



Ecophysiology of *Faidherbia albida*; effect of pruning on tree  
water relations, cambium dynamics and understorey wheat  
productivity in Ejerssa Joro, Ethiopia

Awol Assefa Toib

Addis Ababa, Ethiopia

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Awol Assefa Toib

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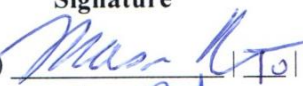
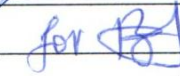



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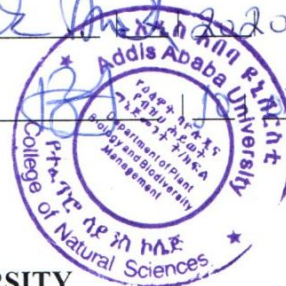
**Awol Assefa Toib**

*A Thesis Presented to the Graduate Programmes of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of philosophy in Plant Biology and Biodiversity Management*

Approved By Examining Board:

Name	Signature	Date
1. Prof. Masresha Fetene (Advisor)		07/07/2020
2. Prof. Catherine Muthuri (Advisor)		10/07/2020
3. Dr. Aster G/Kirstos (Advisor)		10/07/2020
4. Dr. Asfaw Degu (Internal Examiner)		10/07/2020
5. Dr. Tilahun Amede (External Examiner)		10/07/2020

Dr. Bikila Warkineh  
Chair of Department or Graduate Programme Coordinator



ADDIS ABABA UNIVERSITY

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Addis Ababa University, 2020

**ABSTRACT**

*Faidherbia albida* (Delile) A. Chev.; is one of the most compatible agroforestry tree species commonly found in agricultural fields in semi-arid region of Ethiopia in association with wheat (*Triticum aestivum*), teff (*Eragrostis tef*) and maize (*Zea mays*). Farmers heavily prune the tree for various purposes. The impact of pruning on tree water relations, cambium growth, and leafing phenology is not well understood. This study was therefore designed to investigate the impact of pruning *F. albida* on tree water use, cambium dynamics, leafing phenology and understory wheat productivity. A field experiment was conducted at Ejerssa Joro Kebele, Lome woreda Oromia Regional State between April 2015 and October 2017. Three of the trees were pruned mimicking the farmers practice while others three were left unpruned as a control. Sap flow rate and sap volume was determined using heat ratio method (HRM). Radial cambium growth was measured using micro dendrometer, leafing phenology was scored every month. Split plot design was employed with 1m<sup>2</sup> areas under both tree managements at 1, 3 and 5m distances and from three directions. Soil moisture from different distances as well as under and

outside of the tree canopy was measured. Photosynthetically Active Radiation (PAR) levels, air temperature, relative humidity (RH) were measured. Soil physical and chemical properties were analyzed from different distances of pruned and unpruned trees from inside and outside of the tree crown of pruned and unpruned trees. Wheat growth, leaf gas exchange and chlorophyll content were measured under each tree management. Wheat productivities (aboveground biomass and grain yield) were measured after the wheat was harvested in October 2015 and 2016. Results showed that both diurnal sap flow rate ( $78.9 \text{ ms}^{-1}$ ) and sap volume ( $4590 \text{ L month}^{-1}$ ) were significantly higher ( $p < 0.05$ ) in unpruned compared with pruned trees. Sap volume from unpruned trees were higher during the dry season as well as when the tree canopy was fully foliated from December to March each year. On the contrary, sap volume was very low when the trees were pruned and during defoliation in unpruned trees, mainly around the onset of the main rainy season. The highest daily sap volume being  $110.7 \text{ L}$  in unpruned tree compared to  $53.5 \text{ L}$  in pruned trees during the dry period, as the result pruning *F. albida* reduced sap volume up to 52%. There was a significant ( $p < 0.05$ ) difference in leaf water potential between midday and predawn in pruned and unpruned trees. However, the difference in midday and predawn leaf water potential in pruned and unpruned were statistically insignificant. A higher cambial growth was observed towards the onset of the dry period in both tree managements. A higher cambial growth was observed in unpruned both in dry and wet season compared with the pruned one. Both temporal and spatial variations of leaflet number per twig were scored. The highest mean leaflet remaining per twig (up to 23) was scored during the dry period (October–January) when the tree crown was fully foliated. However, number of leaflets declined towards March and May each year followed by complete defoliation from May to June each year. The leaf

number/twig remaining in June and October was significant ( $p < 0.05$ ) in 2015. Higher rate of assimilation ( $A$ ) of wheat leaves was recorded ( $4.8 \mu\text{mol m}^{-2} \text{s}^{-1}$ ) at 1 m distance under unpruned *F. albida* but declined with increasing distances away from the tree trunk. Rate of assimilation of wheat leaves showed significant ( $p < 0.05$ ) difference between 1 m and 5 m distance of same tree. Total chlorophyll content (based on SPAD readings) of wheat grown under unpruned *F. albida* was significantly ( $p < 0.05$ ) higher compared to under pruned trees. However, no significant difference was observed in RWC of wheat leaves under both tree managements and along the different distances. Soil organic carbon, nitrogen and available phosphorous under unpruned trees were significantly ( $p < 0.05$ ) higher compared with the soil under pruned tree of similar distances. Wheat grain yield under unpruned *F. albida* tree was significantly ( $p < 0.05$ ) higher compared with outside of same tree as well as under and outside of pruned tree. The grain yield found at 1, 3, and 5m distances from the trunk of pruned tree was lower by 26, 27 and 29%, respectively, than the grain yield of wheat under unpruned *F. albida* at similar distances. The highest biomass ( $3.29 \text{ t ha}^{-1}$ ) was found under unpruned *F. albida* and the lowest ( $2.10 \text{ t ha}^{-1}$ ) was found outside of pruned tree. Pruning reduced wheat biomass by 30 and the grain yield by 27%; however, the difference in aboveground biomass within unpruned tree under and outside the tree canopy and outside of pruned *F. albida* was insignificant. The results showed that pruning *F. albida* canopy reduces the complementarity benefits of wheat productivity and significantly reduces tree water uptake. In general, the crown of unpruned *F. albida* improved microclimate condition such as reduced PAR level significantly and reduced air temperature up to 6%. A higher soil moisture content as well as majority of soil macronutrients found under unpruned were higher which contributes to

*enhance understorey wheat productivity. Therefore, farmers should be encouraged to retain the branches of F. albida in order to optimize agricultural productivity and to increase yield where evapotranspiration is the limiting factor in semi-arid Ethiopia.*

**Key words:** *Cambium dynamics, Ejerassa Joro, Fabel, Faidherbia albida, heat ration methods, PAR, pruning, reverse phenology, Sap volume, SPAD, Water use efficiency.*

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## LIST OF ACRONYMS

A	Assimilation rate
ACIAR	Australian Center for International Agricultural Research
AES	Atomic Emission Spectrometry
BD	Bark Depth
CD	Crown Diameter
CSA	Climate Smart Agriculture
DBH	Diameter at Breast Height
DW	Dry Weight
E	Transpiration Rate
ESs	Ecosystem Services
EthioSIS	Ethiopian Soil Information System
FAO	Food and Agriculture Organization
Fi	Sap flow rate at time <i>i</i>
FRC	Forest Research Center
FW	Fresh Weight
gs	Stomatal conductance
HRM	Heat Ration Methods
ICP	Inductively Coupled Plasma
ICRAF	International Center for Research on Agroforestry
IRGA	Infra-red Gas Analyzer
LAI	Leaf Area Index
Masl	Meter above sea level
MCF	Moisture Correction Factor
MoA	Ministry of Agriculture
RH	Relative Humidity
RWC	Relative Water Content
SE	Density of water
SFM	Sap Flow Meter
SPAD	Soil and Plant Analysis Development

## **1.0 INTRODUCTION**

Sub-Saharan Africa is known with high level of poverty and diminished ecosystem services (ESs) due to natural and human induced factors such as deforestation (Kuyah *et al.*, 2016). Land degradation has emerged as the main threatening challenge in dryland areas of the continent where degradation of natural resources such as loss of vegetation and soil fertility reduction ultimately end up with food insecurity and poverty (Gauri, 2019). Globally, arid and semi-arid regions account about 30% of the world in which 20% of the people are inhabited where the soil is exposed to severe degradation problem (Sivakumar *et al.*, 2005; Malagnoux, 2007). Arid and semi-arid regions occupy up to 75% in Kenya and 50% in Ethiopia where people live below the poverty line (Jama and Zeila, 2005).

Climate change creates temperature rise and dry condition across the globe in general and large portion of Africa and Asia in particular influences negatively agricultural productivity (Kimani *et al.*, 2013). An increase in climate change has many implications on agricultural productivity and the living condition of local people, especially in a country whose economy is mainly dependent on rain-fed agriculture (Kiros Hadgu *et al.*, 2013).

Climate change does not affect the globe equally. Developing countries in general and sub-Saharan African in particular have been the most affected due to greater vulnerability as well as limited knowledge and technology to adaptation (Knox *et al.*, 2012; Ali, 2017). The rise in temperature condition in the past few decades has been fairly rapid in many parts of agricultural regions around the world due to an increase in greenhouse gases and the trend shows it will continue to increase (Lobell and Gourdji, 2012).

Climate change affects agricultural productivities and crop yield, which leads farmers to engage in natural resource extraction such as deforestation, which further degrades the environment (Chianu *et al.*, 2006). Environmental degradations threaten farming in African and reduce crop productivities by 40%, where soil and climate are getting worse for better crop production (Knox *et al.*, 2012). Agricultural production is mainly dependent on favorable environmental condition; however, the sector in Africa is the most affected due to frequent drought and shift to marginal agriculture (Khaoma, 2007; Bandara and Cai, 2014). Unfavorable weather and climate change strongly influence agriculture and are a threat to the established farming system (Gornall *et al.*, 2010). Drought is one of major problems in many part of the world affecting agricultural productivity. The number of drought days could increase by 20% in most part of the world by 2080 and the number of people exposed to drought could increase to 9-17% in 2030 and 50-90% in 2080 (Hallegatte *et al.*, 2016).

The major part of Ethiopia is arid and semi-arid and highly exposed to desertification and drought. The country is dependent on climate sensitive economic sectors such as agriculture and livestock (Melese Geize, 2019). Reduced numbers of rainy days and delayed rainfall that causes terminal drought during grain filling period are the most serious problems of agriculture in Ethiopia (Kassie *et al.*, 2013). The mean annual temperature exhibited a significant warming trend of 0.12–0.54 °C per decade and is expected to increase to 1.4-4.1 °C by 2080; whereas, annual rainfalls is expected to decline with faster rate (Fazzini *et al.*, 2008; Kassie *et al.*, 2013). Under these conditions climate-smart agriculture is one possible means to

reduce the impact on agricultural production and ecosystem services (Raza *et al.*, 2019).

Integrating trees in the farm systems has been an ancient practice until it got institutional attention in the 1970s and the 1980s when the concept of agroforestry system emerged (Pinho *et al.*, 2012). Trees can be incorporated in many farming landscapes providing a range of ecosystem services that support livelihoods (Sinclair, 1999). Spatial and/or temporal arrangements of trees such as remnants of cleared forests and woodlands, deliberately preserved in the farmlands influence positively the understorey crops (Bonkoungou, 2001). It is an important practice to alter the soil system by capturing both wetfall and dryfall which influences chemical condition of the soil positively (Rhoades, 1996).

Trees play a vital role in modifying microclimate as well as assisting in the utilization of resources such as water, nutrients and light (Jerneck and Olsen, 2013). Trees and shrubs contribute a major role in buffering climate variability (Bayala *et al.*, 2014). They have the potential to recharge the ground water table by enhancing infiltration rate, reducing runoff and evaporation. As a result, the understorey crops are benefitted through hydraulic lift from the intercropped trees which enrich soil moisture and nutrients not accessible to the understorey crops (Ong *et al.*, 2002).

Intercropping trees with annual crops, especially in drylands was discouraged for various reasons due to lack of awareness, such as the belief that it depletes ground water resources (Ilstedt *et al.*, 2016). Nevertheless, intermediate and optimum tree cover is known to maximize groundwater table by increasing infiltration rate of rainwater (Tobella, 2016).

Agroforestry is considered as an approach to solve land-use problems by allowing farmers to produce food, fodder and fuel products simultaneously on the same unit of land (Badege Bishaw and Abdu Abdulkadir, 2003). The system refers to an ecological based natural resource management systems through the integration of trees in agricultural farms for sustainable economic production and environmental benefits (ICRAF, 1990). It also provides income for livelihood in rural households in Ethiopia for many decades. However, the area coverage of trees had declined due to pressure from agricultural intensification (Amare Degninet *et al.*, 2018).

All trees are not equally important for agroforestry purpose. Limited numbers of trees are preferred by farmers in semi-arid areas of Africa based on their compatibility and positive interaction with the accompanying crops (Broadhear *et al.*, 2003). Trees also increase crop productivity through temperature regulations, retaining soil structure and enriching soil organic matter and nutrient recycling (Palm, 1995). One of the most compatible agroforestry trees is *Faidherbia albida* known in ameliorating soil microclimate by reducing heat stress and retaining soil moisture (Adam, 2012). *Faidherbia*-crop based land use systems are the most effective in recycling soil fertility compared to sole cropping systems (Schroth *et al.*, 2001).

Incorporation of *F. albida* in the arid and semi-arid parts of Africa has been reported very important in soil conservation and soil nutrient improvement beneath the tree (Dangasuk *et al.*, 1999a). The tree alters both physical and chemical properties of soil, aided by soil fauna which are involved in litter decomposition and adding nitrogen via nitrogen fixation. The extensive root system of the tree helps in scavenging nutrient and water and redistributing beneath the tree canopies (Rhoades,

1996). The tree also improves soil structural stability and chemical and biochemical properties of the soil (Kamara and Haque, 1992).

*F. albida* is known for its reverse leafing phenology which makes it the most compatible in the agroforestry systems, through improving soil nutrient and reducing soil moisture evaporation (Orwa *et al.*, 2009). Litterfall from integrated *F. albida* trees improves the soil organic matter as well as bringing long term microclimate modification on soil biological and chemical property which is vital to enhance understorey crop productivity (Jones, 2011). Decomposition and subsequent mineralization of litterfall of the tree provide additional nutrient into the soil which is important to enhance crop productivity (Chuyong and Acidiri, 2017).

### **1.1.The influence of *F. albida* on accompanying crops**

Intercropping of perennial trees may exert complementary, competitive or neutral effect on the annual crops; the type of interaction depends on the tree physiological performance such as water use efficiency as well as root architecture (Siriri *et al.*, 2010). Compatible trees in farming systems provide an enormous potential to mitigate the effects of drought to ease desertification and to rehabilitate the degraded soil, boosting food productions as well as providing an alternative means for soil fertility (Toppo and Raj, 2018). Extreme temperature is another biotic stress that stunts crop growth causing crop failure. However, the shade from *F. albida* lessens soil surface temperature which allows farmers to grow many crops beneath the tree (Williams, 1991).

The positive impact of *F. albida* on crop performance and soil fertility has been reported for many years across Africa. For instance, yield of millet, groundnut and

sorghum was 30-200% higher under the tree compared to open area, as a result of soil fertility and favorable microclimate condition created by the tree referred to as ‘albida effect’ (Dangasuk *et al.*, 1999; Rhoades, 1999).

The grain yield of sorghum, wheat and teff was higher by 100, 40 and 10%, respectively where *F. albida* trees were intercropped comparing with the sole cropping system (Dechassa Jiru, 1995). Similarly, the maize yields under *F. albida* have been 200-400% higher than the national average in Zambia and Malawi (Ventola, 2013).

