize system indicating that the costs exceed the benefits over the 5-year cycle. The NPVs remain positive under both a lower (6%) and higher (10.5%) discount rate. The cash flows are positive for the first two years becoming negative in the last three years due to declining maize yields.
- The B-C ratio is less than 1.0 for the alley cropping system indicating that the costs exceed the benefits across the 5-year period. The B-C ratio is approximately 0.6 indicating that the benefits are just over half the costs. Labour time associated with weeding and pruning is the key cost driver.
- The B-C ratio is approximately 1.0 for the sole maize system indicating that the costs and benefits are relatively even over the 5-year period.
- The costs of the alley cropping system are higher than that of the sole maize system, while the maize yields under the sole maize system are higher than those of the alley cropping system as a result of competition for water and light. The sole maize system appears financially more favourable than the alley cropping system, however maize yields under the sole maize system decline overtime.
- The pruning costs are the key cost difference between the alley cropping and sole maize systems. Reducing the pruning costs by half increases the NPV (-34 135) and B-C ratio (0.67), however the NPV remains negative and the B-C ratio remains less than 1.0 under both a lower (6%) and higher (10.5%) discount rate. In this case, there were no direct benefits associated with the tree pruning (e.g. fodder biomass or fuel wood) to offset the costs and the integration of the prunings did not yield benefits in terms of maize yields due to the competition for water and light.

Table 7.9 Comparison of the costs and benefits of the alley cropping and conventional sole maize production systems (R/ha, 2018)

ALLEY CROPPING AND SOLE MAIZE SYSTEMS (R/ha, 2018)										
Costs and benefits	ALLEY CROPPING					SOLE MAIZE				
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	**40,603.57**	**25,817.86**	**25,817.86**	**25,817.86**	**28,139.29**	**17,838.67**	**15,838.67**	**15,838.67**	**15,838.67**	**15,838.67**
Cash expenses	19,264.29	550.00	550.00	550.00	550.00	2,660.00	660.00	660.00	660.00	660.00
Land preparation (contractor)	2,000.00	0.00	0.00	0.00	0.00	2,000.00	0.00	0.00	0.00	0.00
Sesbania seedling propagation	16,714.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maize seed	550.00	550.00	550.00	550.00	550.00	660.00	660.00	660.00	660.00	660.00
Labour costs	21,339.29	25,267.86	25,267.86	25,267.86	27,589.29	15,178.67	15,178.67	15,178.67	15,178.67	15,178.67
Transplant sesbania seedlings	1,160.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant maize (Nov)	3,571.43	3,571.43	3,571.43	3,571.43	3,571.43	892.96	892.96	892.96	892.96	892.96
Weed - 1st (Nov)	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14
Weed - 2cd (Dec)	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14	5,357.14
Harvest maize - grain (Apr)	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86
Harvest maize - stover (Apr)	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86	892.86
Harvest maize - shell (Apr)	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71	1,785.71
Prune sesbania - 1st (Nov)	0.00	2,321.43	2,321.43	2,321.43	2,321.43	0.00	0.00	0.00	0.00	0.00
Prune sesbania - 2cd (Jan)	0.00	2,321.43	2,321.43	2,321.43	2,321.43	0.00	0.00	0.00	0.00	0.00
Prune sesbania - 3rd (May/Jun)	2,321.43	2,321.43	2,321.43	2,321.43	0.00	0.00	0.00	0.00	0.00	0.00
Mulch plots (Nov)	0.00	446.43	446.43	446.43	446.43	0.00	0.00	0.00	0.00	0.00
Cut sesbania (final) (May/Jun)	0.00	0.00	0.00	0.00	4,642.86	0.00	0.00	0.00	0.00	0.00
BENEFITS	**25,057.14**	**11,146.28**	**11,146.28**	**11,146.28**	**20,146.28**	**26,310.00**	**16,968.84**	**13,575.07**	**10,860.06**	**8,688.05**
Maize grain (Apr)	17,480.13	9,999.52	9,999.52	9,999.52	9,999.52	18,354.14	14,518.66	11,614.93	9,291.94	7,433.55
Maize stover (Apr)	7,577.01	1,146.76	1,146.76	1,146.76	1,146.76	7,955.86	2,450.18	1,960.14	1,568.12	1,254.49
Fodder - sesbania biomass (final cu	0.00	0.00	0.00	0.00	9000.00	0.00	0.00	0.00	0.00	0.00
Cash flow	(15,546.43)	(14,671.58)	(14,671.58)	(14,671.58)	(7,993.01)	8,471.33	1,130.17	(2,263.60)	(4,978.62)	(7,150.63)

Table 7.10 Summary of appraisal indicators for the alley cropping and sole maize production systems at varying discount rates (6%, 8% and 10.5%), across a 5-year time frame

Tillage system	Indicator	6%	8%	10.5%
Alley cropping	Net present value	(40,630)	(39,468)	(38,119)
	Benefit-cost ratio	0.64	0.63	0.63
Sole maize	Net present value	6,184	6,583	7,032
	Benefit-cost ratio	1.10	1.11	1.12

A comparison of the viability of the two systems with different daily labour rates is summarised in Table 7.11 and shows that a positive cash flow for the alley cropping system is only achieved at a labour rate of R50/day in the final year when the hedgerows are cut down.

Table 7.11 Sensitivity analysis for alley cropping and sole maize considering labour rates of R50/day, R100/day and R160/day

Labour rate R50/day										
Costs and benefits	**ALLEY CROPPING**					**SOLE MAIZE**				
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	29,934	13,184	13,184	13,184	14,345	11,589	9,589	9,589	9,589	9,589
Cash expenses	19,264	550	550	550	550	2,660	660	660	660	660
Labour costs	10,670	12,634	12,634	12,634	13,795	8,929	8,929	8,929	8,929	8,929
BENEFITS	25,057	11,146	11,146	11,146	20,146	26,310	16,969	13,575	10,860	8,688
Cash flow	**(4,877)**	**(2,038)**	**(2,038)**	**(2,038)**	**5,802**	**14,722**	**7,380**	**3,987**	**1,272**	**- 900**
Labour rate R100/day										
Costs and benefits	**ALLEY CROPPING**					**SOLE MAIZE**				
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	40,604	25,818	25,818	25,818	28,139	17,839	15,839	15,839	15,839	15,839
Cash expenses	19,264	550	550	550	550	2,660	660	660	660	660
Labour costs	21,339	25,268	25,268	25,268	27,589	15,179	15,179	15,179	15,179	15,179
BENEFITS	25,057	11,146	11,146	11,146	20,146	26,310	16,969	13,575	10,860	8,688
Cash flow	**(15,546)**	**(14,672)**	**(14,672)**	**(14,672)**	**(7,993)**	**8,471**	**1,130**	**(2,264)**	**(4,979)**	**(7,151)**
Labour rate R160/day										
Costs and benefits	**ALLEY CROPPING**					**SOLE MAIZE**				
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 0	Year 1	Year 2	Year 3	Year 4
COSTS (variable costs)	53,353	40,925	40,925	40,925	48,353	31,177	29,177	29,177	29,177	29,177
Cash expenses	19,264	550	550	550	550	2,660	660	660	660	660
Labour costs	34,089	40,375	40,375	40,375	47,803	28,517	28,517	28,517	28,517	28,517
BENEFITS	25,057	11,146	11,146	11,146	20,146	26,310	16,969	13,575	10,860	8,688
Cash flow	**(28,296)**	**(29,778)**	**(29,778)**	**(29,778)**	**(28,207)**	**(4,867)**	**(12,209)**	**(15,602)**	**(18,317)**	**(20,489)**

7.5 Conclusion

The cost-benefit analysis has made an important contribution to the project. What is clear is that there are many benefits of agroforestry systems that potentially make them more sustainable than conventional monoculture systems. However, there are a number of factors that make these systems difficult for adoption – labour requirements is clearly a large drawback for agroforestry, but other less obvious challenges include lack of access to planting material (this was actually raised by a farmer at a farmers' day).

The project was able to explore different woody species and different agroforestry (Spatial and temporal) arrangements, which was useful as it provided a good basis for providing recommendations to farmers. The alley cropping system was the least viable because the prunings were all retained to sustain crop production but the alley width was too narrow and the *S. sesban* hedgerows were too competitive. Widening the alley might reduce competition but will also reduce the amount of material available for soil amelioration, which may not be able to sustain stable maize yields over time. The improved fallow system looked more attractive, though farmers have to make the choice to take land out of production for two years which may be problematic where land is limited. The silvopastoral system looked most promising, as the inclusion of the pigeon pea woody component added a substantial amount of high quality fodder and the cost of establishment was much less than for *S. sesban* because it was directly seeded rather than transplanting seedlings. One challenge to widespread adoption of silvopastoral systems is that most farmers would not specifically grow fodder for their livestock. As livestock numbers increase and compete with other land uses, there may be greater need for farmers to produce fodder and then such systems may become more relevant.

If farmers need to hire labour to plant, weed, harvest and so on, the introduction of agroforestry may not be attractive. If they are able to use family labour and there are limited job opportunities then these systems may prove to be useful. It is clear from the cost benefit analyses, that in general maize production is not an economically viable enterprise if the cost of labour is included and yet many households do still see value in growing maize.

7.6 References

Mullins, D., Botha, J.P., Mosaka, D.D., Jurgens, F.X. and Majoro, T.J. (Conningarth Economists). 2014. A manual for cost benefit analysis in South Africa with specific reference to water resource development. 3rd Edition. Pretoria: Water Research Commission. Report no. TT 598/14.

8 CONCLUDING CHAPTER

Agroforestry provides a range of benefits that include improved diets and income generation, reduced environmental degradation, and improved soil fertility and structure. There are a range of different woody species used in agroforestry systems, both indigenous and introduced. This study focused on multi-purpose, short-lived woody legumes. Many of the widely used agroforestry species are not permitted in South Africa due to their invasive nature. The complication of agroforestry is the potential competition that exists between the woody species and the understorey crop for water, light or nutrients. Competition can be managed by pruning the shoots and/or roots of the woody species. While much work has been done on agroforestry systems, there is fairly limited work done in South Africa and this study sought to broaden our understanding of the opportunities that agroforestry provides to strengthen smallholder agricultural systems. The study took into account the factors that other studies have identified as hindrances to the adoption of agroforestry, such as the labour requirements of pruning and mulching and the lack of availability of planting material.

A number of sites for the research were investigated in KwaZulu-Natal and a decision was taken to conduct controlled research at the research farm of the KwaZulu-Natal Department of Agriculture and Rural Development's at Owen Sithole College of Agriculture (OSCA) and the privately owned Fountainhill Estate at Wartburg. In addition sites were identified for participatory action research with smallholder farmers at Bergville and Ixopo/Highflats. A sequential agroforestry system comprising improved fallows was the first agroforestry system tested. This was duplicated at OSCA and Wartburg and comprised combinations of pigeon pea and *S. sesban* with *Panicum maximum* or maize. With the maize systems it was possible to have a simultaneous system in the first year while the trees established. After the two-year tree fallow the trees were cut back to ground level and maize was established across the plots, benefiting from the improved soil nutrient status and structure resulting from the woody legumes. At OSCA the trial had to be re-established in the second growing season and thus the *S. bispinosa* was replaced with S. sesban. At OSCA, the maize crop was not successful over the first three seasons due to drought and monkeys and was finally abandoned such that the systems continued with *the P. maximum* and were more focused on fodder production.

