

**THE ASSESSMENT OF THE IMPACT OF CASUARINA CUNNINGHAMIANA  
MIQ.(RIVER-SHE-OAK) WINDBREAK ON MACADAMIA TREES ORCHARDS IN  
LIMPOPO PROVINCE, SOUTH AFRICA**

**BY**

**MICKFANAKA MWIHOMEKE**

**STUDENT NO: 11553838**

**SUBMITTED IN FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF  
MASTER OF ENVIRONMENTAL SCIENCES**

**IN**

**THE SCHOOL OF ENVIRONMENTAL SCIENCE**

**DEPARTMENT OF ECOLOGY AND RESOURCE MANAGEMENT**

**UNIVERSITY OF VENDA**

**PRIVATE BAG X 5050**

**THOHOYANDOU**

**0950**

**SUPERVISOR: PROF R.B. BHAT**

**CO-SUPERVISORS: MR. M.H. LIGAVHA-MBELENGWA AND MR. J.N.STEYN**

**MARCH 2013**

## Declaration

This thesis is dedicated to my beloved parents Steven and Dayness, my lovely sisters Tundonde and Tswana, my grandmother Maria and the poetry club members. Special thanks to the staff and students of the University of Venda.

I MickfanakaMwihomeke, hereby declare that this dissertation for the Degree of Master of Environmental Science in Ecology and Resource Management at the University of Venda, hereby submitted by me and has not been submitted previously for any degree or examination at this or any other university, that is my own work in design and execution and that all reference materials contained herein have duly been acknowledged.

Signature..... *Mfanaka* .....

Date..... *3/4/2013* .....

## Dedication

This thesis is dedicated to my beloved parents Steven and Dayness, my lovely sisters Tundonde and Tusana, my grandmother Maria and the poetry club members. Special thanks to the Lord, Almighty God.

To my supervisor Prof. R.B Bhal, and my co-supervisor Mr. M.H Ligavha-Mbelengwa thank you for your great assistance and support. Working with you made the journey to be full of wisdom and learning. I also thank Mr. J.N Steya for his help on the design of the research and guidance at various stages of this study.

I would like to thank Mr. P.A. Abama for welcoming and allowing me to use his farm for my study. Additionally, I would like to express my sincere appreciation for their strength and support when days were tough.

Thank you to my friends: Sany Kaburiso, Mulaio Rawaoundi, Mathameli. Poozy, and others who supported me in my research work.

Thank you to my family: Ntse Daboa, MadanAmbani, Mbedzilazzy, Maida Fresh, Mulaio Rawaoundi, Mulaio Rawaoundi. I say thank to you.

Finally to my beloved Mother, I thank you for the love and bless you gave me throughout my research work.

## Acknowledgements

I would like to acknowledge the following individuals for their support and assistance throughout this study:

- To my supervisor Prof. R.B Bhat, and my co-supervisor Mr. M.H Ligavha-Mbelengwa thank you for your great assistance and support. Working with you made the journey to be full of wisdom and learning. I also thank Mr. J.N Steyn for his help on the design of the research and guidance at various stages of this study.
- I also thank Mr. Fritz Ahrens for welcoming and allowing me to use his farm for my study.
- My mother and my father. I would like to express my sincere appreciation for their financial support and encouragement when days were tough.
- I also thanks my brotherly friends Sonny Kaburise, Mulalo Ramulondi, Mathamela, Pessy, and Glen and all those who assisted in my research work.
- To all my field assistance, Masia Dalton, Mudau Ambani, Mbedzi Lassy, Mauda Fresh, Modiba Zikwe and Nenzhelelefuluhelo. I say thanks to you.
- Finally to my closest Josephinah, I thank you for the love and ideas you gave me throughout my research work.

## Abstract

This study focused on the investigation of *Casuarina cunninghamiana* Miq. windbreaks trees associated with macadamia orchards. Field observations showed that macadamia trees near the windbreaks have poor growth in terms of leaves and number of branches, root collar diameter and fruit yield. This problem is prevailing despite the application of drip irrigation and fertilizers to young *Macadamia tetraphylla* trees possibly due to underground competition for water and nutrients with *C. cunninghamiana* roots that might grow and extend to near-by rows where *Macadamia tetraphylla* would be growing; such roots may even extend to distant rows; however from *Casuarina cunninghamiana* roots exposure there is no actual distance recorded as to how far the roots of *C. cunninghamiana* windbreaks have extended towards the orchards. Unless this problem is solved, farmers in the study areas may resort to the removal of windbreaks like what is being done by other farmers that are growing avocado and kiwi fruits trees at Haenertsburg in Limpopo Province.

Our findings after trenching revealed that water, nutrients and stomatal conductance have been improved in trenched sites compared to those in not trenched sites. This study has indeed established the kind of interaction between *C. cunninghamiana* and *M. tetraphylla* that cause the poor growth of Macadamia in the Luvuvhu areas (farms).

This study has provided baseline information on the management of *C. cunninghamiana* windbreaks and may contribute to a reduction of their impacts on macadamia orchards in Luvuvhu farms and elsewhere in South Africa.

**Key words;** *Casuarina cunninghamiana* Miq, fruit orchard, growth performance and yield, Limpopo Province, *Macadamia tetraphylla*, windbreaks impacts.

<b>Contents</b>	<b>Page</b>
2.1.10 Additional Benefits of Windbreaks	10
2.2 Disadvantages of Living Windbreaks	10
2.4 Management When Windbreaks Compete for Water, Nutrients and Light	12
2.5 Ecology of Caturra (Curtain Grass)	13
2.7 Plant Factors, Environment and Water Use	14
<b>Declaration</b>	<b>i</b>
<b>Dedication</b>	<b>ii</b>
<b>Acknowledgements</b>	<b>iii</b>
<b>Abstract</b>	<b>iv</b>
<b>Table of Contents</b>	<b>v</b>
<b>List of Figures</b>	<b>vii</b>
<b>CHAPTER ONE: INTRODUCTION</b>	<b>1</b>
1.1 Background of the study	1
1.2 Problem Statement	2
1.3 Research Questions	3
1.4 Research Aim and Objectives	3
1.4.1 Aim	3
1.4.2 Main Objective	3
1.4.3 Specific Objectives	4
1.5 Thesis Statement	4
1.6 Delineation and Limitations	4
1.7 Significance of the Study	5
1.8 Underlying Assumptions	5
<b>CHAPTER TWO: LITERATURE REVIEW</b>	<b>6</b>
2.1 Benefits of Windbreaks Worldwide and in South Africa	6
2.1.1 Reduction of Disease	6
2.1.2 Yield Increase of Crops	6
2.1.3 Support Wildlife Habitat	7
2.1.4 Reduction of Soil Loss	7
2.1.5 Reduction of Nutrient Loss	7
2.1.6 Reduction of Evapotranspiration	8
2.1.7 Reduction of Irrigation Loss	8
2.1.8 Reduction of Physical Abrasion to Crops	9
2.1.9 Reduction of Agricultural Chemical Drift	9

2.1.10	Additional Benefits of Windbreaks .....	10
2.2	Disadvantages of Living Windbreaks .....	10
2.4	Management When Windbreaks Compete for Water, Nutrients and Light .....	12
2.5	Ecology of <i>Casuarina cunninghamiana</i> .....	13
2.7	Plant Factors, Environment and Water Use .....	14
2.8	Tree Species and Water Use.....	16
2.9	Plant Existence, Growth and Competition for Water .....	17
2.10	Water Stress on Photosynthesis and Rate of Respiration .....	17
2.11	Comparative Ecology of <i>Casuarina cunninghamiana</i> and <i>Macadamia tetraphylla</i> .....	18
2.12	Macadamia Production Areas in South Africa and Worldwide .....	19
2.13	Ecology and Practices for Cultivation of Macadamia .....	20
2.13.1	Soil and Moisture Requirements .....	20
2.14	General Cultivation Practices in Macadamia .....	22
2.15	Managements Strategies in Agroforestry Used to Reduce Underground Competition.....	23
<b>CHAPTER THREE: DESCRIPTION OF THE STUDY AREA.....</b>		<b>27</b>
3.1	Ecological Description of the Study Area .....	27
3.1.1	Location.....	27
3.1.2	Land Use .....	28
3.1.3	Climate .....	28
3.1.4	Soils.....	28
3.1.5	Vegetation .....	28
<b>CHAPTER FOUR: STUDY METHODOLOGY .....</b>		<b>30</b>
4.1	Experimental Layout and Data Collection .....	30
4.2	Plant Water Status Measurements .....	30
4.3	Leaf Stomatal Conductance Measurements .....	30
4.4	<i>Macadamia tetraphylla</i> Nutrient Analyses after <i>Casuarina cunninghamiana</i> Root Cutting	31
4.5	Plant Development Measurements .....	31
4.6	Data Analysis .....	31
<b>CHAPTER FIVE: RESULTS AND DISCUSSION .....</b>		<b>33</b>
5.1	Water Potential.....	33
5.2	Discussion .....	67
<b>CHAPTER 6: CONCLUSION AND RECOMMENDATIONS.....</b>		<b>72</b>
<b>References .....</b>		<b>73</b>

## List of Figures

<b>Figure 1</b> <i>Casuarina cunninghamiana</i> windbreak removal in avocado fruits trees at Haenertsburg in Limpopo Province.....	26
<b>Figure 2</b> Map showing the location of the study area.....	27
<b>Figure 3</b> Water potential for trenched and not-trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.....	34
<b>Figure 4</b> Water potential for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.....	36
<b>Figure 5</b> Stomatal conductance for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.....	38
<b>Figure 6</b> Means of Boron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	39
<b>Figure 7</b> Means of Calcium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	41
<b>Figure 8</b> Means of Iron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	42
<b>Figure 9</b> Means of Potassium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	44
<b>Figure 10</b> Means of Magnesium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	46
<b>Figure 11</b> Means of Manganese concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	47

**Figure 12** Means of Sodium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....49

**Figure 13** Means of Zink concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....50

**Figure 14** Means of Phosphorus concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....52

**Figure 15** Means of root collar diameter at 6m, 14m and 20m between trenched and not trenched treatment.....53

**Figure 16** Means of root canopy diameter at 6m, 14m and 20m between trenched and not trenched treatment.....55

**Figure 17** Means of tree height at 6m, 14m and 20m between trenched and not trenched treatment.....56

**Figure 18** Means of number of new shoots at 6m, 14m and 20m between trenched and not trenched treatment.....58

**Figure 19** Mean Stomatal conductance for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak 24/5/2012.....60

**Figure 20** Mean Stomatal conductance for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak 27/9/2011.....61

**Figure 21** Mean Water potential for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak 16/4/2011.....63

**Figure 22** Mean Water potential for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak 27/8/2011.....65

**Figure 23** Mean Water potential for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak 08/10/2011.....65

## List of Tables

<b>Table 1</b> Difference between water potential of the first of recording and second date of recording.....	33
<b>Table 2</b> Means for difference between water potential of the first of recording and second date of recording.....	34
<b>Table 3</b> Difference between water potential of the first of recording and third date of recording.....	35
<b>Table 4</b> Means for difference between water potential of the first of recording and third date of recording.....	36
<b>Table 5</b> Difference between stomatal conductance of the first recording and second date of recording.....	36
<b>Table 6</b> Means for difference between stomatal conductance of the first of recording and second date of recording.....	37
<b>Table 7</b> Two-way Analysis of Variance (with interaction) for Dependent Variable Boron.....	38
<b>Table 8</b> Means of Boron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	39
<b>Table 9</b> Two-way Analysis of Variance (with interaction), Dependent Variable Calcium.....	40
<b>Table 10</b> Means of Calcium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	41

**Table 11** Two-way Analysis of Variance (with interaction), Dependent Variable Fe.....41

**Table 12** Means of Iron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....42

**Table 13** Two-way Analysis of Variance (with interaction), Dependent Variable Potassium.....43

**Table 14** Means of Potassium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....44

**Table 15** Two-way Analysis of Variance (with interaction), Dependent Variable Magnesium.....44

**Table 16** Means of Magnesium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....45

**Table 17** Two-way Analysis of Variance (with interaction), Dependent Variable Manganese.....46

**Table 18** Means of Manganese concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....47

**Table 19** Two-way Analysis of Variance (with interaction), Dependent Variable Sodium.....48

**Table 20** Means of Sodium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....49

**Table 21** Two-way Analysis of Variance (with interaction), Dependent Variable Zink.....49

**Table 22** Means of Zink concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....50

**Table 23** Two-way Analysis of Variance (with interaction), Dependent Variable Phosphorus.....51

<b>Table 24</b> Means of Phosphorus concentrations at 6m, 14m and 20m between trenched and not trenched treatment.....	52
<b>Table 25</b> Two-way Analysis of Variance (with interaction), Dependent Variable root collar diameter.....	52
<b>Table 26</b> Means of root collar diameter at 6m, 14m and 20m between trenched and not trenched treatment.....	52
<b>Table 27</b> Two-way Analysis of Variance (with interaction), Dependent Variable canopy diameter.....	54
<b>Table 28</b> Means of canopy diameter at 6m, 14m and 20m between trenched and not trenched treatment.....	54
<b>Table 29</b> Two-way Analysis of Variance (with interaction) Dependent Variable, tree height.....	55
<b>Table 30</b> Means of tree height at 6m, 14m and 20m between trenched and not trenched treatment.....	56
<b>Table 31</b> Two-way Analysis of Variance (with interaction), Dependent Variable number of new shoots.....	57
<b>Table 32</b> Means of number of new shoots at 6m, 14m and 20m between trenched and not trenched treatment.....	58
<b>Table 33</b> Two-way Analysis of Variance (with interaction), Dependent Variable: stomatal conductance 24/5/2011.....	58
<b>Table 34</b> Means for difference between stomatal conductance of the first date of recording.....	59

<b>Table 35</b> Two-way Analysis of Variance (with interaction), Dependent Variable: stomatal conductance 3/9/2011.....	60
<b>Table 36</b> Means for difference between stomatal conductance of the second date of recording.....	61
<b>Table 37</b> Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 16/4/2011.....	62
<b>Table 38</b> Mean xylem water potential of the first date of recording 16/4/2011.....	66
<b>Table 39</b> Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 27/8/2011.....	63
<b>Table 40</b> Mean xylem water potential of the second date of recording 27/8/2011.....	64
<b>Table 41</b> Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 8/10/2011.....	65
<b>Table 42</b> Means for difference between water potential of the first of recording and second date of recording.....	66

## CHAPTER ONE: INTRODUCTION

### 1.1 Background of the study

Windbreaks or shelterbelts are common practice worldwide that are established to monitor wind-related agricultural problems such as soil erosion, physical damage to crops (Sudmeyer & Scott, 2002) and crop disease (Gottwald & Timmer, 1995). For production of macadamia nuts it is a recommended practice in Australia to use *Casuarina cunninghamiana* or *Eucalyptus microcorys* as permanent windbreak trees. The windbreaks are normally established a few years (1-3 years) just before planting macadamia. Trenching or pruning of windbreak roots extending into the farm is recommended to minimize underground competition between windbreaks and crops (Kort, 1988; van Noordwijk & Purnomosidhi, 1995; Schroth, 1995).

In South Africa the majority of farmers do not practice trenching near windbreak trees. Probably they are not fully aware of the benefits and how to put them into practice. Currently the negative effects of *C. cunninghamiana* on neighboring high value horticultural crops such as avocado and macadamia tree orchards are prevalent in many parts of the Limpopo Province. This has led to many farmers opting to remove *C. cunninghamiana* windbreak trees in order to minimize their negative effects on *Macadamia tetraphylla* (*M. tetraphylla*).

However the removal of windbreaks has many side effects for crop productivity, crop damage for example, protection of macadamia trees from strong winds that could disturb fruit setting, breakage of branches, protection of macadamia from influx of windborne insect pests and disease pathogens and prevention of soil and moisture loss from young macadamia trees through evapotranspiration and soil erosion by strong winds. In addition to the above the removal of *C. cunninghamiana* windbreak trees is contrary to the promotion of agroforestry

and afforestation programs in agricultural environments to serve multiple uses and for environmental protection such as enhancing carbon sequestration and reducing greenhouse gas emission.

*Casuarina cunninghamiana* being one of the most environmentally tolerant exotic tree species capable to grow in a wide range of marginal and degraded soils, the species is a high priority for use in afforestation for environmental protection. Although *C. cunninghamiana* together with *C. equisetifolia* and *C. glauca* have all been declared alien invasive trees in South Africa and also in the United States of America, their above-mentioned unique value can nevertheless be realized through better management such as trenching to minimize the negative effects on adjacent crops.

## 1.1 Research Aim and Objectives

### 1.2 Problem Statement

The ability of *Casuarina cunninghamiana* to deplete ground water resources and hence its influence on macadamia growth and yield is not known. Farmers and extension staff do not know the causal factor or mechanisms for the poor growth of fruit trees impacted upon by casuarina windbreaks and the effects of root ripping as one of the management interventions is also not known and hence not practiced by many farmers.

#### 1.2.1 Main Objective

To establish the impact of *C. cunninghamiana* plants on the growth and production of *Macadamia integrifolia* in agricultural orchards.

### 1.3 Research Questions

In order to address the above problem this study will focus on answering the following questions:

- i) Do *C. cunninghamiana* plants cause water depletion at their growing sites with *M. tetraphylla*?
- ii) Does *C. cunninghamiana* plants water use influence the growth of *M. tetraphylla* due to competition?
- iii) Do *C. cunninghamiana* plants deplete the amount of soil nutrients such that they impact on the growth of *M. tetraphylla*?

### 1.4 Research Aim and Objectives

#### 1.4.1 Aim

To assess the impact of *C. cunninghamiana* used as windbreaks on *M. tetraphylla* tree orchards and how *C. cunninghamiana* influences the growth and productivity of *M. tetraphylla*.

#### 1.4.2 Main Objective

To establish the impact of *C. cunninghamiana* plants on the growth and production of *M. tetraphylla* in agricultural orchards.

### 1.4.3 Specific Objectives

To compare macadamia trees performance adjacent to casuarina windbreak trees with trenched and those adjacent to casuarina windbreak trees with roots not trenched and also their performance away from the casuarina windbreaks with respect to the following:

- i) Plant water status
- ii) Stomatal leaf conductance
- iii) Plant development by measuring the following; root collar diameter, canopy diameter, number of new shoots and tree height
- iv) Plant nutrient accumulation

## 1.5 Thesis Statement

*Casuarina cunninghamiana* as invasive alien plants result in high water and nutrient extractions from the environment where they grow compared to the adjacent crop, *Macadamia tetraphylla* in the study area. This results in competition for water and nutrients leading to poor growth of the adjacent *M. tetraphylla* trees.