### **1.2. Regeneration potential and the challenges of *F. albida***

Despite numerous ecological and economic benefits of *F. albida* tree, conservation of the species remains the most challenging problem (Koech *et al.*, 2014). The current *F. albida* population is affected both by environmental factors and human disturbance (Noulekoun *et al.*, 2017). For instance, regeneration of the tree was threatened by increased pressure from land use changes (Moser, 2006). In addition to the existing natural regeneration problem, anthropogenic pressures, such as agricultural intensification and free grazing as well as weed competition reduce the regeneration potential of the tree (Goda, 2005).

The population of *F. albida* in Meskan District of Guraghe zone is dominated by higher diameter classes, while those having DBH classes below 5 cm was only 2%. Farmers in this area do not cut the whole tree, but heavily lop the branches for various purposes (Getahun Haile *et al.*, 2014). In addition to regeneration problems, absence of young *F. albida* trees as well as, uneven age stand distribution of the tree in the floodplain of Zimbabwe has also been reported to be an indication of population reduction (Gope *et al.*, 2014).

The existing stand of *F. albida* in Southeastern Ethiopia was dominated by matured trees more or less having similar age classes; however, the number of seedling found was very low. Matured *F. albida* trees were 20 ha<sup>-1</sup>; while young seedling was only from 2-4 ha<sup>-1</sup> which does not guarantee sustainability of the species in the study area (Laike, 1992). In the coming 1-2 decades, it is estimated that the tree population will diminish to one tree per ha as the result of uncontrolled management, free grazing and no tradition of replacing fallen tree. Unwise utilization and unmanaged grazing are the most common challenges reducing the population of the tree to critical level (Sida *et al.*, 2018). Predation of the seeds by Coleoptera is causative agent for virus that reduces germination and viability of the seed is another serious challenge (Abraham Yirgu and Minilik Tsega, 2015).

### **1.3. Effects of pruning on tree growth and the accompanying crop productivity**

Pruning of the branches of intercropped agroforestry trees to reduce competition of different resources such as water, nutrient and light between the two components is a common practice (Peter and Lehmann, 2000). Pruning of *F. albida* is common practice every 3-4 years from mid to late dry seasons for various purposes, such as, for fuelwood and fencing, which induces the branches to grow vigorously during the onset of the rainy season unlike unpruned *F. albida* (Depommier, 1998; Laike, 1992).

Intensive pruning of *F. albida* has been described as the main challenge that hinders regeneration potential of the tree (Sida *et al.*, 2018). The practice not only affects leaf flushing time, but also affects flowering and fruit setting stages (Depommier, 1998). It also reduces the extent of shading and the yield of the understorey crops due to high surface evapotranspiration (Bayala *et al.*, 2013). Pruning the branches

has been reported to hinder root growth and distribution; ultimately reducing below ground competition (Bayala *et al.*, 2004).

Pruning may reduce transpiration rate of *F. albida*. Frequent pruning of the entire shoot biomass reduces complementarity effect of the tree with annual crops such as microclimate improvement and mobilization of nutrient to the understorey crop (Schroth *et al.*, 2001). On the contrary, pruning the branches of the trees has been found to improve grain yield. For instance, shoot, and root pruning increased the grain yield of maize by 88, 40, 11 and 31% adjacent to *Calliandra*, *Alnus*, *Sesbania* and tree mixture systems, respectively, relative to unpruned ones (Siriri *et al.*, 2010).

The study area, Ejerssa Joro Kebele, is found in the Great Rift Valley Systems of Ethiopia, where *F. albida* is widely used as agroforestry tree. This area is known for its high temperature, high evapo-transpiration, and wind erosion which are common abiotic stress factors that exacerbate soil erosion. Intercropping compatible agroforestry trees, such as *F. albida* in association with annual crops has critical importance to the agricultural productivity of the region. However, extensive pruning of the entire branches of *F. albida* leaving the main trunk is common practice by farmers in this region for various purposes such as for fencing their backyards and agricultural fields during the planting periods. The implication of pruning the branches of the tree needs to be better understood as this might be one possible reason that the tree does not adhere strictly to completely reverse phenology particularly in the Great Rift Valley System in general and in the study area in particular.

The tree starts to defoliate during the onset of the main rain season (beginning June) and later the leaf starts to flush beginning of July and the crown become almost fully

foliate from October to March during the study period (2015 and 2016). Although different research indicated the impact *F. albida* on the understorey crop productivity and its influence on the soil nutrient; however, the effect of pruning the braches on tree water relations, leafing phenology, the cambium growth and understorey crop physiology has not been addressed so far.

### **Statement of the problem**

Intercropping perennial trees with annual crops is a common and old tradition practiced by smallholder farmers in semi-arid and arid regions of the country for immediate economic and long term ecological benefits, such as buffering extreme temperature, fighting desertification and preventing wind erosion (Sida *et al.*, 2018). A decline in vegetation cover will adversely affect all aspects of rural life in which trees and shrubs generally serve not only for household appliance and fuelwood but also as shade for crops and human shelter (Gajaseni and Gajaseni, 1999; Fujiki *et al.*, 2009; Fadl, 2010 and Pramova *et al.*, 2012). In the long term, depletion of vegetation cover aggravates ecological fragility and contributes to gradual degradation of natural resources such as, soil erosion, nutrient depletion and losses of biological diversity (Nair, 1993). Population pressure for more agricultural land, overgrazing, lack of alternative source for fuelwood and home appliance as well as fencing materials are the major causes for declining of forest cover in the country. On the other hand, information to raise farmer's awareness on the effects of intercropping compatible agroforestry trees such as *F. albida* on soil condition and microclimate modification particularly in semi-arid and arid region Ethiopia is very scarce. Today in modern agriculture, agroforestry is considered as long term biological balance between agricultural and livestock production systems. As a

result, agroforestry is getting more attention to solve the problems mentioned above and become an alternative means to combat climate change and to improve crop productivities especially in arid and semi-arid regions.

### **Justification of the study**

Farmers usually prune *F. albida* trees every 2-3 years without affecting the main trunk for various purposes, such as for fencing their backyards and agricultural fields especially during the main cropping seasons. Not only pruning *F. albida* but also cutting *Acacia tortilis* trees for charcoal production is also common activities in the study area. Although different studies have been reported on the complementarity benefit of *F. albida* with most crops, the tree water uptake has not been addressed so far. Understanding and monitoring seasonal and diurnal tree water budget is very important to characterize drought tolerance property of the tree as well as to determine the type of interaction on the resource between the accompanying crops. Data on tree water relations of *F. albida* is important for better utilization of the tree for agroforestry purpose. On the other hand the information on the impact of pruning on leafing phenology offers strong evidence on whether the tree competes with annual crops for underground resources. Ecophysiological studies of the tree as well as the influence of the tree on understorey wheat productivities, such as whether the tree-crop interaction is competitive or supplementary with the understorey crops will provide insight to what extent of pruning the branches of *F. albida* influences on cambium growth of the tree as well as understanding understorey wheat physiology will tell us the suitability of the intercropped trees.

#### **1.4. Research hypothesis**

- ✓ Pruning the branches of *F. albida* does not affect the soil nutrients status beneath the tree
- ✓ Both diurnal and seasonal tree water relation is not affected by pruning the branches of *F. albida*
- ✓ Both cambium dynamics and annual circumference growth is not affected by pruning the branches of *F. albida* tree
- ✓ Pruning the branches of *F. albida* does not improve physiological performance, aboveground biomass and grain yield of the accompanying wheat

### 1.5. Research questions

- ✓ To what extent, the soil nutrients are affected by pruning of the branches of *F. albida* tree?
- ✓ To what extent does pruning the branches of *F. albida* affect diurnal and seasonal sap volume of the tree?
- ✓ To what extent does pruning of *F. albida* affects annual circumference change and radial cambial dynamics?
- ✓ To what extent is there a synchrony in leaf defoliation of *F. albida* during the main cropping season around the study area?
- ✓ How are the physiological response, aboveground biomass and grain yield of the understorey wheat under unpruned and pruned *F. albida* tree affected at different distances from the tree trunk?

## 1.6. Objective of the study

### 1.6.1. General Objective

- To investigate the impacts of pruning *F. albida* on water relations of the tree, cambium dynamics, leafing phenology as well as understory wheat productivity and the soil physicochemical characteristics under different radial distances of the *F. albida* canopy at Ejeerssa Joro Kebele, Ethiopia.

#### 1.6.1.1. Specific objectives

- ✓ To compare the soil physicochemical property under unpruned and pruned *F. albida* trees at difference distances from the tree trunk
- ✓ To compare diurnal and seasonal tree water relations of unpruned and pruned *F. albida*
- ✓ To understand the effect of pruning on cambial dynamics and annual circumference growth of *F. albida* tree
- ✓ To understand the leaf foliation and defoliation patterns in unpruned *F. albida* in the study area and to understand whether it is synchronizing or not with the accompanying wheat
- ✓ To evaluate the wheat physiological performance, aboveground biomass and grain yield under unpruned and pruned *F. albida* tree from different distances of the tree trunk.

## CHAPTER TWO

### 2.0. LITERATURE REVIEW

#### 2.1. Agroforestry parkland

Parklands are the most known widespread agroforestry systems in semi-arid Africa; which provide various useful ecosystem services such as soil nutrient and water cycles and buffering climatic extremes (Boffa, 1999). Scattered trees common in semi-arid and sub-humid climatic regions also known as parklands are usually formed by naturally grown or propagated from seeds (Hailemariam Kassa *et al.*, 2010). Scattered trees are common in the Ethiopian agricultural landscape, most often in semi-arid and sub-humid zones of the country (Kindeya Gebrehiwot, 2004). Farmers in semi-arid region of African grow annual crops along with perennial trees for various economic incomes such as fruits, firewood, fodder and medicinal purposes. There are different uses of scattered trees in agricultural landscapes, such as for microclimate modification and, soil nutrients improvements. They become a focal points for future large-scale ecosystem restoration, which otherwise may lead to a shift to undesirable ecological regimes (Manning *et al.*, 2016). However, such functions of parkland systems come about when the parklands are properly managed (Nikiema, 2005).

Trees in agricultural landscapes are critical for conservation of soil biota and providing ecosystem services. Incorporating trees with annual crops provide a wide range of economic and ecological outcomes such as improving crop yield, biomass and soil nutrient as well as other immediate income from the tree products.

However, there are gaps in the current knowledge to implement the systems in large scale (Reed *et al.*, 2017).

Parklands differ in the tree species they contain and the management type or the difference in cultivation. Parkland could also harbor native woody trees and herbaceous species and regenerated by farmers (Eguale Tadesse *et al.*, 2019). Information related to parkland agroforestry tree species in relation to its biodiversity, tree management types and its role in biodiversity conservation has an implication on the suitability of the systems in climate change mitigation (Solomon Estifanos, 2018).

Agricultural landscapes in Great Rift Valley System of Ethiopian are dominated by scattered trees of which *F. albida* is the most dominated one along with *Acacia tortilis* and *Balanites aegyptiaca* (Tsegu Ereso, 2019). The region is characterized by low soil fertility and susceptibility to degradation through wind erosion and nutrient mining coupled with a fragile environment. There is widespread agreement that the system has to be improved through incorporation of compatible agroforestry trees for sustainable agricultural production (Sanda and Atiku, 2013).

One of the most dominant scattered trees in agricultural fields especially in the Great Rift Valley regions of Ethiopia is *F. albida* (Iiyama *et al.*, 2017). The tree is a well-known compatible agroforestry tree used by farmers in arid and semi-arid region of Africa due to its complementarity benefit to the underneath crops and soil nutrient improvements (Dangasuk *et al.*, 1999). The tree is better adapted in many part of the world, including in semi-arid and sub humid region, due to its morphological plasticity, such as having deep and lateral root system to explore water from ground water table (Roupsard *et al.*, 1999; Orwa *et al.*, 2009). The taproot of the tree

penetrates and extends to about 12.6 m during the early stage. The presences of lateral root systems reflect the flexibility of the tree to access water from the upper soil horizons during the wet season (Alexander and Ouedraogo, 1992).

*F. albida* is known for its peculiar characteristic known as “reverse phenology”. Unlike other deciduous trees, it drops its leaves during the rainy season and starts flushing towards the onset of the dry season (Barnes and Fagg, 2003). As the result, the tree does not compete with the underneath crops for water and nutrients as it enters into physiological dormancy during the main cropping season (Dangasuk *et al.*, 1999).

The inverted leafing phenology of *F. albida* makes it an important agroforestry tree due to absence of competition with understorey crops, particularly during the dry periods and it use as an alternative source of fodder (Gassama-Dia and N’Doye, 2003). The physiological mechanism for the nature of the reverse leafing phenology of the tree is not yet studied (Butenschoen *et al.*, 2011).

The tree loses much water through evaporation but survives due to having extensive tap root systems and reaches to the ground water table where it can access adequate water to replace the water lost via transpiration (Floyd, 2016). The tap root of the tree serves like a hydraulic pump of water at night, when transpiration is low it redistributing on soil surface making moisture accessible to crops (Alexandre and Ouedraogo, 1992). The lateral roots of the tree also serve as conduit for nutrients redistributing under the tree canopies (Rhoades, 1999). The moisture residual from mature trees is used to enhance effective use of water and to ease competition for the understorey crops; as the result, it is considered as drought stress avoidance options

to the intercropped shrubs, herbs and annual crops (Kizito, 2005; Schoonmaker *et al.*, 2008).

Trees in agricultural landscapes are critical for conservation of soil biota and providing ecosystems services, regardless of an intensive management, which is an obvious challenge globally in agricultural landscapes (Gibbons *et al.*, 2008). One of the advantages of intercropping deep rooted perennial trees is for making accessible water and nutrient which is far beyond the crop root zone (Richards and Caldwell, 1987). As the result, a scattered trees serves as “nurse plants” due to pronounced nursing effects in harsh environments not only for the underneath crops but also to seedling from the proximity trees where water and nutrient availability are the most critical factors (De Boever, 2015).

Trees in agricultural landscape play an important role in generating household income and providing favorable habitat for biological diversity (Yadessa Abebe *et al.*, 2009). They are also important to smallholder farming systems in Ethiopia allowing intensification through tree-crop interaction (Sida *et al.*, 2018). Intercropping compatible agroforestry trees is important for maintaining healthy agricultural landscape as well as for biodiversity conservation compared with similar agroecological conditions.

Despite the economic and ecological importance of scattered trees in agricultural landscapes, the system is threatened due to agricultural intensification and expansion as well as urbanization (Plieninger *et al.*, 2015). The pressure on agricultural demands has been increased due to increasing population and land degradation as well as expansion of urbanization (Kumar *et al.*, 2008). The most direct threats for

scattered trees are clearing by human being, soil erosion, and ecological instability; especially, in the lowland areas (Supuka and Uhrin, 2016). Currently, sustainable food production has become one of the major challenges in the twenty first century due to climate variability, land degradation and biodiversity loss (Singh and Singh, 2017).

Expansion of modern agriculture in Western Africa which demands agricultural inputs and heavy duty machines has become the main challenge that reduces the traditional systems (Barnes and Fagg, 2003). Excessive pruning of the branches and pod harvesting especially in the dry period is considered as the most challenging activities in most areas which reducing the regeneration potentials of the trees (Koech *et al.*, 2016). Ethiopia like other developing countries is vulnerable to climate change which is expected to have a far reaching effect on sustainable development. Overcoming this environmental challenge by an appropriate intervention within the country context is mandatory (Ahmed Hussien, 2011).