The allow cropping trials at Wartburg comprised four sub-trials: Trial 1 compared the effect of retaining or removing prunings for *S. sesban*/maize and pigeon pea/maize treatments; Trial 2 compared the effect of hedgerow cutting height on tree and grass biomass in a pigeon pea/*P. maximum* silvopastoral system; Trial 3 compared the effect of hedgerow cutting height on tree and grass biomass in a *S. Sesban*/maize system and Trial 4 investigated the effect of a non-legume (i.e. maize) on nodulation and nitrogen fixation of *S. sesban* and pigeon pea. The alley cropping systems comprised 3 m wide alleys between hedgerows of trees planted 0.75 cm apart within the hedgerow. A number of greenhouse trials were conducted at UKZN to test some of the effects of pruning under more controlled conditions. Water use of the different agroforestry systems was investigated at both OSCA and Wartburg, relying mainly on Watermark sensors, which provided soil water tension values at three depths (200, 500 and 1200 mm). From the water tension values it was possible to determine both the soil water content (cm^3/cm^3) and total soil water storage (SWS) for the 1200 mm profile. A plot from trial 1 (*S. sesban*/maize) and trial 2 (pigeon pea/*P. maximum*) were used to investigate soil water dynamics in alley cropping systems. Sensors were placed at three depths at three points within each plot (treeline, alley centre – and midway between the treeline and alley centre). SWC and SWS were determined for the different points within each plot. Water use (evapo-transpiration) and water productivity in terms of biomass production and crude protein supply per unit water used were investigated and showed the benefit of integrating woody species in terms of both measures of productivity.

The experiences of smallholder farmers at Ixopo/Highflats and Bergville were variable in terms of both species and agroforestry systems. At Bergville farmers initially showed interest in pigeon pea but it proved to be intolerant of the cold conditions and there might be value in introducing short season varieties that can produce a grain yield within the first growing season. The Bergville site also allowed for investigations into different agroforestry systems that were based on *Vachelia karroo*, but the trees were mature and provided competition for light and water. Digging a trench between the row of trees and the adjoining plots to destroy superficial roots from competing with the crop did seem to show some potential. At Ixopo farmers experimented with a number of systems using pigeon pea and S. sesban and generally found that the trees competed too severely with the maize when intercropped but saw value in growing them in their farms as a source of fodder.

Cost-benefit analyses were undertaken for the three main systems (Alley cropping with *S. sesban* and maize; silvopastoral with pigeon pea and *P. maximum* and improved fallow with pigeon pea and maize). While the *S. sesban*/maize system did not look at all promising, the other two systems – especially the silvopastoral system, looked reasonable except for the high cost of labour for managing the woody component. The decisions of farmers to engage in agroforestry are unlikely to be made based only on the financial viability of the systems, but may be attractive given that they diversify their systems and provide multiple benefits.

Overall, the project met the general aim of the project, which was **to develop agroforestry systems that make effective use of available water and improve rural livelihoods.** In terms of the specific aims, the extent to which they were achieved is discussed below:

- Specific aim 1: To review relevant research reports pertaining to agroforestry, simulation modelling, impacts on soil water and water use productivity – *this was achieved*.
- Specific aim 2: To identify sites and determine requirements of farmers that will inform choice of species (trees, shrubs and grasses) and the integration of trees, shrubs and forage into the farming system – *this was achieved, with farmers' requirements being further understood through the on-farm work*.
- Specific aim 3: To identify and test best spatial and temporal arrangements (layouts) for agroforestry systems – *two alley cropping systems as well as an improved fallow were tested through the formal trials, with additional systems such as boundary planting were tested by smallholder farmers. Thus this aim was achieved*.
- Specific aim 4: To measure water use of agro-forestry systems and their impacts on soil water status – *this aim was achieved although the robustness of the findings could have been more robust if the instrumentation had been replicated across the trials.*
- Specific aim 5: To determine economic and social benefits and costs of the agroforestry system – *this was achieved by undertaking a financial analysis of the three systems and a qualitative analysis of the socio-economic and environmental benefits of agroforestry compared with monoculture systems.*
- Specific aim 6: To develop guidelines for extension on agroforestry systems – *this was achieved, drawing on the findings of the formal trials, on-farm work and farmers' days.*

To conclude, this study has shown the value and the complexity of agroforestry systems. It has highlighted that competition between the different components of the system must be effectively managed. Furthermore, the high labour requirements of these systems must be considered when deciding to integrate woody species into existing agricultural systems. Having decided on a mix of species, farmers still need to make decisions about how to manage the woody component, which benefits to maximise (given the trade-offs between fodder provision and soil fertility for example). While the participatory action research has shown that farmers are interested in testing agroforestry systems and have adapted the practices that were introduced, the extent to which adoption occurs can only be assessed over the longer term.

While the timeframe of this project allowed for an evaluation of systems in terms of crop yields, water use and even on the effect on soil macrofauna, it did not allow for an evaluation of the effect on soil nutrient status, nor for a measure of how crop yields decline over time in monoculture systems. These are aspects that could only be addressed by longer term trials. Another aspect that requires future work is evaluation of the agroforestry systems in terms of animal performance. The nutritional value of browse from *S. sesban* and pigeon pea, as well as the extent to which it can effectively complement low quality forage needs to be established.

APPENDIX 1: CAPACITY BUILDING

Introduction

This section of the report covers the involvement of postgraduate students in the research, as well as organisational strengthening and community-level development.

Student information

Three students worked on the project. Their' research contributed to the project objectives as follows:

Project objectives	M Musokwa	T Makhubedu	B Letty
To develop agroforestry systems that make effective use of available water and improve livelihoods	X	X	X
To review relevant research reports pertaining to agroforestry, simulation modelling, impacts on soil water and water use productivity	X	X	X
To identify sites and determine requirements of farmers that will inform choice of species (trees, shrubs, and grasses) and the integration of trees, shrubs and forage into the farming system			
To identify and test best spatial and temporal arrangements (layouts) for agroforestry systems	X	X	X
To measure water use of agroforestry systems and their impacts on soil water status	X		X
To determine economic and social benefits and costs of the agroforestry systems	X	X	X
To develop guidelines for extension on agroforestry systems.	X	X	X

<u>MSc. Agric student: Misheck Musokwa</u>

Misheck Musokwa, a Zimbabwean national, registered at University of KwaZulu-Natal for MSc in Agriculture; Crop Science. His supervisor was Professor Paramu Mafangoya, who is also a member of the project team. He was responsible for the sequential cropping trials conducted at Fountain Hill Estate, Wartburg and at Owen Sithole College of Agriculture, Empangeni. He submitted his MSc dissertation in early December 2016 and graduated in 2017.

As part of the capacity building process, Misheck Musokwa has received training and mentorship on Aquacrop and Hydrus by Dr Tafadzwa Mabhaudhi and Professor Simon Lorentz, respectively. Misheck attended a Hydrus course at George at NMMU. The course was run by Professor Lorentz.

The research has allowed him to develop new skills such as conducting measurements of leaf area index, downloading and interpreting weather data, determining retentivity curves and analysing soil water data.

<u>Status</u>: Graduated April 2017

<u>Dissertation title:</u> Water use in agroforestry systems

<u>Abstract:</u> Water scarcity and declining levels of soil fertility are the major causes of low crop productivity under smallholder farmers in Southern Africa. A field experiment was conducted in 2015/16 season at Fountainhill Estate, Wartburg to evaluate water use, water use efficiency, productivity and Land Equivalent ratio in Zea-mays (maize) intercropped with either Cajanus cajan (L) Millsp (pigeon pea) or

Sesbania bispinosa (Jacq) A. Wright var. bispinosa (*S. bispinosa*).The experiment had 5 treatments: sole maize; sole pigeon pea; sole *S. bispinosa*; maize + *S. bispinosa* and maize + pigeon pea laid out in a randomized complete block design (RCBD) replicated three times. Time domain reflectometry (TDR) probes were placed at 20 cm, 50 cm and 120 cm below ground level at each treatment component to measure soil water content. Sole treatments of maize and pigeon pea had significant (P<0.05) higher WUE of 6.28 kg/hamm and 5.77 kg/ha mm respectively. Pigeon pea + maize recorded a significantly (P<0.05) higher WUE of 5.47 kg/ha mm. The lowest was recorded on *S. bispinosa* + maize (0.292 kg/ha mm) and sole *S. bispinosa* (0.425 kg/ha mm) subject to the provision that the calculations were based on changes in soil water content rather than actual measurements of water uptake by the trees and crops. Sole maize had significant (P<0.05) higher grain yields of 1867 kg/ha while maize + pigeon pea yielded 604 kg/ha and the lowest maize yield was 538 kg/ha from maize + *S. bispinosa*. Pigeon pea had significant (P<0.05) higher seed yield of 1073 kg/ha for monoculture and 1029 kg/ha for intercrop as compared to 207 kg/ha for sole *S. bispinosa* and 58.3 kg/ha in intercrop. Land Equivalent ratio (LER) was higher in maize + pigeon pea (1.23), as compared to maize + *S. bispinosa* (0.6). Overall sole maize outperformed maize + tree intercrops in terms of grain yield. The least grain yield was recorded on maize + *S. bispinosa* which again recorded lowest WUE. Sole pigeon pea had higher seed yield although statistically there were no difference with pigeon pea + maize intercrop. In terms of WUE similar results were recorded among sole pigeon pea and pigeon pea + maize. It is beneficial to have a combination of pigeon pea + maize in smallholder farming systems because pigeon pea can act as a ‘risk crop’ during drought years. This combination is also supported by higher LER values. Despite low yields of maize which can be compensated by the yield, the practice of agroforestry involving pigeon pea saves a substantial (23%) land which can be subsequently be used for other production crops.

Key words: cropping systems, maize, pigeon pea, water use efficiency

<u>PhD student: Misheck Musokwa</u>

Misheck Musokwa commenced his PhD studies in 2017, building on the research that he undertook for his MSc, which looked at the effectiveness of improved fallows. Professor Paramu Mafongoya continued as his supervisor.

<u>Status:</u> Graduated in September 2019.

Misheck Musokwa attended the Pan-African Soil Challenge (PASCAL) training from 26-30 November 2018 in Accra, Ghana. PASCAL is a project funded by the German Ministry of Education and Research (BMBF) within the scope of the DFG Ideas Competition International Research Marketing. It aims to initiate a knowledge and technology transfer bridge (Science Bridge) between Germany and Africa in the areas of soil science, nutrition and hydrology. It had two main components: a training unit in terrestrial modelling followed by an interactive ‘hackathon’.

<u>PhD student: Thabo Makhubedu</u>

At the start of the WRC project Thabo Makhubedu, identified as a PhD student, was still completing a MSc. Agriculture at University of KwaZulu-Natal under supervision of Professor Albert Modi. He registered for a PhD in February 2016. He was awarded an NRF bursary for 2016 on the basis of the MTech that he already held and received additional support through this WRC project.

His studies were based on the four trials being undertaken at Fountainhill Estate and the pot trials being conducted at UKZN. His research focused on the biological nitrogen fixation of the leguminous shrubs. He was supervised by Professor Mafongoya and Professor Scogings at UKZN.

Status: Thesis submitted for examination December 2019 (Anticipated graduation in April 2020).