## 1.6 Delineation and Limitations

Natural growth conditions of *C. cunninghamiana* in riparian zones leads to an expectation that it is a water loving plant, although the same species can as well grow away from the riparian zones under human interventions. Riparian ecosystems compared to terrestrial ones are unique in terms of having different alluvial soil types, nutrients influx and water content and plants growing there are adopted to relatively high water availability; with my given time and limitation of resources my focus will be on the following factors: xylem water potential of *M. tetraphylla*, physiology of *M. tetraphylla* plants with regard to stomatal conductance as

an indicator of water stress imposed by casuarina windbreaks, macadamia growth development and nutrient accumulation in *M. tetraphylla*.

## 1.1 Benefits of Windbreaks Worldwide and in South Africa

### 1.7 Significance of the Study

South Africa is a water scarce country dominated by semi-arid and arid climatic zones with very few places having fairly high rainfall and few rivers with permanent water flow. Therefore efficient management and use of water resources should be a major objective which should receive the highest priority. The research will contribute towards the baseline information that can support the planning and management of *C. cunninghamiana* as invasive alien plant used in farming systems to minimize potential adverse impact on water resources.

### 1.8 Underlying Assumptions

The assumption is that other environmental factors may also contribute to the depletion of water resources under the *C. cunninghamiana* growing areas, but in this case such are held constant, for example, surface runoff, water loss through evaporation and soil conditions.

## 2.1.2 Yield Increase of Crops

By influencing temperature and evapotranspiration windbreaks help to increase nitrogen uptake by crops by better plant growth and yield (Gish & Kaita, 1970). Even in dry years and in arid environments crops protected by windbreaks have shown to have better development

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 Benefits of Windbreaks Worldwide and in South Africa

#### 2.1.1 Reduction of Disease

In Florida citrus is one of the major agricultural products and its yield has been severely impacted upon by citrus canker (*Xanthomonas axonopodis* sp. *citri*). This has also been observed in citrus orchards of South Africa. Citrus canker is caused by bacteria, which are vectored by wind and rain. Citrus canker dispersal has been documented at long distances due to blowing rainstorms (Gottwald *et al.*, 1992 & Graham & Gottwald, 1992). Citrus fruits that contain canker are undesirable and may not reach market quality.

By reducing wind speed windbreaks act as a barriers to the spread of the pathogens. Studies have shown that citrus groves surrounded by windbreaks are less infected by canker (Leite & Mohan, 1990). Windbreaks have been shown to help to reduce the rate of canker local and long-distance spatial distribution in Florida and many parts of the world more effectively than the use of copper-based bactericides, which have been used as standard method for canker control (Gottwald & Timmer, 1995). Windbreaks will likely reduce the spread of infections from many other horticultural fruit crops.

#### 2.1.2 Yield Increase of Crops

By influencing temperature and evapotranspiration windbreaks help to increase nitrogen uptake by crops for better plant growth and yield (Shah & Kalra, 1970). Even in dry years and in arid environments crops protected by windbreaks have shown to have better development

and fair increase in yield, that is, between 3 and 20 times the windbreaks heights at the cropped areas (Sudmeyer & Scott, 2002) compared to areas where windbreaks are not planted.

### 2.1.3 Support Wildlife Habitat

Windbreaks can also provide benefits for wildlife specifically when multiple plant species are in use, windbreaks can serve as a feeding, nesting, and resting sites for many birds, mammals, amphibians and reptiles. Some birds are known to be useful in pollination process; insectivorous birds may use the windbreaks as a perch, thereby reducing the population of insects and rodents from damaging the crops. Snakes that are sheltered in the windbreaks may also reduce vertebrates that are pests to crops.

### 2.1.4 Reduction of Soil Loss

Soil erosion is the primary concern where fields are subjected to regular high winds. Windbreaks can reduce soil erosion by ameliorating wind speed across open fields. The susceptibility of soil to erosion is a function of particle size; clay and silt particles are easily removed from the surface at low wind speeds while sand particles need relatively high wind speeds. It can be expected that windbreaks will reduce erosion on the leeward side of trees in protected zones.

### 2.1.5 Reduction of Nutrient Loss

Nutrient loss from wind-eroded soil can be a major problem in areas where nutrients are concentrated in the top layer of soil. Studies show that wind-transported soil contains a

significant amount of nutrients and, in most cases, has a higher nutrient level than the remaining topsoil in the field (Leys &McTainsh, 1994, Larney*et al.*, 1998, Nuberg, 1998 &Sudmeyer& Scott, 2002a). It has been suggested that wind erosion causes a significant amount of soil loss in Florida like many other parts of the world for example the Sahel region of West Africa (Gillette, 1986 &DeWiest& Livingston, 2002).Therefore in those areas where fields are regularly fertilized and left after harvest problems of great concern are caused. Windbreaks are able to reduce wind speeds so both soil erosion and nutrient loss can be reduced, providing good economic support to farmers.

#### 2.1.6 Reduction of Evapotranspiration

Moisture stress, caused by a combination of wind, high temperatures and low humidity, is immediately apparent in many crops such as vegetables and other shallow-rooted herbaceous crops. Moisture stress leads to wilting, stomata closure, and cessation of photosynthetic activity, which ultimately leads to plant death. Fruit set on vegetable crops can be seriously reduced if water becomes limited. Because windbreaks control wind speed behind the barrier, they reduce evaporation from bare soil and transpiration from crops (Cleugh, 2002), thus making plants behind the windbreaks less likely to suffer from moisture stress and reducing the irrigation requirements.

#### 2.1.7 Reduction of Irrigation Loss

In countries that highly depends on agriculture, water consumption in agricultural areas brings a great debate especially in countries of water scarcity like South Africa, since it is important to irrigate orchards as required. Windbreaks are documented to have increased the

efficiency of overhead irrigation by reducing wind speed and keeping sprayed water only on the targeted sites of plants (Andreuet *et al.*, 2009).

#### 2.1.8 Reduction of Physical Abrasion to Crops

Wind-transported soil particles also contaminate vegetables and fruits that later reduce their quality. Frictional marks from high-speed wind also reduce the quality of leafy vegetables, fruits, flower crops, bedding plants, and other crops. This becomes a concern during the onset of flowers and fruits and significantly windbreaks can reduce the intensity of these problems because the windbreak will trap the soil particles that are carried by the wind as it move across the orchards and deprive the fruit quality.

#### 2.1.9 Reduction of Agricultural Chemical Drift

Chemicals, including insecticides, fungicides, herbicides, and so on are regularly applied in aqueous sprays to agricultural fields. During their application, small droplets remain suspended in the air and are easily carried to non-targeted areas by the wind (drifts). Drifts can cause health and environmental problems to people, wildlife and habitats (Cleugh, 1998). Windbreaks therefore can act as buffers in such environments to control both the above-ground movement of pesticide drifts and their underground movement into the environment such as in wetlands and water resources.

### 2.1.10 Additional Benefits of Windbreaks

Windbreaks to some extent add aesthetic value to the landscape by screening undesirable sights and increasing property value. Windbreaks also provide various ecosystem services including carbon sequestration, nutrient cycling and water quality.

## 2.2 Disadvantages of Living Windbreaks

Even though windbreaks are known to have great advantages to crops there are number of demerits farmers and growers have report with the use of windbreaks, windbreaks have tend to Compete for moisture and nutrients but such phenomena have been observed in sites where no proper management was done (John&Sandra, 2006), shading have also been a technical concern with the use of windbreak and to crops that are sensitive to shade there have been poor yields and crop growth(Chaput& Tuskan,1991).

When the farmer initiate for the windbreak another disadvantage could be based on the material and labor costs for establishing the windbreak, during the planting time labor is needed and such a farmer need to have a source of money in order to support the planting of windbreak, windbreak are also known to have a capability to occupies valuable land that crops could be planted and also tend to compete for light with adjacent crops (Greb& Black, 1961), windbreak also increased humidity within adjacent areas which can slow drying periods to crops such as maize and others as well as fruit and such to an extent can favor some fungal pathogens that may harm the crops.

Windbreak also requires water and this become another demand to the farmer if the water for irrigation is scarce especially in dry and arid environment, windbreaks also interferes with the movement of machinery such as tractors within the farm and another disadvantage of a

windbreak is also the fact some windbreak tree species are not tolerant to freezing environments and that makes it impossible to maximize the benefits of windbreaks in cold environments, windbreak trees with shallow root systems can easily be blown over by the strong winds and due to that adjacent crops can be damaged and windbreak tree itself will be of no use again.

Whilst windbreak have been widely used by farmers, the establishment of windbreak takes time in order to be fully effective some trees such as casuarina takes up to five to ten years to be effective other disadvantages is some windbreaks may attract wild animals and birds and act as a shelter which will then damage the crops.

### 2.3 Competition Management of Field Windbreaks with Crops

In order to obtain maximum benefits from windbreaks, it must be properly managed throughout its lifetime. In the initial years, windbreaks may require as much care as a seasonal crop so they can become well established and maintain vigor, but over time they will require less maintenance and provide the many benefits of increased wind protection for years of crop production. Windbreaks management depends on factors such as site conditions where the windbreaks are planted (soil and climate), the species used in the windbreaks, spacing within a row and between rows, and other elements of windbreaks design once these factors have been determined, developing a management plan can be much easier.

## 2.4 Management When Windbreaks Compete for Water, Nutrients and Light

Competition between windbreaks and crops for moisture, nutrients, and light can be an issue. This becomes serious if both trees and crop roots use the same area in the soil profile. One way to reduce competition is by pruning the tree roots to the depth occupied by crop roots using commercially available root pruners. Root pruning can increase crop yield in the windbreak-crop interface at least for a few years (Sudmeyer *et al.*, 2002). But tree roots may have to be pruned once every couple of years and pruning becomes difficult with deep-rooted species. Shade-tolerant crops can be used next to the windbreaks to reduce the effects of light competition. In areas where access roads and irrigation ditches are widely used, both roots and above-ground competition can be reduced by placing access roads on one side of the windbreaks and irrigation ditches on the other side of the windbreaks.

Very dense windbreaks can be as bad as none at all. Turbulence on the leeward side of dense windbreaks can cause more damage to crops than the unobstructed wind. Pruning and thinning may be required for dense windbreaks in order to maintain the desired porosity and reduce wind turbulence (Okorio, 2000).

Windbreak trees should generally not be pruned, but if need be, pruning should focus on young, multi-stemmed trees smaller than 2 inches in diameter (Wray *et al.*, 2005). Young trees with many stems or forking can be pruned to contain only one dominant stem. This will create a single-stemmed tree that will grow faster and taller than if it is not pruned. Branches can also be pruned to create desired porosity.

With older, more established trees, you may need to thin or remove trees from the windbreaks if tree crowns have limited space to grow. The selection of tree(s) to remove will depend on the number of rows in the windbreaks and one's management objectives. Thinning

options include the following: removal of every other tree, removal of an entire row, or simply thinning around the crowded trees. It is wise to remove the trees that have poor vigor, are deceased, or are dying and leave the healthier and perhaps larger trees. One should nevertheless always keep one's desired level of porosity in mind so that you do not inadvertently over-thin.

## 2.5 Ecology of *Casuarina cunninghamiana*

*Casuarina cunninghamiana* is usually a medium-sized to tall plant attaining 20 – 35 m in height and 0.5 - 1.5 m in diameter. It is the largest of the genus in Australia, although in open country in the north of the area of occurrence, such as southeast of the Gulf of Carpentaria in Queensland and in the northern territory, it may be only 12 m in height and straggly in appearance.

*Casuarina cunninghamiana* typically occurs in narrow belts along fresh watercourses throughout eastern Australia from southern new South Wales to Northern Queensland, its occurrence is being determined by the presence of fresh water; the species has a wide range of altitude from sea level to about 1000 m above the sea level and the climate varies from warm sub-humid to warm semi-arid, with a mean maximum temperature for the hottest month of 25 - 40<sup>0</sup>C and a minimum of 0 - 15<sup>0</sup>C, rainfall varies from 500 to about 1500 mm per annum, but as the tree is of riverine origin, rainfall alone is no indicator of the total moisture available.

*Casuarina cunninghamiana* grows as pure stands on river and stream banks in open-forest formations, especially in the belt between normal water level and maximum flood level and occasionally on adjacent river flats. The species may extend for short distances up the rocky hillsides, chiefly on limestone soils. The soils range from fine-textured sands through to

gravel in terraces of old river courses (Arthur & Craig 2006). In the typical riverine location the roots have access to flowing water or seepage; in other locations they usually have access to ground moisture additional to that derived from normal rainfall and this lead to an expectation *C. cunninghamiana* is a water loving plant and might therefore have to develop adaptive mechanisms to satisfy their water consumption levels. When planted outside their natural habitat *C. cunninghamiana* show an ability to grow satisfactorily on relatively dry soil (Arthur & Craig, 2006).

## 2.6 Uses of *Casuarina cunninghamiana* Worldwide and in South Africa

In South Africa casuarina trees are used as plants of choice in agricultural ecosystems for windbreaks in orchards (John & Sandra, 2006). *Casuarina cunninghamiana* have an attractive appearance and they are fast growing trees, and are used for ornamental planting as well as for shade. The wood of most casuarina plants are dense and very hard. They make excellent fuel used particularly in India and China, this is because they produce good heat and also because of being relatively smokeless when burnt.

Casuarina plants are also used for paper pulp in the Philippines, United States of America and Okinawa, and in southern coastal China they are used as resource trees for windbreaks. They are widely planted as street trees and in parks for sand stabilization after beach mining activities and mining spoil dumps (Burns *et al.*, 1998).

## 2.7 Plant Factors, Environment and Water Use

Terrestrial plants are exposed to different water regimes both seasonally and diurnally and if they have to survive they must have mechanisms for adjusting to changes in environmental water conditions. Traditionally the source region of soil water uptake by plants have been

difficult to assess (Ehleringer&Dawson, 1992); the distance through which water will move upwards from the water table towards the dry zone surrounding a root depends on the plant tolerance for stress and soil properties that influence hydraulic conductivity, whilst availability of water within a soil depends in part on how quickly and how far water will move upwards from the water table towards an absorbing root or into the soil during a rainstorm. The presence of roots at a given depth in the soil profile is not necessarily a reliable indicator of their relative contribution to total water uptake (Ehleringer& Dawson, 1992). Evergreen Mediterranean species tended to rely on rain water while deciduous species relied almost extensively on more dependable ground water (Valentini *et al.*, 1992).

Ehleringer&Dawson (1991) concluded that streamside trees actually use little stream water, whilst Le Roux *et al.*, (1997) discovered that both grass and woody species use water from the upper layers of the soil profile during the dry and wet seasons in West African humid savanna; on the other hand it has been found that deciduous Brazilian cerrado tree species have access to deeper sources of soil water than evergreen species (Jackson *et al.*, 1999). However, very little information is available as to what extent tree species and vegetation types deplete ground water. It has always been expected that larger trees have preference to tap deeper sources of soil water than smaller trees; seasonal causes of water use and soil water partitioning were also associated with leaf phenology. Species with smallest seasonal variability in leaf fall increasingly tapped deep sources of soil water as the dry season progressed (Jackson *et al.*, 1999). Dawson and Pate (1996) also observed seasonal shifts in source water utilization among Australian phreatophytic species with dimorphic root system.

## 2.8 Tree Species and Water Use

Water availability has been positively correlated with tree species diversity at the global, continental and regional scales (Paine *et al.*, 2009), with particular regions, water availability is modulated by rainfall seasonality and horizontal patterns of distribution. Consequently niche differentiation with respect to soil water availability is a direct determinant of both regional and local scale distribution of tropical plants (Engelbrecht *et al.*, 2007). High hydraulic sufficiency ensures an adequate water supply to canopy-top leaves in tall trees. The distribution of tropical forest species is shaped in accordance with tolerance to low water status as well as resistance to run-away xylem embolism (Kursaret *et al.*, 2009). However drought tolerance seems unlikely to be driven by variation in nutrient availability (Engelbrecht *et al.*, 2007). The ability of tree species to grow under particular water mechanisms is related to the trade-off between efficiency and safety for water use as well. Thus tree species would possess distinguishable leaf and xylem function traits enabling to define patterns of habitat specific use.

Effects of water stress on plant growth have been studied extensively (Labanauskas *et al.*, 1989) but few is known about studies examining the effects of water stress on transpiration in many plant communities; transpiration is strongly affected by water availability within the plant. Water shortage results in a net increase in the total soluble nitrogen of the stressed tissues of a plant (Karamanos *et al.*, 1986); there is evidence also from other studies that show that plants can change in their water balance with their stage of development (Morgan, 1977).

## 2.9 Plant Existence, Growth and Competition for Water

Each and every plant species is able to exist and produce successfully only within a definite range of environmental conditions; plants are not evenly distributed in nature and different environmental conditions of resources, neighbours and disturbance are but a few of the factors that influence the population dynamics and pattern of plants. Plant species have remarkably mesic requirements for good germination and seedling development such as abundant moisture, natural pH, low salinity and moderate temperature ( Barbour *et al.*, 1977) and such a combination of conditions may occur only occasionally in nature which influence plant growth and productivity.

Competition results in mutual adverse effects to organisms that utilize a common resource in short supply, such as short supply of water and other environmental resources. Unlike competition for light, in which larger plants disadvantage by shading smaller ones, belowground competition for soil resources become more severe. Belowground competition mostly decreases with an increase in water and nutrient levels within the soil.

## 2.10 Water Stress on Photosynthesis and Rate of Respiration

Leaf respiration rates decreased under drought in most species; under water stress environments dehydration of plant tissue can result in an increase in oxidative stress which causes deterioration in chloroplast structure and an associated loss in chlorophyll. This then leads to a decrease in the photosynthetic activity in a plant. While several studies described water stress induced decreased respiration rate (Gonzalez-Meleret *al.*, 1997 and Haupt-Herting *et al.*, 2001), certain other studies presented unaffected rates (Lawlor, 1976 and Loboda, 1993). Therefore the decline in plant respiration in response to drought seems to be part of a systemic metabolic response, which occurs under conditions where drought severely

restricts carbon dioxide availability inside the leaf cells, therefore, resulting into a risk of secondary oxidative stress (Flexaset *et al.*, 2004).

## 2.11 Comparative Ecology of *Casuarina cunninghamiana* and *Macadamia tetraphylla*

Both *C. cunninghamiana* and *M. tetraphylla* are native plants of Australia, sharing almost the same climatic conditions. The *Macadamia tetraphylla* nuts grow in remnant rainforest (Gross, 1995 and Stanley and Ross, 1986), preferring partially open areas such as rainforest edges (Ryan, 2006).