## **2.2. Tree-crop interaction in the agroforestry parklands**

As trees are grown in association with crops competition for limited resources mainly nutrients, water and light occur and managing this competition to optimize utilization of the resources is critical in the systems. A combination of factors, such as climate, and management types among others, determine whether a system is characterized by competition or facilitation (Krampien and Badege Bishaw, 2015). There are differences among the different components (trees, crops, and livestock) in agroforestry systems. As the result, characterization of tree species interims of these components is vital to determine the extent of tree-crop interactions (Ong *et al.*, 2007). Interaction between intercropped trees and crops for the available resources

depend on the type of species, the root architecture and water use. Those with deep root can access water from ground water table and become less competitive with the accompanying crops (Kizito *et al.*, 2005). *Acacia nilotica* had negative effect on sorghum productivity than *Prosopis juliflora* due to competition of soil moisture from the crop root zones (Jones *et al.*, 1998). Competition for water between trees and crops would arise from infertile soil in tropics where water resource is limited (Palm, 1995). The net effects of this interaction are always determined by the impacts of the tree components on the other part (s) or on the overall systems, such as resources availability as well as utilization, pest and diseases incidence and allelopathy (Rao *et al.*, 1998).

Most trees have tap root systems that extend the roots and explore and redistribute water and nutrient to the underneath crops via hydraulic lift (Weil and Mughogho, 2015). Nutrient, moisture retention, and optimum environmental condition played a vital role for 9.8% increment of sorghum grain under *Balanitis* tree canopy (Kassa *et al.*, 2010; Coulibaly *et al.*, 2014). However, the grain yield was lower close in proximity to the tree compared to far from the tree (Miyagawa *et al.*, 2017).

### **2.3. Origin and distribution of *Faidhrbia albida***

*F. albida* is one of the perennial agroforestry trees commonly found throughout the Sahel zones of West Africa, eastern and southern Africa (Boffa, 1999). The tree is native to Africa and Middle East; it is also found in the eastern, central and southern part of Africa along the riverbank on alluvial soil. It is widely distributed in semi-arid Africa mostly in agroforestry parklands (Roupsard *et al.*, 1999). The tree is also found in tropical and subtropical regions of the world such as Middle East and it has been

introduced to India, Pakistan, Nepal, Peru, Cyprus, and Cape Verde (Daldoum and Ameri, 2014).

The tree is one of the dominant trees in semi-arid tropical Africa which is affected with severe drought for long periods, receiving annual rainfall from 500-1500mm (Fagg and Barnes, 1990). However, the origin of the tree is not well understood, there are different suggestions by different scientists, for instance, it might have originated in Sahara before desertification and then distributed to East and Southern part of Africa (Barnes and Fagg, 2003). The tree is also found on seasonal and perennial rivers banks and streams on sandy alluvial soil or on flat land where vertisols is predominant (Dangasuk, 2006). It can also grow in humid areas of the Sudan-Guinean zone which is known with paddy fields where the ground water table varies from 1.5-4.5 meter in different seasons (Dupuy and Dreyfus, 1992).

*F. albida* tree can grow from 270 meter above sea level (masl) in Palestine up to 2500 masl in Jebel Marra of Sudan; however, the optimum altitudinal range of the tree ranges from low to middle (270-2700 m) with low to medium mean annual rainfall (250-1200mm) as well as mean temperature from 18 to 30°C (Wickens, 2009). The tree is also widely distributed throughout the dry zone of tropical Africa known with receiving rainfall of 500-1000 mm annually (Legesse Negash, 2010). The presence of the tree in such diverse ecological zone is due to an adaptation potential to different environmental regions, for instance the tree grow very well in Senegal where it receives annual rainfall of 400 mm for three months only (Bello *et al.*, 2015).

#### **2.4. *F. albida* regeneration status and the challenges**

Intercropping 1-20 *F. albida* trees per hectare with annual crops are common practice in Ethiopia, for instance in Hararghe highlands. In Debrezeit, *F. albida* tree are intercropped with annual crops; while, intercropping *Cordia african* with maize is common in Western Ethiopia (Melese Worku, 2017).

There is variation in WUE and carbon fixation among vegetation types mainly driven by weather condition such as annual temperature and precipitation (Xiao *et al.*, 2013). So understanding the nature of interactions between trees and annual crops in particular with physiological studies are important, as physiological processes are a key for understanding genetic potential of the trees (Kramer, 1986). Physiological indices such as WUE and gas exchange measurements of the trees are important for comparative assessment of tree species and their suitability for agroforestry purposes (Muthuri *et al.*, 2009; Zobiolo *et al.*, 2010).

Integration of *F. albida* with Maize and Sorghum maintains association of beneficial Arbuscular mycorrhizal fungi which protect the crops from *Striga* colonization that are able to reduce the grain yield causing stunted growth of the crops (Emiru Birhane *et al.*, 2016). The tree improves crop growth through the amount and quality of litter it produce as well as through its association of heterotrophic community (Reich, 2005). Leaf shedding during the rainy season becomes an opportunity as rate of decomposition becomes faster when microbial activities become higher (Dangasuk *et al.*, 1999). As the result of decomposition and subsequent mineralization of litter, *F. albida* improves the soil nutrient eventually improving crop productivity (Chuyong and Acidiri, 2017).

## 2. 5. Taxonomy of *F. albida*

*Faidherbia albida* (Del.) A. Chev.; belongs to family Leguminosae and subfamily Mimosoideae (Daldoum and Ameri, 2014). The tree is known in Ethiopia with different local names: *grar* in Amharic, *garbi* in Orominga, *garsha* in Tigringa. The tree is the only member of the genus *Faidherbia*, commonly named as ‘apple ring’ tree due to the shapes of the pods, it is also one of the largest trees reaching to the height of 30 m and known with rounded branches, the bark is rough and dark brown or smooth greenish-grey; the branches are white to ashy grey (Orwa *et al.*, 2009; Kashimwa *et al.*, 2017).

The average life span of *F. albida* extends to 70-90 years but sometimes some individual have been reported to be up to 150 years old tree as found in Zambia (Tchapda *et al.*, 2017). The leaves of *F. albida* are green to grey consists with 3.0-7.5 cm long and 2-8 cm wide and consisting of 2-12 pairs of pinnate ranges from 2.5 to 5.5 cm, the leaflet consists of 6 to 23 leaves; thorns are thickened from the base, up to 3 cm long which develops in pairs at the base of the leaves (Moser, 2006). The long spiked flowers, fruits which are twisted, glabrous and shiny, the fruits are soft and fleshy while it is green, twisted in shape containing 10-30 dark, shiny and brown seeds (Fadipe *et al.*, 2015).



*Photo plates 1.3.1 F. albida leaves and thorn (a) flowers (b) and pods (c)* (photo taken labeled in “a” and “c” was taken in Novemer 2018 by

Awol A., while, “b” was taken from: (<https://www.google.com/search?q=Faidherbia+albida+flower>).

There are two distinct ecotypes, Ecotype “A” which is adapted where ground water table is deeper and there is severe drought, is the most common in the Western African Plateau and Ecotype “B” of Eastern and Southern Africa which requires riparian environment (Weil and Mughogho, 2015). In contrast to the report by Weil and Mughogho (2015), the type of *F. albida* tree found in Ethiopia particularly in Great Rift Valley systems belongs to Ecotype “A”, perhaps the region is known with frequent drought and the ground water table is found from 35-55 meter below the surface. However, there are also riparian *F. albida* trees along the Awash River in Ethiopia.

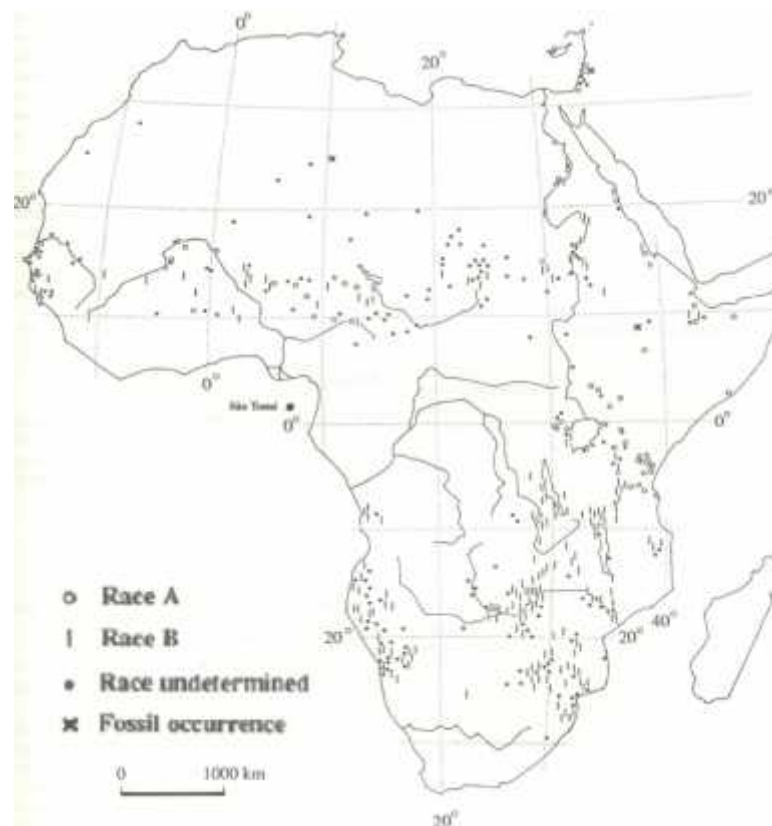


Figure 2.1 Distribution of *F. albida* from West to East and down to Southern part of Africa (Boffa, 1999)

The tree was previously included in the genus *Acacia albida*. Following different research, it was found that, the tree possesses unusual characteristics which are different from other *Acacia* species. Later following immunological studies and cladistic analysis, the taxon was removed from *Acacia* and the tree named *F. albida* (Bello *et al.*, 2015). Phytochemical characteristics and the presence of eglandular petioles and anthers as well as connate filaments at the base, were basic for categorizing it to the monotypic genus (Dunham, 1991).

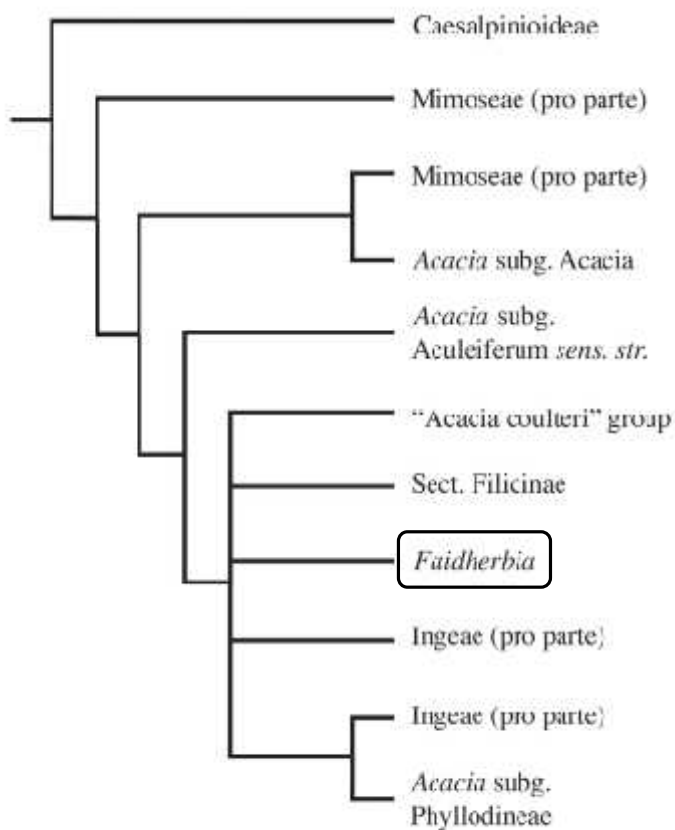


Figure 2.2 Simplified cladogram based on chloroplast DNA sequence data (Source: Maslin, 2003).

## **2.6. Ecological importance of *F. albida***

Agriculture in the 21<sup>st</sup> century is faced with a dilemma. There is a need to increase the global food supply. However, declining soil nutrient and water availability from adverse effect of climate change has become a serious challenge. Nevertheless, the challenges offer opportunities to promote food security through integration of compatible agroforestry trees to combat harsh environments (Tubiello *et al.*, 2008). There are a number of interests in ecosystems services from the forests and trees. However, detail understanding on the contribution of trees for food production and livelihood is limited (Reed *et al.*, 2017). Integration of agroforestry provides a number of direct incomes such as wood energy which is important to reduce human impact on natural forest, improving soil fertility, providing ecosystem services and optimizing local climate condition (Mbow *et al.*, 2014).

Integration of compatible perennial trees can reduce land degradation, mitigate climate change improve food security (Luedeling *et al.*, 2016). Scattered trees especially in the semi-arid climate provide many ecological benefits to the understorey crops. However, shading from large and evergreen trees negatively affects yield through competition for both aboveground and below resources (Rao *et al.*, 1998). Fast growing trees, especially exotic tree species, are becoming a huge concern in many tropical countries, so special consideration has to be given to long term water budget because the trees may interact negatively with annual crops.

Incorporation of perennial trees is considered an alternative means to improve food security and reduce land degradation (Luedeling *et al.*, 2016). Agroforestry plays a significant role in conservation of biodiversity such as different fauna and flora which

are involved in different ecosystem services (Jose, 2009). Intercropping of agroforestry trees with annual crops is an alternative and sustainable means to enhance biodiversity (Sanchez, 1995).

From the beginning of agriculture, many farmers intentionally planted or left trees as part of their agricultural landscape for shelter, food and fodder; however, despite the contribution of trees in tropical farming systems, the knowledge related to the use on the farm and the landscape has been consolidated recently into a science of agroforestry but still much remain unknown about the relationship between the different components (McNeely *et al.*, 2006). Mature trees on agricultural landscapes becoming a shelter for soil biota as well as important in ecosystems services. However, the density of trees decline from time to time due to an extensive use of the land for agricultural purpose reducing the rate of regeneration (Gibbons *et al.*, 2008).

According to the most predicting models, global warming will affect arid land through the rise in temperature and decreasing the rainfall intensity, leading to severe scarcity of water and rise in the desertification risk (Malagnoux, 2007). *F. albida* parklands provide microclimate for soil moisture retention by optimizing air temperature and the PAR levels particularly during the mid-day which is important to improve water use efficiency to the understorey crops (Jones *et al.*, 1997; Ong and Swallow, 2003; Sida *et al.*, 2018). The crown of the tree is used to enhances percolation rate and recharging ground water table (Ilstedt *et al.*, 2016). For instance, in the open grazing and cultivated land, infiltration rate was very low due to high runoff and limited percolation rate which causes low soil moisture retention up to 29% compared with controlled area (Abdu Abdulkadir and Fentaw Yimer, 2011).

In addition to ecosystems services of *F. albida* such as carbon sequestration, soil nutrient enrichment and biodiversity conservation, the tree can also play an important role of recharging ground water table by enhancing percolation rate (Negri, 2018). *F. albida* is known for providing different ecological benefits such as carbon dioxide sequestration and improving soil fertility in the changing climate (Noulekoun *et al.*, 2016).

The potential of *F. albida* in conservation of biodiversity has attracted wider attention among agroforestry and conservation scientists. Biological activity has been found to be five times higher under the tree canopy than in the open area during the cropping periods. However, the potential contribution of agroforestry in conservation is limited as insufficient areas are used (McNeely *et al.*, 2006).

In general agroforestry bundle high biodiversity conservation such as it becomes a refuge for birds and insects which are important in reduction of agricultural pest as compared to annual and perennial crop systems do; however, there are gaps with regard to domestication and promotion of the systems (Swallow and Boffa, 2006).