Title: Quantification of symbiotic nitrogen fixation in agroforestry systems

Abstract: In southern Africa, erratic rainfall patterns and low soil N fertility combine to limit crop production in smallholder farming systems. Additionally, livestock production is constrained by quality and all year-round availability of fodder. The incorporation of leguminous plants, especially N_2-fixing woody trees, present an alternative strategy for improving crop and livestock productivity. In many agroforestry systems, trees are regularly pruned to avoid shading of associated crops, enhance nutrient cycling or for harvesting high quality fodder for livestock. The thesis evaluated the influence of tree pruning management, management of tree prunings and associated crop or fodder species on symbiotic N_2 fixation of *Sesbania sesban* using the ^{15}N natural abundance technique. The effect of pruning frequency on biomass productivity, non-structural carbohydrate (NSC) level and symbiotic N_2 fixation was tested under glasshouse conditions. The results showed that increased pruning frequency decreased above- and below ground dry matter (DM), NSC levels and N_2 fixation and this decrease in aboveground DM correlated with reduced levels of starch (R^2 = 0.66, P<0.001), sugar (R^2 = 0.75, P<0.001) and total non-structural carbohydrates (R^2 = 0.76, P<0.001). More frequent pruning significantly decreased nodulation, percentage N derived from the atmosphere and N_2 fixed. Field experiments in Wartburg were performed to assess the effect of pruning height and tree pruning management, and associated species on symbiotic N_2 fixation of *Sesbania sesban* and *Cajanus cajan* (pigeon pea). In assessing the effect of pruning height on N_2 fixation by pigeon pea, it was found that pruning at 60 cm significantly decreased total N (%N) (P≤0.05), percentage of N derived from atmospheric N_2 (P≤0.05) and amount of N_2 fixed (%Ndfa) (P≤0.05) as compared with unpruned and those pruned at 90 cm height. Field experiment evaluating the influence of management of prunings (retained vs. removed) revealed that management of tree prunings did not have any negative effects of on symbiotic N_2 fixation rates of either pigeon pea or *S. sesban*. The amount of N_2 fixed by both species was, however, generally increased by retention of prunings. Symbiotic N_2 fixation of pigeon pea was, however, lower in November compared to February, whilst a contrasting pattern was observed for *S. sesban*. The last experiment assessed the influence of an agroforestry system (sole cropping vs. intercropping) on pruning dry matter (DM) and N_2 fixation of pigeon pea (*Cajanus cajan* (L) Millsp.), and also compared N_2 fixation estimates obtained by the total N difference method with those obtained by the ^{15}N natural abundance method. Results showed that pruning DM yield and symbiotic performance (measured as %N, $\delta^{15}N$, N_2 fixed) and soil N uptake were significantly decreased by intercropping. The percentage of N derived from atmospheric N_2 (%Ndfa) was increased by intercropping compared to sole cropping. Linear trends were observed between the ^{15}N natural abundance and the total N difference methods for the amount of N_2 fixed but not %Ndfa. Taken together, the results from these experiments showed that pruning more frequently or at a lower height could decrease the desirable benefits of legume trees on soil fertility improvement, particularly N and may further contribute to a decline in availability of forage and livestock productivity. Furthermore, retaining both leaves and twigs in plots can immobilize significant amounts of N thus forcing the trees to rely more on symbiotic N_2 fixation. Also, the regression models found for amount of N_2 fixed obtained using the ^{15}N natural abundance and total N difference methods could be useful for predicting amount of N_2 fixed by pigeon pea in situations where ^{15}N isotope ratio mass spectrometer is not available.

PhD student: Brigid Letty

Brigid Letty undertook a PhD through Crop Science at UKZN under the supervision of Prof Mafongoya. Her studies were also based on the four trials being undertaken at Fountainhill Estate and the pot trials being conducted at UKZN. Status: Thesis submitted for examination November 2019 (Anticipated graduation in April 2020).

Title: Optimising fodder production from Sesbania sesban and pigeon pea (*Cajanus cajan*) in silvopastoral systems

Abstract:
Smallholder livestock production in South Africa is characterised by low productivity. In part this is due to sub-optimal levels of nutrition, particularly during the dry season when high quality forage is in short supply. The integration of woody legumes into agricultural systems to provide a source of high quality fodder is seen as a useful and affordable way of addressing this, and can be termed silvopastoralism. The current research made use of two woody legumes, namely pigeon pea (*Cajanus cajan*) and *Sesbania sesban*. One field trial integrated pigeon pea in hedgerows with *Panicum maximum*, while the other integrated *S. sesban* hedgerows into maize cropping. A key management intervention with hedgerows in silvopastoral systems is the repeated cutting of the woody plants to provide a source of fodder and to reduce the competitive interactions between the components of the system for light, water and nutrients. The challenge with hedgerow pruning is that woody species (and provenances) differ in their tolerance of pruning and it can lead to a reduction in biomass production and even to mortalities. Systems need to be managed so as to optimise the production of the different components, which is why nutritional yield is an effective means of comparing systems. Hedgerow pruning also affects concentrations of non-structural carbohydrates, both starch and simple sugars. Plants draw on their starch reserves to support recovery from pruning and defoliation. The reserves take time to be replenished, and if they are cut while their reserves are still compromised, this can ultimately lead to their death. Hedgerow cutting height is one factor that can be manipulated in an effort to limit competition while not negatively affecting the production of fodder from the woody component. In the current field trials, cutting heights of 60 cm and 90 cm were compared for pigeon pea, while cutting heights of 50 cm and 75 cm were compared for *S. sesban*. Generally the lower cutting heights led to reduced fodder production ($P<0.05$), and did not improve the yields of the understorey crop significantly. In both the pigeon pea/*P. maximum* system and the *S. sesban*/maize system, the nutritional yields were significantly higher than those of the sole *P. maximum* and sole maize respectively ($P<0.05$). Cutting of the woody plants was found to have significant effects on non-structural concentrations. For the pigeon pea, there were higher stem sugar concentrations in the cut trees than the uncut control ($P<0.05$), but no difference as a result of cutting height. For the *S. sesban* plants, the 50 cm cutting height reduced stem starch concentration relative to the uncut control ($P<0.05$), but once the control was cut back to allow for planting of maize in the alleys between the hedgerows there were no longer any significant effects of treatment ($P>0.05$). The total non-structural carbohydrate concentration of the stems was also higher for the uncut control ($P<0.05$). Mortality rates are not reported for *S. sesban* plants, but there was a trend towards the cut pigeon pea plants having higher mortality rates than the uncut ones (which were similar for the two cutting heights), though this was not significant. It does suggest though that the increase in sugars was due to mobilisation of starch reserves, which may have contributed to the mortalities that were experienced during the winter when frost occurred. Given that there were no differences in stem starch concentrations it was concluded that the pigeon pea plants were drawing on reserves in their roots or in their branches to support recovery. In addition to the field trials, a pot trial was conducted to evaluate five *S. sesban* provenances harvested from natural populations in northern KwaZulu-Natal in terms of their tolerance of cutting at different cutting heights (45 cm, 30 cm and 15 cm) over three cutting events. Besides measuring biomass production, the effect of cutting height on non-structural carbohydrate concentrations in the roots and stems was determined. One of the provenances (TM202) was clearly less productive than the others, but even they showed a reduction in biomass production across cutting events and with cutting height. This illustrates the need to avoid severe pruning that reduces biomass production. The pot trial also provided additional information about the effect of cutting height on non-structural carbohydrate concentrations. Starch concentrations of both the root and stem were lower for the 15 cm cutting height, which also resulted in lower sugar: starch ratios ($P<0.05$). They were also lower for TM202 than the vigorous provenance BL101 against which they were compared ($P<0.05$). This study has provided insights into the use of hedgerows comprising woody legumes in semi-arid areas to provide a source of high quality fodder that can be used to

supplement pasture or maize residue. The study has provided insights into the cutting heights that can be recommended to smallholder farmers wishing to integrate such interventions into their farming systems. It has provided a better understanding of how non-structural carbohydrates respond to cutting in these two species, and how this affects productivity and could impact on mortality rates. While these systems are more complex to manage than monocultures they definitely offer benefits in terms of nutritional yield.

Keywords: agroforestry, hedgerow, pruning, maize stover, *Panicum maximum*

Other student involvement

Thabisile Cele, an Honours Student at UKZN also supervised by Professor Scogings, assisted Mr Makhubedu with determining diurnal patterns in carriers of fixed nitrogen in pigeon pea plants. She used the results for her project module, which she passed.

In June 2017, the project hosted two students from the University of Virginia – USA. The students were given a task to document and characterise the key of farming system with the experimenting farmers in Ixopo. Guidelines to understand farmer's circumstances were developed to guide the discussion with farmers, in order to understand how AF compliments current production systems. The key outcome of the engagements revealed that farmers are keen about AF and have realised that it is long-term cultivation process. There is a growing interest amongst the experimenting farmers and some neighbours to propagate trees locally so that planting material is made available locally. Even though the experimenting farmers have not seen the tangible benefits of the trees for the past two seasons (2015/2016), they remain positive that with biomass transfer they will be able to see benefits in terms of the maize yield.

Organisational development

Staff members from the INR have developed skills in a number of areas through this project. Firstly, a number of staff members attended a training in Hydrus modelling, which was provided by Simon Lorentz (SRK). Another training that was attended was AquaCrop, provided by Tafadzwa Mabhaudi. This then led to a one-day exposure to APSIM (Agricultural Production Systems sIMulator), which is better able to model integrated cropping systems. The INR team has also become capacitated in terms of instrumentation for measuring soil water characteristics.

Junior staff attended training in Participatory Innovation Development (PID), which has been funded through NUFFIC and supported by the Royal Tropical Institute in Netherlands. This has developed skills in conducting on-farm research where farmers play a role in designing, conducting and monitoring research trials. This has informed the farmer experimentation being undertaken at Bergville and Ixopo. The involvement of the INR intern Nonjabulo Bambalele, who has just completed her MSc, also allowed for further capacity development.

Simone Chetty is taking on the modelling component of the project. She is a hydrologist working as a scientist at INR and is being mentored by Prof Lorentz. When she went on maternity leave, she handed over this role to INR intern Mlungisi Shabalala.

More recently, the INR team has learnt about rabbit farming as a way of integrating small livestock into the agroforestry system. This is the first exposure that we have had to this enterprise opportunity. Guidance is being provided by Judy Stuart who runs Future Farmers, an NGO based in Howick.

Community development activities

Capacity development of local communities has been through two key sets of activities, namely PAR and farmers' days. The joint experimentation (participatory action research) has developed a common understanding of the purpose and principles of experimentation as well as an appreciation of the roles of agroforestry trees. The process of working as a team to plan and plant the trial has been a capacity development opportunity for the farmer and for the INR staff and interns.

The involvement of local farmers who are members of the GrainSA farmer learner group both at Ixopo/Highflats and Bergville has allowed for more effective sharing of the findings.

Rabbits as a part of an integrated farming system

Rabbit keeping was identified as an opportunity within agroforestry for income generation by women. Phumelela Shezi from Highflats was sent for a week's experiential learning with Judy Stuart from Future Farmers, who also has a rabbit business. Ms Shezi opted for starting with a pair of New Zealand Whites. She was provided with a cage and rabbits and material for constructing a second set of cages. A local man, Mr Phungula, used the first cage as a design for the second set, which he adapted to make three cages.

Involvement of learners

Emazabekweni Primary School involvement – Through Phumelela Shezi's initiative, a trial was initiated at school. There was no biomass transfer practiced at school since the trial was only initiated in November 2017. In January 2018, school children participated in the practical demonstration of sowing *Sesbania* trees at school. However, the germination of trees was poor, and more trees will be sown in spring for the purpose of planting in the school garden, and for children and educators who might be keen in planting trees at home. Two grade 6 learners and their Life Science educator also participated in the farmer's day held in March 2018 at Wartburg research station.

APPENDIX 2: PAPERS AND PRESENTATIONS

Introduction

Members of the project team made presentations at range of symposia and fora and made submitted a number of papers to peer-reviewed journals.

Papers by Misheck Musokwa

Paper 1: Evaluation of agroforestry systems for maize (*Zea mays*) productivity in South Africa

Misheck Musokwa, Paramu Mafongoya & Simon Lorentz (2019) Evaluation of agroforestry systems for maize (*Zea mays*) productivity in South Africa, South African Journal of Plant and Soil, 36:1, 65-67, DOI: 10.1080/02571862.2018.1459898

Abstract
Maize (Zea mays L.) is the staple food crop grown by most smallholder farmers in South Africa. Decline in soil fertility and expensive chemical fertilisers affect maize production by these farmers. Smallholder farmers cannot afford chemical fertilisers because these are expensive. Agroforestry systems offer cheap alternatives to expensive chemical fertilisers. A field experiment was established in the 2015/16 season at Wartburg. The objective of the study was to evaluate maize yields and productivity in agroforestry systems. The experiment had five treatments: sole (maize; pigeon pea; or Sesbania bispinosa); maize + Sesbania bispinosa; maize + pigeon pea laid out in a randomized complete block design replicated three times. The yield was in order: sole maize > maize + pigeon pea ≥ maize + pigeon pea. The land equivalent ratio (LER) was in the sequence maize + pigeon pea > sole pigeon pea > maize + S. bispinosa > sole S. bispinosa ≥ sole maize. Maize yield might be increased in the following season as a subsequent crop in the same field because of residual nutrients that would have been enhanced and set free for plant uptake during the previous season. Pigeon pea is recommended in agroforestry systems with maize because of its higher LER and combined production of grain for human and livestock consumption and firewood.