*Macadamia* tree prefers fertile, well drained soils and a rainfall of 1000 to 2000 mm per annum and temperatures not falling below 10<sup>0</sup>C, with an optimum temperature of 25<sup>0</sup>C, *Macadamia* roots are shallow and the parent trees can be damaged by winds (Orwaet *et al.*, 2009). Thus protection by windbreaks is essential, but the shallow root system may be a major problem leading into severe competition with other plants whose roots are also shallow in this case *C. cunninghamiana* which is being used as the windbreak tree in agricultural systems.

*Casuarinacunninghamiana* species is reported to tolerate annual precipitation of 500 to 2000 mm per annum and mean annual temperatures of 4 to 30<sup>0</sup>C and pH of 5.0 to 7.7; the natural populations are confined along rivers and streams forming part of riparian vegetation. Being a riparian tree species it implies that these plants demand large amount of water. *Casurinacunninghamiana* are nitrogen fixing woody plant species and can tolerate soils with marginal fertility (Elfers, 1988).

In the state of Florida, United States of America casuarina has been regarded as an invasive plant and also in South Africa; in Papua New Guinea casuarina is used in crop rotation to restore nitrogen to the soil and in South Africa the most valuable use of *C.*

*cunninghamiana* appears to be for windbreaks. It is also possible to use them for fuel wood. There are more than three tree species of casuarina plants namely. *C. glauca*, *C. equisetifolia*, and *C. cunninghamiana* are listed as noxious weeds in Florida, United States America (Arthur & Craig, 2006).

## 2.12 Macadamia Production Areas in South Africa and Worldwide

Macadamia tree belongs to the family Proteaceae, of which two species *Macadamia integrifolia* and *Macadamia tetraphylla* together with their hybrids are economically important for cultivation. These are among the Australian plants with commercial food value (Mason, 1982). Macadamia are among the most developed horticultural crops for farming worldwide. Though Australia has been the main producer of macadamia worldwide, South Africa has experienced considerable growth over the past 10 years with production of macadamia increasing more than fivefold, with total revenue generated from sales increasing from R32 million in 1996 to R276 million in 2006 (SAMAC, 2006). Hence many more farmers in South Africa are converting more of their agricultural land to produce macadamia and many other high value fruits trees. In South Africa, macadamia plants were first introduced into the country at the beginning of the 1960s and the industry has grown into a major world producer of macadamia nuts; South Africa was the third largest producer of macadamia nuts by the year 2007. The main growing area of macadamia in South Africa is Levubu and Tzaneen, both in the Limpopo Province, Hazyview to Barberton in Mpumalanga and the coastal region of Kwazulu Natal, wanting to develop and produce quality macadamia nuts, South African macadamia Growers Association (SAMAC) is the industry body formed in 1970s by a group of growers seeking to pool resources in order to address their common problems and issues. In windy areas of South Africa *M. tetraphylla* is grown in areas

protected from wind to reduce damage thereof and casuarina plants are the windbreaker trees of choice by many farmers.

*Macadamia tetraphylla* plants are grown in Australia, Brazil, Israel, Thailand, United States of America, Kenya, Malawi, Swaziland, South Africa, Zimbabwe, Costa Rica, New Zealand, and Guatemala (Cracker, 2000), macadamia are in demand around the world, in Australia macadamia are the only native plant to be successfully developed as commercial food crop (Mason, 1983). Macadamia trees grow well in fertile and well drained soils of tropical and temperate regions mainly in high rainfall areas.

## 2.13 Ecology and Practices for Cultivation of Macadamia

### 2.13.1 Soil and Moisture Requirements

Macadamia tree species originate in the subtropical rainforests of Australia mainly on the sub-humid eastern parts of Queensland and the Northeastern parts of New South Wales. These places have rich soils and high annual rainfall. Though these macadamia species are native in high rainfall places, they can tolerate a wide range of moisture conditions and can grow well in a wide range of soil types but perform well in well drained soils. The ability to form proteoid roots which absorb more nutrients and water help macadamia trees to adapt in poor soils in South Africa. Also young macadamia trees have a high requirements of nitrogen and phosphorus but low requirement for potassium until bearing of fruits starts. Leaf analysis studies can provide an insight into the macadamia plant requirements and uptake of soil nutrients and water (Orwaet *al.*, 2009).

Macadamia trees do not have a clearly defined tap root system and these make young trees particularly sensitive to wind blow in regions with strong wind. Hence many literatures

suggest that it is important to plant windbreaks preferably a few years before planting macadamia orchard. The shallow root system also makes macadamia to be prone to drought. Because of these macadamia production areas in South Africa are mostly found in places with mean annual rainfall ranging between 800 and 1200 mm. Where rainfall is scarce orchard in production can be assisted by irrigation.

### 2.13.2 Temperature Limits Influencing Growth and Productivity of Macadamia Trees

Temperature around the ground surface is controlled by the amount of incoming and outgoing solar radiation. There is spatial and temporal variation of incoming solar radiation caused by local factors. At continental scale the presence of large inland water bodies, elevation or altitude, topography and cloudiness influence incoming solar radiation and hence temperature. Thus temperature and altitude are often used synonymously as co-variants since altitude influences environmental conditions mainly temperature. Terrain aspect towards the main angle of the sun can also locally influence surface temperature (Kathyet *al.*, 1997).

Temperature can directly and indirectly influence many aspects of plant growth and development. Temperature stress and low light conditions can cause flower and fruit abortion which is a yield limiting factor in many crops (Bucciet *al.*, 2006). There may be genetically determined differences in plant phenotypes as a result of adaptation to different temperature and other environmental conditions. These differences affect competition for nutrients and water resources and hence productivity and product quality. Cultural practices such as selective breeding, irrigation, application of windbreaks, fertilization and pruning can be applied to reduce the inherent variation. However before the different cultural practices are applied it is important to understand how the individual plant species responds to different temperature conditions.

In the case of macadamia trees temperature is the main climatic variable determining growth and productivity. The optimum temperature for photosynthesis in young *M. tetraphylla* trees is reported to be between 25 - 35°C. Young trees can be killed by frost if the temperature gets below -5°C and also crop yield can be reduced in places with high temperatures. *Macadamia tetraphylla* is grown mainly within the tropical regions and some in the temperate regions not exceeding these temperature limits. At the altitude above 600 m, the grade quality of macadamia kernels as well as total nut production is reduced. Places with hot and dry tropical savanna climate may not be suitable for *M. tetraphylla* production unless there is possibility for irrigation and use of windbreaks to minimize temperature fluctuations in the farms.

#### 2.14 General Cultivation Practices in Macadamia

Cultivation practices aim to increase and sustain production of macadamia. For example a wide range of rootstocks have been developed to facilitate the planting of macadamia fruit trees on a wide range of soils (MacDaniels 1979). Rootstocks are also developed to enhance resistance of macadamia trees to pests and disease pathogens, tree growth vigor, for cold tolerance, fruit quality and tolerance of various soil conditions including poor drainage soils, drought, high or low pH and salinity. It is therefore important to take into account the types of rootstocks used when it comes to estimating or studying water use efficiency of macadamia trees.

## 2.15 Managements Strategies in Agroforestry Used to Reduce Underground

### Competition

The use of windbreaks is an important goal of combining trees and crops in agroforestry farming systems such is to make better use of the environmental resources required by plants for growth and production. A drawback to introducing windbreaks trees such as *Casuarina cunninghamiana* into agroforestry systems aiming to enhance crop production is that the trees and crop may compete for resources. Competition for environmental resources between windbreaks trees and crops results when exploitation of a resource by windbreak trees, for example water, light and nutrients reduces the growth and productivity of the crop; this holds where a nutrient or water is the resource that is most limiting to production; below-ground competition is most important therefore in semi-arid regions, water is often the most limiting resource to crops and competition for water can weaken the effectiveness of agroforestry systems (Smith *et al.*, 1998).

In east Africa Govindarajan *et al.*, (1996) and McIntyre *et al.*, (1997) identified competition for water as the major reason for the poor performance of hedgerow intercropping systems in semi-arid areas and both identified that zones where seasonal rains were not sufficient the uptake of water by hedges reduced the availability of water to adjacent crops of maize or cowpea causing losses in yield.

### 2.16 Tree Root Pruning (Tronching) in the Windbreaks Agro-forestry Practice

In order to successfully use windbreaks in farming systems to increase productive use of resources it is wise to ensure that the trees and crop exploit different resource pools, particularly at times when the availability of a resource is potentially limiting. Where trees and crops exploit distinct resource pools, they are complementary in their use of resources and are said to exhibit complementarity in resource use (Onget *et al.*, 1996). In order to achieve

complementarity for belowground resources, it is recommended to use deep-rooted tree species in agroforestry (Anderson & Sinclair, 1993). However there is a lack of information on root distributions in agroforestry systems which has resulted in lack of knowledge of which tree species are more suitable for windbreaks in agroforestry than others, based on their few lateral roots near the soil surface, for example in highlands of east and central Africa *Grevillea robusta* is used in agroforestry because of its deep rooting, with few superficial lateral roots (Howard *et al.*, 1997).

When windbreak trees are well-established they are capable of capturing more soil water and nutrients than crops. Such and reduces water and nutrients availability to the crops and thus limit growth and production. Root pruning by deep ripping could be used to reduce the dominance of tree roots near the soil surface; the effectiveness of root pruning over time is also uncertain since there is little information available on re-growth after root pruning and crop immediately and long term impacts after root pruning. It is also advisable that the ideal tree for agroforestry should have a deep root system and little root proliferation near the top of the profile, thereby enabling the crop to utilize resources from near the soil surface; the trees should have sole access to deeper layers (Schroth, 1995).

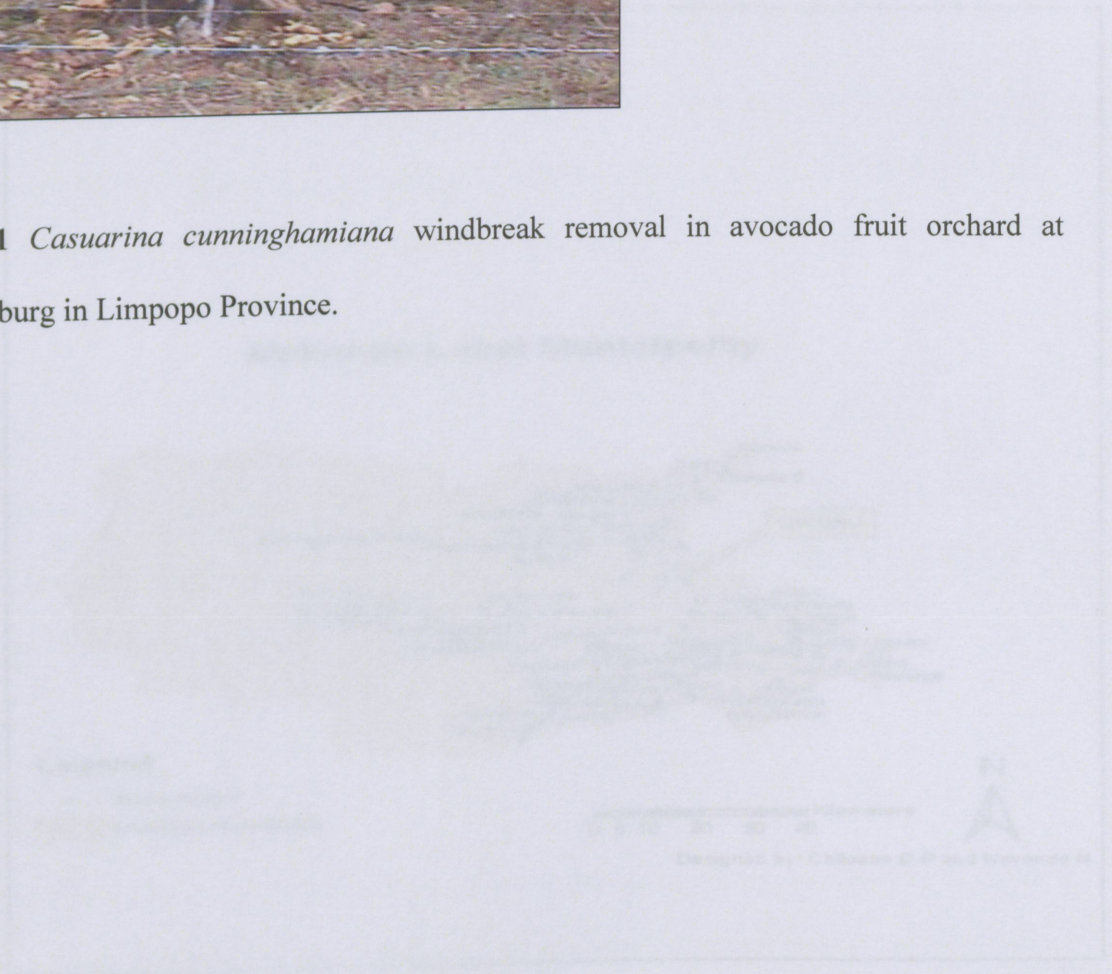
## 2.16 Tree Root Pruning (Trenching) in the Windbreaks Agro-forestry Practice

Integration of trees in agroforestry farming systems needs to be done with proper management to minimize possible negative effects of trees. There are many experiences where some tree species have resulted into negative effects to crops and have discouraged farmers to continue planting them. For example in West Usambara Mountains Tanzania, it has been clearly shown that sugar cane crop yields was heavily reduced in not

trenched contour strips with *C. cunninghamiana* where it was interplanted with *Grevillea robusta*, *Calliandra calothyrsus*, and *Croton megalocarpus* (Mwihomeke, 1989). Tree roots in farming systems extend at a considerably greater distances and depths than of many crop roots (Stone & Kalisz, 1991); therefore tree root pruning (root trenching) is a potential tool for managing belowground competition when trees and crops are grown together in agroforestry systems. The investigation on the effects of tree root pruning on shoot growth and root distribution and on yield of adjacent crops in sub-humid Uganda areas showed that *Casuarina equisetifolia* tree which is slightly different from *Casuarina cunninghamiana* and *M. eminii* were the most competitive tree species with crops, and *G. robusta* and *M. lutea* the least competitive (Telli *et al.*, 2008). Trends in crop yield data also provided a strong evidence of the redistribution of root activity following root trenching, with competition increasing on the not trenched side of tree rows. Several studies in tropical agroforestry systems have also shown that belowground competition for resources such as water and nutrients can be minimized by pruning tree roots (trenching), and their results have strongly been inspiring (Korwar & Radder, 1994 & Hocking & Islam, 1997); Medina Research Centre roots from a casuarina windbreaks were detected at a distance of 20m from the windbreaks. this had then brought a suggestion that for such trees with shallow root systems trenching along the windbreaks should be done at an early stage of development to encourage deeper rooting; the depth of trenching can be at least one meter in deep sandy soils with time roots can grow below the ripping line. In these soil roots of established trees can be pruned to depths of 3 m, 6 m and 10 m to prevent roots from entering the crop lands; irrigation of windbreaks can also reduce the invasion of cropped areas by roots of invaders for water acquisition.



**Figure 1** *Casuarina cunninghamiana* windbreak removal in avocado fruit orchard at Haenertsburg in Limpopo Province.



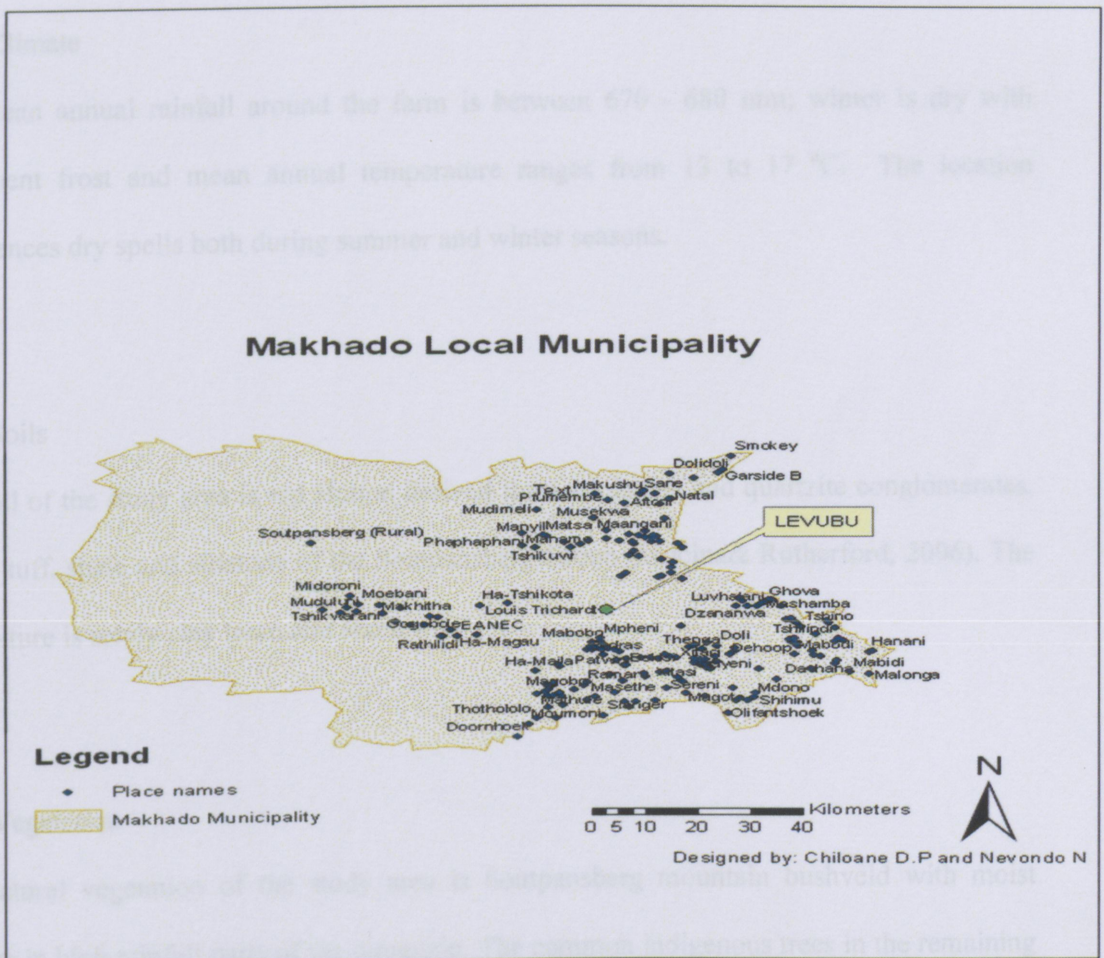
**Figure 2** Map showing the location of the study area

## CHAPTER THREE: DESCRIPTION OF THE STUDY AREA

### 3.1 Ecological Description of the Study Area

#### 3.1.1 Location

The study was conducted in the farm Sterkstroom 6LT which is located in Luvuvhu near Albasin Dam along the R524 road. At  $23^{\circ} 04' 01, 64''$  S and  $30^{\circ} 04' 32, 13''$  E, the farm is on the eastern foot slopes of the Soutpansberg Mountain ranges.