*F. albida* is taken as one of the most important species due to its positive role to improve smallholder agriculture in developing countries by recovering the degraded lands (Barnes and Fagg, 2003). The tree significantly improves the soil nutrient with different magnitude under the tree canopy compared with the neighborhood and the control plot (Diallo *et al.*, 2019). The tree is known for its atmospheric nitrogen fixation as well as for capturing nutrient which is not accessible to understorey crops (Sanda and Atiku, 2013).

*F. albida* contribute 4-6 times more nitrogen and 6-10 times more phosphorous incorporated from aboveground litterfall to the understory crops than root turnover and dieback, but the soil pH is slightly acidic (Dunham, 1991; Palm, 1995). However, litter nutrient release depends on time of leaf phenophase, litter types and decomposition rate (Rhoades, 1999).

Higher organic carbon content of soil contributes to improved water retention of up to 10-20% compared with low organic content. Organic matter improves both soil texture and water adsorption properties (Rawls *et al.*, 2003). Uses of agroforestry trees with high organic matter (both aboveground and belowground) are one of the strategies in climate change mitigation (Lorenz and Lal, 2014).

In spite of all economic and ecological importance of the tree, some disagreement with the number of recommended trees existing per hectare, in most of the cases the recommended trees per hectare ranges from 12-100; but this may consider the age and the size of the trees. For instance in Malawi, the number of *F. albida* tree per ha ranges from 20-25 with canopy diameter of 8-12 m and 0.5-1.3 m DBH. On the other hand, in few localized area of Eastern and Southern Africa, the numbers of trees observed were 6 to 10 matured trees per hectare (Weil and Mughogho, 2015).

## **2.7. Economic importance and ethnobotany of *F. albida***

*F. albida* agroforestry farming systems is spread in the semi-arid and sub-humid Africa and it is the most sustainable practice known with a potential in contributing significant role for both ecological and economic benefits (Mieche, 1986). The system can potentially provide options to improve livelihoods through simultaneous production of food, fodder and firewood (Vikas, 2016). There are numerous economic

benefits of intercropped *F. albida* tree, for instance farmers in West African countries are known by using for fodders for livestock during the dry seasons, firewood as well as medicinal purpose (Pramova *et al.*, 2012). The tree has a number of economic benefits such as beekeeping, medicine, timber production, fencing, fuelwood and fodder (Barnes and Fagg, 2003). It provides a range of products such as fruit, fertilizer, nuts, resins etc (Gajaseni and Gajaseni, 1999; Fadl, 2010). The tree can also be used to make various crafts items (Umar *et al.*, 2010).

The seed of *F. albida* is used for human consumption, flowers can supply honey bees with nectar, the bark is used for traditional medicines and the wood is used for fencing and crafts (Orwa *et al.*, 2009; Mokgolodi *et al.*, 2011). Dry fruit of *F. albida* can be stored and become an alternative source of fodder during the early period when the grass is completely unavailable and when the land is ready for planting (Hirai, 2017). For instance, large *F. albida* trees can produce about 175kg of pods per tree which is equivalent to earning 600 USD per year from the pod sale (Moser, 2006). The seed contain crude protein 20.6% and 40.1% carbohydrate making it important as a fodder (Mokgolodi *et al.*, 2011).

The leaves and pods of *F. albida* become a source of complementary sources such as protein, minerals and vitamins during the dry period (Umar *et al.*, 2010). The bark of *F. albida* is known to be most efficient and cost effective for the removal of chromium; Cr (VI) up to 97% when the pH was set to the optimum range i.e., pH 2 (Gebremedhin Gebrehawaria *et al.*, 2015). Ethyl acetate fraction *F. albida* showed remarkable effects on blood glucose level and reduced weight loss in diabetes (Kashimawo *et al.*, 2017). Traditionally, the tree is used to cure diseases such as

diarrhea, leprosy, pneumonia, cough and easy delivery during child birth (Orwa *et al.*, 2009). Bark or roots of the *F. albida* alone or a mixture of both is used for traditional medicine preparation for external or internal usage. It is also recommended against respiratory infections, sterility, digestive problems, dysentery, backache, malaria, fever, heart and circulatory problems and dental infections (Fagg and Barnes, 1990).

*F. albida* has numerous ecological and economic importance. Different report have shown that soil nutrients found under *F. albida* tree is higher as the result of which crop productivity beneath the tree canopy is found to be higher compared with the crop without trees. The study area is found in Great Rift Valley Systems where *F. albida* agroforestry parkland is predominant. The tree is known with peculiar reverse leafing phenology as the result, interaction for resources such as light and moisture between the tree and the accompanying crops is minimum. However, the effect of pruning of *F. albida* on tree water relations, leaf foliation/defoliation patter of the tree as well as its influences on the understorey wheat physiology has to be understood.

## CHAPTER THREE

### 3.0. MATERIALS AND METHODS

#### 3.1. Description of the study area

The experimental site is located in Ejerssa Joro Kebele, 83 Km South-East of Addis Ababa situated in the Great Rift Valley Systems located at 8°30'29.56"N 39°04'21.77"E at an elevation of 1690 masl. The study area is known with unimodal rainfall pattern. The average annual rainfall is between 800-1000 mm, mainly from July to September, sporadic rain sometimes happening between March and June.

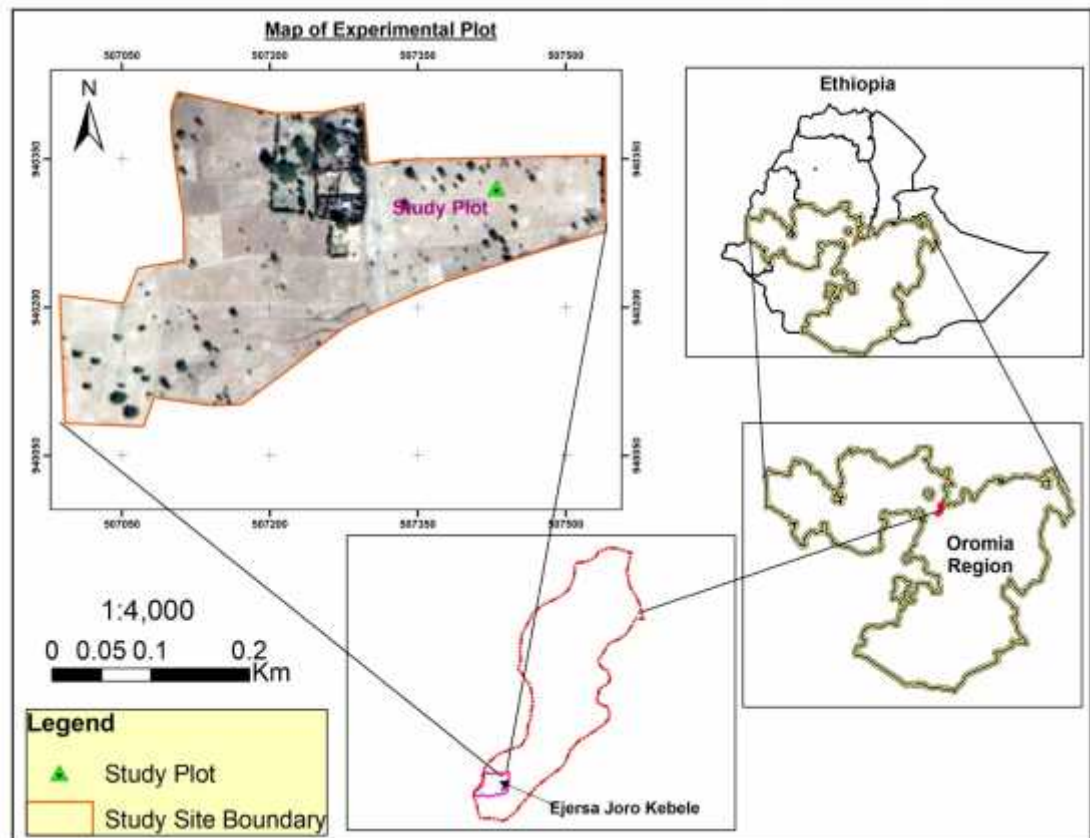


Figure 3.1 Map of the study area

The region experiences erratic rainfall, frequent drought, and a harsh environment for cropping. The daily mean temperature ranges from 18 to 24°C (Mengistu, 2009). The experimental site contains scattered trees such as *F. albida*, *Acacia tortilis* and *Balanitis aegyptica*.

### **3.2. Tree selection**

Since the study intended to compare unpruned and pruned *F. albida* trees under several parameters, the experimental plots were established under ten unpruned and pruned trees, from three directions (1, 3 and 5 m) from the boles of the trees and from three directions for *F. albida*-wheat interaction and leafing phenology study, of which three unpruned and three pruned trees were used for sap flow experiments, leaf water potential, cambium growth of *F. albida* and for soil moisture measurements. Special attention was given while selecting unpruned trees for this experiment. The study trees were selected considering the size of canopy area, DBH and having reasonable distance between the trees. Farmers heavily prune (up to 100%), i.e. complete removal of the branches from the trees without affecting the trunk. As the aim was understanding tree-crop interactions under both pruned and unpruned *Faidherbia albida*-wheat systems, comparable sizes and age classes (20-25 years) were selected following the discussions with land owners.

### **3.3. Tree management and plot establishment**

To select the trees, some criteria were used such as considering enough distances between the trees which was important to avoid overlapping of the tree crowns and for ease of comparing tree-crop interactions under (1 and 3m) and outside (5m) distance from each of the experimental trees. Wheat growth measurement such as shoot height and tiller number, aboveground biomass and grain yield were measured under 10 unpruned and pruned trees from three directions and three distances under and outside from the tree trunk.

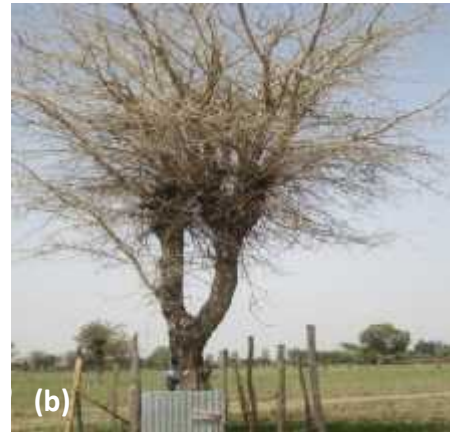
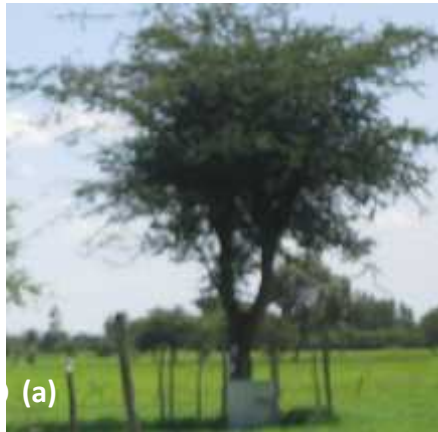


Photo 3.3.1 unpruned *F. albida* in August (a) and in June (b) in 2016 in Ejerssa Joro Kebele Ethiopia.

The crown diameter of unpruned trees was measured from four directions and the mean was recorded. The circumference of the trees was measured from three directions using a tape at DBH ca 1.3 m from the ground, and the mean value was recorded.



Photo 3.3.2 Pruned *F. albida* in August (c) and in May (d) in 2015 in Mojo Ethiopia

### 3.4. Environmental data of the study area

Thermohygrometer and rain guage were installed to measure temperature, relative humidity and rainfall, respectively of the study area from June 2015-June 2016. Temperature and relative humidity were recorded every day and the rainfall data was

measured using measuring cylinder after every rain. The land was ploughed twice using oxen drawn plough; between April and June before sowing the crops. *Fabel* (type of wheat variety) was sown on 7<sup>th</sup> of July, 2015 and 2016 using overdressing method and most of the seeds emerged in one week time.

### **3.5. Soil moisture measurement**

Soil moisture was measured using Profile Probe type PR1/6 together (Delta-T Devices Ltd, Cambridge, UK). This instrument provides moisture measurements at various depths within the soil profile (10-100 cm). The profile probe together with the HH2 moisture meter (Delta-T Devices Ltd, Cambridge, UK) was used to measure the soil moisture from different soil depths. ATL1 fibre glass access tubes, 1154 mm in length and 28 mm in diameter, were installed in augured holes at 1m distance (under the tree canopy) and another access tube was installed outside the tree crown (6 m) in the same direction under unpruned and pruned *F. albida* trees. A total of twelve access tubes were installed at 1 m and 6 m distances from the bole of the tree and covered with the plastic caps to protect from rain, dust and debris entering in the access tubes. Volumetric water contents were simultaneously determined from six depths classes i.e. 10, 20, 30, 40, 60 and 100 cm to provide moisture contents expressed in units of  $\text{m}^3 \text{m}^{-3}$  (i.e.  $\text{m}^3$  of water per  $\text{m}^{-3}$  of soil) or percentage soil moisture content. Measurements were made in the first week of every month beginning from 10:00 am local time. The data were recorded directly from the display of the HH2 meter.

### **3.6. Photosynthetically Active Radiation (PAR)**

Photosynthetically Active Radiation (PAR) were measured using ceptometer. Ambient PAR levels was measured using (Ceptometer, Accupar Ceptometer LP-80, Australia)

both under unpruned and pruned *F. albida* at 1, 3 and 5m distances from the bole of the tree; whereas, different levels of internal light sources (2000, 1500, 1000, 500, 100, and  $0\mu\text{molm}^{-2}\text{S}^{-1}$ ) were set to measure physiological responses of the wheat under and outside of unpruned and pruned trees.

### 3.7. Experimental set-up

The experimental design for wheat growth, physiological and biomass measurement aboveground biomass and grain yield measurement was adopted from Huxley (1985).

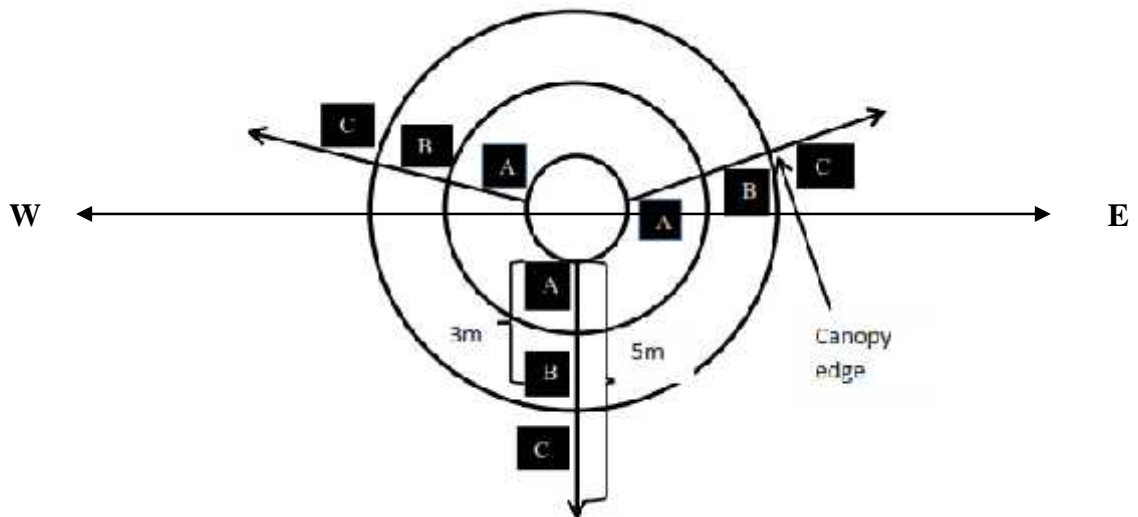


Figure 3.7 Experimental set-up ('Y' frame sampling transect)

Experimental plots were established (split plot design) under ten unpruned and ten pruned trees from three distances (1, 3 and 5m) from the bole of the tree and from three directions of which three of unpruned and three pruned trees were used for sap flow experiments, leaf water potential measurement, cambial growth of *F. albida* and soil moisture measurements.