Keywords: agroforestry, maize, pigeon pea, smallholder farmers

Paper 2: Agroforestry system for reversing land degradation in South Africa

Journal: Land degradation and Development
Current Status: Attending comments from the editor

Paper 3: Monitoring of soil water distribution and water use efficiency on maize grown after-two year pigeon pea fallow in South Africa

Journal: Agricultural Water Management
Current Status: Attending the comments of the editor

Paper 4: Evaluation of *Panicum maximum* Intercropped with *Cajanus cajan* and *Sesbania Sesban*

Journal: African Forage Science
Status: Submitted

Papers by Thabo Makhubedu

Makhubedu TI*, Letty BA, Mafongoya PL and Scogings PF. Effects of pruning frequency on biomass productivity, nonstructural carbohydrate reserves and nitrogen fixation by *Sesbania sesban.* Submitted to *South African Journal of Plant and Soil*.

Status: Rejected, still looking for another relevant journal

Makhubedu TI*, Letty BA, Mafongoya PL and Scogings PF. The influence of pruning height on symbiotic nitrogen fixation in a tree-based fodder production system. Accepted for publication in *African Journal of Range and Forage Science*.

Status: Accepted

Makhubedu TI*, Letty BA, Mafongoya PL and Scogings PF. Tree pruning management effects on symbiotic N_2 fixation of *Cajanus cajan* and *Sesbania sesban.* Submitted to Journal of *Biology and Fertility of Soils*.

Status: Under review

Makhubedu TI*, Letty BA, Mafongoya PL and Scogings PF. Dinitrogen fixation as influenced by an agroforestry system measured by ^{15}N natural abundance and total N difference methods. Submitted to Journal of *Plant and Soil*.

Status: Under review

Papers by Brigid Letty

Paper 1: Cutting height effect on non-structural carbohydrates, biomass production and mortality rate of *Cajanus cajan*

Authors: BA Letty, T Makhubedu, PF Scogings and P Mafongoya

Agroforestry Systems (awaiting feedback) to be resubmitted

Abstract
In Southern Africa, livestock production by smallholder farmers is limited by an inadequate nutrition during the dry season. This can be addressed by the introduction of woody fodder species, which can be regularly pruned to provide a source of high quality feed. However, pruning affects the productivity and survival of the trees and thus it is necessary to determine the optimum cutting height. Cutting affects the productivity and survival of trees because it affects concentrations of non-structural carbohydrates, which are used to support their recovery. The trial was established in November 2016, ran over two growing seasons (2016/2017 and 2017/2018) and concluded in June 2018. The four treatments comprised three silvopastoral systems with *P. maximum* planted between pigeon pea hedgerows that were cut at 60 cm (PPPM60) and 90 cm (PPPM90) above the ground, or left uncut (PPPM0) and sole *P. maximum.* Over the two year period, the pigeon pea plants cut at 90 cm above ground produced significantly more leaf, twig and total biomass than the plants cut at 60 cm. Cutting height also had a significant effect on the percentage twig, with pigeon pea plants cut at 90 cm having significantly higher percentage twig than those cut at 60 cm ($P<0.05$). There was a significant effect of cutting height on stem sugar concentration and sugar: starch ratio but not for starch and total NSC concentration ($P>0.05$). The tree mortality rates were higher for pruned relative to unpruned trees, but the effect was not significant ($P>0.05$). It was concluded that timing and severity of cuts is important, especially in

areas where frost occurs. Future research should consider the effect of pruning on non-structural carbohydrate concentration and total pool in the roots to better understand the reasons for reduced production and tree mortalities.

Keywords: silvopastoral, pigeon pea, agroforestry, pruning

Improved fodder production from the inclusion of pigeon pea in a *Panicum maximum* pasture

Authors: BA Letty, TI Makhubedu, PF Scogings and P Mafongoya

Abstract

Livestock production by smallholder farmers in southern Africa is often constrained by lack of access to sufficient good quality fodder during the dry season. The objective of the study was to quantify benefits of introducing tree fodder hedgerows into pastures and to investigate hedgerow cutting height. Four treatments comprised silvopastoral systems with *P. maximum* planted between pigeon pea hedgerows that were cut at 60 cm (PPPM60) and 90 cm (PPPM90) above the ground or left uncut (PPPM0) and the control, which was sole *P. maximum* (PM). Over the first two growing seasons, the pigeon pea and the grass were each harvested four times. Total fodder production of PPPM60 and PPM90 was significantly higher (18.97 and 17.50 ton ha^{-1} respectively) than PPPM0 or PM (12.90 and 15.51 ton ha^{-1} respectively), both of which comprised only grass fodder. Over the two year period, the hedgerows resulted in a significant ($P<0.05$) decrease in grass production, but the higher cutting height produced significantly more browse ($P<0.05$). Browse samples from February 2018 and grass samples from June 2018 were investigated as a source of conserved fodder. The effect of treatment on the nutritional content of the different fodder components as well as the overall nutritional yield was investigated. Treatment had no effect on any nutrients except for grass neutral detergent fibre, which was significantly higher for PPPM90 ($P<0.05$). In terms of nutritional yields, the treatments that provided grass and browse had significantly higher crude protein and phosphorus yields ($P<0.05$). Zinc yield was significantly lower for PM than for PPPM60. Acid detergent fibre for PPPM90 was significantly higher than PM and PPPM0 ($P<0.05$). It was concluded that there are significant benefits of including hedgerows of fodder trees into grass pastures as they increase the quantity and quality of feed available to livestock.

Keywords: Silvopastoral system, agroforestry, smallholder, hedgerows

African Journal of Range and Forage Resources (awaiting feedback)

Posters and presentations

2016 events

Fountainhill Symposium
Presentation: Water use in agroforestry systems (Authors: Misheck Musokwa, Paramu Mafongoya and Simon Lorentz)
Venue: Fountainhill Estate, Wartburg
Date: 19 October 2016

Evaluating the dynamics of N2 fixation, non-structural carbohydrates reserves, biomass yield and impacts on soil water in pruned *Sesbania sesban* and *Cajanus cajan* (Thabo Makhubedu and Brigid Letty)

UKZN Postgrad research and innovation day
Poster presentation: Evaluation of agroforestry systems for maize (*Zea mays* l.) productivity in South Africa (Authors: Misheck Musokwa, Paramu Mafongoya and Simon Lorentz)
Venue: UKZN Howard Campus, Durban
Date: 29 November 2016

Combined Congress
Poster presentation: Evaluation of agroforestry systems for maize (*Zea mays* l.) productivity in South Africa (Authors: Misheck Musokwa, Paramu Mafongoya and Simon Lorentz)
Venue: Klein-Kariba Bela Bela
Date: 23-26 January 2017

EVALUATION OF AGROFORESTRY SYSTEMS FOR MAIZE PRODUCTIVITY IN SOUTH AFRICA

Misheck Musokwa[1], Paramu Mafongoya[1] and Simon Lorentz[2]

[1]University of KwaZulu-Natal, Centre for Environment, Agriculture and Development, Bag X 01, Scottsville, 3209, Pietermaritzburg, South Africa

[2] University of KwaZulu-Natal, Centre for Water Resources Research, P/Bag X 01, Scottsville, 3209, Pietermaritzburg, South Africa

INTRODUCTION

Maize (*Zea mays* L) is the dominant staple food crop grown by most smallholder farmers in South Africa (Mashingaidze, 2006). However, low inherent soil fertility is one of the identified limitations in maize production in the smallholder farming systems. Consequently, agroforestry has been widely practiced in Sub-Saharan Africa because of its prominent effects in soil fertility improvement, reducing soil and water losses and improving land-use efficiency (Mafongoya *et al*, 2006; Oluyede *et al*, 2011).

However, competition between crops and trees for resources also exists and there are several indices which have been developed to describe competition but they have not been evaluated in simultaneous agroforestry systems in South Africa.

Objectives:

- To evaluate maize yields in agroforestry systems
- To evaluate competition between trees and crops using competition indices in agroforestry systems

MATERIALS AND METHODS

The experiment was established at Fountainhill Estate, Wartburg (latitude 29°27'2" S; longitude 30°32'42" E and altitude 853 m above sea level) The site has an annual precipitation of 805 mm.The minimum temperature is 3.3 °C and the maximum is 37. 4°C.

The experiment had five treatments (1) sole maize, (2) sole pigeonpea, (3) sole *S. bispinosa* (4) maize + *S. bispinosa*, (5) maize + pigeonpea. The experiment was laid out in a randomised complete block design (RCBD) replicated three times with 15 plots (6 m x 8 m). The field was then ploughed using a disc plough in December 2015. Planting was done in January 2016. *S. bispinosa* was transplanted while pigeonpea was direct seeded. An open pollinated maize variety, Okavango, was used. Pigeonpea and *S. bispinosa* were planted at a spacing of 1 m inter-row and 1 m intra-row. A mixed crop of trees and maize had 1 m inter-row and 0.4 m intra row spacing for maize. Sole maize had 0.8 m inter-row and 0.5 m intra-row spacing with maize plant population of 25 000 plants/hectare in both sole and intercrop. Trees were introduced at 10 000 plants per hectare. No fertilizer was applied to simulate small-scale farmers conditions.

Figure 1: Agroforestry treatments at Wartburg-Fountainhill in 2015/2016 Season: Photo credit: Misheck Musokwa (2016)

RESULTS & DISCUSSIONS

Maize grain, cob mass and stover yields were significantly higher in sole maize plots compared to intercrops (Table 1). This might have been caused by competition for available resources like water, nutrients and light. This study agrees with the results of Mathew *et al* (2001) who found higher yields in sole maize compared to intercrop in Mpumalanga.This study is also in line with the results of Kwesiga *et al* (1999) who found that intercropping maize with trees during the first year of the 2-year fallow has a negative effect on the maize yield.

Table 1: Maize yields attributes at Fountainhill Estate for 2015/16

Treatments	Grain (kg/ha)	Cob (kg/ha)	Stover (kg/ha)
Maize + S.bispinosa	538a	742a	101.7a
Maize + Pigeonpea	604a	762a	107.9a
Sole Maize	1867b	2753b	314.2b
Lsd (0.05)	446.6	543.7	72.5

Numbers followed by same letters are not significantly different at $P<0.05$ according to Fisher's Protected Lsd

Land Equivalent Ratio (LER) was used to evaluate competition between trees and maize. Maize grown in association with pigeonpea had a LER greater than 1 (1.23), which indicated that the agroforestry system was more beneficial than monocropping systems or maize + S bispinosa (Figure 2). These results concur with Edje (2014) who found that intercropping maize with pigeonpea was more productive than either crop in monoculture in Swaziland (LER 1.94).

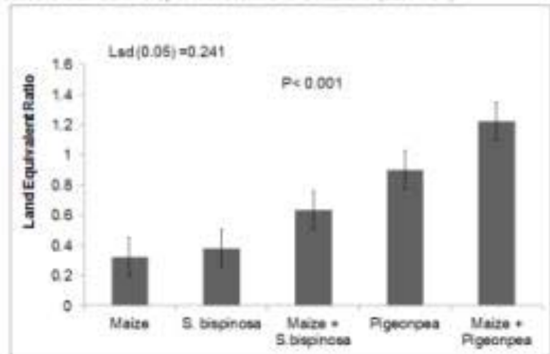


Figure 2: Land Equivalent Ratios for different cropping systems at Fountainhill in 2015/16 season

Despite lower yields of maize (which can be compensated for by the pigeonpea), the practice of agroforestry involving maize with pigeonpea saves substantial land which can subsequently be used for other crop production. Pigeonpea is recommended in agroforestry systems with maize due to its higher LER and combined production of grain for human and livestock consumption, soil fertility replenishment and firewood.