**Figure 2:** Map showing the location of the study area

The farm was covered by fruit orchards mainly planted macadamia, lychee, avocados and mangoes as main fruit trees. Within the study area in the farm, three varieties of macadamia have been planted and on the eastern side the planting pattern starts with variety 849 then variety 842 followed by variety 849 again in this series. On the western side only one variety Beaumont has been planted; however all sides used a single root stock of Beaumont. At the time of this study macadamia trees were about four years old, *C. cunninghamiana* trees were 15 years old with an average height of 18 – 20 m.

### 3.1.3 Climate

The mean annual rainfall around the farm is between 670 - 680 mm; winter is dry with infrequent frost and mean annual temperature ranges from 13 to 17 °C. The location experiences dry spells both during summer and winter seasons.

### 3.1.4 Soils

The soil of the study area is red Hutton derived from sandstone and quartzite conglomerates, basalt, tuff, shale and siltstone of the Soutpansberg Group (Mucina & Rutherford, 2006). The soil texture is sandy clay loam and shallow.

### 3.1.5 Vegetation

The natural vegetation of the study area is Soutpansberg mountain bushveld with moist thickets in high rainfall parts of the mountain. The common indigenous trees in the remaining natural vegetation patches include the following; *Catha edulis*, *Bridelia mollis*,



#### 4.1 Experimental Layout and Data Collection

A split plot design was used in this study with two main treatments which are trenched and not trenched adjacent to the casuarina windbreaks and each of the two treatments replicated three times in all the three rows adjacent to the windbreaks. In each treatment and replication data collection was done on three macadamia trees on the first, three on the second and three on the third rows; data were collected one month after ripping of *C. cunninghamiana* roots to obtain the immediate effects of trenching.

#### 4.2 Plant Water Status Measurements

Xylem water potential were conducted on both control and experimental treatments per each row using a Scholander pressure bomb in the field (Scholander *et al.*, 1964); a leafy twig was selected randomly from the branch of any particular tree then cut free from the branch, a total number of three macadamia trees were assessed per each treatment. The leaf was then immediately inserted into the pressure chamber. Leaf water potential was measured within 1 to 2 minutes of cutting it from any selected macadamia parent plant by slowly pressurizing the chamber until sap emerged from the cut end of the leafy twig.

#### 4.3 Leaf Stomatal Conductance Measurements

Stomatal conductance in  $\text{mmol m}^{-2}\text{s}^{-1}$  was measured using the steady state Leaf Porometer (Decagon Devices, model version 6). Mature exposed canopy leaves of similar ages of the three *M. tetraphylla* plants per each treatment of the three rows was measured for both the upper and lower surface of the leaves. A fixed diffusion path of the Leaf Porometer was

clamped to the surface both on the upper and lower surfaces of the leaf to measure stomatal conductance; measurements were taken on clear sunny days around mid-day to avoid the influence of cloud cover on plant respiration.

#### **4.4 *Macadamia tetraphylla* Nutrient Analyses after *Casuarina cunninghamiana* Root Cutting**

Healthy *Macadamia tetraphylla* leaves were detached from any particular tree in both treatments, that is, trenched and not trenched in all the replications of the three rows. Leaves were then sent to Madzivhandila Agricultural College Laboratory for K, P, Ca, Mg, Na, Fe, B, Mn and Zn nutrients level analysis.

#### **4.5 Plant Development Measurements**

Plant heights were measured by a height meter rod. Root collar diameters were measured using a diameter tape, whilst canopy diameters were measured using a tape measure, and a number of new shoots were counted at all branches of the plant when the newly formed shoots became visible. All measurements were taken on three plants in each replication five months after trenching and still during experimental period.

#### **4.6 Data Analysis**

Data for all the variables on plant measurements for each row adjacent to the windbreak was first summarized, SPSS version 19 (statistical package for social sciences) general linear model was used for conducting the analysis of variance (ANOVA), full factorial model was used to enable determine whether there was a significant interaction between two factors



(treatment and distance), graphs were drawn using Microsoft excel, distances were used as a dependent variable to determine differences between rows.

### 5.1 Water Potential

Table 1 Difference between water potential of the first of recording and second date of recording.

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	P-value
Row Distance	WP12 <sup>ns</sup>	268,569	2	134,285	14,939	,000
Treatment	WP12 <sup>ns</sup>	2,894	1	2,894	,321	,574
Interaction	WP12 <sup>ns</sup>	30,843	2	15,421	2,318	,070
Error	WP12 <sup>ns</sup>	432,982	48	9,020		
Corrected Total	WP12 <sup>ns</sup>	736,228	53			

R Squared = .427 (Adjusted R Squared = .365) \* Degree of Freedom \*\* Difference between the Water Potential of the 1<sup>st</sup> date of recording and the second date of recording

A two-way ANOVA was used to explore the significance of row treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, system water potential between first date of measurement and the second, the R-squared value for this analysis was 0.42). 42.7% of the variation of water potential is explained by trenching and distance, 57.3 % of the variation is unexplained, the F-ratio for interaction was 2.318 with 2 degrees of freedom, the p-value for interaction was 0.070, which is higher than the alpha level of 0.05, and there was no significant interaction between trenching and distance.

The F-ratio for distance was 14.939 with 2 degrees of freedom and a p-value of 0.000, which is less than the alpha value of 0.05, there were significant differences among the means in water potential for the three distances, the p-value for treatment (trenching) was 0.574 with 1

### 5.1 Water Potential

**Table 1** Difference between water potential of the first of recording and second date of recording.

Source	Dependent Variable	Type III Sum of Squares	Df *	Mean Square	F	P-value
Row Distance	WP12**	269.509	2	134.755	14.939	.000
Treatment	WP12**	2.894	1	2.894	.321	.574
Interaction	WP12**	50.843	2	25.421	2.818	.070
Error	WP12**	432.982	48	9.020		
Corrected Total	WP12**	756.228	53			

R Squared = .427 (Adjusted R Squared = .368) \* Degrees of Freedom \*\* Difference between the Water Potential of the 1st date of recording and the second date of recording

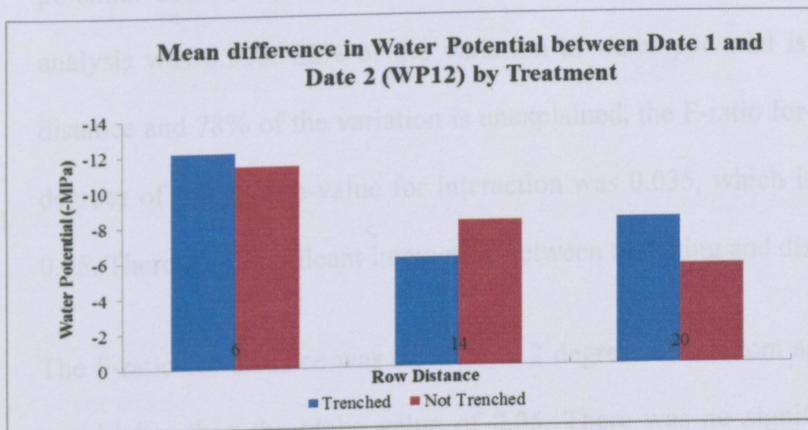
A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, xylem water potential between first date of measurement and the second, the R-squared value for this analysis was 0.427. 42.7% of the variation of water potential is explained by trenching and distance. 57.3 % of the variation is unexplained, the F-ratio for interaction was 2.818 with 2 degrees of freedom, the p-value for interaction was 0.070, which is higher than the alpha level of 0.05, and there was no significant interaction between trenching and distance.

The F-ratio for distance was 14.939 with 2 degrees of freedom and a p-value of 0.000, which is less than the alpha value of 0.05. There were significant differences among the means in water potential for the three distances, the F-ratio for treatment (trenching) was 0.321 with 1

degrees of freedom and a p-value of 0.574 which is higher than alpha of 0.05. There was no significant difference in means of water potentials between the trenched and not trenched and all three distances between time one and time two of measurements.

**Table 2 Means for difference between water potential of the first of recording and second date of recording.**

Row Distance (meters)	Mean water potential differences (-MPa)	
	Trenched	Not Trenched
6	-12.167	-11.389
14	-6.111	-8.167
20	-8.278	-5.611



**Figure 3 Water potential for trenched and not-trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.**



**Table 3 Difference between water potential between first of recording and third date of recording.**

Source	Dependent Variable	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	WP13**	8.813	2	4.407	.353	.704
Treatment	WP13**	69.814	1	69.814	5.598	.022
Interaction	WP13**	89.926	2	44.963	3.605	.035
Error	WP13**	598.600	48	12.471		
Corrected Total	WP13**	767.153	53			

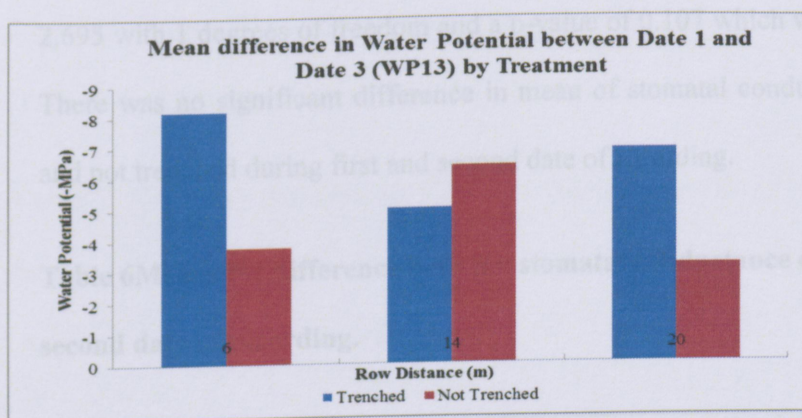
R Squared = .220 (Adjusted R Squared = .138) \* Degrees of Freedom \*\* Difference between the Water Potential of the 1st date of recording and the third date of recording

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, xylem water potential between first date of measurement and the third, the R-squared value for this analysis was 0.220. 22% of the variation in water potential is explained by trenching and distance and 78% of the variation is unexplained, the F-ratio for interaction was 3.605 with 2 degrees of freedom, p-value for interaction was 0.035, which is less than the alpha level of 0.05. There was significant interaction between trenching and distance.

The F-ratio for distance was 0.353 with 2 degrees of freedom and a p-value of 0.704, which was higher than the alpha value of 0.05. There was no significant differences among the means water potential for the three distances used, the F-ratio for treatment (trenching) was 5.598 with 1 degrees of freedom and a p-value of 0.022 which was less than alpha of 0.05. There were significant differences in means of water potential between the trenched and not trenched from the first to the third date of recording.

**Table 4 Means for difference between water potential of the first of recording and third date of recording.**

Row Distance (meters)	Mean water potential (-MPa)	
	Trenched	Not Trenched
6	-8.189	-3.767
14	-5.000	-6.356
20	-6.889	-3.133



**Figure 4 Water potential for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.**

**Table 5 Difference between stomatal conductance of the first recording and second date of recording.**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	2627.579	2	1313.790	11.244	.000
Treatment	314.892	1	314.892	2.695	.107
Interaction	20.575	2	10.287	.088	.916
Error	5608.256	48	116.839		
Corrected Total	8571.301	53			

R Squared = .346 (Adjusted R Squared = .278) \* Degrees of Freedom

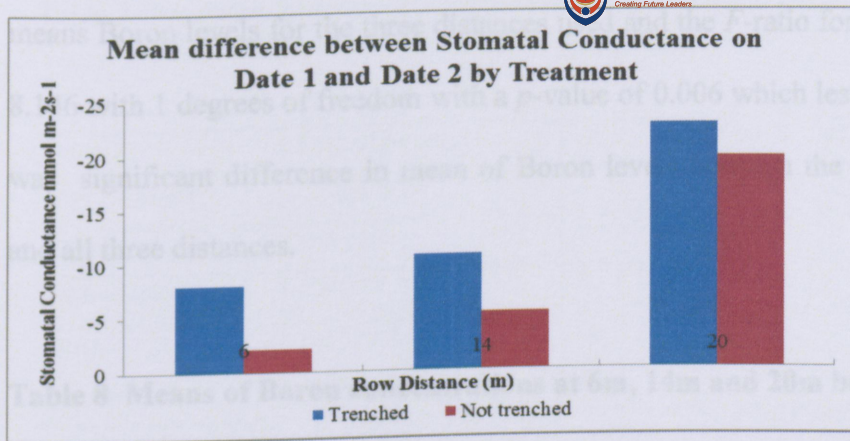
A two-way ANOVA was used to explore the significance of the treatment (trenched or not trenched) with a blocking factor (distance 6, 14 or 20 m), and their interaction, stomatal conductance between first and second date of measurements, the R-squared value for this

analysis was 0.346. 34.6% of the variation in stomatal conductance is explained by trenching and distance. 65.4% of the variation is unexplained, F-ratio for interaction was 0.088 with 2 degrees of freedom and the p-value for interaction was 0.916, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 11.244 with 2 degrees of freedom and a p-value of 0.000, which is less than the alpha value of 0.05. There were significant differences among the means of stomatal conductance for the three distances used, the F-ratio for treatment (trenching) was 2.695 with 1 degrees of freedom and a p-value of 0.107 which was higher than alpha of 0.05. There was no significant difference in mean of stomatal conductance between the trenched and not trenched during first and second date of recording.

**Table 6 Means for difference between stomatal conductance of the first of recording and second date of recording.**

Row Distance (meters)	Sum of Squares	DF	Mean Square	F	p-value
Distance	69585.561	2	34792.781	257.766	.000
Interaction				0.146	.916
				0.507	.606
6			-8.033		
14			-10.700		
20			-22.656		



**Figure 5** Stomatal conductance for trenched and not trenched macadamia sampled trees at 6m, 14m and 20m from the windbreak.

**Table 7** Two-way Analysis of Variance (with interaction) for Dependent Variable

**Boron**

Source	Sum of Squares	Df*	Mean Square	F	p-value
Row Distance	68685.661	2	34342.831	257.700	.000
Treatment	1085.585	1	1085.585	8.146	.006
Interaction	135.023	2	67.511	0.507	.606
Error	6396.809	48	133.267		
Corrected Total	76303.078	53			

R Squared = .916 (Adjusted R Squared = .907) \* Degrees of Freedom

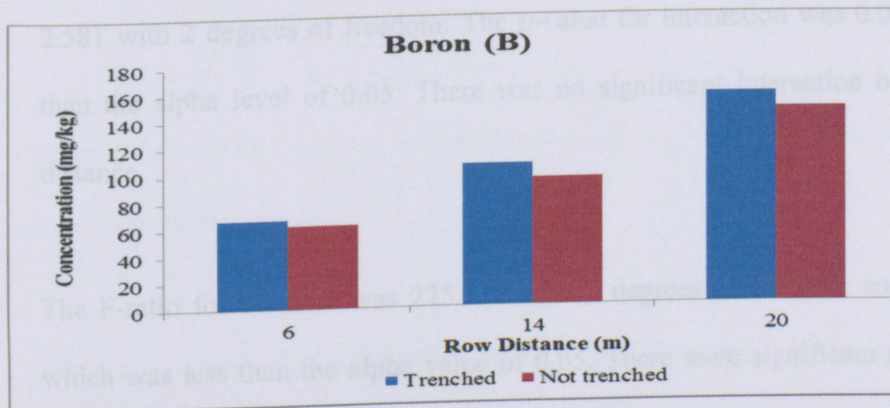
A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, R-squared value for this analysis was 0.916. 91.6% of the variation in Boron concentrations is explained by trenching and distance. 8.4% of the variation is unexplained. The F-ratio for interaction was 0.507 with 2 degrees of freedom; p-value for interaction was 0.606, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 257.700 with 2 degrees of freedom and a p-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the

means Boron levels for the three distances used and the  $F$ -ratio for treatment (trenching) was 8.146 with 1 degrees of freedom with a  $p$ -value of 0.006 which less than alpha of 0.05. There was significant difference in mean of Boron levels between the trenched and not trenched and all three distances.

**Table 8 Means of Boron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance	Mean Boron Concentrations (mg/kg)	
	Trenched	Not trenched
6	66.972	62.477
14	106.011	94.887
20	157.268	145.987



**Figure 6 Means of Boron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**



**Table 9 Two-way Analysis of Variance (with Interaction), Dependent Variable Calcium**

Source	Sum of Squares	Df*	Mean Square	F	p-value
Row Distance	18300.162	2	9150.081	225.171	.000
Treatment	165.263	1	165.263	4.067	.049
Interaction	209.745	2	104.873	2.581	.086
Error	1950.538	48	40.636		
Corrected Total	20625.709	53			

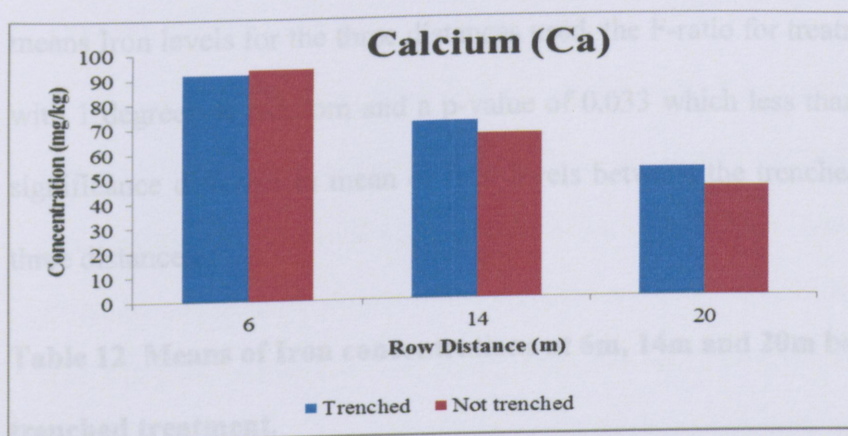
R Squared = .905 (Adjusted R Squared = .896) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.905. 91% of the variation in calcium concentrations is explained by trenching and distance. 9% of the variation is unexplained. The F-ratio for interaction was 2.581 with 2 degrees of freedom. The *p*-value for interaction was 0.086, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 225.171 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means calcium levels for the three distances used, the *F*-ratio for treatment (trenching) was 4.067 with 1 degree of freedom and a *p*-value of 0.049 which less than alpha of 0.05. There was significant difference in means of Calcium levels between the trenched and not trenched and all three distances.