### **3.8. Soil physical analysis**

#### **3.8.1. Soil texture analysis**

Soil samples were collected up to the depth of 30cm from each sub-plot from different distances and directions under unpruned and pruned *F. albida* trees. The soil samples were mixed thoroughly and air dried. Soil texture analysis was conducted following Juo (1978). Five percent of dispersing agent was prepared from sodium hexametaphosphate. Fifty gram of sodium hexametaphosphate was diluted in 50 mL beaker using distilled water and mixed very well and the solution was transferred into the measuring cylinder and finally labeled to the volume (1L) with distilled water. Fifty gram of air dried soil passed with 2mm sieve was weighed using digital balance (Adam Equipment Co. Ltd. Bond Avenue Milton, UK) and placed in 50 mL beaker, 100 mL of the dispersing agent (5% of sodium hexametaphosphate) was added and stirred for 4-8 minutes until the aggregated soil were deflocculated. The solutions were stirred for 15 minutes using mechanical stirrer, and then, the solution was transferred from the beaker into the measuring cylinder; all the remaining particles in the beaker were transferred by washing the beaker and labeled to the mark using distilled water. By placing the stopper of the measuring cylinder, the solution was vigorously shaken back and forth 40 times.

The solutions were placed in the stable bench and Amyl alcohol was added to remove the foams created while shaking the mixture. Hydrometer was inserted carefully and the first relative density of the solution was recorded in 40 seconds followed by measuring the temperature of the solution using thermometer. The solution was kept until the second measurement was taken. Finally the second hydrometer and temperature readings were taken after 3 hours.

The soil texture classes were classified using the following formula and soil type was categorized from the soil triangle.

$$\% \text{ Sand} = 100 - [H1 + 0.2 (T1 - 68) - 2]^2$$

$$\% \text{ Clay} = [H2 + 0.2 (T2 - 68) - 2]^2$$

$$\% \text{ Silt} = 100 - (\% \text{ sand} + \% \text{ Clay})$$

*Where H1 is the first hydrometer reading after 40sec; T1 is the first temperature reading after 40 seconds while 0.2 was added since the temperature of the solution was above 20°C and 0.2 was subtracted for the addition of sodium hexametaphosphate.*

### **3.8.2. Soil chemical analysis**

#### **3.8.2.1. Soil pH**

Soil samples were air dried and sieved with 2mm mesh size. Soil pH was measured in 1:2 (W/V) following Juo (1978). The pH meter was calibrated using pH 4 and pH 7 buffer solutions prior to measurement of the solutions. Twenty gram of the air dried soil transferred into 100 mL beaker and 40 mL distilled water was added and stirred well using glass rod. The solution was allowed to stand for 30 minutes with intermittent stirring. The pH electrode was immersed in the soil-water suspension in the beaker; finally the pH of the soil was measured using pH meter (Hanna instruments, HI 9024 micrometer, Portugal).

#### **3.8.2.2. Total nitrogen**

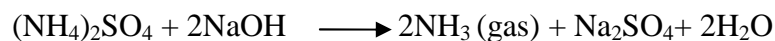
Soil total nitrogen was analyzed following the Macrokjeldhal method described by Van Schouwenberg and Walinge (1973). This method, three successive steps: Digestion of the soil samples was conducted using the digestion block (Thubotherm, Kjeldhal digestion block, Konigswinter, Germany) using H<sub>2</sub>SO<sub>4</sub> (97%), 30% H<sub>2</sub>O<sub>2</sub>

(30%), Potassium sulphate (K<sub>2</sub>SO<sub>4</sub>), cupric sulfate (CuSO<sub>4</sub>.5H<sub>2</sub>O) and selenium powder were added in the ratio of 10:1:0.1 (w/w), respectively. Air dried soil samples, passed with 0.5 mm size sieve, was weighed (0.3 g) and transferred into the Kjeldhal test tubes (250 mL). Two gram of the catalyst mixture, 7 mL of H<sub>2</sub>SO<sub>4</sub> and 3 mL of H<sub>3</sub>BO<sub>3</sub> were added in 250 mL of Kjeldhal test tube. The sample was digested in four successive steps, 100, 75, 60 and 50, which is equivalent to 1500, 1125, 900 and 750 watt, respectively.

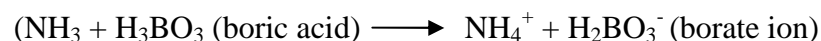
Hydrogen peroxide is used to accelerate decomposition of organic matter and also used as antifoaming when digestion is in progress; whereas, potassium sulphate is used to raise the temperature and cupric sulfate and selenium powder are used to hasten the reaction. Digestion of the soil using concentrated sulfuric acid and the catalyst converts any form of nitrogen found in the soil to ammonium ion (NH<sub>4</sub><sup>+</sup>) and other byproducts such as carbon dioxide and water. Ammonium ion (NH<sub>4</sub><sup>+</sup>) binds with sulfate ion (SO<sub>4</sub><sup>-</sup>) and remains in the solutions as ammonium sulfate.



*Distillation* was conducted using distillation unit (vapodest Kjeldhal distillation unit, Konigswinter, Germany) using 40% NaOH and the distilled samples were received using 2% H<sub>3</sub>BO<sub>3</sub>.



The third step was *titration* using digital dispensing pipette filled with 0.1N H<sub>2</sub>SO<sub>4</sub> until the color changes from light green to pale or violate color.



Total nitrogen percentage was calculated using the following formula:-

$$\% N = [(a-b) * N * 0.014 * mcf * 100] / S \dots\dots\dots (1)$$

Where a = titrant volume of 0.1N H<sub>2</sub>SO<sub>4</sub> for the sample; b = titrant volume for 0.1N H<sub>2</sub>SO<sub>4</sub> for the blank; N = normality (0.1) of H<sub>2</sub>SO<sub>4</sub>, prepared for titration; S= Dry weight of sample; 0.014=molecular equivalent of nitrogen; mcf = moisture correction factor of the sample

### 3.8.2.3. Soil organic carbon

Soil organic carbon was determined following Walkley and Black (1934), using potassium dichromate and concentrated sulfuric acid as an oxidizing agent. One gram of soil that passed with 0.5mm size sieve was transferred to 500 mL Erlenmeyer flask with two blanks; 10 mL of 1.0N K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> and 20 mL concentrated H<sub>2</sub>SO<sub>4</sub> were added both to the sample and the blank in the fume cupboard and swirled for a while and allowed to stand for 30 minutes, then 100 mL distilled water was added and allowed to stand and to cool. Finally 10 mL concentrated orthophosphoric acid and 0.5 mL barium diphenylamine sulphonate indicator were added, respectively before titration. Both the sample and the blank was titrated using 0.5N ferrous sulfate solution until the color changes to purple or blue and the indicator was added drop by drop until the color flashes to light green.

Percentage of organic carbon was calculated using the following formula.

$$\% C = [N * (V1 - V2) * 0.39 * mcf] / S \dots\dots\dots (2)$$

Where: N=normality (0.5) of ferrous sulfate solution (V1=volume 0.5N ferrous sulfate solution used to titrate the blank, V2= volume 0.5N ferrous sulfate solution used to titrate the sample, S= weight of air dry sample in gram, 0.39 is equivalent weight of carbon, mcf is moisture correction factor (the difference between air dried and oven dried of the soil after the soil is dried in the drying oven at 105°C for 24hrs).

#### 3.8.2.4. Available phosphorous

Ammonium fluoride ( $\text{NH}_4\text{F}$ ) (1N) was prepared from 37g of ammonium fluoride which was diluted into one liter volumetric flask using distilled water and labeled to the mark using distilled water and transferred into polyethylene bottle. Hydrochloric acid (0.5N) was prepared from 20.2 mL concentrated HCl in 500 mL with distilled water under fume board. Extracting solution was prepared from 15 mL of 1.0N ammonium fluoride and 25 mL of 0.5N HCl into 460 mL distilled water. Stannous Chloride ( $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ ) was prepared as color contracts, 15g  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  in 25 mL of concentrated HCl and stored in dark polyethylene bottle and kept in refrigerator. Ammonium Molybdate ( $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$ ) was prepared from 15g of ammonium Molybdate in 350 mL 10N HCl in one liter volumetric flask and cooled at room temperature, the mixture diluted using distilled water and labeled to the mark using distilled water.

The last step was to dilute the Stannous Chloride: 1mL of  $\text{SnCl}_2$  stock solution was transferred with 333 mL distilled water. One gram of air dried soil sample was passed with 2mm size sieve and transferred into 15 mL centrifuge tube and 7 mL of extraction solution was added. The mixture was shaken for one minute followed by a mechanical shaker and the suspension was centrifuged at 2000 rpm for 15 minutes. After 15 minute 2 mL of the clear supernatant was transferred into 20 mL test tubes. Five milliliter of distilled water and 2 mL of Ammonium Molybdate solution was added. The mixture was thoroughly shaken and 1mL of  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  was added to create the contrast and mixed again. After 5 minutes absorbance of the solution was measured using spectrophotometer (Jenway 6300 spectrophotometer, UK) at 660 nm wavelengths.

Phosphorous standard solution (2.5mg/L) was prepared from dihydrogen orthophosphate ( $\text{KH}_2\text{PO}_4$ ), a total of 0.2195g dihydrogen orthophosphate was weighed using analytical balance (Denver instruments, XE-50, Colorado, USA) and transferred to one liter volumetric flasks containing distilled water and labeled to the volume. In the meantime series of phosphorous standard solution was prepared (1ppm, 2ppm, 3ppm, 4ppm and 5ppm) from the stock solution. Absorbance of the standard solution was measured using the same spectrophotometer mentioned above.

#### **3.8.2.5. Exchangeable sodium**

Sodium was extracted from air dried soil samples after the soil was soaked in neutral ammonium acetate (pH 7) which is efficient and effective to displace sodium ions ( $\text{Na}^+$ ). Neutral ammonium acetate solutions (1N) was prepared from 570 mL of glacial acetic acid (99.5%) mixed with deionized water to the volume of 5 L, then 690 mL of concentrated ammonium hydroxide ( $\text{NH}_4\text{OH}$ ) and deionized water was added up to 9.9 L, the pH of the solution was checked and  $\text{NH}_4\text{OH}$  was added drop by drop to make the solution neutral (pH 7) and labeled to 10 L mark. Soil passed with 2 mm mesh size was transferred into 50 mL conical flask and 200 mL of 1N neutral ammonium acetate solution and allowed for 18 hours by string occasionally. Part of suspension was transferred and 20 mL of 1N ammonium acetate was added and placed to the rotary shaker for 2 hours.

After the sample was shaken and centrifuged for 10 minutes at 6000 rpm and the supernatant was filtered using filter paper whatman No.1 (11 $\mu\text{m}$ ). Five milliliter of the suspension was transferred into 50 mL volumetric flask and diluted to the mark using 1M ammonium acetate solution.

Standard solution was prepared from sodium chloride prior to sodium ion analysis from the soil sample, whereas; the stock solution containing of 5ppm of sodium chloride was prepared in 1N ammonium acetate solution. A series of standard solutions (1ppm, 2ppm, 3ppm, 4ppm and 5ppm) were prepared from stock solution by adding 4 ml, 3 ml, 2 mL and 1mL of 1N ammonium acetate solution and the blank contain 1N ammonium acetate solution. The samples were aspirated and finally the concentration of sodium was determined using flame photometer (Flamephotometer, CL 378. India).

#### **3.8.2.6. Exchangeable potassium**

Exchangeable potassium was determined after the soil was extracted using 1N ammonium acetate solution and concentration of potassium ion was determined using flame photometer (Flamephotometer, CL 378. India). Extracting solution was prepared from ammonium acetate solution prepared from concentrated acetic acid and concentrated ammonium hydroxide solution, 57 mL of concentrated acetic acid ( $\text{CH}_3\text{COOH}$ ) was added into 800 mL distilled water and 68 mL of concentrated ammonium hydroxide ( $\text{NH}_4\text{OH}$ ) solution. The mixture was kept for some time until it cools. The mixture was adjusted to pH 7 by adding  $\text{CH}_3\text{COOH}$  and  $\text{NH}_4\text{OH}$ , finally the solution was labeled to the mark using distilled water.

The standard solution was prepared from KCl dried in the oven at  $105^\circ\text{C}$  for 2 hours and cooled in a desiccator and 1.907 g KCl was dissolved in 500 mL deionized water and labeled to 1 L using distilled water. The stock solution contains 1000 ppm of potassium ion ( $\text{K}^+$ ). The standard solution was prepared from the stock solution as follows 2, 4, 6, 8, 15 and 20 mL stock solution was poured and 98, 96, 94, 85 and 80 mL of 1N ammonium acetate solution was added, respectively. After, the standard

curve was prepared from KCl and aspirated in the flamephotometer. Five gram of the soil was transferred in 250 mL of conical flask and 25 mL neutral ammonium acetate and shake for 5 minute on the orbital shaker, after 5 minute the solution was filtered using a Watman No.1; subsequently, the samples were aspirated and  $K^+$  concentration was determined from the screen of plamephotometer.

### **3.9. Water relations of *F. albida***

#### **3.9.1. Sap flow rate and sap volume of *F. albida***

Sap flow measurement was recorded from January 2015 to July 2016, using Heat Ratio Method (HRM). The principle of HRM working in measuring the sap flow in xylem tissue is using a short pulse as a heat tracer; the ratio of the heat passed in the two symmetrically placed thermocouples sensors and the amount of sap flow and the direction can be calculated. Before sap flow sensors are installed in the sap wood area of the tree, the following procedures were considered:

- The dead bark was removed gently using scalpel from the tree where the thermocouple sensors were installed.
- The bark depth was determined using the micro-core
- The sap wood area was determined using increment borer and methyl orange dye was used as an indicator to estimate the sap wood area.
- The drill guide was tied at DBH (1.3m) from the ground for proper configuration the sensors in the sap wood part of the tree and to maintain the proper alignment of the heat ration sensors.
- The tree was drilled using appropriate drilling pins by applying gentle pressure first from the top side followed by the middle and followed by the lower sensor (there was 0.5cm distance between each sensors)

- After drilling the wood, the SM1 copper-constant thermocouples sensors, (ICT International Pvt. Ltd, Australia) were greased to minimize the friction between the thermocouple sensors and the hole in the sap wood.

The lower sensors was used to detect the upward movement of sap and the middle one was used to generate heat powered by the internal battery which is recharged from the solar panel and the third and the upper one was used to detect the downward movement of the sap or reverses flow. The thermocouple sensors were designed to evaluate the spatial variability of the sap flux across the sap wood area, the inner sensor was 2.25cm and the outer one was 0.75cm.

Thermal diffusivity was calculated following Roupsard (1999); after the cylindrical wood sample was excavated using the increment corer (50cm long and 80mm diameter) from both unpruned and pruned trees. The cylindrical woods were cored from each tree where the sap flow gauges were installed; it was kept in zip locked polyethylene bags and covered using aluminum foil to protect evapotranspiration. Fresh weight was determined using analytical balance (Denver instruments, Colorado, USA). Subsequently it was dried in the oven (Heraew, GMBH, Hanau, Germany) at 70°C until constant weight was maintained. Finally dry weight was measured using the same balance and the sap content was calculated (Fresh weight-dry weight of the core samples). The volume of the cylindrical wood cores were determined using the cylinder formula ( $V= r^2h$ ).