REFERENCES

1.Edje O.T (2014) Effects of intercropping maize [Zea-mays] with pigeonpea [Cajanus Cajan] on seed yield, fiber and fuel wood, in the Middleveld, Swaziland. African Journal of Applied Agricultural Sciences and Technologies

2. Kwesiga F.R., Franzel S., Place F., Phiri D., Simwanza C.P. 1999. Sesbania sesban improved fallows in eastern Zambia: Their inception, development, and farmer enthusiasm. Agroforestry Systems 47: 49-66

3. Mafongoya P.L., Kuntashula E., Sileshi, G., 2006. Managing soil fertility and nutrient through fertilizer trees in southern Africa. In Uphoff, N., Ball, A. S., Fernandes, E., et al (Eds). Biological Approaches to Sustainable Soil Systems. Taylor & Francis, pp 273-289

4. Mathews, C., Jones, R. B. and Saxena, K. B. [2001]. Maize and pigeonpea intercropping systems in Mpumalanga, South Africa. International Chickpea and Pigeonpea Newsletter 8: 52-53

5. Mashingaidze K (2006). Farmer-participatory maize (Zea maize L.) cultivar evaluation and selection in Eastern Cape Province of South Africa. Presented at the 2006 International Plant Breeding Symposium. Mexico City, Mexico

6. Oluyede Clifford Ajayi, Frank Place, Festus Kehinde Akinnifesi & Gudeta Weldesemayat Sileshi (2011) Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). International Journal of Agricultural Sustainability, 9:1, 129-136

2017 events

Fountainhill Symposium
Presentation: Investigation of agroforestry systems: Agronomic performance and impacts on soil water – an overview of results thus far (Authors: M Musokwa, T Makhubedu and B Letty)
Venue: Fountainhill Estate, Wartburg
Date: 19 October 2016

UKZN Research Day, Howard College
Students working on the project made two contributions at the research day. Thabo Makhubedu presented a poster at the Research Day and won an award for best poster. He used the award to cover his participation in the World Agroforestry Conference in France in 2019.

Presentation: Alternative fodder production systems for South Africa (Authors: M Musokwa, P Mafongoya and S Lorenz)
Venue: UKZN Westville Campus
Date: 26 October 2017

Poster: The influence of pruning frequency on biomass productivity and nodulation of *Sesbania sesban* (Thabo Makhubedu, Brigid Letty, Peter Scogings and Paramu Mafongoya)
Venue: UKZN Westville Campus
Date: 26 October 2017

THE INFLUENCE OF PRUNING FREQUENCY ON BIOMASS PRODUCTIVITY AND NODULATION OF *SESBANIA SESBAN*

Thabo Makhubedu, Brigid Letty, Peter Scogings and Paramu Mafongoya

School of Agriculture, Earth and Environmental Sciences

Introduction

In recent years, efforts have been made to explore options of incorporating legume trees into traditional farming systems for improving soil nitrogen (N) fertility. Due to their capacity to fix N_2 in association with rhizobia, legume trees offer alternative options for coping with soil N deficiencies. In alley cropping, fodder banks or cut-and-carry silvopastoral systems, tree legumes are severely pruned for minimizing shade, enhancing nutrient cycling or harvesting fodder for livestock. The aim of this study was to to assess the effect of four pruning frequencies on biomass productivity and nodulation of *S. sesban* under glasshouse conditions. This research is funded by the Water Research Commission and is part of a larger project titled: WATER USE OF AGROFORESTRY SYSTEMS FOR FOOD, FORAGE AND/OR BIOFUEL PRODUCTION (K5/2492//4).

Materials and Methods

Two month-old seedlings were transplanted into 5 L free draining pots containing a mixture of the Umgeni River sand and vermiculite, and irrigated weekly with 1 L of 1/8 strength Hoagland nutrient solution. At three months after transplanting (MAT), the seedlings were inoculated and subjected either to no pruning or to one of three pruning frequencies (3, 6 and 9 month intervals), with each pruning removing shoot biomass above initial 50% height. The treatments were arranged in a complete randomized design with four replications. After each pruning, and at final harvest, removed biomass was partitioned into stem, green leaves, twigs, branches, roots and nodules. The components were weighed, oven-dried at 60°C for 72 h, and weighed again for dry matter (DM) yield determinations. Analysis of variance was done using the GenStat version 18.1.

Figure 1: Propagation conditions and seedling emergence of *S. sesban* (A & B), and pruned *S. sesban* trees at 50% height at 3 MAT (C) and at 6 MAT (D).

Table 1: Final harvest and cumulative total dry matter yield (g plant^{-1}) of *S. sesban* as affected by pruning frequency.

Treatment	Stem	Branch	Twig	Leaf	Total
	Final harvest dry matter yield (g plant^{-1})				
PF0	57.82a	35.90b	0.87a	9.83a	104.42a
PF1	16.56b	49.50a	0.70a	9.33a	76.10a
PF2	13.20b	15.17c	1.83a	6.50b	49.90c
PF3	17.88b	8.00c	1.67a	5.83b	51.26c
LSD$_{(0.05)}$	6.36	7.81	1.29	2.01	11.13
F-value	104.04***	56.36***	1.84NS	9.38**	88.24***
	[a] Cumulative dry matter yield (g)				
PF0	57.82a	35.90b	0.87b	9.83c	104.42a
PF1	17.52b	49.50a	0.77b	12.11b	79.89b
PF2	14.26b	26.03c	2.19ab	17.66ab	60.14c
PF3	19.10b	34.86b	3.31a	29.48a	86.74b
LSD$_{(0.05)}$	6.27	8.45	1.58	6.58	14.69
F-value	101.68***	12.48***	5.54**	16.89***	14.75***

PF0, PF1, PF2, PF3: unpruned, pruned once, pruned twice, pruned 3 times
[a] Including previous prunings

Table 2: Root dry matter yield (g plant^{-1}), root length (cm) nodule number (no. of nodules plant^{-1}) and nodule dry weight (g plant^{-1}) of *S. sesban* subjected to three different pruning frequencies.

Treatment	Final harvest			
	Root		Nodulation	
	Dry weight	Length	Dry weight	Number
PF0	74.56a	68.03a	2.90a	164.7a
PF1	65.45a	58.75a	2.82a	162.3a
PF2	47.02b	47.85b	2.71a	140.0a
PF3	42.78b	44.20b	1.97b	110.3b
LSD$_{(0.05)}$	12.15	9.98	29.10	29.10
F-value	14.60***	11.17***	12.49**	7.15**

Acknowledgements

Water Research Commission
University of KwaZulu-Natal
My Colleagues
National Research Foundation
Institute of Natural Resources NPC

Figure 2: Severely pruned (E), well recovering (F) and profusely nodulated (G) *S. sesban* tree.

Findings

- Total shoot DM yield of unpruned trees at final harvest were significantly higher than all the pruning treatments (Table 1).
- Similarly, cumulative shoot DM production was significantly greater in unpruned tree relative to pruning treatments.
- In terms of cumulative ligneous tissue, DM production of plants was significantly higher in less frequently pruned trees (Figure 3).
- In contrast, the most frequently pruned trees recorded the highest non-ligneous dry matter production (Figure 4).
- Root dry weight and length at final harvest was significantly reduced by increased pruning frequency (Table 2).
- Nodule DM and nodule number of plants were not significantly affected by pruning frequency except for PF3 plants.

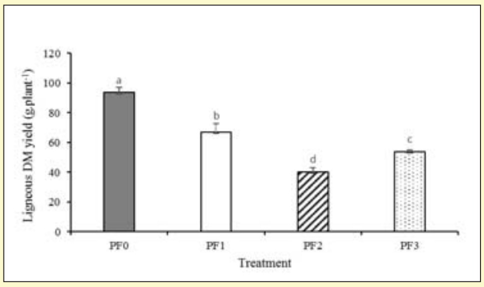


Figure 3: Cumulative ligneous (woody stems + branches) dry matter yield (g plant^{-1}) of *S. sesban* as affected by pruning frequency.

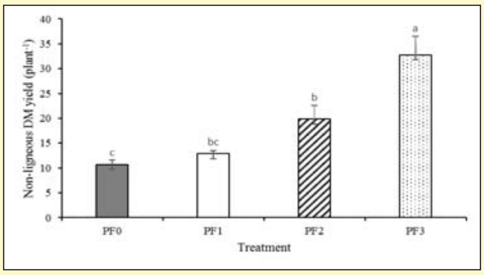


Figure 4: Cumulative non-ligneous (edible twigs + leaves) dry matter yield (g plant^{-1}) of *S. sesban* as affected by pruning frequency.

Conclusions

The findings of this study indicate that increased pruning frequency may result in gradual depletion of reserve carbohydrates in the plants to such an extent that plants may no longer be capable to grow vigorously.

2018 events

Fountainhill Symposium
Papers were presented by Thabo Makhubedu and Misheck Makhubedu at the annual research symposium held at Fountainhill Estate in October 2018.

Papers were titled as follows:

- Pruning residue effect on symbiotic performance of Pigeon pea and Sesbania sesban in alley cropping systems (Thabo Makhubedu & Brigid Letty)
- Investigation of agroforestry systems: Agronomic performance and impacts on soil water – An overview of results thus far (Misheck Musokwa).

Food2030 Conference
Brigid Letty presented an oral presentation at the Food2030 Conference at University of Honenheim in Stuttgart, Germany in September 2018.

Presentation: Opportunities that agroforestry offers for increasing the resilience of food production systems (Authors: B Letty, T Makhubedu and M Musokwa

2019 events

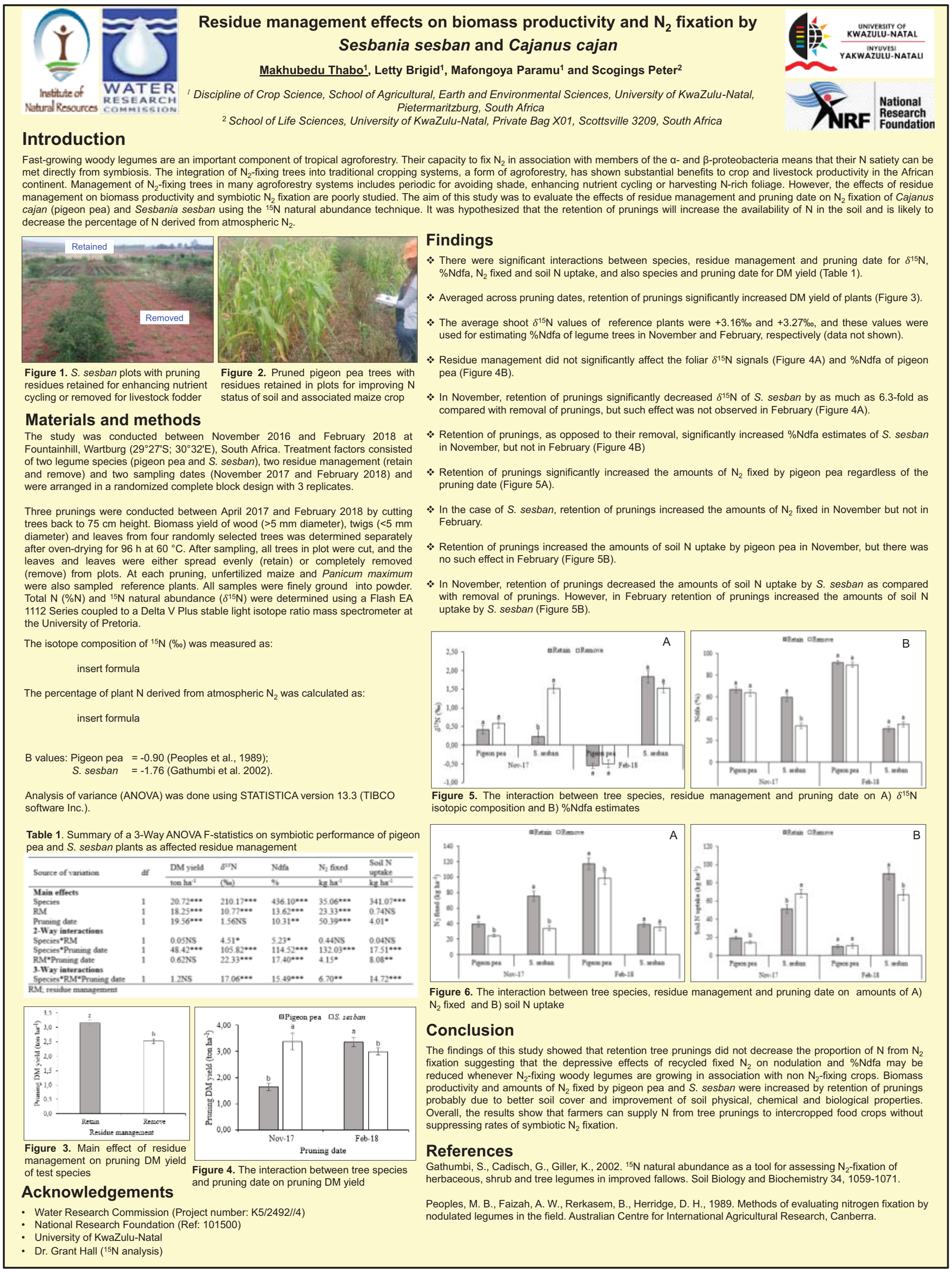
World Agroforestry Conference
Poster: Effects of improved pigeon pea fallows on biological and physical soil properties and their relationship with maize yield (Authors: Musokwa M., Mafongoya P., Lorentz S)