**Table 10 Means of Calcium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Calcium Concentrations (mg/kg)	
	Trenched	Not trenched
6	92.032	93.984
14	71.763	66.550
20	51.558	44.323



**Figure 7 Means of Calcium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 11 Two-way Analysis of Variance (with interaction), Dependent Variable Fe**

Source	Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	13652.768	2	6826.384	160.570	.000
Treatment	205.105	1	205.105	4.824	.033
Interaction	221.383	2	110.692	2.604	.084
Error	2040.644	48	42.513		
Corrected Total	16119.901	53			

R Squared = .873 (Adjusted R Squared = .860)

\*Degrees of freedom

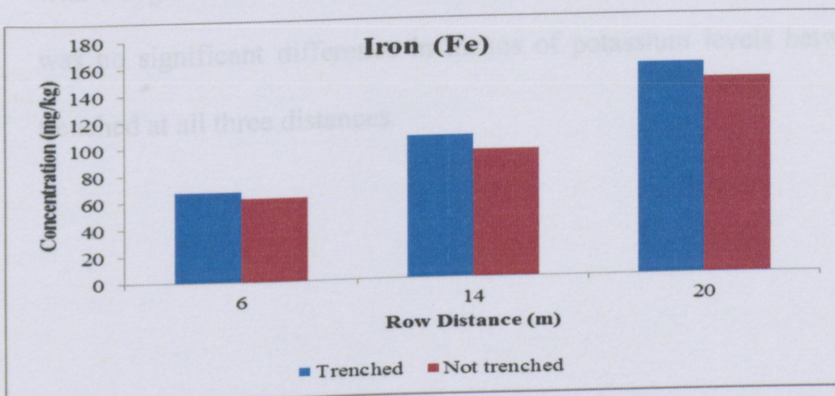
A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.873. 87% of the variation in Iron concentrations is explained by

trenching and distance. 17% of the variation is unexplained. The F-ratio for interaction was 2.604 with 2 degrees of freedom and p-value for interaction was 0.084, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 160.570 with 2 degrees of freedom and a p-value of 0.000, which is less than the alpha value of 0.05. There were significant differences among the means Iron levels for the three distances used, the F-ratio for treatment (trenching) was 4.824 with 1 degrees of freedom and a p-value of 0.033 which less than alpha of 0.05. There was significance different in mean of Iron levels between the trenched and not trenched and all three distances.

**Table 12 Means of Iron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Iron concentrations (mg/kg)	
	Trenched	Not trenched
6	66.972	62.477
14	106.011	94.887
20	157.268	145.987



**Figure 8 Means of Iron concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 13 Two-way Analysis of Variance (with interaction), Dependent Variable**

**Potassium.**

Source	Type III Sum of Squares	Df*	Mean Square	F	p-value
Row Distance	4384.448	2	2192.224	48.570	.000
Treatment	21.895	1	21.895	.485	.489
Interaction	289.461	2	144.731	3.207	.049
Error	2166.489	48	45.135		
Corrected Total	6862.293	53			

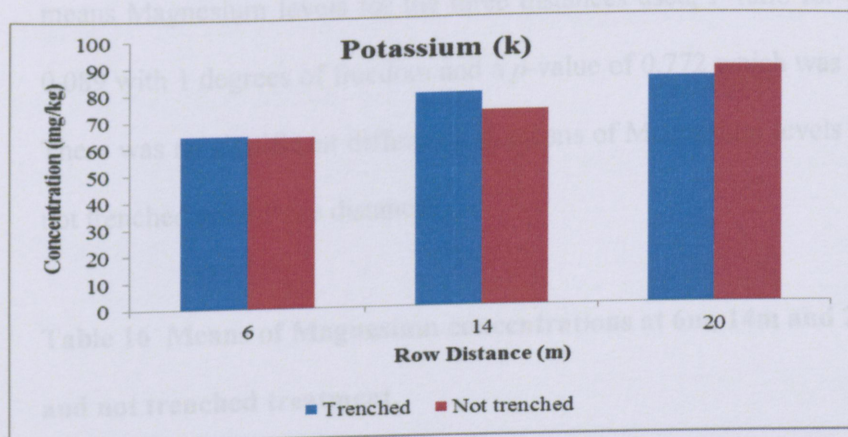
R Squared = .684 (Adjusted R Squared = .651) \* Degrees of Freedom

A two-way ANOVA used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.684. 68.4% of the variation in potassium concentrations is explained by trenching and distance. 31.6% of the variation is unexplained, F-ratio for interaction is 3.207 with 2 degrees of freedom, *p*-value for interaction was 0.049, which was lesser than the alpha level of 0.05. There was significant interaction between trenching and distance.

The F-ratio for distance was 48.570 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means potassium levels for the three distances used. The *F*-ratio for treatment (trenching) was 0.485 with 1 degrees of freedom and a *p*-value of 0.489 which was higher than alpha of 0.05. There was no significant difference in means of potassium levels between the trenched and not trenched at all three distances.

**Table 14 Means of Potassium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Potassium concentration (mg/kg)	
	Trenched	Not trenched
6	64.485	63.811
14	79.567	72.347
20	84.164	88.238



**Figure 9 Means of Potassium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 15 Two-way Analysis of Variance (with interaction), Dependent Variable Magnesium**

Source	Type III Sum of Squares	Df*	Mean Square	F	p-value
Row Distance	100.147	2	50.074	1.364	.265
Treatment	3.131	1	3.131	.085	.772
Interaction	42.685	2	21.342	.581	.563
Error	1762.530	48	36.719		
Corrected Total	1908.493	53			

R Squared = .076 (Adjusted R Squared = -.020) \* Degrees of Freedom

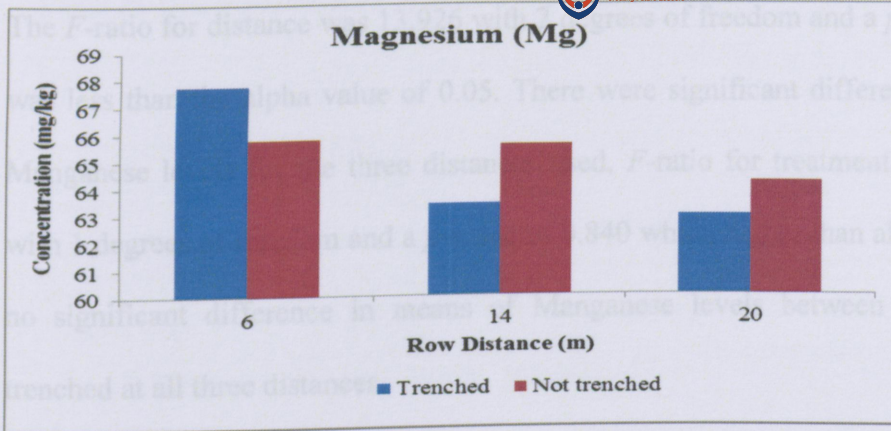
A two-way ANOVA used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.076. 7.6% of the variation in Magnesium concentrations is explained by

trenching and distance. 92.4% of the variation is explained, F-ratio for interaction was 0.581 with 2 degrees of freedom and  $p$ -value for interaction was 0.563, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 1.364 with 2 degrees of freedom and a  $p$ -value of 0.265, which was higher than the alpha value of 0.05. There was no significant differences among the means Magnesium levels for the three distances used,  $F$ -ratio for treatment (trenching) was 0.089 with 1 degrees of freedom and a  $p$ -value of 0.772 which was higher than alpha of 0.05. There was no significant difference in means of Magnesium levels between the trenched and not trenched at all three distances.

**Table 16 Means of Magnesium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Magnesium concentrations (mg/kg)	
	Trenched	Not trenched
6	67.763	65.791
14	63.352	65.537
20	62.930	64.162



**Figure 10 Means of Magnesium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 17 Two-way Analysis of Variance (with interaction), Dependent Variable**

**Manganese.**

Source	Sum of Squares	Df*	Mean Square	F	p-value
Row Distance	1915.758	2	957.879	13.926	.000
Treatment	2.837	1	2.837	.041	.840
Interaction	14.787	2	7.393	.107	.898
Error	3301.705	48	68.786		
Corrected Total	5235.085	53			

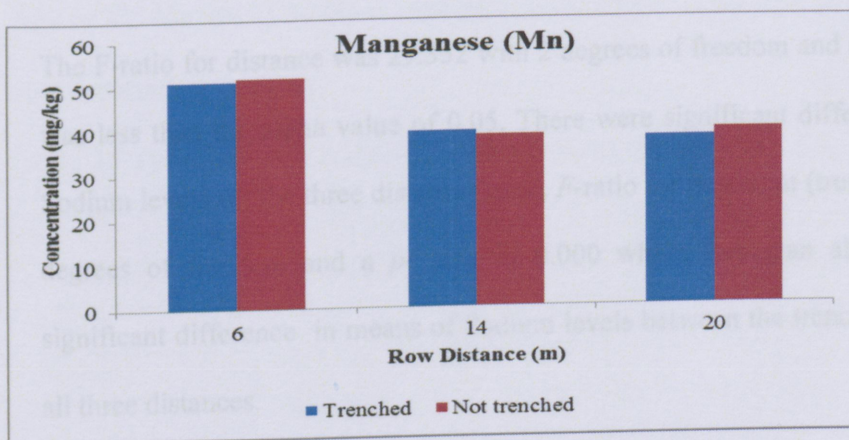
R Squared = .369 (Adjusted R Squared = .304) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.369. 36.9% of the variation in Manganese concentrations is explained by trenching and distance. 63.1% of the variation is unexplained, F-ratio for interaction was 0.107 with 2 degrees of freedom and *p*-value for interaction was 0.898, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The  $F$ -ratio for distance was 13.926 with 2 degrees of freedom and a  $p$ -value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means Manganese levels for the three distances used,  $F$ -ratio for treatment (trenching) was 0.041 with 1 degrees of freedom and a  $p$ -value of 0.840 which higher than alpha of 0.05. There was no significant difference in means of Manganese levels between the trenched and not trenched at all three distances.

**Table 18 Means of Manganese concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Manganese concentrations (mg/kg)	
	Trenched	Not trenched
6	51.144	51.788
14	39.488	38.582
20	37.818	39.455



**Figure 11 Means of Manganese concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 19 Two-way Analysis of Variance (Interaction), Dependent Variable Sodium**

Source	Type III Sum of Squares	Df <sup>a</sup>	Mean Square	F	p-value
Row Distance	1987.105	2	993.553	29.352	.000
Treatment	537.290	1	537.290	15.873	.000
Interaction	51.463	2	25.731	.760	.473
Error	1624.793	48	33.850		
Corrected Total	4200.651	53			

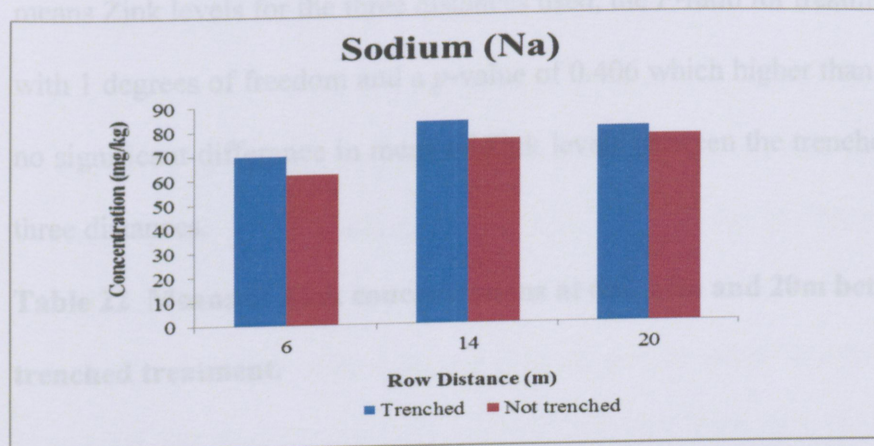
R Squared = .613 (Adjusted R Squared = .573) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.613. 61.3% of the variation in Sodium concentrations is explained by Trenching and Distance. 38.7% of the variation is unexplained; *F*-ratio for interaction was 0.760 with 2 degrees of freedom. The *p*-value for interaction was 0.473, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The *F*-ratio for distance was 29.352 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means Sodium levels for the three distances used, *F*-ratio for treatment (trenching) was 15.873 with 1 degree of freedom and a *p*-value of 0.000 which less than alpha of 0.05. There was significant difference in means of Sodium levels between the trenched and not trenched and all three distances.

**Table 20 Means of Sodium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Sodium concentrations (mg/kg)	
	Trenched	Not trenched
6	69.641	62.148
14	83.230	75.354
20	79.937	76.381



**Figure 12 Means of Sodium concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 21 Two-way Analysis of Variance (with interaction), Dependent Variable Zink**

Source	Type III Sum of Squares	Df <sup>a</sup>	Mean Square	F	p-value
Row Distance	59368.042	2	29684.021	332.596	.000
Treatment	62.800	1	62.800	.704	.406
Interaction	1262.523	2	631.261	7.073	.002
Error	4283.977	48	89.250		
Corrected Total	64977.341	53			

R Squared = .934 (Adjusted R Squared = .927) \* Degrees of Freedom

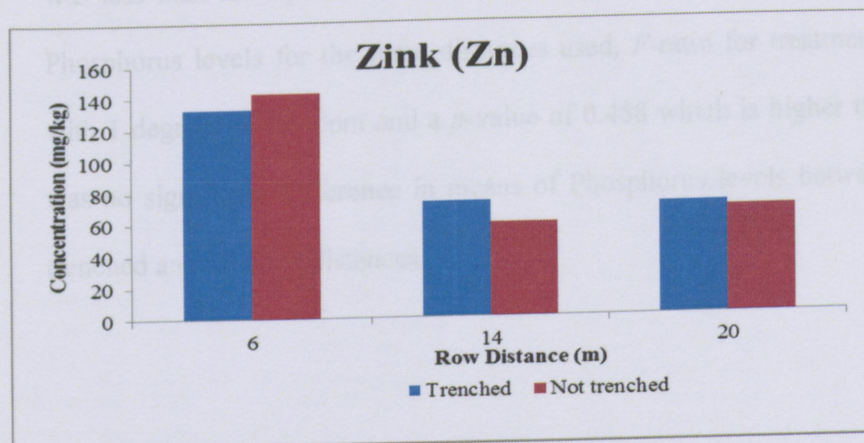
A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.934. 93.4% of the variation in Zink concentrations is explained by trenching and distance. 6.6% of the variation is unexplained, *F*-ratio for interaction was

7.073 with 2 degrees of freedom and the  $p$ -value for interaction was 0.002, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The F-ratio for distance was 332.596 with 2 degrees of freedom and a  $p$ -value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means Zink levels for the three distances used, the  $F$ -ratio for treatment (trenching) was 0.704 with 1 degrees of freedom and a  $p$ -value of 0.406 which higher than alpha of 0.05. There was no significant difference in mean of Zink levels between the trenched and not trenched at all three distances.

**Table 22 Means of Zink concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row distance (meters)	Mean Zink concentrations (mg/kg)	
	Trenched	Not trenched
6	132.734	142.684
14	72.716	58.996
20	70.343	67.642



**Figure 13 Means of Zink concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 23 Two-way Analysis of Variance (with interaction), Dependent Variable**



**Phosphorus**

Source	Type III Sum of Squares	Df*	Mean Square	F	Sig.
Row Distance	2858.787	2	1429.394	32.658	.000
Treatment	24.536	1	24.536	.561	.458
interaction	541.816	2	270.908	6.190	.004
Error	2100.896	48	43.769		
Corrected Total	5526.035	53			

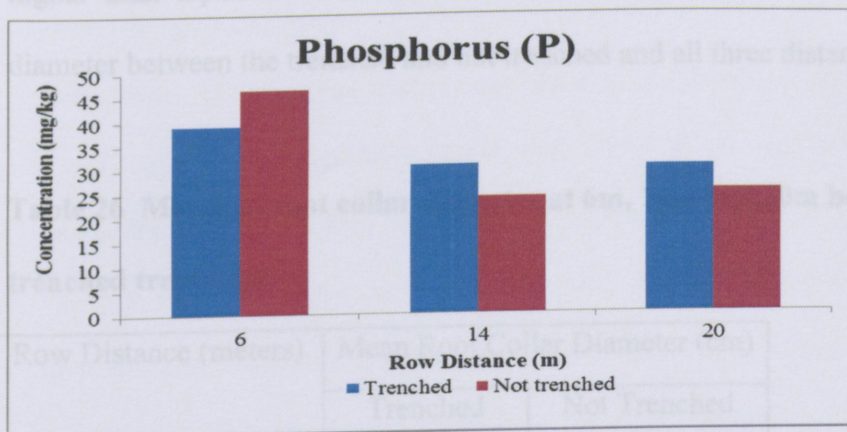
R Squared = .620 (Adjusted R Squared = .580) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trenched or not trenched) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The R-squared value for this analysis was 0.620. 62% of the variation in Phosphorus concentrations is explained by trenching and distance. 38% of the variation is unexplained, *F*-ratio for interaction was 6.190 with 2 degrees of freedom and *p*-value for interaction was 0.004, which was less than the alpha level of 0.05. There was significant interaction between trenching and distance.

The *F*-ratio for distance was 32.658 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means Phosphorus levels for the three distances used, *F*-ratio for treatment (trenching) was 0.561 with 1 degrees of freedom and a *p*-value of 0.458 which is higher than alpha of 0.05. There was no significant difference in means of Phosphorus levels between the trenched and not trenched and all three distances.

**Table 24 Means of Phosphorus concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

Row distance (meters)	Mean Phosphorus concentrations (mg/kg)	
	Trenched	Not trenched
6	39.156	46.722
14	30.589	24.011
20	30.233	25.200



**Figure 14 Means of Phosphorus concentrations at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 25 Two-way Analysis of Variance (with interaction), Dependent Variable root collar diameter**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	187.169	2	93.585	47.694	.000
Treatment	1.081	1	1.081	.551	.462
Interaction	2.186	2	1.093	.557	.577
Error	94.184	48	1.962		
Corrected Total	284.620	53			

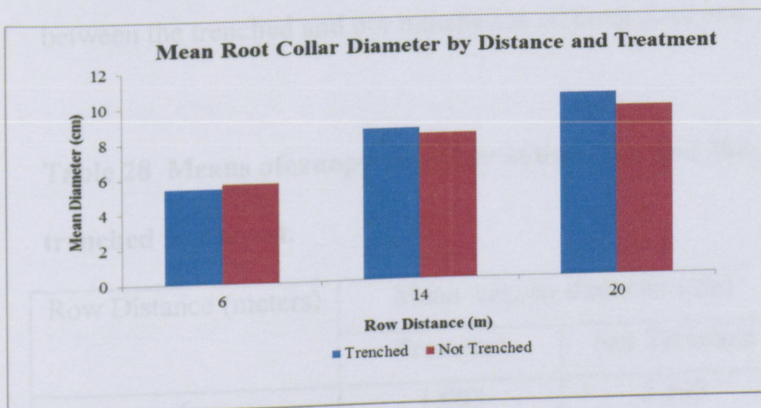
\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, *F*-ratio for

interaction is 0.557 with 2 degrees of freedom. The  $p$ -value for interaction was 0.577, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance. The  $F$ -ratio for distance was 47.694 with 2 degrees of freedom and a  $p$ -value of 0.000, which was less than the alpha value of 0.05. There significant differences among the means of root collar diameter for the three distances used. The  $F$ -ratio for treatment (trenching) is 0.551 with 1 degrees of freedom and a  $p$ -value of 0.462 which was higher than alpha of 0.05. There was no significant difference in means of root collar diameter between the trenched and not trenched and all three distances.