The Sap Flow Tool (SFT) (ICT International, Australia) was used to convert heat pulse velocity to sap velocity. The sensors record the data every 10 minutes and the

data was averaged every 30 minutes. In order to calculate the sap flow rate and sap volume using sap flow tool software (version 1.4.1.).

Heat pulse velocity,  $V_h$  ( $\text{cm hr}^{-1}$ ) is logarithmically related to the ratio of temperature increases from both upward and downstream of the heater sensors

$$V_s = \frac{k}{x} \ln \left( \frac{v_1}{v_2} \right) \times 3600 \dots \dots \dots (3)$$

Where  $k$  is the thermal diffusivity of fresh wood weight,  $x$  is the sensor distance between the sensors from the heater probe and  $v_1$  and  $v_2$  are the increase in temperature of the upstream and downstream sensors, respectively.

The Sap Flow Tool (SFT) (ICT, International, Australia) was used to convert heat pulse velocity to sap velocity.

$$V_s = \frac{k}{x} \ln \frac{(v) \rho_b (c_w + m_c C_s)}{\rho_s C_s} v_h \dots \dots \dots (4)$$

Where  $V_s$  is the sap velocity ( $\text{cm hr}^{-1}$ ).  $k$  is the thermal diffusivity ( $\text{cm}^2 \text{s}^{-1}$ ) of the sap wood, 0.00025 the reference thermal diffusivity ( $\text{cm}^2 \text{s}^{-1}$ ),  $B$  the wound correction factor,  $\rho_b$  the density of wood ( $\text{Kg m}^{-3}$ ),  $c_w$ , the specific heat capacity of wood matrix ( $1200 \text{Kg}^{-1} \text{C}^{-1}$ ),  $C_s$ , the specific heat capacity of sap (water only,  $4182 \text{Kg}^{-1} \text{C}^{-1}$ ),  $\rho_s$ , the density of water ( $1000 \text{Kg m}^{-3}$ ),  $M_c$ , then water content of the sapwood ( $\text{Kg Kg}^{-1}$ ) and  $V_h$  the heat pulse velocity ( $\text{cm hr}^{-1}$ ) at a given position.

To convert sap velocity to sap volume first the sap velocity was multiplied by the cross sectional area of the sap wood for the sap flow sensors located (2cm for outer and 1.5cm for the inner cm) so that SFT produce the sap flow rate for each sensors in each measurement time in  $\text{cm}^3 \text{hr}^{-1}$ , and finally sap flow rate was converted to sap volume ( $\text{L h}^{-1}$ ).

$$\text{Sap volume} = \frac{F_i}{1000} \frac{A}{100} \dots \dots \dots (5)$$

Where  $F_i$  is the sap flow rate at time  $i$  ( $\text{cm}^3 \text{ hr}^{-1}$ ) and  $A$  is then cross sectional area of the tree trunk where the sensors were installed.

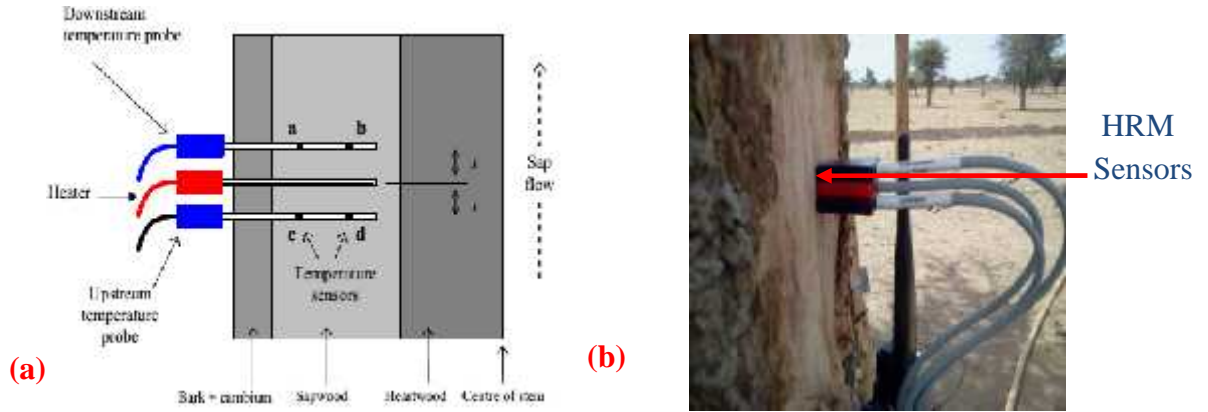


Figure. 3.9.1a. Sap flow sensors located in the outer and inner side of sap wood area of the tree the middle (red) one is heated probe and Photo 3.7.1b installed sap flow gauges in *F. albida* in Ejerssa Joro Ethiopia.

### 3.9.2. Stem water potential

Predawn and midday leaf water potential ( $\psi_w$ ) of the twigs were measured using pressure chamber (Skype Moisture Equipment Corp., Santa Barbara, CA, USA). Six twigs were collected from six unpruned and pruned trees from three directions at equidistant of the tree crown. Midday (12:00-1:00PM) leaf water potential was measured when sap flow was expected to be maximum and predawn (4:30-11:30AM) when sap flow was expected to be low. The twigs were cut using sharp cutter and collected in a zip locked polyethylene bags and kept wrapped using aluminum foil to prevent evapotranspiration until measurement was conducted. Leaf water potential

experiment was conducted during the main cropping season (September 15, 2015 and 2016).

The following preconditions were considered during leaf water potential measurements:

- For both predawn and mid-day stem leaf water potential measurement, the twigs were collected from similar position to avoid biases arising from the spatial difference within the tree crown.
- Twigs were attached to the pressure chamber using appropriate rubber sealing to minimize the leakage finally paste was used to seal the space between the space of the rubber sealing and the twigs.
- Metal rubber was used to seal the chamber where the twigs were kept in the vessel and lower stem washer was properly kept in place
- After the chamber was connected to the cylinder via the chord, the chamber was turned on and the number displayed on the screen was adjusted to zero before filling the chamber.
- The fill button on the pressure chamber was located to the fill position to let in the gas in the chamber from the cylinder. Depending on the water status of the plant, the pressure scale should be turned either 0-20 or 0-200 bars.
- Once the sap was ooze out on the cut surface of the twigs, the hold button was pressed immediately to avoid underestimating the water status of the tree.
- After the value from the screen was recorded the compressed air was released from the chambered by turning the key into the vent position before the next measurement was conducted,

- Finally, the data displayed on the screen was frozen and adjusted to zero before the next stem water potential measurement was conducted.

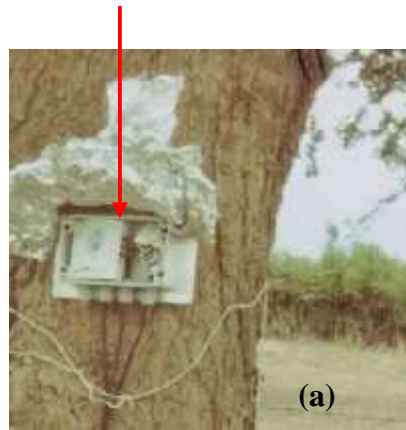
### **3. 10. Tree growth measurement**

#### **3. 10.1. Cambium dynamic and stem growth change**

Before the point dendrometer was installed to measure the cambium dynamics on unpruned and pruned *F. albida* trees, the following preconditions were considered:

- The dead bark was removed gently without damaging the living tissue of the tree.
- Two holes were drilled to the height of DBH to fasten the dendrometer up to the depth of 6 cm and 4mm wide on the left and right side (ca 5.5 cm) apart from the measuring point.
- Two screws were installed in the hole and screwed firmly using the nuts, so that the sensor rod was properly placed on the living part of the wood.
- The cables and the sensors were kept and fixed together with the tree trunk and protected to avoid accidental damage such as falling of the branches and the leakage from the rain.
- The sensors were reset every month by relaxing the screw gently during the entire study period, especially during the rainy periods (mid of June to end of September) otherwise, the sensors become tightly attached to the tree trunk and the data will be linear or constant.

### Dendrometer data logger



### Point dendrometer sensor

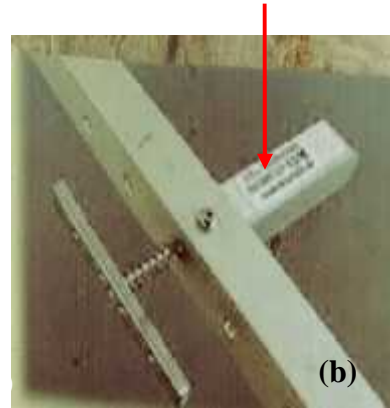


Photo 3.10.1. Data logger fixed on *F. albida* tree (a) and point dendrometer (b)

### 3.10.2. Stem growth measurement

Circumference of unpruned and pruned *F. albida* were measured using tape from three directions at DBH (ca 1.3m) from the ground during the beginning of the experiment (June 2015) and at the end of the experiment (June 2016) finally the mean of DBH of both tree management were taken.

### 3.11. Leaf foliation/defoliation of *F. albida*

A total of six twigs (braches having less than 5cm in diameter) about 10 cm long were tagged from ten unpruned *F. albida* trees at equidistance of the tree crown. The numbers of leaflets remaining per twigs were scored every month, most often in the first week of every month following Bianchini *et al.* (2006).

### 3.12. Physiological measurement of wheat

#### 3.12.1. Relative water content (RWC) of the wheat

Relative water content (RWC) of the wheat was determined following Abdalla and El-Koshiban (2007). Three leaves of the wheat were collected from five stands of the wheat under unpruned and pruned of the tree at 1, 3 and 5m distance and from three directions of each sub-plot. The leaves were kept in the zip locked polyethylene bags and covered with aluminum foil finally kept in the icebox. Approximately 2cm<sup>2</sup> leaf discs were trimmed using cutter and fresh weight was weighed using analytical

balance (Denver instruments, XE-50, Colorado, USA) having the precision of 0.0001g and then floated on the Petri Dish using distilled water for 6 hours.

Turgid weight was measured after removing the water droplet on the surface of the leaf disc; after turgid weight was determined, subsequently the leaf discs were dried in the drying oven at 70°C for 24 hours, and finally dry weight of the leaf disc was measured using the same analytical balance.

RWC was calculated using the following formula.

$$\text{RWC} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100 \dots \dots \dots (6)$$

Where, FW is Fresh weight, TW - turgid weight and DW is dry weight

### **3.12. 2. Soil Plant Analysis development (SPAD)**

Total chlorophyll content of the wheat leaf was measured following Shah et al. (2017).

Total chlorophyll contents of the wheat leaves were measured using chlorophyll content meter (SPAD-502, Minolta Co. Ltd, Japan). The SPAD 502 chlorophyll meter is extensively used in agricultural science for rapid measurement of total chlorophyll content; non-destructive and inexpensive. There are two light emitting diode (LEDs). The SPAD (*Soil Plant Analysis Development*) meter measures the transmittance in the red region (650nm) and the infrared region (940nm), the transmittance value is proportional to the chlorophyll content of the leaves. The SPAD measurements were taken from the flag and the second leaves (top to down) of the wheat under unpruned and pruned trees at 1, 3 and 5m distances and from three directions. A total of 15 SPAD readings were taken from the middle of each leaf finally the mean value was taken.

### 3.12.3 Wheat gas exchange measurement

Wheat leaf gas exchange measurement was conducted from 9:30 am to 12:00 am on 15-16 September, 2015 and 2016. The measurements were carried out from five randomly selected wheat stands from each quadrat under unpruned and pruned trees at 1, 3, and 5m distances and three directions. The chamber was clipped from the flag and second leaves (top to down) using an open-gas portable photosynthesis system with infrared gas analyzer (IRGA) (LI-6400, LI-COR, Lincoln, Nebraska, USA) (Photo 3.10). The infra-red gas analyzer system is equipped with the leaf chamber having clip area of 6 cm<sup>2</sup>. The rates of net photosynthesis (A), transpiration (E), stomatal conductance to water vapor (gs) and instantaneous water use efficiency (WUE<sub>i</sub>) was calculated from the ratio of net photosynthesis to transpiration rate. For the light response curve, we used internal light resource starting from 2000 up to zero  $\mu\text{molm}^{-2}\text{S}^{-1}$  with an interval of 200  $\mu\text{molm}^{-2}\text{S}^{-1}$

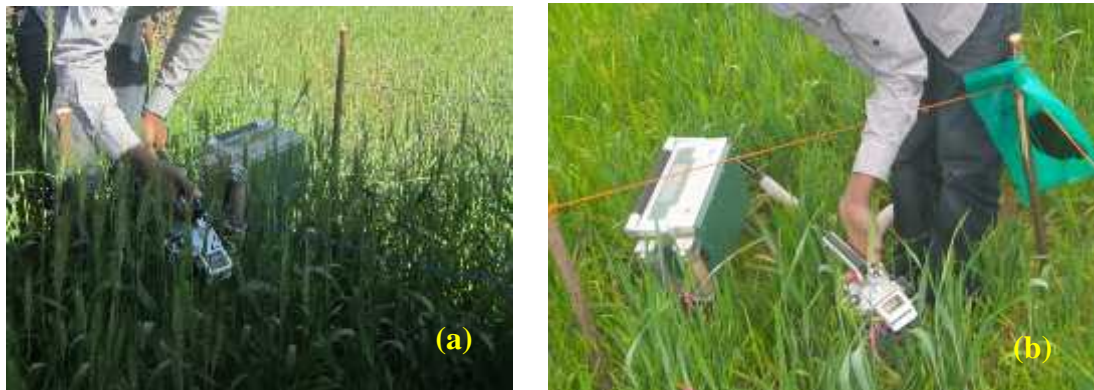


Photo 3.12.3 wheat gas exchange measurement using Li-Cor 6400 portable photosynthetic system from under unpruned the tree canopy (a) and under pruned tree (b)

Light response curve of the wheat was determined from outside of the tree crown (open area) where gas exchange of the wheat was taken using internal light resource

from licor photosynthesis system. Different light sources were used from (0-2000 $\mu\text{molm}^{-2}\text{S}^{-1}$ ) and 5 readings net assimilations were recorded from each light levels. The light level was adjusted first from 2000  $\mu\text{molm}^{-2}\text{S}^{-1}$  and continued to up to zero with 500 PAR level intervals.

### **3.13. Wheat growth measurement**

#### **3.13.1 Shoot height**

Wheat shoot height was measured using tape in mid-September 2015 and September 2016 from where physiological measurement was conducted. A total of ten stands were randomly selected from the four corners and the center under unpruned and pruned of *F. albida* at 1, 3 and 5m distances and from three directions, finally the mean value was taken.

#### **3.13.2. Tiller number**

The number of tillers was counted from each sub-plot where the shoot height was measured under unpruned and pruned *F. albida* at 1, 3 and 5m distances and three directions and finally the mean value was taken.

### **3.14. Wheat Biomass measurement**

#### **3.14.1. Wheat aboveground biomass and grain yield**

The wheat was harvested in October, 2015 and 2016. The heads were trashed and the grain yield was separated from the straw and the straw was weighed from 1m, 3m and 5m distance and three directions of the tree trunk under unpruned and pruned trees using top load balance (Salter No 50, England) and the grain yield was air dried in the Ecophysiology Laboratory, Addis Ababa University, until constant weight was maintained finally the grain yield was weighed using analytical balance (Denver instruments, XE-50, Colorado, USA) having the precision of 0.0001g.