Abstract: Land degradation and declining soil properties, have affected agricultural productivity. Sub Saharan Africa (SSA) is experiencing the rapid increase in the percentage of rural households farming on degraded land as compared to other regions in the world. Use of legume trees such as pigeon pea improved fallows, is one of the agroforestry system that can restore degraded soils. The objectives of the study were to: Evaluate biological (soil macrofauna species diversity & richness) and physical soil properties (infiltration rate & aggregate stability) of the two-year-pigeon pea improved fallow compared to non-fertilized continuous maize crop and to relate maize grain yield to biological and physical soil properties. The study was conducted in KwaZulu-Natal Province at Fountain hill Estate (29°27'2" S; 30°32'42" E) and 853 m. A randomized complete block design replicated three times was used with 5 treatments, continuous unfertilized maize (T1), natural fallow – then maize (T2), pigeon pea intercropped with grass in (1st year) – then pigeon pea (2nd year) – then maize (3rd year) (T3), maize intercropped with pigeon pea (1st year) – then pigeon pea (2nd year) – then maize 3rd year (T4). Two-year pigeon pea fallow then maize on 3rd year (T5). Pigeon pea fallows were planted as pure stands at a spacing of 1 m by 1 m, direct seeded in 2015/2016 season. The fallows were terminated in November 2017, and then maize was planted in all plots. Soil macrofauna was sampled using steel monoliths. Infiltration rate was measured using double rings. Aggregate stability was measured using a modified wet-sieving technique. Data was analysed using Estimate S, Correlation and Regression analysis and GENSTAT C. Significant difference ($P<0.05$), were observed on soil macrofauna species richness and diversity as indicated by the order T5 (17.44d) >T4 (13.33c) ≥ T3 (10.56bc) ≥ T2 (9.67b) > T1 (6.00a) and T5 (1.75b) ≥ T2 (1.66b) ≥T4 (1.62b) > T1 (0.78a) ≥ T3 (0.98a) respectively. Significant differences ($P<0.05$) were observed on Infiltration rate (mm/hr) T5 (29.81c) > T3 (20.99b) ≥ T2 (19.11b) ≥ T4 (15.97ab) ≥ T1 (10.78a) and aggregate stability (mm) – T5 (11.45c) > T3 (10.13bc) ≥ T2 (8.99b) ≥ T4 (11.20c) ≥ T1 (5.02a). Maize grain yield was significantly higher ($P < 0.05$) with the following order T5 (3787d) >T4 (2922c) ≥ T3 (2852c) ≥ T2 (2294b)>T1 (993a) kg/ha. Positive correlation was observed between infiltration rates ($r2 = 0.73$), soil aggregate stability ($r2 = 0.92$), soil macrofauna species

richness (r2= 0.99) against maize grain yield. Increase in aggregate stability and infiltration can increase potential for rapid capture of rainfall. This will also decrease the potential for runoff, erosion, and evaporation leaving more water available for maize crop use. This ultimately leads to a more sustainable viable system and under climate change variability maize crop may go under dry spell, hence it will create resilient maize cropping system.

Keywords: aggregate stability, agricultural productivity, agroforestry, infiltration rate, soil macrofauna.

Poster: Residue management effects on biomass productivity and N_2 fixation by *Sesbania sesban* and *Cajanus cajan* (Makhubedu Thabo, Letty Brigid, Mafongoya Paramu and Scogings Peter)



Residue management effects on biomass productivity and N_2 fixation by *Sesbania sesban* and *Cajanus cajan*

Makhubedu Thabo[1], Letty Brigid[1], Mafongoya Paramu[1] and Scogings Peter[2]

[1] *Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa*

[2] *School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa*

Introduction

Fast-growing woody legumes are an important component of tropical agroforestry. Their capacity to fix N_2 in association with members of the α- and β-proteobacteria means that their N satiety can be met directly from symbiosis. The integration of N_2-fixing trees into traditional cropping systems, a form of agroforestry, has shown substantial benefits to crop and livestock productivity in the African continent. Management of N_2-fixing trees in many agroforestry systems includes periodic for avoiding shade, enhancing nutrient cycling or harvesting N-rich foliage. However, the effects of residue management on biomass productivity and symbiotic N_2 fixation are poorly studied. The aim of this study was to evaluate the effects of residue management and pruning date on N_2 fixation of *Cajanus cajan* (pigeon pea) and *Sesbania sesban* using the ^{15}N natural abundance technique. It was hypothesized that the retention of prunings will increase the availability of N in the soil and is likely to decrease the percentage of N derived from atmospheric N_2.

Retained
Removed

Figure 1. *S. sesban* plots with pruning residues retained for enhancing nutrient cycling or removed for livestock fodder

Figure 2. Pruned pigeon pea trees with residues retained in plots for improving N status of soil and associated maize crop

Materials and methods

The study was conducted between November 2016 and February 2018 at Fountainhill, Wartburg (29°27'S; 30°32'E), South Africa. Treatment factors consisted of two legume species (pigeon pea and *S. sesban*), two residue management (retain and remove) and two sampling dates (November 2017 and February 2018) and were arranged in a randomized complete block design with 3 replicates.

Three prunings were conducted between April 2017 and February 2018 by cutting trees back to 75 cm height. Biomass yield of wood (>5 mm diameter), twigs (<5 mm diameter) and leaves from four randomly selected trees was determined separately after oven-drying for 96 h at 60 °C. After sampling, all trees in plot were cut, and the leaves and leaves were either spread evenly (retain) or completely removed (remove) from plots. At each pruning, unfertilized maize and *Panicum maximum* were also sampled reference plants. All samples were finely ground into powder. Total N (%N) and ^{15}N natural abundance ($\delta^{15}N$) were determined using a Flash EA 1112 Series coupled to a Delta V Plus stable light isotope ratio mass spectrometer at the University of Pretoria.

The isotope composition of ^{15}N (‰) was measured as:

insert formula

The percentage of plant N derived from atmospheric N_2 was calculated as:

insert formula

B values: Pigeon pea = -0.90 (Peoples et al., 1989);
S. sesban = -1.76 (Gathumbi et al. 2002).

Analysis of variance (ANOVA) was done using STATISTICA version 13.3 (TIBCO software Inc.).

Table 1. Summary of a 3-Way ANOVA F-statistics on symbiotic performance of pigeon pea and *S. sesban* plants as affected residue management

Source of variation	df	DM yield	$\delta^{15}N$	Ndfa	N_2 fixed	Soil N uptake
		ton ha⁻¹	(‰)	%	kg ha⁻¹	kg ha⁻¹
Main effects						
Species	1	20.72***	210.17***	436.10***	35.06***	341.07***
RM	1	18.25***	10.77***	13.62***	23.33***	0.74NS
Pruning date	1	19.56***	1.56NS	10.31**	50.39***	4.01*
2-Way interactions						
Species*RM	1	0.05NS	4.51*	5.23*	0.44NS	0.04NS
Species*Pruning date	1	48.42***	105.82***	114.52***	132.03***	17.51***
RM*Pruning date	1	0.62NS	22.33***	17.40***	4.15*	8.08**
3-Way interactions						
Species*RM*Pruning date	1	1.2NS	17.06***	15.49***	6.70**	14.72***

RM; residue management

Figure 3. Main effect of residue management on pruning DM yield of test species

Figure 4. The interaction between tree species and pruning date on pruning DM yield

Findings

- There were significant interactions between species, residue management and pruning date for $\delta^{15}N$, %Ndfa, N_2 fixed and soil N uptake, and also species and pruning date for DM yield (Table 1).
- Averaged across pruning dates, retention of prunings significantly increased DM yield of plants (Figure 3).
- The average shoot $\delta^{15}N$ values of reference plants were +3.16‰ and +3.27‰, and these values were used for estimating %Ndfa of legume trees in November and February, respectively (data not shown).
- Residue management did not significantly affect the foliar $\delta^{15}N$ signals (Figure 4A) and %Ndfa of pigeon pea (Figure 4B).
- In November, retention of prunings significantly decreased $\delta^{15}N$ of *S. sesban* by as much as 6.3-fold as compared with removal of prunings, but such effect was not observed in February (Figure 4A).
- Retention of prunings, as opposed to their removal, significantly increased %Ndfa estimates of *S. sesban* in November, but not in February (Figure 4B)
- Retention of prunings significantly increased the amounts of N_2 fixed by pigeon pea regardless of the pruning date (Figure 5A).
- In the case of *S. sesban*, retention of prunings increased the amounts of N_2 fixed in November but not in February.
- Retention of prunings increased the amounts of soil N uptake by pigeon pea in November, but there was no such effect in February (Figure 5B).
- In November, retention of prunings decreased the amounts of soil N uptake by *S. sesban* as compared with removal of prunings. However, in February retention of prunings increased the amounts of soil N uptake by *S. sesban* (Figure 5B).

Figure 5. The interaction between tree species, residue management and pruning date on A) $\delta^{15}N$ isotopic composition and B) %Ndfa estimates

Figure 6. The interaction between tree species, residue management and pruning date on amounts of A) N_2 fixed and B) soil N uptake

Conclusion

The findings of this study showed that retention tree prunings did not decrease the proportion of N from N_2 fixation suggesting that the depressive effects of recycled fixed N_2 on nodulation and %Ndfa may be reduced whenever N_2-fixing woody legumes are growing in association with non N_2-fixing crops. Biomass productivity and amounts of N_2 fixed by pigeon pea and *S. sesban* were increased by retention of prunings probably due to better soil cover and improvement of soil physical, chemical and biological properties. Overall, the results show that farmers can supply N from tree prunings to intercropped food crops without suppressing rates of symbiotic N_2 fixation.

References

Gathumbi, S., Cadisch, G., Giller, K., 2002. ^{15}N natural abundance as a tool for assessing N_2-fixation of herbaceous, shrub and tree legumes in improved fallows. Soil Biology and Biochemistry 34, 1059-1071.

Peoples, M. B., Faizah, A. W., Rerkasem, B., Herridge, D. H., 1989. Methods of evaluating nitrogen fixation by nodulated legumes in the field. Australian Centre for International Agricultural Research, Canberra.