**Table 26 Means of root collar diameter at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean Root Collar Diameter (cm)	
	Trenched	Not Trenched
6	5.406	5.656
14	8.622	8.246
20	10.389	9.667



**Figure 15 Means of root collar diameter at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 27 Two-way Analysis of Variance (Interaction), Dependent Variable canopy diameter**

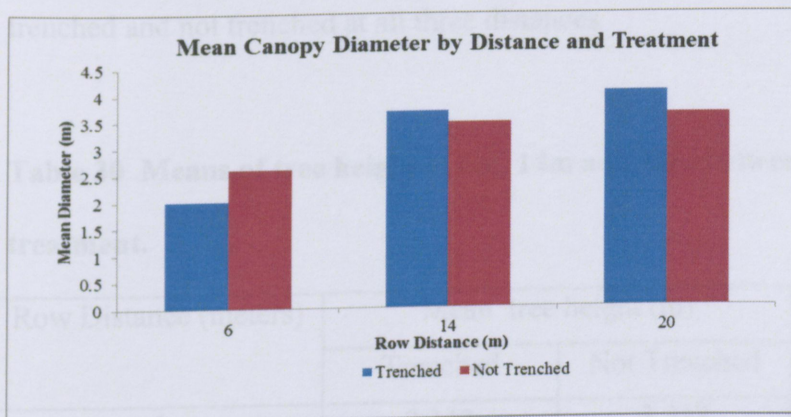
Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	24.349	2	12.174	37.215	.000
Treatment	.004	1	.004	.012	.914
Interaction	2.642	2	1.321	4.037	.024
Error	15.703	48	.327		
Corrected Total	42.697	53			

\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. *F*-ratio for interaction was 4.037 with 2 degrees of freedom. The *p*-value for interaction was 0.024, which was less than the alpha level of 0.05. There was significant interaction between trenching and distance. The *F*-ratio for distance was 37.215 with 2 degrees of freedom and a *p*-value of 0.000, which was lesser than the alpha value of 0.05. There were significant differences among the means of canopy diameter for the three distances used. The *F*-ratio for treatment (trenching) was 0.012 with 1 degrees of freedom and a *p*-value of 0.914 which was higher than alpha of 0.05. There was no significant difference in mean of canopy diameter between the trenched and not trenched at all three distances.

**Table 28 Means of canopy diameter at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean canopy diameter (cm)	
	Trenched	Not Trenched
6	1.997	2.595
14	3.686	3.461
20	4.043	3.619



**Figure 16 Means of canopy diameter at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 29 Two-way Analysis of Variance (with interaction) Dependent Variable, tree height**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	17.534	2	8.767	32.929	.000
Treatment	.400	1	.400	1.504	.226
Interaction	.937	2	.469	1.760	.183
Error	12.780	48	.266		
Corrected Total	31.652	53			

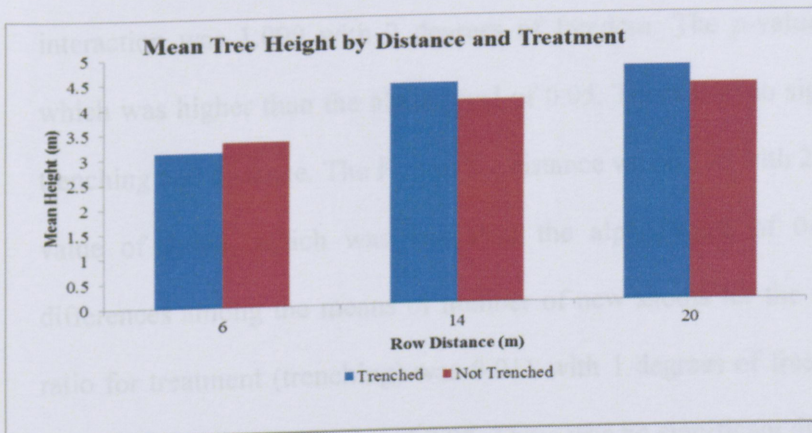
\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The  $F$ -ratio for interaction was 0.469 with 2 degrees of freedom and  $p$ -value for interaction was 0.183, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance. The  $F$ -ratio for distance is 32.929 with 2 degrees of freedom and a  $p$ -value of 0.000, which was less than the alpha value of 0.05. There were significant difference among the means of tree height for the three distances used. The  $F$ -ratio for treatment (trenching) was 1.504 with 1 degrees of freedom and a  $p$ -value of 0.226 which is higher than

alpha of 0.05. There was no significant difference in means of tree height between the trenched and not trenched at all three distances.

**Table 30 Means of tree height at 6m, 14m and 20m between trenched and not trenched treatment.**

Row Distance (meters)	Mean tree height (m)	
	Trenched	Not Trenched
6	3.113	3.313
14	4.431	4.088
20	4.723	4.350



**Figure 17 Means of tree height at 6m, 14m and 20m between trenched and not trenched treatment.**



**Table 31 Two-way Analysis of Variance (with interaction), Dependent Variable**

**number of new shoots**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Row Distance	366.333	2	183.167	6.583	.003
Treatment	.296	1	.296	.011	.918
Interaction	61.148	2	30.574	1.099	.341
Error	1335.556	48	27.824		
Corrected Total	1763.333	53			

\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction. The F-ratio for interaction was 1.099 with 2 degrees of freedom. The *p*-value for interaction was 0.341, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance. The F-ratio for distance was 6.583 with 2 degrees of freedom and a *p*-value of 0.003, which was less than the alpha value of 0.05. There were significant differences among the means of number of new shoots for the three distances used. The *F*-ratio for treatment (trenching) was 0.011 with 1 degrees of freedom and a *p*-value of 0.918 which was higher than alpha of 0.05. There was no significant difference in means of number of new shoots between the trenched and not trenched at all three distances.

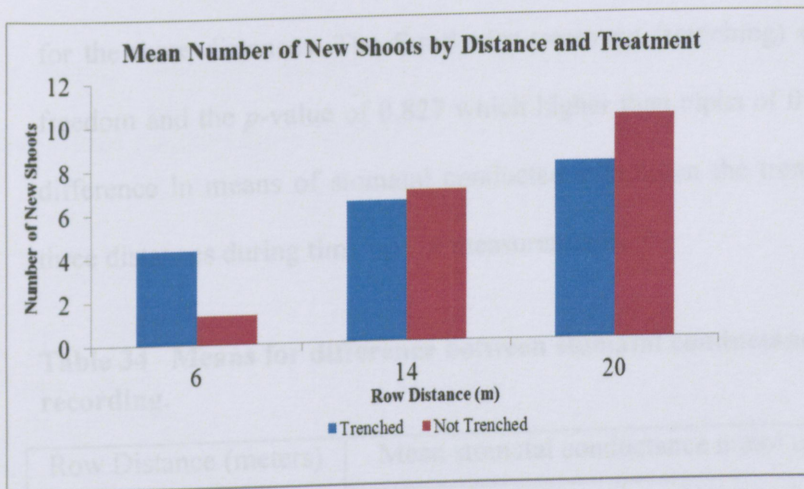
**Table 33 Two-way Analysis of Variance (with interaction), Dependent Variable:**  
Stomatal conductance 24/5/2011

Source	Type III Sum of Squares	Df	Mean Square	F	P-value
Treat	2.579	1	2.579	.045	.827
Row Distance	438.174	2	219.087	8.755	.001
Interaction	68.883	2	34.441	.643	.530
Error	2571.844	48	53.580		
Corrected Total	3581.480	53			

R Squared = .282 (Adjusted R Squared = .207)

**Table 32 Means of number of new shoots at 6m, 14m and 20m between trenched and not trenched treatment**

Row Distance (meters)	Mean new numbers of shoots	
	Trenched	Not Trenched
6	4.333	1.333
14	6.444	6.889
20	8.111	10.222



**Figure 18 Means of number of new shoots at 6m, 14m and 20m between trenched and not trenched treatment.**

**Table 33 Two-way Analysis of Variance (with interaction), Dependent Variable: stomatal conductance 24/5/2011**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Treat	2.579	1	2.579	.048	.827
Row Distance	938.174	2	469.087	8.755	.001
Interaction	68.883	2	34.441	.643	.530
Error	2571.844	48	53.580		
Corrected Total	3581.480	53			

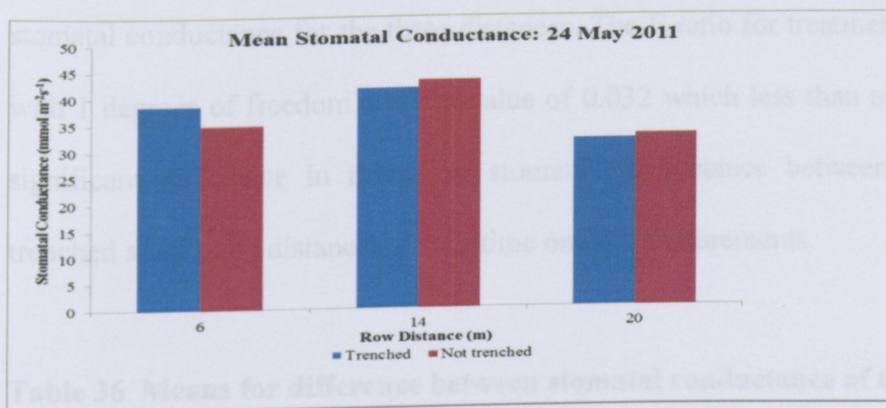
R Squared = .282 (Adjusted R Squared = .207)

\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, stomatal conductance on first date of measurement. The R-squared value for this analysis was 0.282. 28.2% of the variation of stomatal conductance is explained by trenching and distance. 71.8 % of the variation is unexplained. The F-ratio for interaction was 0.643 with 2 degrees of freedom and *p*-value for interaction was 0.530, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance. The F-ratio for distance was 8.755 with 2 degrees of freedom and a *p*-value of 0.001, which was less than the alpha value of 0.05. There were significant differences among the means in stomatal conductance for the three distances. The F-ratio for treatment (trenching) was 0.048 with 1 degrees of freedom and the *p*-value of 0.827 which higher than alpha of 0.05. There was no significant difference in means of stomatal conductance between the trenched and not trenched at all three distances during time one of measurements.

**Table 34 Means for difference between stomatal conductance of the first date of recording.**

Row Distance (meters)	Mean stomatal conductance $\text{mmol m}^{-2}\text{s}^{-1}$	
	Trenched	Not trenched
6	38.600	34.978
14	41.767	43.133
20	31.789	32.733



**Figure 19 Mean Stomatal conductance for treched and not treched macadamia sampled trees at 6m,14m and 20m from the windbreak 24/5/2012.**

**Table 35 Two-way Analysis of Variance (with interaction), Dependent Variable: stomatal conductance 3/9/2011.**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Treatment	374.460	1	374.460	4.861	.032
Row Distance	1290.225	2	645.112	8.375	.001
Interaction	133.481	2	66.741	.866	.427
Error	3697.289	48	77.027		
Corrected Total	5495.455	53			

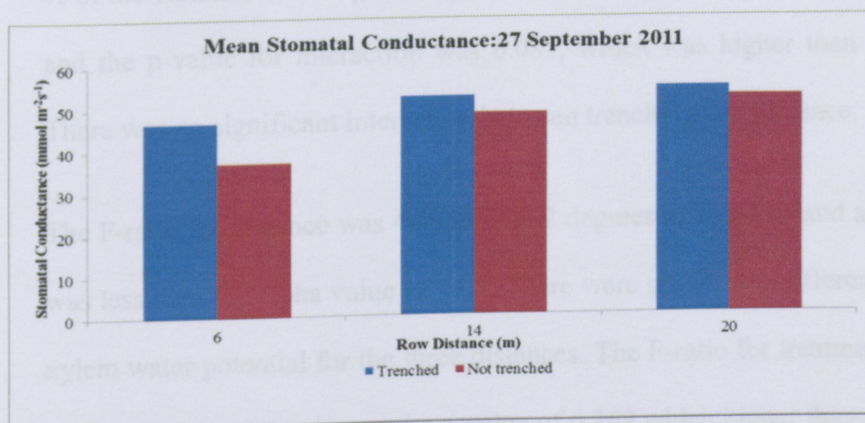
R Squared = .327 (Adjusted R Squared = .257) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, stomatal conductance during the second date of measurement. The R-squared value for this analysis was 0.327. 32.7% of the variation of stomatal conductance is explained by trenching and distance. 67.3 % of the variation is unexplained. The F-ratio for interaction was 0.866 with 2 degrees of freedom and the *p*-value for interaction was 0.427, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance. The F-ratio for distance was 8.375 with 2 degrees of freedom and a *p*-value of 0.001, which was less than the alpha value of 0.05. There were significant differences among the means in

stomatal conductance for the three distances. The F-ratio for treatment (trenching) was 4.861 with 1 degrees of freedom and a p-value of 0.032 which less than alpha of 0.05. There was significant difference in means of stomatal conductance between the trenched and not trenched at all three distances during time one of measurements.

**Table 36 Means for difference between stomatal conductance of the second date of recording.**

Row Distance (meters)	Mean Stomatal Conductance ( $\text{mmol m}^{-2}\text{s}^{-1}$ )	
	Trenched	Not trenched
6	46.633	37.056
14	52.467	48.411
20	54.444	52.278



**Figure 20 Mean Stomatal conductance for trenched and not trenched macadamia sampled trees at 6m,14m and 20m from the windbreak 27/9/2011.**

**Table 37 Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 16/4/2011.**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Treatment	6.338	1	6.338	.822	.369
Row Distance	692.861	2	346.431	44.938	.000
Interaction	40.954	2	20.477	2.656	.081
Error	370.036	48	7.709		
Corrected Total	1110.188	53			

R Squared = .667 (Adjusted R Squared = .632)

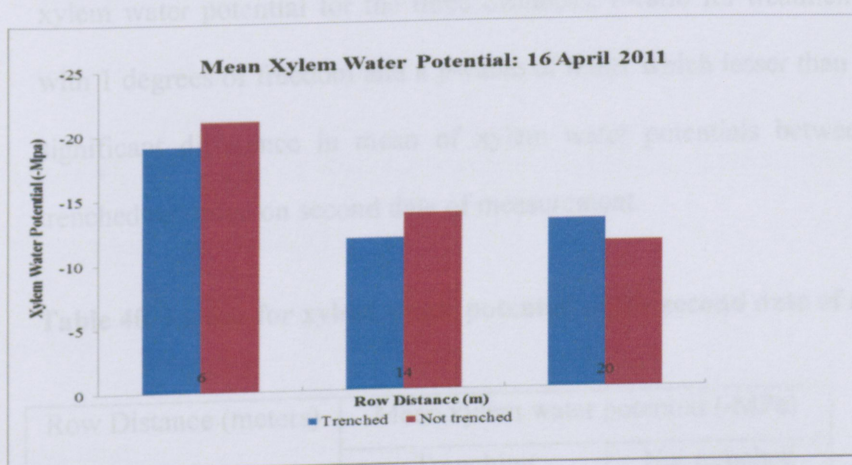
\* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, xylem water potential between first date of measurement. The R-squared value for this analysis was 0.667. 66.7% of the variation of xylem water potential is explained by trenching and distance. 33.3 % of the variation is unexplained, *F*-ratio for interaction was 2.656 with 2 degrees of freedom and the *p*-value for interaction was 0.081, which was higher than the alpha level of 0.05. There was no significant interaction between trenching and distance.

The *F*-ratio for distance was 44.938 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means in xylem water potential for the three distances. The *F*-ratio for treatment (trenching) was 0.822 with 1 degrees of freedom and a *p*-value of 0.369 which higher than alpha of 0.05. There was no significant difference in means of xylem water potentials between the trenched and not trenched at all three distances between time one and time two of measurements.

**Table 38 Means for difference between water potential of the first date of recording.**

Row Distance (meters)	Mean xylem water potential (-MPa)	
	Trenched	Not trenched
6	-19.111	-21.056
14	-11.833	-13.722
20	-13.111	-11.333



**Figure 21 Mean Water potential for trenced and not trenced macadamia sampled trees at 6m,14m and 20m from the windbreak 16/4/2011.**

**Table 39 Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 27/8/2011.**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Treatment	17.796	1	17.796	13.748	.001
Row Distance	98.454	2	49.227	38.028	.000
Interaction	19.231	2	9.616	7.428	.002
Error	62.136	48	1.294		
Corrected Total	197.617	53			

R Squared = .686 (Adjusted R Squared = .653) \* Degrees of Freedom

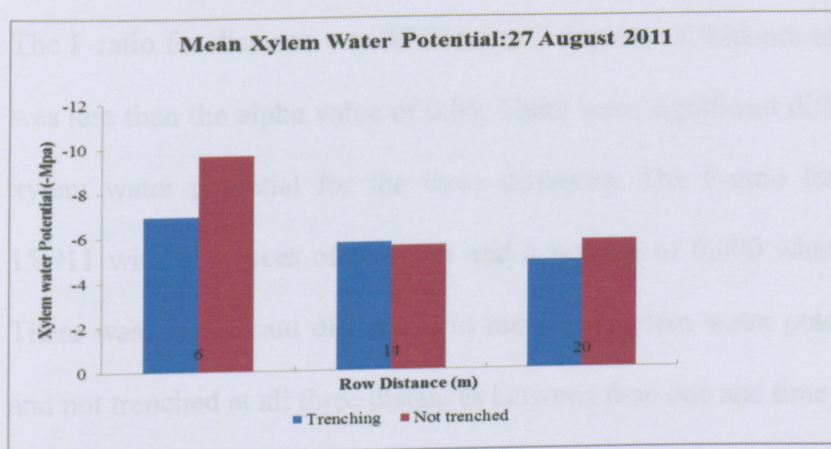
A two-way ANOVA is used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, xylem water potential

between second date of measurement. The R-squared value for this analysis was 0.686. 68.6% of the variation of xylem water potential is explained by trenching and distance. 31.4 % of the variation is unexplained; *F*-ratio for interaction was 7.428 with 2 degrees of freedom. The *p*-value for interaction was 0.002, which was lesser than the alpha level of 0.05. There was a significant interaction between trenching and distance.