### **3.15. Data analysis**

Analysis of variance (ANOVA) General Linear Model (GLM) with Tukey's corrections for comparison of means was used to compare the effect of pruning *F. albida* on water relations (leaf water potential and sap volume) and leafing phenology, understorey wheat productivity (aboveground biomass and grain yield) and as well soil nutrient. Test was considered at  $p < 0.05$ .

All statistical analysis was performed using SPSS version (version 16, SPSS Inc. and Chicago, USA).

The graphs were generated using Sigma plot software (version 11.0).

Sap flow rate and sap volume of the tree were analyzed using sap flow tool software (ICT international, version 1.4.1).

## CHAPTER FOUR

### 4.0 RESULT

#### 4.1. Environmental data of the study area

The highest mean relative humidity (48%) was recorded in July and August 2015 and in July 2016. The highest mean monthly maximum ( $28^{\circ}\text{C}$ ) and minimum ( $25^{\circ}\text{C}$ ) temperatures were recorded in January and November 2015, respectively. Maximum (480 mm) rainfall was recorded in July 2016; whereas, those periods having lower than 100 mm rainfall were, February, March, June, September, October, November and December 2015 as well as January, February, March, April, May 2016. This shows there was great variability in rainfall intensity and distribution in the study area. The maximum rainfall fell in three of the four months, from June to September (Fig. 4.1).

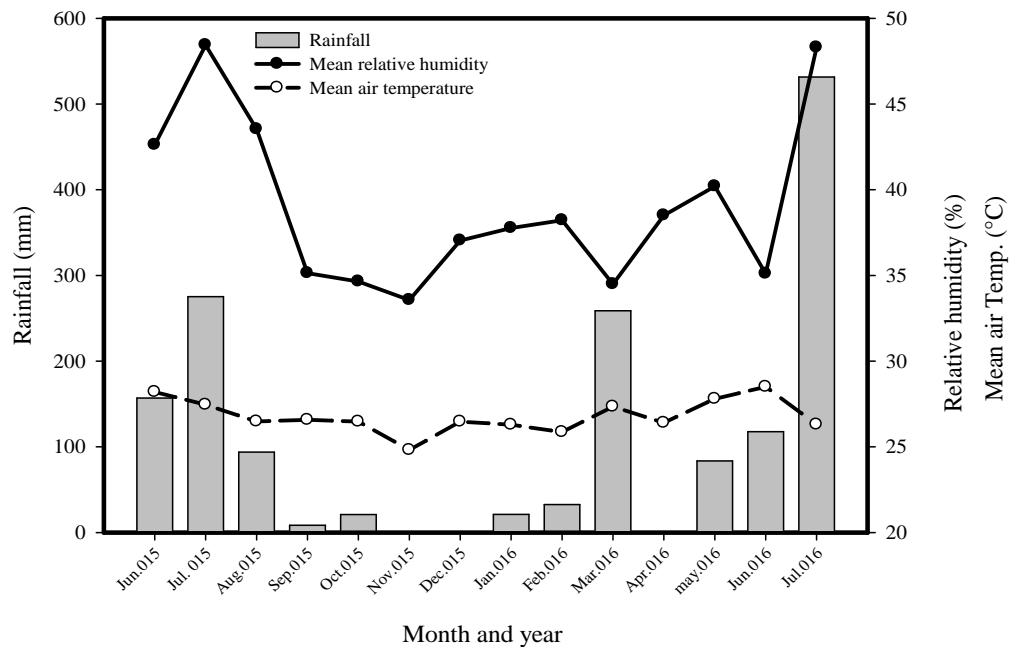


Figure 4.1 Rainfall (mm), mean temperature ( $^{\circ}\text{C}$ ) and mean relative humidity (%) of Ejerssa Joro kebele between June 2015 and July 2016.

#### 4.2. Photosynthetically Active Radiation (PAR)

PAR level was measured using ceptometer measured at midday under unpruned *F. albida* at 1m distance was significantly ( $p < 0.05$ ) lower compared with same tree at 3 and 5 meter distances as well as under pruned tree across all the distances. The mean PAR level under unpruned trees were  $456.5 \pm 134$ ,  $1505 \pm 409$ , and  $2062.5 \pm 12$   $\mu\text{molm}^{-2}\text{s}^{-1}$  measured at 1, 3 and 5 meter distances, respectively, whereas the mean PAR level under pruned trees were  $2008.7 \pm 201$ ,  $2192 \pm 51$  and  $1929 \pm 418$   $\mu\text{molm}^{-2}\text{s}^{-1}$  measured at 1, 3 and 5 meter distances, respectively (Fig. 4.2).

The PAR level was reduced by 77% under unpruned *F. albida* due to the light interception by the canopy of the tree.

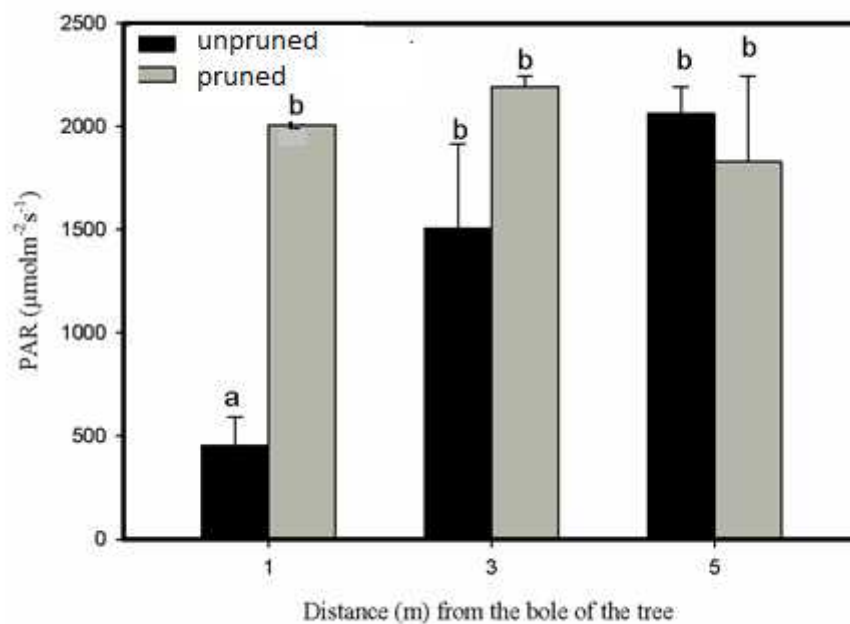


Figure 4.2 PAR levels under unpruned and pruned *F. albida* recorded from different radial distances of the tree trunk; mean  $\pm$ S.E (n=10).

### 4.3. Tree characteristics of the study trees

Table 1 Tree growth parameters during the beginning of the study period (2015)

Tree characteristics in 2015			
Tree management type	Height (m)	DBH (cm)	CD (m)
Unpruned	8.5	57.3±4.0	4.6±0.1
Unpruned	12.0	49.3±1.3	4.1±0.12
Unpruned	10.0	40.7±2.3	4.4±0.17
Pruned	6.0	57.3±3.5	2.3±0.08
Pruned	5.5	38.2±2.9	1.8±0.02
Pruned	5.0	35.6±1.2	1.7±0.09

Where, DBH is diameter at breast height and CD is crown diameter, (mean; n=10±SE).

### 4.4. Soil profile moisture measurement

Figure 4.4.1 shows the time courses of soil moisture under (1m) and outside (6m) from pruned and unpruned *F. albida* tree crown between June 2015 and June 2016. The average soil moisture percentage measured at one meter under unpruned *F. albida* was significantly ( $p<0.05$ ) higher compared with the soil moisture measured at 6 meter distance of under pruned trees at 6 meter distance. Soil moisture was highest in August and declined towards the dry period (November to May). The highest soil moisture percentages were 41.3% and 23.5% measured in August 2015 at 1m distances under unpruned and pruned *F. albida*, respectively; whereas, the lowest soil moisture measured in June 2015 and in 2016 from 6 m distances were 5.7 and 4.5% under unpruned and pruned tree, respectively. However, soil moisture percentage measured under pruned tree did not show significant difference ( $p>0.05$ )

across the distances. Pruning the branches of *F. albida* reduced soil moisture retention by 56% in August and 78% in June (Fig. 4.4.1 a&b).

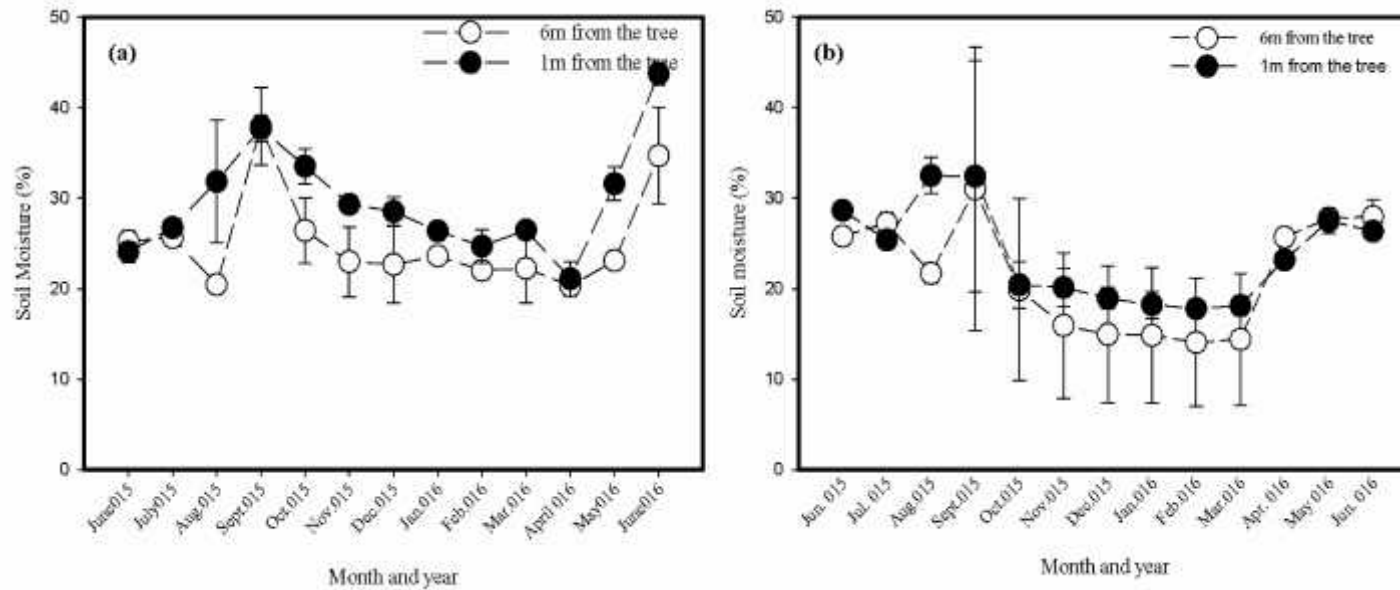


Figure 4.4.1 Soil moisture percentage under unpruned (a) and pruned (b) at 1m distance (●) and 6 m distance (○) from the tree trunk in different months, mean  $\pm$ SE (n=12)

Not only temporal but also spatial variation was observed in soil moisture percentage under the different tree managements. Soil moisture percentage showed an increment in different soil depths (10 to 100cm) during the wet periods (July-October); however, soil moisture

percentage was significantly ( $p < 0.05$ ) higher under unpruned compared with pruned *F. albida*. The mean soil moisture percentage measured from 100, 60, 40, 30, 20 and 10 cm depth were  $34.9 \pm 3.6$ ,  $31.4 \pm 1.4$ ,  $32.5 \pm 2.2$ ,  $28.0 \pm 1.4$ ,  $21 \pm 3.2$  and  $18.9 \pm 2.9$  under unpruned *F. albida*, respectively (Fig. 4.4.2a); whereas, soil moisture percentage recorded under pruned *F. albida* at similar depths were  $32.2 \pm 1.1$ ,  $29.9 \pm 1.6$ ,  $22.8 \pm 1.4$ ,  $20.8 \pm 1.5$ ,  $17.5 \pm 1.1$  and  $24 \pm 1.1$ , respectively (Fig. 4.4.2b). There was a statistically ( $p < 0.05$ ) significant difference in soil moisture measured from different soil depths under unpruned compared to pruned *F. albida*; however, temporal soil moisture measured under pruned in different depths did not show significant difference.

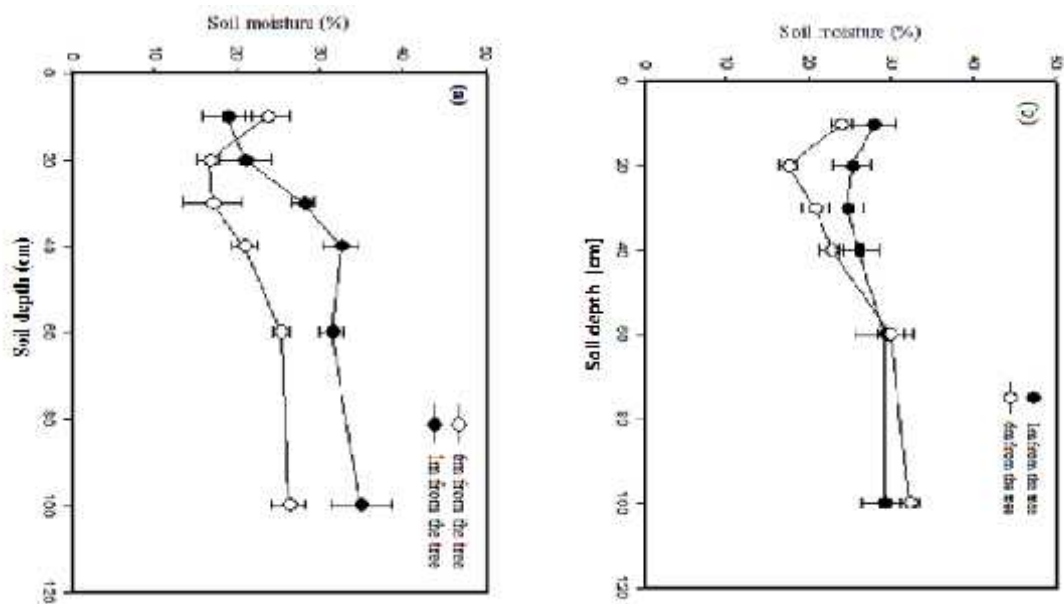


Figure 4.4.2 Depth-wise soil moisture under unpruned (a) and pruned (b) at 1 meter (○) and 6 meter distance (●) from the tree trunk; mean  $\pm$  SE (n=12)

Table 2 Soil moisture percentage difference at 1m depth under unpruned and pruned tree

Soil depth (cm)	Soil moisture (%) at 1 m under UP	Soil moisture (%) at 1m under P	Soil moisture difference (%)
10	24±1.1	18.9±2.9	21.2
20	21±3.2	17.5±1.1	20.2
30	28.0±1.4	20.8±1.5	25.7
40	32.5± 2.2	22.8±1.4	29.8
60	31.4±1.4	29.9±1.6	4.70
100	34.9± 3.6	32.2±1.1	7.70

#### 4.5. Soil physical and chemical property under unpruned and pruned *F. albida* trees

##### 4.5.1. Soil physical property

The soil particle size under unpruned and pruned *F. albida* showed relatively higher percentage of sand followed by silt and clay. Clay percentage proportion was slightly higher under unpruned and pruned tree at 1m distance and showed declined trends as we go away from the bole of the tree under unpruned tree but there was no clear pattern of clay content was observed under pruned tree. Silt percentage increased under unpruned tree away from the tree trunk, on the other hand, silt percentage showed inconsistency under pruned tree like the clay content. Both soil particle size and soil types were also independent to the tree managements as well as the different distances from the tree trunk (Table 3).