Acknowledgements

- Water Research Commission (Project number: K5/2492//4)
- National Research Foundation (Ref: 101500)
- University of KwaZulu-Natal
- Dr. Grant Hall (^{15}N analysis)

Fountainhill Research Symposium
Presentation: Experiences from the agroforestry trials at Fountainhill Estate
(B Letty, T Makhubedu and M Musokwa)
10 October 2019
Wartburg

SASAS-KZN
Brigid Letty presented at the symposium of the South African Association of Animal Science KwaZulu-Natal Branch at Cedara in October 2019.

Presentation: Agroforestry opportunities for fodder production in smallholder systems (Brigid Letty, Thabo Makhubedu and Zanele Shezi)

Abstract: Smallholder livestock systems are characterised by low levels of production. In sourveld areas this is largely due to the decline in quality of natural pastures over winter, while in sweetveld areas, there is generally a shortage of feed in the dry winter months. The integration of wood legumes such as pigeon pea (*Cajanus cajan*) and *Sesbania sesban* might be an intervention that can provide a source of high quality fodder to supplement poor quality pastures and maize residues. A project funded by the Water Research Commission was implemented by the Institute of Natural Resources over a five year period. Two alley cropping systems (firstly *S. sesban* and maize and secondly *Panicum maximum* and pigeon pea) were tested at Fountainhill Estate in Wartburg. At the same time these two species were also introduced to farmers at Ixopo/Highflats to evaluate within their own systems. While the suitability of the species for alley cropping was questionable due to the competition with the maize crop, farmers found them useful sources of fodder and found other ways to use them. For example maize farmer, Mr Mkhize, planted them the contours in his maize fields, while other farmers planted them around the boundaries of their yards. Besides testing the trees' appropriateness for the climatic conditions of the area, and for their usefulness as a source of fodder or for improving soil fertility, we also worked with farmers to test some feed rations using dried leaf material of both species. What has been clear from the research process is the need to allow farmers to evaluate new ideas for themselves under their own conditions.

Key words: agroforestry, silvopastoral systems, *Sesbania sesban*, pigeon pea

Popular articles

Article in local newspaper of Ixopo (NIX)

Agricultural M@TTERS Smallholder Farmers Experiment With Agroforestry (AF) Systems at Ixopo

Zanele Shezi

Introduction to Agroforestry

The Institute of Natural Resources NPC (INR) is working with smallholder farmers at Ixopo through a Water Research Commission (WRC) - funded project titled "Water Use of Agroforestry systems for food, forage and/or biofuel production" (Project no: K5/2492//4). This research project is investigating agroforestry systems that make effective use of available water and improve livelihoods through increased crop and fodder production. Agroforestry (AF) can be described as a farming system that integrates crops and livestock with trees and shrubs simultaneously or sequentially. It has the potential to increase crop yields, diversify farm produce, minimise risks, conserve resources and improve livelihoods. AF integrates different land use systems and adopts an interdisciplinary approach to farming. It also provides farmers with services such as conserving soil and moisture, improving soil fertility, reducing wind erosion and providing shelterbelts and/or windbreaks. It is a long-term cultivation process. Generally, changes in soil properties are observed in the period of 5-10 years.

Site Identification

The Ixopo site was identified through interactions with the Ixopo office of KZN Department of Agriculture and Rural Development, which provides support to the local Ubuhlebezwe Livestock Association, as well as the Traditional Authority in the area. Through these engagements, the concept of agroforestry was introduced to farmers. Ultimately, the aim of the engagements was to understand and characterise farmer's production systems and to determine how agroforestry could be included in the production system, considering farmers own experiences and key constraints. The two main constraints identified by farmers was a shortage of fodder to sustain livestock during the dry seasons and low crop yields. Based on these constraints, on-farm trials were developed with farmers who provided suggestions on how the experiments should be conducted. The Participatory Action Research (PAR) approach is employed to facilitate on farm research, with a view to strengthening farmer participation and guiding research activities. The details of these participatory agroforestry experiments are discussed below.

Testing of tree species on farm

In November 2015, the INR started experiments with five farmers in their homestead gardens. The primary objective of the farmers is to increase crop yields and provide livestock fodder. Various tree species, namely pigeon pea (uDali), *Sesbania sesban* (Umsokosoko) and *Faidherbia albida* (umhlalankwazi) are being assessed for suitability to the local environment. The trees experienced severe hail storms at an early growth stage and as a result some trees were damaged. The pigeon pea and *Faiderbia albida* showed adaptive traits because they survived winter months. A farmer field day was held in April 2016. The purpose was for farmers to share information about the different experiments in the first phase of the project. Agroforestry is a new concept to most farmers. They were a bit concerned about integrating trees with commercial crops. The main concern was that the trees will consume more water and nutrients in the soil, leaving little available for the commercial crops. It was strongly emphasised to farmers that the purpose of participatory research is to test methods in order to find out what is working and what is not. Their participation and feedback is of utmost important to inform the research agenda. This will give an indication of whether agroforestry is beneficial in farming systems that can be adopted by farmers.

Figure 1 : Farmers observing the growth of trees during the farmers' day.

2016/2017 Trials

The on-farm experiments for the 2016/17 growing season started with planning and designing of trials in farmer's gardens where plots have been demarcated for intercropping trees and maize, as well as trees planted on their own.

Ms Joyce Dlamini's trial description

Manual tillage was used for preparing the land. Since we are considering low input systems, no chemical fertilizer was used when planting. The trial, as shown above, has seven plots. They consist of (1) sole maize the control (2) sole Sesbania sesban, sole pigeon pea, as well as maize intercropped with Sesbania sesban and Pigeon pea in an alley cropping arrangement. The additional maize sole plots planted will be used to test the benefits of biomass transfer. Biomass transfer will involve pigeon pea and Sesbania sesban. This procedure involves applying harvested Pigeon pea and Sesbania sesban biomass to the maize plots. The aim is to increase soil fertility in the maize plots.

Mr T.P Dlamini's trial description

This farmer practices minimum tillage when planting in the lower parts of his maize field, therefore the same method was adopted for the experiment. The trial has 8 plots, which consist of maize, sole pigeon pea, sole *Sesbania sesban* as well as maize intercropped with pigeon pea and *Sesbania sesban*. The maize plots are divided into two, half with and half without fertilizer. The maize without fertilizer will serve as control. The aim is to evaluate crop growth and yields of maize with fertilizer, without fertilizer and with biomass transfer. The same method of biomass transfer used in Ms Joyce Dlamini's trials will be used here.

Mr Sizwe Mtshali trial description

This farmer is mainly interested in increasing fodder for livestock. He has an area of unmanaged kikuyu (*Pennisetum clandestinum*) adjacent to his home. At the beginning of the project there was poor growth of the kikuyu due to continuous grazing. An area was fenced off to allow the kikuyu to rest. Pigeon pea and *Sesbania sesban* trees were introduced into the enclosure. The kikuyu has recovered and is growing faster, thus competing with the pigeon pea and *Sesbania sesban*. The farmer has been harvesting kikuyu for his cows using the cut and carry system. There is a substantial difference between the kikuyu in the enclosure and in the open area outside. which is continually grazed by animals. The kikuyu in the enclosure had grown above 35cm height over a period of five months (December 2015 to April 2016). It is hoped that this experiment will educate livestock owners to consider practicing resting in their grazing areas.

Current outcomes and concluding remarks

Normally, for the trees used in the trials (*Faidherbia* and *Sesbania*), it is recommended to cut the leaves and pods to feed livestock, rather than allowing direct grazing on the trees. Pigeon pea appears more favourable to farmers because of its multipurpose use for instance as fodder and for human consumption or sale. Farmers were able to harvest seeds from pigeon pea trees, which allowed them to expand the cultivated area. Seeds harvested were also shared with other interested farmers. Generally, farmers felt that the trees grew well in local conditions. They also learnt how the trees benefit the soils and can be fed to livestock. The emerging lessons have been used to design 2016/2017 experiments based on farmers' observations and feedback.

Figures 2: Trial layout at Miss Dlamini's garden.

Figures 3: Ms Dlamini in the Sole Sesbania plot

Figure 4 : Mr Mtshali's kikuyu field before fencing.

Figure 5: Kikuyu and tree species in the enclosure.

For more info contact: Ms Zanele Shezi
Tel: 033 3460 796
Email: zshezi@inr.org.za

APPENDIX 3: LIST OF CONTACTS FOR SITE IDENTIFICATION PROCESS

SITE	PROJECT TEAM	CONTACT DETAILS
Nansindlela Training Centre	Brigid Letty	Morag Peden (Project leader of previous INR AF project) 082 841 3217 pedenm@ukzn.ac.za
Dundee Research Station	Brigid Letty	Erika van Zyl (Researcher) 082 321 3960 Erika.VanZyl@kzndard.gov.za
Biyela, Melmoth	Zanele Shezi	Roy Dandala (Lima staff) 083 764 2967 Mrs Gumede 0739214833
Owen Sithole College of Agriculture, Empangeni	Brigid Letty Zanele Shezi Zinhle Ntombela Misheck Musokwa	Francois du Toit (Farm manager) 082 745 0070 Francois.Dutoit@kzndard.gov.za
Zwelisha, Bergville	Brigid Letty Zanele Shezi Zinhle Ntombela Misheck Musokwa Sylvester Selala	Simon Mbhele (Farmer) 0735954268 Nokuthula Makhaza (Farm assistant) 0720816512
Ixopo/Highflats	Brigid Letty Zanele Shezi Zinhle Ntombela Misheck Musokwa Sylvester Selala	Mr T.V. Dlamini 0837520193 (Chairperson of Ubuhlebezwe Livestock Ass.) Mr Sizwe Mtshali 0785415791 Mrs Joyce Dlamini 0827998828 Mr M. Mkhize 0633717582 Inkosi T.P Dlamini 0735301693
Fountain Hill Estates	Brigid Letty has made contact	Edwin Gevers ehgevers@gmail.com 0833214100

APPENDIX 4: QUESTIONNAIRE WHEN VISITING FARMERS AT IXOPO/HIGHFLATS

Please fill in the spaces provided or circle the letter with the appropriate answer

1. Name and surname:____
2. Contact number

3. Sex:
   Female
   Male

4. Age at last birthday: _______________________________________

5. Marital Status:

   Married
   Divorced/Separated
   Widowed
   Never married (single)

6. Location details

Ward		District		GPS	
Village					

7. Type of farming systems?

8. Land holding
0.5-2 ha
2-4 ha
>4 ha

9. What are the main crops grown by the farmers?

   Cereals/grains (maize, sorghum, wheat)
   Legumes (Dry beans, cowpeas, etc.)
   Cash crops (Tobacco, cotton)
   Tuber crops (Sweet potatoes, potatoes, cassava)
   Garden crops (fruits and vegetables)
   Orchard crops/ Fruit trees
   Plantation (timber),
   Sugarcane
   Any trees?
   Other (Please name them:
   ____

10. What farm animals do you keep? And Numbers?

   Cattle
   Sheep
   Goats
   Donkeys
   Chickens
   Pigs
   Other; please specify ____

11. Main challenges being faced in your farming systems

---

12. Have you ever heard about “Agroforestry”?
    Yes
    No.

    If yes, where did you hear about it?

    At school
    At College
    During in-service training at work
    In project training or project being implemented in my ward/district
    At a conference/meeting

13. Are you willing to participate in agroforestry project that can address some of your challenges?

What challenges would you be most interested in to be addressed:

- Firewood shortages
- Fodder
- Soil fertility
- Low productivity (crops and livestock)

APPENDIX 5: TIME DOMAIN REFLECTROMETRY

Time domain reflectometry (TDR) is a non-destructive technique for the simultaneous measurement of soil water content and soil electrical conductivity. The TDR system propagates a balanced waveform, which travels down a coaxial cable and waveguide and is influenced by the type of material surrounding the conductors (Topp, Davis & Annan 1980). 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 propels 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.

For calibration purposes, gravimetric soil water moisture was determined for each of the plots that had instruments to calibrate observed water content against data provided by the TDR. .