The *F*-ratio for distance was 38.028 with 2 degrees of freedom and a *p*-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means in xylem water potential for the three distances, *F*-ratio for treatment (trenching) was 13.748 with 1 degrees of freedom and a *p*-value of 0.001 which lesser than alpha of 0.05. There was significant difference in mean of xylem water potentials between the trenched and not trenched recorded on second date of measurement.

**Table 40 Means for xylem water potential of the second date of recording.**

Row Distance (meters)	Mean xylem water potential (-MPa)	
	Trenching	Not trenched
6	-6.944	-9.667
14	-5.722	-5.556
20	-4.833	-5.722



**Figure 22 Mean Water potential for trenched and not trenched macadamia sampled trees at 6m,14m and 20m from the windbreak 27/8/2011.**

**Table 41 Two-way Analysis of Variance (with interaction), Dependent Variable: Xylem water potential 8/10/2011.**

Source	Type III Sum of Squares	Df*	Mean Square	F	P-value
Treatment	118.222	1	118.222	15.911	.000
Row Distance	579.741	2	289.871	39.011	.000
Interaction	83.065	2	41.532	5.590	.007
Error	356.660	48	7.430		
Corrected Total	1137.688	53			

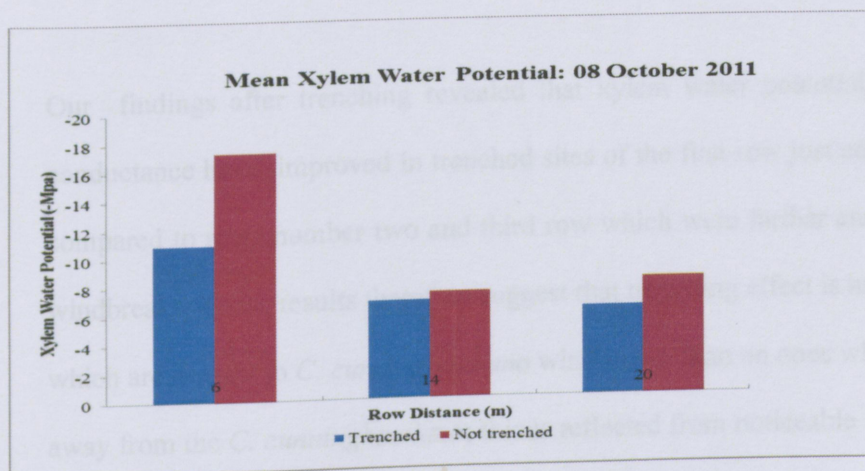
R Squared = .687 (Adjusted R Squared = .654) \* Degrees of Freedom

A two-way ANOVA was used to explore the significance of the treatment (trench or no trench) with a blocking factor (distance 6, 14 or 20 m), and their interaction, xylem water potential between first date of measurement. The R-squared value for this analysis was 0.687. 68.7% of the variation of xylem water potential is explained by trenching and distance. 31.3 % of the variation is unexplained. The F-ratio for interaction was 5.590 with 2 degrees of freedom. The *p*-value for interaction was 0.007, which was lesser than the alpha level of 0.05. There was a significant interaction between trenching and distance.

The F-ratio for distance was 39.011 with 2 degrees of freedom and a p-value of 0.000, which was less than the alpha value of 0.05. There were significant differences among the means in xylem water potential for the three distances. The F-ratio for treatment (trenching) was 15.911 with 1 degrees of freedom and a p-value of 0.000 which lesser than alpha of 0.05. There was significant difference in means of xylem water potentials between the trenched and not trenched at all three distances between time one and time two of measurements.

**Table 42 Means for difference between xylem water potential of the third date of recording.**

Row Distance (meters)	Mean xylem water potential (-MPa)	
	Trenched	Not trenched
6	-10.922	-17.289
14	-6.833	-7.367
20	-6.222	-8.200



**Figure 23 Mean Water potential for trenched and not trenched macadamia sampled trees at 6m,14m and 20m from the windbreak 08/10/2011.**

## 5.2 Discussion

Windbreaks are planted for sustainable agriculture but may negatively impact on crop yields and growth adjacent to them due to underground competition; therefore suitable tools to mitigate competition must be applied at the windbreak-crop interface to improve crop yields and growth; however there are other factors that may determine the growth and production of orchards crops such as site quality where a crop grows. It is therefore imperative to decide which underground management practices are more sustainable when farmers use windbreaks. The impacts of windbreak roots underground must be well addressed, and when the mitigation tool has been implemented for underground competition management, information on how a plant performs after implementing the mitigation tool needs to be carefully and intensively monitored; trenching along the windbreak in the current study had exposed an immediate response of *Macadamia tetraphylla* plants after trenching along the *Casuarinacunninghamiana*; underground competition brought about by the Casuarina roots was minimized (Table 3).

Our findings after trenching revealed that xylem water potential, nutrients and stomatal conductance have improved in trenched sites of the first row just adjacent to the windbreaks compared to rows number two and third row which were farther and farthest away from the windbreaks; These results therefore suggest that trenching effect is more pronounced on areas which are nearest to *C. cunninghamiana* windbreaks than on ones which are relatively farther away from the *C. cunninghamiana*; this is reflected from noticeable increase in new shoots at the first row at the trenched sites even though it was not statistical significant (Figure 18). Significant differences for new number of shoots were obtained by row distance from the windbreak (Figure 51) that is to say second and third rows generally were having more new

shoots than first row (Table 32). This could be due to an improvement in moisture availability to plants from the soil after minimizing the competition for water on the first row and for difference between row distance could be due to less competition by windbreak as the distance increase away from the casuarina windbreak trees. Such findings have also been observed elsewhere in plant studies for example Silva (2009), but little is known about macadamia and other horticultural crops in tropical and semi-arid climates like South Africa in the Limpopo Province.

It has also been suggested that the increase in the number of new shoots and plantlets is an indicator of a site quality (Letey *et al.*, 1961); this is evidently supported by our results as noticed in the first row of which more new shoots were produced by macadamia in trenched sites. These observations were immediately noticed at the onset of plant growth; results on macadamia tree production based on root collar diameters (Table 25), tree heights (Table 29), and canopy diameter (Table 27) apart from the production of new shoots did not give out a clear indication that trenching indeed has a significant impact during the period of this study. Such observations could be due to the time length of collection of tree production data since the response of tree growth to trenching is not necessarily very quick and immediate. Therefore for macadamia response to trenching with regard to tree production can be well and maybe fairly documented by looking at the number of new shoots than many other variables of tree production when observing the immediate impacts of trenching of *C. cuninghamiana*. It is therefore advisable for future work to consider both immediate and long term response of macadamia and/or many other horticultural crops grown in fields where research similar to this current one are conducted.

Nutrient levels on trenched sites on the first row had shown the response of root pruning, this could be due to soil moisture though significant differences were only obtained on Boron

,Calcium, Iron and Sodium while for Phosphorus, Manganese, Magnesium, Potassium and Zink did not shown to have any significant difference. Such findings support the argument that high root proliferation of casuarina windbreaks do lead to high nutrient depletion. It has been reported by other research work that the uptake of Iron and Manganese is often increased by flooding or an increase in water level in the soil because ferric and Manganic forms are converted to soluble ferrous and manganous forms (Jones and Etherington, 1970) And such has been observed in this study for Iron but not Manganese at all distances. It is fair to argue that there is lack of availability of oxygen in the soil because casuarina roots deplete water near the macadamia plants. Other research works have shown that decreasing the oxygen concentration around *Pinuselliotti* roots results in the inhibition of the absorption of the Phosphorus, Calcium, and Magnesium (Shoulders and Ralston, 1975); our finding are in concord with the findings by Shoulders and Ralston (1975) in terms of Phosphorus and Magnesium (Figure 14 and Figure 10); There is nevertheless still a huge amount of work to be conducted that should assess the impacts of oxygen on *Macadamia tetraphylla* at all growth stages. With such trend of nutrient accumulation observed after trenching especially on the first and second rows one could therefore confidently argue that casuarina root proliferation have impacts on nutrients acquisition by *Macadamia tetraphylla*. It could therefore be justifiable to consider trenching as a fair mitigation tool to lessen negative effects of casuarina roots on the accumulation of nutrients around crop plants.

During the period of this study xylem water potential accelerated with time in trenched sites compare to not trenched; there was a slight increase in xylem water potential in the first row than on the second and third rows at all dates of measurements (Table 37, Table 39 and Table 41) no significant difference was obtained on the first date of measurement but on the second and third dates significant differences were obtained; there was however certain individual

trees in rows that had more xylem water potential in not trenched than in trenched rows, the reason as to why some of the plants gave opposite measurements than expected especially in not trenched sites can be ascribed to the sizes of particular trees. Trees somehow varied in terms of sizes but due to the nature of our study and the number of individual trees available, all trees adjacent to the windbreaks were considered for sampling; notwithstanding that our findings can be supported by the work of Weiner (1990) and Schwinning and Weiner (1998) in which plants acquired resources proportional to their sizes.

Another explanation to our findings can be due to unequal root biomass distribution of casuarina windbreak at sites of the macadamia trees. Such therefore naturally results into different level of competition; it is therefore reasonable to argue that where casuarina roots are more dense water with nutrients will be depleted more than where casuarina roots are sparse.

The results also showed an increase in leaves stomatal conductance rates in trenched sites especially in the first row and such was consistent to all dates of measurements (Figure 19 and Figure 20). This is a fair indication that soil moisture content improved greatly in trenched sites very close to the casuarina windbreak trees plants. On the second date of measurement an increase in stomatal conductance was also found in the second and third rows unlike the second date of measurement and significant difference was obtained (Table 35). Such peculiar observation should not be uncommon because individual plants farther and farthest away from each other should naturally compete less. We observed no casuarina roots in the second and third rows during our excavation work; therefore the failure to obtain significant difference between the trenched and not trenched treatments to some variables of

our measurements on the second and third rows can indeed be ascribed to the absence of casuarina roots at far distances from the windbreaks.

From our results the magnitude of windbreaks impact decreases with increasing distances away from *C. cunninghamiana* and also in relation to trenching. Flexas and Medrano (2002) concluded that stomatal closure was the earliest plant response to mild drought stress and also with increasing drought stress and such findings confirms with our findings (Table33). Our results are also supported by those of Schultz (2003) who found that the restriction of stomatal conductance to maintain a positive balance between carbon uptake and water loss is one of the first responses to water stress in field-grown grapevines.

The fact that there was more variation in terms of all measured variables (i.e., plant water status, stomatal leaf conductance, plant development, plant nutrient accumulation) among macadamia trees near the windbreaks and those far away from them could be fairly justified by trusting that casuarina windbreak trees in the study area indeed have an influence on nutrient physiology, water relations and development of macadamia plants.

## CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

The observed relationships between young macadamia growth performance and their distance from the windbreaks and also how they respond to trenching has been interpreted in terms of the disruptive mechanisms that is brought by *C. cunninghamiana* windbreaks. Therefore trenching per se is a promising option to farmers who resort to the removal of windbreaks due to their negative impacts on crops in agricultural lands of the Limpopo Province, South Africa.

Poor growth and yields of young macadamia adjacent to the windbreaks as a problem is still prevailing in the study area because farmers do not apply trenching or root pruning along the windbreak to minimize root competition with adjacent macadamia trees. Removal of windbreaks will forfeit the many benefits of farming with windbreaks. However, there is pressing need for research on the relative importance of root competition compared to other effects like shade, allelopathy of casuarina, and the importance of breeding macadamia trees that are tolerant to competition, shade and allelopathic effects of casuarina windbreaks.



## References

- ANDERSON, L.S. and SINCLAIR, F.L. (1993). Ecological interactions in agroforestry systems. *Agrofor.* 6, 57–91pp.
- ANDREU, M.G., TAMANG, B., ROCKWOOD, D.L. and FRIEDMAN, M.H. (2009). Potential woody species and species attributes for windbreaks in Florida. FOR224. Gainesville: University of Florida Institute of Food and Agricultural Sciences.
- ARTHUR, W.W and CRAIG, R. E. (2006). Species Profiles for Pacific Island Agroforestry.
- BARBOUR, M.G., CUNNINGHAM, G., OECHEL, W.C. and BAMBERG, S.A. (1977). Creosote bush: biology and chemistry of *Larrea* in new world deserts. 48 - 91pp.
- BUCCI, S.J, GOLDSTEIN, G., MEIZER, F.R, FRANCO, A.C., CAMPANELLO, P., SHOLZ, F.G. (2006). Mechanisms contributing to seasonal homeostasis of leaf water potential and predawn disequilibrium between soil and plant water potential in Neotropics savanna trees. *Forestry Research* 16: 326 – 331pp.
- BURNS, R.M., MOSQUERA, M.S and WHITMORE, J.L. (1998). Useful Trees of the Tropical Region of North America. North American Forestry Commission.
- CHAPUT, L.J. and TUSKAN, G.A. (1991). Field Windbreak Management and Its Effect on Adjacent Crop Yield a Preliminary Investigation.
- CLEUGH, H.A. (1998). Effects of windbreaks on airflow, microclimates and crop yields. *Agroforestry Systems* 41: 55-84pp.

- CLEUGH, H.A. (2002). Parameterizing the impact of shelter on crop microclimates and evaporation fluxes. *Australian Journal of Experimental Agriculture* 42:859-874pp.
- CRACKER INC. (2000). World Consumption and Production Trends.
- DAWNSON, T. E. and PATE, J.S. (1996). Seasonal water uptake and movement in root system of phreatophytic plants or dimorphic root morphology. A stable isotope investigation. *Oecologia* 107: 13 – 17pp.
- DEWIEST, D.R. and LIVINGSTON, E.H. (2002). The Florida storm water, erosion, and sedimentation control inspector's manual. Florida Department of Environmental Protection/Nonpoint Source Management Program, Tallahassee, Florida.
- DIGIAMBERARDINO, T. (1986). Changes in a southeast Florida coastal ecosystem after elimination of *Casuarina equisetifolia*. *Tree physiology* 79:15 – 18pp.
- EHLERINGER, J.R and DAWSON, T.E. (1991). Streamside trees that do not use stream water. *Nature*.350: 335 – 337pp.
- EHLERINGER, J.R. and DAWSON, T.E. (1992). A Water uptake by plants: perspectives from stable isotope composition. *A Plant Cell Environment* 15: 1073 – 1082pp.
- ELFERS, S. (1988). Element stewardship abstract for *C. equisetifolia*. *Forestry Research* 14: 221 – 223pp.
- ENGELBRECHT, B.M, COMITA, J. CONDIT, R. RURSAR, T.A. TYREE, M.T. TURNER, B.L. and HUBGELL, S.P. (2007). Drought sensitive shapes species distribution patterns in tropical forests. *Nature* 447: 80 – 82pp.
- FLEXAS, J.MEDRANO, H. (2002). Effects of drought on photosynthesis in grapevines under field conditions: an evaluation of stomatal and mesophyll limitations. *Functional Plant Biology* 29: 461–471pp.

- FLEXAS, J., BOTA, J., LORETO, F., CORNIC, G., SHARKEY, T.D (2004). Diffusive and metabolic limitations to photosynthesis under drought and salinity in  $C_3$  plants. *Plant biology* 269-279pp.
- GILLETTE, D.A. (1986). Wind erosion. In: C. Carlson (ed.). *Soil conservation: Assessing the national resources inventory, Volume 2*. National Academy Press, Washington, D.C. Pp. 129-162pp.
- GONZALEZ-MELER, M.A. (1997). Effects of prolonged drought stress and nitrogen deficiency on respiratory oxygen uptake of bean and pepper leaves. *Photosynthetic*, 34: 505-512pp.
- GOTTWALD, T.R. and TIMMER, L.W. (1995). The efficacy of windbreaks in reducing the spread of citrus canker caused by *Xanthomonas axonopodis* sp. *citri*. *Trop. Agric.* 72: 194-201pp.
- GOTTWALD, T.R. GRAHAM, J.H. and EGEL, D.S. (1992). Analysis of foci of infection of Asiatic citrus canker in a Florida citrus orchard. *Plant Diseases* 76:386-396pp.
- GOVINDARAJAN, M, RAO, M.R., MATHUVA, M.N. and NAIR, P.K.R. (1996) Soil-water and root dynamics under hedgerow intercropping in semiarid Kenya. *Agron. J.* 88, 513-520pp.
- GRAHAM, J.H. and GOTTWALD, T.R. (1992). Research perspectives on eradication of citrus bacterial diseases in Florida. *Plant Diseases* 75:1193-1200pp.
- GREB, B.W .and BLACK, A.L. (1961). Effects of windbreak plantings on adjacent crops. *J. Soil and Water Conserv.* 16(5):223-227.
- GROSS, C.L. (1995). Macadamia in Orchard. *Flora of Australia* 16: 419 – 425pp.

- HAUPT-HERTING, S. (2001). A new approach to measure gross carbon dioxide fluxes in leaves. Gross carbon dioxide assimilation, photo respiration and mitochondrial respiration in the light in tomato under drought stress. *Plant Physiol* 126: 388-396pp.
- HOCKING, D. AND ISLAM, K. (1997). Trees on farms in Bangladesh: Growth of top and root-pruned trees in wetland rice fields and yields of understory crops. *Agrofor. Syst.* 39:101–115pp.
- HOWARD, S.B, ONG, C.K., BLACK, C .R. and KHAN, A. A. H (1997). Using sap flow gauges to quantify water uptake by tree roots from beneath the crop rooting zone in agroforestry systems. *Agrofor. Syst.* 35, 15–29.
- JACKSON, P.C., MEIZER, F.C., BUSTAMATE, M., GOLDSTEIN, G., FRANCO, A., RUNDEL, P.W., CALDAS, L, I., GLER, E., and CAUSIN, F. (1999). Partitioning of soil water among tree species in a Brazilian Cerrado Ecosystem. *Tree Physiology* 19: 717 – 724pp.
- JOHN, O.T. and SANDRA, H. (2006). Windbreaks for Citrus.
- JONES, H.E and ETHERINGTON JR. (1970). The effect of manganese on root extension of *geum rivale*. 238-243pp.
- KARAMANOS, A. J., DROSSOPOULOS, J.B., and NIAVIS, C.A. (1986). Water stress-induced alterations.
- KATHY L. YOUNG, MING-KO WOO AND SYLVIA A. EDLUND. (1997). Influence of Local Topography, Soils, and Vegetation on Microclimate and Hydrology at a High Arctic Site, Ellesmere Island, Canada 29: 270-281pp
- KORT, J. (1988). Benefits of windbreaks to field and forage crops. *Agriculture Ecosystem and Environment* 22/23: 165 – 190pp.
- KORWAR, G.R. and RADDER, G.D. (1994). Influence of root pruning and cutting interval of *Leucaena* hedgerows on performance of alley cropped rabi sorghum. *Agrofor. Syst.* 25:95–109pp.