To enable volumetric water content (VWC) to be calculated from the TDR probe readings, soil samples were collected from undisturbed soil cores at each depth near the instruments. The samples were weighed and dried in an oven at 100°C for 24 hours and then reweighed. Gravimetric values were converted to VWC using bulk density values determined for undisturbed soil cores of known volume. This procedure was repeated several times during the 2015/2016 cropping season to span the range between extreme soil wetness and dryness. The figures were used to establish the relationship between VWC and probe reading for all sampling depths.

A moisture release curve was constructed to establish soil moisture content at field capacity (FC), permanent wilting point (PWP) and intermediate values. FC was used to establish the moisture content at which drainage began. Three undisturbed soil samples were collected using pF rings for the 0 cm, 15 cm, 30 cm, 60 cm and 90 cm horizons from pits dug close to the experimental site. These were placed in a sand batch chamber and completely wetted before being subjected to matric pressure of 0-90 cm to span the range between FC and PWP; samples were equilibrated for 4-5 days before completing the measurement. VWC was determined for each soil sample for all tensions applied; mean VWC values for each soil depth were plotted against the corresponding TDR probe count to determine the moisture release curve.

APPENDIX 6: NUTRITIONAL VALUE OF THE FODDER CROPS FROM THE AGROFORESTRY TRIAL AT ZWELISHA

In order to compare the nutrient content of the fodder crops grown on-farm with a commercial dairy ration, samples of the Vachellia leaf, cocksfoot and lespedeza were sent to the laboratory for nutrient content analysis. The results from the Feed Laboratory at Cedara are presented in Table A.1, which also shows the nutrient content of two commercial feeds available from Meadow Feeds, namely Multilak and TMR (total mixed ration).

Table A.1 Nutrient content of commercial feed vs own produced feed.

	Commercial Feed		Own Production		
Nutrients (g/kg)	Meadow Multilak	Meadow TMR	Lespedeza	Cocksfoot	*Vachellia* leaves
CP	160	150	319.81	378.55	119.90
ADF	120	135	340.57	379.83	271.00
NDF	200	280	410.40	592.02	348.80
Ca	15	9.5	6.67	3.01	16.70
P		3	3.27	4.01	1.20

The Vachellia leaves were found to have crude protein (CP) content of 12%, while the commercial dairy rations had 15-16% CP. The Lespedeza and cocksfoot had CP of 32% and 38% respectively.
Acid detergent fibre (ADF) and neutral detergent fibre (NDF) are estimates of the less digestible structural carbohydrates. Basically, ADF consists of cellulose and lignin, while NDF includes cellulose and lignin as well as the hemi-celluloses. Feed digestibility is the proportion of forage DM that is able to be digested by the animal, and this declines as the plant matures. Dry matter digestibility (DMD%) expresses all of the solubilized materials as a portion of the DM of the sample. DOMD% expresses solubilised organic matter as a portion of the DM of the sample. Metabolisable energy (ME) is an estimate of the energy content potentially available to the ruminant animal, being the energy retained for metabolic purposes and expressed as a proportion of DM (i.e. MJ/kg). ME can be calculated as follows: ME = DOMD% x 0.16 for pastures and other forages (Hill Laboratories, 2017).

Given that the nutritional requirements of a lactating dairy cow are: %CP >16; %ADF <21; and %NDF <28 (More detail is provided in Table A.2), the high ADF and NDF of the fodder crops (%NDF of 41, 59 and 35 for lespedeza, cocksfoot and Vachellia, respectively), is a limitation although the %CP was high.

A ration containing *Vachellia* leaves has been formulated by the provincial Department of Agriculture's animal scientists at Cedara. It comprises 20 kg high protein concentrate (HPC), 65 kg maize grain, 15 kg acacia leaves, 1 kg P12 and 1 kg salt and provides a ration comprising 17% CP, 4.6% ADF and 8.4% NDF. It is anticipated that this ration will be tested with the farmer Mr Mbele.

Hills Laboratories (2017) also provide a summary of general figures for feed value of different forms of forage (Table A.2)

Table A.2 Indicative feed requirements for ruminants (Hills Laboratory, 2017)

Animal	Crude Protein (%CP)	Acid Det. Fibre (%ADF)	Neutral Det. Fibre (%NDF)	Digestibility (%DOMD)	Metabolisable Energy (M/kg)
Cattle (Beef)	>12	19	25	61	9.5 – 10.5
Dairy Cow – Dry	>12	27	35	56	8.6
Dairy Cow - Lactation	>16	21	28	71	11
Calf	>16	>16	23	69	11
Sheep	9 – 12	20 – 25	25 – 35	55 – 65	8 – 10
Lamb	11 – 14	16 – 20	20 – 25	65 – 75	9 – 11

Table A.3 Typical feed values of a number of forage options

Feed Type	Dry Matter (%)	Crude Protein (%)	Acid Det.Fibre (%)	Neutral Det.Fibre (%)	Digestibilty (%DOMD)	Metabolisable Energy (MJ/kg)
Mixed Pasture	12 – 25	20 – 30	20 – 30	30 – 45	65 – 80	9 – 12
Pasture Silage	25 – 30	14 – 20	20 – 35	30 – 45	65 – 75	9 – 11
Cereal Silage	35 – 40	8 – 12	25 – 40	35 – 60	55 – 65	8.5 – 10.5
Maize Silage	25 – 35	6 – 9	25 – 35	35 – 50	60 – 70	9.5 – 11
Lucerne Forage	15 – 25	20 – 30	25 – 30	35 – 45	60 – 70	9 – 12
Lucerne Hay	85 – 90	18 – 25	25 – 35	35 – 50	55 – 65	8 – 11

Another source of average figures for forage quality in Australia is shown below in Table A.4, where cocksfoot has a much lower %CP but a similar %ADF to that obtained for the samples from Zwelisha.

Table A.4 Average nutrient composition of common forage crop/pasture species (extracted from a database maintained by NSW DPI, Malau-Aduli (2007))

Pasture	CP (%)	ME (MJ/kg DM)	ADF (%)	DMD (%)
Ryegrass	16	9.8	30.5	65
Lucerne	18	9.2	36.1	62
Barley	13	11.3	16.3	75
Wheat	14	11.4	16.5	76
Clover	15	9.9	28.9	66
Cocksfoot	12	8.8	36.4	59
Canola	19	10.3	28.1	68
Chicory	18	9.8	31.9	65
Lupins	30	11.1	27.2	74
Linseed	32	11.5	24.9	77
Oats	11	10.4	23.3	69
Triticale	12	12.4	7.2	83

The %CP obtained for the cocksfoot from Zwelisha (38%) appears rather high. Peri et al. (2007), exploring the effect of different light intensities on cocksfoot growing under 10-year old pine trees, documented CP of 18.6% under high light intensity (in combination with DM production of 8.2 t DM/ha/year in the open (100% of photosynthetic photon flux density-PPFD) and 22.5% under reduced light intensity (24% of PPFD), with production of 3.8 t DM/ha/year

Regarding variation in nutritional content between cultivars and with stage of maturity, a study on Tall Fescue, conducted by Kaufonga (2015) in New Zealand, revealed that, for example, one variety (TF 1) had the following CP: 20.7% in November, 32.2% the following May, and 26.2% in November. However, for TF 4, CP% varied as follows: 13.3% in November, 24.5% in the following May and 14.6% in November. This demonstrates that the quality of the cocksfoot may decline substantially as it matures.

While fodder production was not measured at Zwelisha, it is interesting to note that according to Van der Colf and Botha (2013), annual production (kg DM/ha) of different cocksfoot cultivars growing under irrigated conditions in the Southern Cape over a two year period, varied between and 14,422 kg and 16,309 kg in the first year and 13,121 kg and 10,118 kg in the second year. Obviously under rainfed conditions this will e substantially reduced.

Cocksfoot appears to be an attractive pasture species for Bergville because it has be grown successfully in areas that receive a minimum of 450 mm, is highly tolerant of aluminium and can be grown on a wide variety of soils with pH ($CaCl_2$) >4 (Hackney, 2007).

The results obtained for the Vachellia leaves compare with a study by Masiku (2013), investigating acacia leaf meal as a protein supplement for goats. He obtained figures for nutrient content provided below in Table A.5

A study by Brown (2016) showed that acacia leaf meal crude protein contents range from 10.6-14.7%, but that supplementation with PEG was necessary to allow for higher levels of inclusion in the diet.

Table A.5 Nutrient content of acacia leaf meal (Masiku, 2013)

CP (g/100g)	ME (Mj/kg)
10.2	10

The nutrient analyses for lespedeza, which show high CP, but also high NDF and ADF, compare with findings of other authors. There is substantial variation between the nutrient content of different cultivars, as demonstrated by Mosjidis (1993), who found the variation captured in Table A.6.

Table A.6 Variation in nutrient composition of genotypes of *Sericea lespedeza* (Mosjidis, 1993)

Nutritional component	Range of values
Crude protein (%)	8.55-12.69
ADF (%)	38.7-50.0
NDF (%)	44.3-62.0

The results obtained for the sample taken from Bergville show substantially higher CP% and marginally lower ADF and NDF figures. This could have been due to the age of the material sampled, with the sample containing mainly leaf and little stem. Since many lespedeza varieties have high tanning levels which reduce digestibility and palatability, supplementation of cattle with polyethylene glycol (PEG) has been found to be effective as a mechanism to overcome these limitations (Mantz, 2007). The high levels of tannins have also been found to reduce faecal egg counts of *Haemonchus contortus* (Wireworm) parasites, thus providing a natural anthelmintic[3].

Another consideration is the calcium: phosphorus (Ca: P) ratio of the forage. The optimal Ca: P ratio in forage for ruminants is 1.75:1, although ratios between 1.1:1 and 7:1 are acceptable (Harty, 2014). From Table A.1 it is clear that the Ca levels are too high relative to P in the Vachellia leaves and too low in the cocksfoot. The lespedeza shows the most favourable ratio of 2.04:1.

[3] USDA NIFA note. Goat Pastures *Sericea lespedeza* http://articles.extension.org/pages/19420/goat-pastures-sericea-lespedeza

References

Brown, D.A. 2016. Evaluation of mixtures of Acacia karroo leaf meal and Setaria verticillata grass hay for indigenous pedit goat production. PhD thesis. University of Limpopo.

Hackney, B. Cocksfoot. Primefact 281, New South Wales Department of Primary Industries.

Harty, A. 2014. Importance of Calcium and Phosphorus in the Ruminant Diet. I GROW. South Dakota State University Extension.

Hill laboratories. 2017. Technical note, Pasture and feed forage quality.

Kaufononga, S. 2015. Comparative response of tall fescue (*Lolium arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.) swards to variation in defoliation interval and height. Master of AgriScience, Massey University, University of New Zealand.

Malau-Aduli, A.E.O. 2007. Energy and protein contents in pastures at different times of the year and feeding tomeet animal nutrient requirements. In: S. Campbell (Editor) Pasture Pickings, Proceedings of the Grasslands Society of Southern Australia 16th Annual Conference, Tasmanian Branch, Launceston, Australia, 16:39-52 (2007).

Mantz, G.K. 2007. Using Polyethylene Glycol to Enhance the Intake of Sericea Lespedeza by Cattle. PhD Dissertation. Utah State University.

Mosjidis, J.A. 1993. Variability for biomass production and plant composition in Sericea lespedeza germplasm – Final Report on a Field and Laboratory Research Program for the Period September 30, 1990, to December 31, 1991. Dept. Agronomy and Soils and Ala. Agric. Exp. Stn, Auburn University, Auburn, AL 36849-5412. https://www.osti.gov/scitech/servlets/purl/10167118

Peri, P.L., Lucas, R.J. and Moot, D.J. 2007. Dry matter production, morphology and nutritive value of *Dactylis glomerata* growing under different light regimes. Agroforestry Systems 70:63-79.

Van der Colf, J. and Botha, P.R. 2013. The production potential of fescue, cocksfoot, perennial ryegrass and Bromus spp. over two years. In Research Article Compilation, Outeniqua Research Farm, 2008-2013. Agri-Connect (Pty) Ltd.