- KURSAR., TANIA BRENES-ARGUEDAS., PHYLLIS, D., COLEY., THOMAS, A. (2009). Pests vs. drought as determinants of plant distribution along a tropical rainfall gradient. *Ecology* 90:7, 1751 – 1761pp.
- LABANAUSKAS, C.K., STOLZY, L.H., and ZENTMYER, G.A. (1989). Rootstock, soil oxygen, and soil moisture effects on growth and concentration of nutrients in avocado plants. pp 118-125 *University of California*.
- LARNEY, F.J., BULLOCK, M.S. JANZEN, H.H., ELLERT, B.H. and OLSON, E.C.S. (1998). Wind erosion effects on nutrient redistribution and soil productivity. *Journal of Soil and Water Conservation* 53:133-140.
- LARNEY, F.J., BULLOCK, M.S., JANZEN, H.H., ELLERT, B.H., OLSON, E.C.S., (1998). Wind erosion effects on nutrient redistribution and soil productivity. *J. Soil & Water Conserv.* 53, 133–140pp.
- LAWLOR, D.W. (1976). Water stress induced changes in photosynthesis photo, respiration, respiration and carbon dioxide compensation 378-387pp.
- LE ROUX., BARIAC, T. and MARIOTTI, A. (1997). Spatial partitioning of soil water resources between grass and shrubs components in a West African humid savanna. *Oecologia* 104: 147 – 155pp.
- LEITE, R.P., and MOHAN, S.K. (1990). Integrated management of citrus bacterial canker caused by *Xanthomonas axonopodis* sp. *Citri* in the State of Parana, Brazil. *Crop Protection* 9:3-7.
- LETEY, J., LUNT, O.R. , STOLZY, I.H., and SZUSZKIEWICZ, T.E. (1961). Plant growth, water use and nutritional response to rhizosphere differential oxygen concentration. *Soil Sci. Soc. Amer. Proc.* 25:183-186pp.

- LEYS, J. and MCTAINSH, G. (1994). Soil loss and nutrient decline by wind erosion – cause for concern. *Australian Journal of Soil and Water Conservation* 7:30-35pp.
- LOBODA, T. (1993). Gas exchange of different spring cereal genotype under normal and drought condition, 567-572pp.
- MACDANIELS, L. H. (1979). Nut tree culture in North America: Northern Nut Growers.
- MASON, R.J. (1983). The effect of harvest time and method on the quality of macadamia nuts. *Food Australia* 35: 184 – 185pp.
- MASON, R.L. (1982). Macadamia nut Quality - The effect of harvesting practices.
- MCINTYRE, B.D., RIHA, S.J., and ONG, C.K. (1997) Competition for water in a hedge-intercrop system. *Field Crops Res.* 52, 151–160pp.
- MORGAN, J.M., (1977). Changes in diffusive conductance and water potential of wheat plants
- MUSINA, L. and RUTHERFORD, M. L. (2006). Vegetation of South Africa, Lesotho and Swaziland. South African Biodiversity Institute, South Africa.
- MWIHOMEKE, S.T. (1989). A comparative study of the rooting depth of *Grevillea robusta*. Interplanted with sugarcane along contour strips. In: Harwood, C.E. (eds.) *Grevillea robusta* in Agroforestry and Forestry. Proceedings of International Workshop ICRAF, Nairobi.
- NUBERG, I.K. (1998). Effects of shelter on temperate crops: a review to define research for Australian conditions. *Agroforestry Systems* 41:3-34pp.
- OKORIO, J. (2000). Light interception and water use in boundary planting agroforestry systems, University of Reading, U.K., 230 p.

ONG, C.K., BLACK, C.R., MARSHALL, F.M. and CORLETT, J.E. (1996). Principles of resource capture and utilization of light and water. In *Tree- Crop Interactions: A Physiological Approach*. pp 73–158.

ORWA, C., MUTUA, A., KINDT, R., JAMNADASS, R., SIMONS, A. (2009). *Agroforestry Database: a tree reference and selection guide version 4.0*.

PAINE, C.E, TIMOTHY, E, HRMS, E and JESUS, R. (2009). Supplemental irrigation increase seedling performance and diversity in tropical forest. *Journal of Tropical Ecology* 25: 171 – 180pp.

RYAN, S. (2006). Conservation Management: Queensland nut tree *Macadamia integrifolia*. 79: 15 – 18pp.

SAMAC. (2006). *Macadamia Farming and Production*.

SCHOLANDER, P. F., HAMMEL, H.T., HEMMINGSEN, E. A. AND BRADSTREET, E. D. (1964). Hydrostatic pressure and osmotic potential in leaves of mangroves and some other plants. 119–125pp.

SCHROTH, G. (1995). Tree root characteristics as criteria for species selection and systems design in agroforestry. *Agrofor. Syst.* 30, 125–143.

SCHULTZ, H. R. (2003) Differences in hydraulic architecture account for near-isohydric and anisohydric behaviour of two field-grown *Vitis vinifera* L. cultivars during drought. *Plant Cell Environ* 26:1393–1405pp.

SCHWINNING, S., WEINER, J. (1998). Mechanisms determining the degree of size asymmetry in competition among plants. *Oecologia* 113: 447–455pp.

SHAH, S.R.H. and KALRA, Y.P. (1970). Nitrogen uptake of plants affected by windbreaks. *Plant and Soil* 33:573-580.

SHOULDERS, E. and RALSTON, C.W. (1975). Temperature, root aeration and light influence slash pine nutrient uptake rates. *For. Sci.* 21:401-410.

SILVA, P. S. L., (2009). Weed control via intercropping with gliricidia. I. Cotton crop. 27: 87-104pp.

SMITH, D. M, JARVIS, P. G and ODONGO, J. C. W. (1998). Management of windbreaks in the Sahel: the strategic implications of tree water use. *Agrofor. Syst.* 40, 83–96.

STANLEY, T. D. and ROSS, E. M. (1986). *Flora of Southeastern Queensland*. 1: 4, 545 – 549pp.

STONE, E.L. and KALISZ, P.J. (1991). On the maximum extent of tree roots. *For. Ecol. Manage.* 46:59–102.

SUDMAYER, R.A. and SCOTT, P.R. (2002). Characterization of windbreak system of the south coast of west Australia. *Australia journal of experimental agriculture* 42: 717 – 727pp.

SUDMEYER, R.A., HALL D.J.M., EASTHAM, J, and ADAMS M.A. (2002). The tree-crop interface: the effects of root pruning in south-western Australia. *Australian Journal of Experimental Agriculture* 42:763-772.

TELLIE, N. WAJJAMUSUKWE. JULIA, W. JANET, L. SPRENT. CHIN ONG. DOUGLAS, D. and OKORIO, J. (2008). Tree growth and management in Ugandan agroforestry systems: effects of root pruning on tree growth and crop yield. 28; 233-242.

VALENTINE, R. SCARASCIA, G.E. MUGNOZZA, G. and EHLERINGER, J.R. (1992). Hydrogen and carbon isotope ratios of selected species of Mediterranean macchiaecosystem. *Functional Ecology* 6: 627 – 637pp.

VAN NOORDWIJK, M. PURNOMOSIDHI, P. (1995). Root architecture in relation to tree–soil–crop interactions and shoot pruning in agroforestry. *Agrofor. Syst.* 30: 161-173.

WEINER, J. (1990). Asymmetric competition in plant populations. *Trends in Ecology and Evolution* 5: 360-364pp.

WODEHOUSE, A. (1972). Casuarina in everglades national park. *Management biologist*. 1972 19pp.

WRAY, P. STERNWEIS, L. and LENAHAN, J. (2005). Farmstead windbreaks: establishment, care, and maintenance. Iowa State University Extension publication.

Appendix A

Table A1: Nutrients accumulation on nine trenched and non-trenched macadamia sampled trees on the first row at 6 m distance from the windbreak.

Treatments	Row no.	Tree no.	Nutrients mg/kg								
			B	Ca	Fe	K	Mg	N	P	Zn	
Trenched	1	1	88.45	94.894	61.711	61.539	72.010	87.252	75.155	40.5	154.984
		2	65.847	81.962	49.691	66.643	69.893	45.174	76.401	38.0	123.655
		3	64.38	93.845	53.415	59.258	54.848	80.453	34.852	41.2	136.063
		4	53.74	91.754	69.396	64.374	71.482	52.856	57.645	34.0	182.956
		5	67.8	88.834	74.642	72.737	82.693	54.512	72.561	30.7	133.138
		6	78.098	92.945	61.441	55.765	67.592	80.307	70.751	39.0	130.745
		7	62.748	93.845	61.431	66.448	75.728	58.563	60.485	40.8	145.763
		8	59.667	75.843	48.417	53.863	61.483	49.395	61.108	32.4	146.345
		9	62.582	81.543	83.763	61.744	62.263	51.516	68.587	42.0	136.962
Not trenched	1	1	62.793	89.094	52.542	65.218	75.021	66.294	50.635	43.9	167.336
		2	58.983	96.745	63.181	61.853	69.343	61.584	54.545	56.6	180.856
		3	55.752	84.745	46.345	70.472	55.474	62.473	68.78	43.3	147.753
		4	66.863	89.574	54.43	67.543	66.483	49.537	65.642	34.0	152.753
		5	62.102	85.354	61.343	66.341	72.587	65.913	37.423	59.6	132.763
		6	80.682	91.663	55.763	72.753	84.552	45.820	67.642	35.5	140.224
		7	61.3	95.663	51.432	60.643	61.374	62.548	61.264	56.8	136.265
		8	49.54	77.277	46.645	62.513	61.423	57.254	63.238	32.4	192.751
		9	64.191	80.631	58.237	60.441	60.642	65.632	71.439	33.4	152.856

Appendices

Appendix A

Table A1: Nutrients accumulation on nine trenched and non-trenched macadamia sampled trees on the first row at 6 m distance from the windbreak.

Treatments	Row no	Tree no	Nutrients mg/kg								
			B	Ca	Fe	K	Mg	Mn	Na	P	Zn
Trenched	1	1	68.45	94.634	61.211	61.539	72.818	47.282	75.155	40.5	114.984
		2	65.847	84.962	49.694	68.843	68.843	45.374	76.401	38.0	123.653
		3	64.36	93.845	65.413	64.859	64.849	60.453	54.862	41.2	136.663
		4	63.24	91.734	69.396	64.374	71.582	52.853	67.643	34.0	132.956
		5	67.8	88.834	54.642	72.732	62.693	54.532	72.361	39.7	133.138
		6	78.698	92.945	62.443	65.763	67.592	40.327	70.251	39.0	120.745
		7	62.748	93.845	61.432	66.643	75.728	58.563	60.439	40.6	145.763
		8	69.067	95.643	48.432	53.869	63.482	49.395	81.108	37.4	149.743
		9	62.542	91.843	53.763	61.743	62.283	51.516	68.552	42.0	136.962
Not trenched	1	1	62.763	99.694	52.542	63.218	75.022	60.294	60.055	43.9	167.336
		2	58.983	96.745	63.131	61.853	63.341	44.584	54.548	56.6	150.856
		3	66.753	84.745	46.543	70.472	59.474	62.473	63.78	43.3	147.753
		4	63.651	89.574	54.43	61.843	66.493	49.532	65.642	34.0	122.753
		5	62.702	98.956	62.542	60.241	72.562	63.918	57.423	59.6	132.763
		6	69.067	93.643	55.763	72.753	64.532	45.820	62.642	35.5	140.224
		7	64.8	96.538	51.432	60.643	61.374	42.548	61.264	56.8	136.865
		8	49.34	97.327	48.643	62.853	65.482	50.294	62.328	37.4	132.751
		9	64.231	88.631	58.267	60.421	63.842	46.632	71.648	53.4	152.856

Table A3: Nutrients accumulation on nine trenched and non-trenched macadamia sampled trees on the third row at 20 m distance from the windbreak.

treatments	Row no	Tree no	Nutrients mg/kg								
			B	Ca	Fe	K	Mg	Mn	Na	P	Zn
trenched	3	1	147.335	58.6745	92.03	73.586	73.856	47.282	81.156	24.4	64.163
		2	148.954	57.171	101.914	80.052	65.954	45.374	84.846	37.8	82.213
		3	167.745	40.9927	86.952	97.765	59.856	20.453	75.876	34.8	74.328
		4	154.843	42.0239	96.945	77.863	63.856	42.853	86.271	31.9	63.112
		5	132.853	40.9927	98.534	83.853	54.856	44.532	69.939	17.8	65.254
		6	166.956	48.453	87.953	77.953	66.547	30.327	88.325	24.5	65.642
		7	158.945	62.63	100.342	97.712	44.851	28.63	82.626	37.2	62.673
		8	174.953	51.322	99.538	85.734	64.861	49.395	78.435	26.8	74.522
		9	162.832	61.763	87.962	82.958	71.736	31.516	71.962	36.9	81.182
Not trenched	3	1	154.965	30.7557	98.956	91.743	62.845	49.294	72.778	29.3	72.758
		2	150.759	52.243	101.742	98.418	59.956	34.584	67.852	19.3	85.732
		3	139.642	55.632	89.794	79.963	74.845	42.473	78.442	24.3	60.974
		4	166.428	56.652	98.856	82.953	62.845	49.532	76.971	16.8	64.207
		5	148.548	50.12	94.561	83.853	61.582	43.918	82.886	28.6	67.423
		6	164.754	41.241	96.945	97.572	57.946	45.820	71.626	24.7	61.154
		7	136.754	44.864	98.956	88.943	63.845	32.548	79.349	38.7	51.753
		8	128.548	32.54	91.966	74.843	71.945	30.294	79.781	26.4	69.113
		9	123.482	34.861	88.945	95.856	61.645	26.632	77.744	18.7	75.664

## Appendix B Trenching adjacent the windbreak using back actor machine

Table B1: Trenching plots adjacent the windbreak.



Table B2: Trenching adjacent the windbreak using back actor machine trenching at a depth of



Table B3: *Casuarina cunninghamiana* windbreak roots cut-off during trenching at a depth of one meter (1m)



## Appendix B

Table B1: Trenching plots adjacent the windbreak.

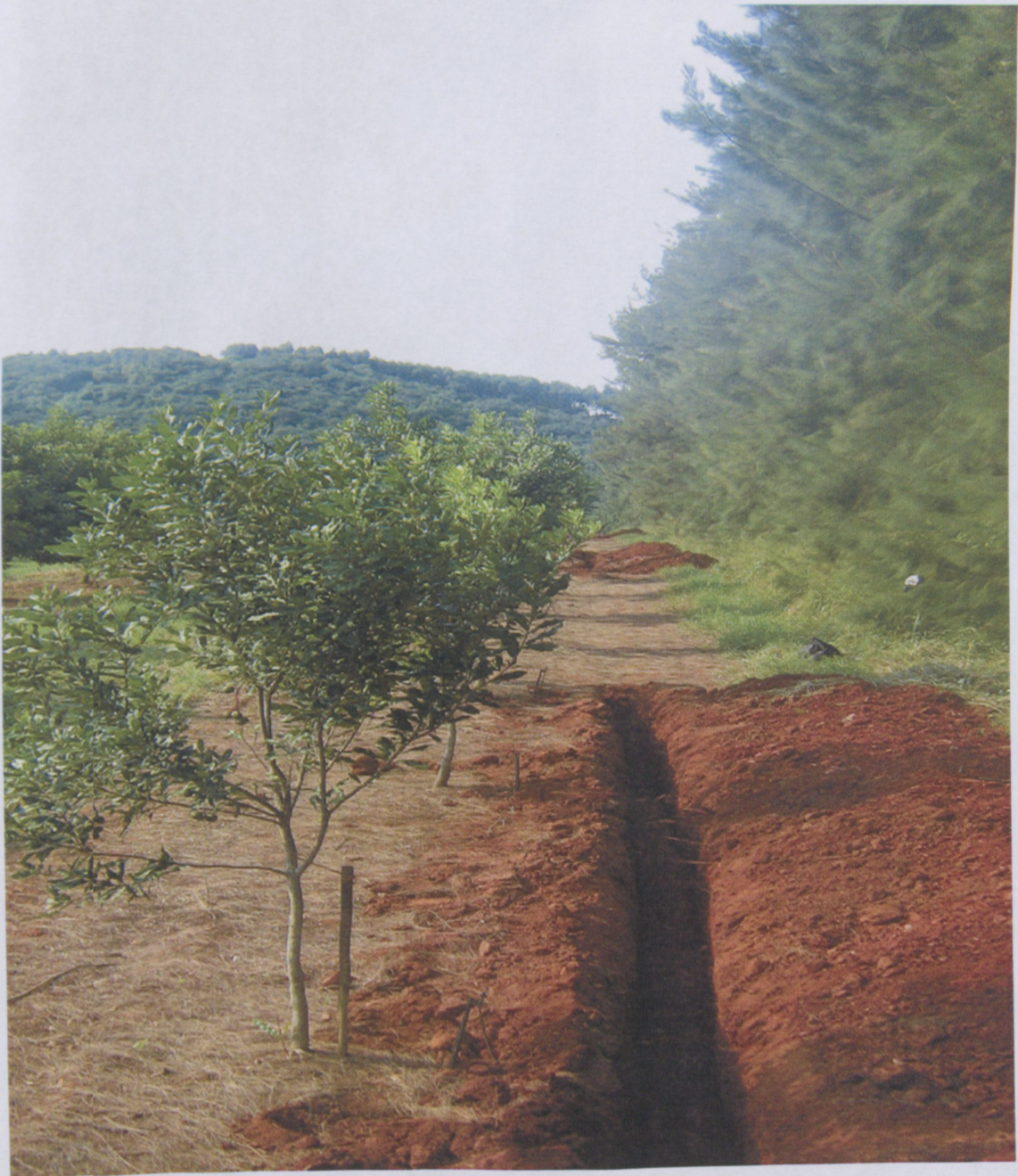


Table B2: Trenching adjacent the windbreak using back actor machine trenching at a depth of



Table B3: *Casuarina cunninghamiana* windbreak roots cut-off during trenching at a depth of one meter (1m)