Table 3. Soil particle percentage and soil type under unpruned and pruned from different radial distances from the bole of the tree.

Tree management and distance (m) from the tree	Soil texture class			Soil type
	Sand (%)	Clay (%)	Silt (%)	
UP-1	61.5±0.0	19.5±0.0	22.0±0.0	Sandy loam
UP-3	51.5± 0.6	16.83±0.6	31.67±0.6	Loamy
UP-5	50.8±0.7	18.16±1.3	31.04±1.2	Loamy
P-1	56.5±0.5	23.5±1.3	20.0±3.0	Sandy Clay loamy
P-3	57.5±1.1	17.5±0.0	25.0±1.2	Sandy loam
P-5	58.8±2.3	18.16±0.6	25.0±2.3	Sandy loam

Where UP is unpruned and P represent pruned tree; mean±SE (n=3)

#### 4.5.2. Soil chemicals property

##### 4.5.2.1. Soil pH

Soil pH measured under unpruned tree from different distances did not show significant difference. However, the soil pH measured under pruned tree showed significant ( $p < 0.05$ ) difference under pruned tree at 3 and 5 meter distances. The pH value of the soil under unpruned tree at 1, 3 and 5m distances were  $5.3 \pm 0.1$ ,  $5.4 \pm 0.0$  and  $5.4 \pm 0.0$ , respectively, on the other hand, the pH of the soil under pruned tree from 1, 3 and 5m distances were  $6.1 \pm 0.1$ ,  $7.2 \pm 0.8$  and  $5.9 \pm 0.1$ , respectively. However, the pH obtained under pruned *F. albida* at 3m distance was neutral (7.2) (Fig. 4.5.2.1).

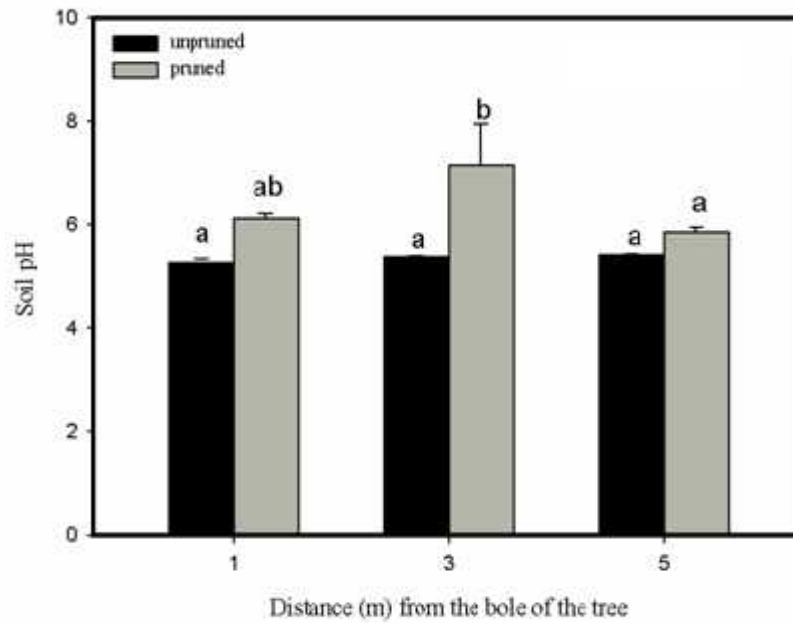


Figure 4.5.2.1. Soil pH under unpruned and pruned *F. albida* tree from different distances radial from the trunk of the tree

#### 4.5.2.2. Percentage of soil total nitrogen

There was a spatial variability of total nitrogen percentage (TN) of the soil between unpruned and pruned *F. albida* as we go away from the bole of the tree. Total nitrogen percentage of the soil under unpruned *F. albida* was significantly ( $p < 0.05$ ) higher compared with pruned *F. albida* at 3 and 5m distances Total nitrogen percentage of the soil under unpruned trees was  $0.46 \pm 0.1$ ,  $0.34 \pm 0.1$  and  $0.28 \pm 0.1$  obtained from 1m, 3m and 5m, respectively; whereas, total nitrogen percentage under pruned tree were  $0.4 \pm 0.06$ ,  $0.17 \pm 0.1$  and  $0.23 \pm 0.1$  obtained from 1, 3 and 5m distance, respectively (Fig. 4.5.2.2).

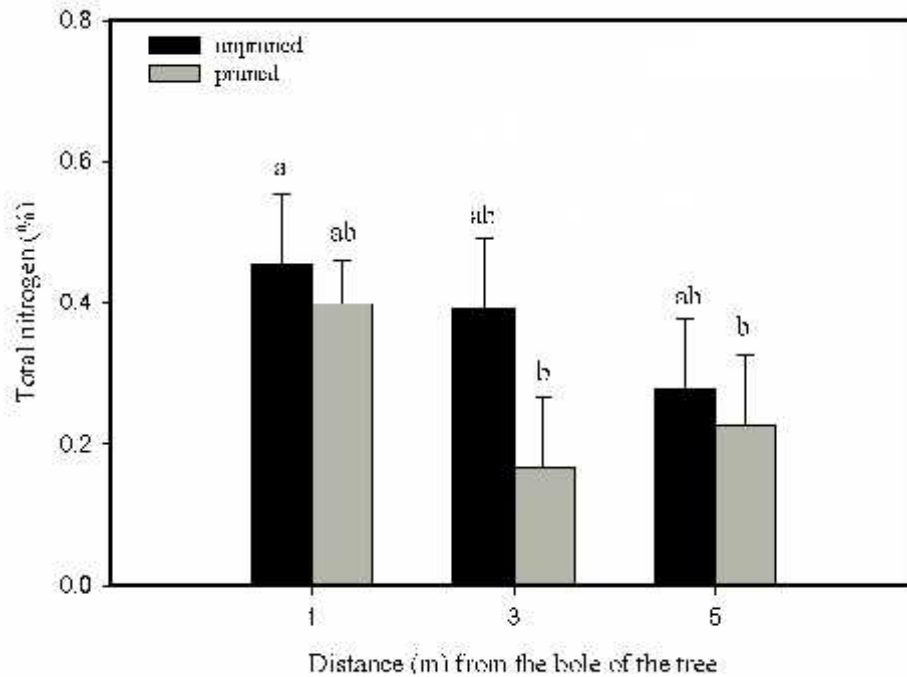


Figure 4.5.2.2 Soil total nitrogen percentage under unpruned and pruned *F. albida* tree from different radial distances of the trunk of the tree. Mean + SE (n=9)

Table 4 Rating of total nitrogen content of the soil according to Landon (1991).

Tree management types and distance from the tree trunk	TN (%)	Low (<0.2)	Moderate (0.2-0.4)	High (>0.4)
Up-1	0.4		✓	
Up-3	0.34		✓	
Up-5	0.2		✓	
P-1	0.4		✓	
P-3	0.17	✓		
P-5	0.23		✓	

Where: Up is unpruned and P is pruned, TN = total nitrogen

#### 4.5.2.3. Soil organic carbon

Soil organic carbon percentage found under unpruned and pruned *F. albida* showed spatial variation like that of total nitrogen percentage of the soil. Organic carbon content of the soil found at 1 and 3m distances under unpruned trees were significantly ( $p < 0.05$ ) higher compared with pruned at similar distances; however, no significance difference of organic carbon were found under pruned tree at 1, 3 and 5m distances as well as with unpruned tree at 5m distance. Organic carbon percentage found under unpruned *F. albida* at the distances of 1, 3 and 5m were  $3.0 \pm 0.39$ ,  $2.5 \pm 0.5$  and  $1.4 \pm 0.6$ , respectively; whereas, soil organic carbon percentage found at 1, 3 and 5m under pruned trees were  $2.1 \pm 0.2$ ,  $1.5 \pm 0.5$  and  $2.1 \pm 0.2$ , respectively (Fig. 4.5.2.3).

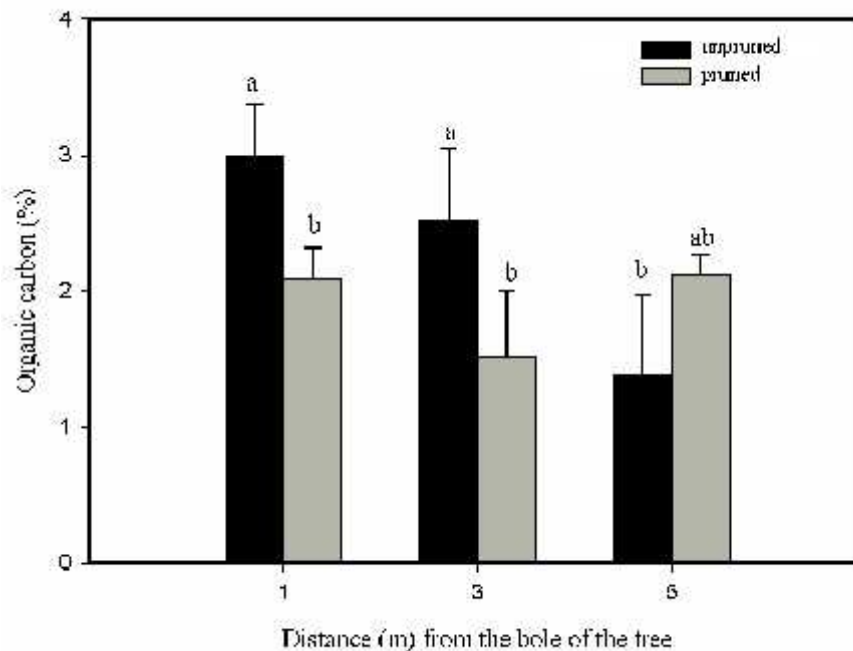


Figure 4.5.2.3 Soil organic carbon percentage under unpruned and pruned *F. albida* tree at different radial distances from the trunk of the tree.

Table 5 Rating of organic carbon (OC) content of the soil according to Landon (1991).

Tree management types and distance from the tree trunk	OC (%)	Low (<0.5)	Moderate (0.5-1.5)	High (>1.5)
Up-1	3.0			✓
Up-3	2.5			✓
Up-5	1.4		✓	
P-1	2.1			✓
P-3	1.5		✓	
P-5	2.1			✓

According to Landon (1991), soil organic matter rating; soil organic carbon found under unpruned tree at 1 and 3 m as well as 1 and 5 m distances under pruned trees were categorized to be a higher range; whereas, soil organic carbon under unpruned and pruned trees at 3 and 5 m distance were rated to moderate range, respectively (Table 6).

#### 4.5.2.4. Soil available phosphorous

Available phosphorous also showed differences within the different tree managements as well as the different distances from the bole of the tree. Available phosphorous obtained under unpruned *F. albida* tree at 1, 3 and 5 m distances were  $24.2 \pm 0.8$ ,  $24.2 \pm 0.9$  and  $20.8 \pm 1.3$  mg/Kg of soil, respectively; on the other hand, available phosphorous obtained under pruned *F. albida* at 1, 3 and 5 meter distances were  $21.9 \pm 1.2$ ,  $10.5 \pm 1.4$  and  $16.6 \pm 4.7$ , respectively. Available phosphorous obtained under unpruned tree was significantly ( $p < 0.05$ ) higher compared with

under pruned tree at 1, 3 and 5 m distances; however, available phosphorous among different tree management across the different distances were not significantly different. In general, available phosphorous content of the soil declined away from the bole of the trees (Fig.4.5.2.4).

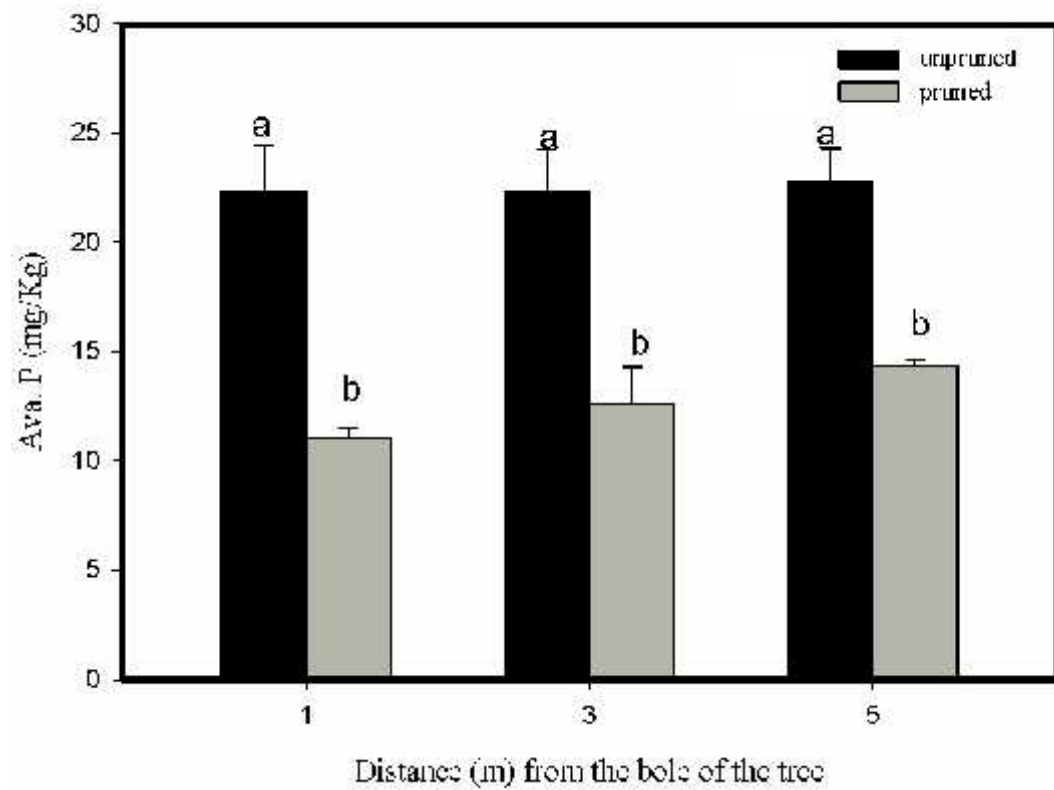


Figure 4.5.2.4 Available phosphorous of soil under unpruned and pruned *F. albida* tree from different radial distances from the trunk of the tree. Mean + SE (n=9)

Table 6 Rating of Available phosphorous (AvP.) content of the soil according to Landon (1991).

Tree management types and distance from the tree trunk	AvP. (mg/Kg)	Low (<10)	Moderate (10-25)	High (>35)
Up-1	24.2		✓	
Up-3	24.2		✓	
Up-5	20.8		✓	
P-1	21.9		✓	
P-3	10.5		✓	
P-5	16.6		✓	

#### 4.5.2.5. Exchangeable potassium (K<sup>+</sup>)

Exchangeable potassium found under unpruned tree was significantly ( $p < 0.05$ ) lower compared with pruned tree at 1 and 3 m distances, but not at 5 m distance from the bole of the tree. Exchangeable potassium found under unpruned tree were  $20.3 \pm 1.3$ ,  $19.9 \pm 0.1$ ,  $19.9 \pm 0.4$  mg/Kg of soil recorded at 1, 3 and 5m, respectively, whereas exchangeable potassium found under pruned *F. albida* were  $22.7 \pm 0.1$ ,  $23.7 \pm 0.3$  and  $21.1 \pm 0.6$  mg/Kg of the soil measured at 1, 3 and 5 meter distances, respectively (Fig. 4.5.2.5).

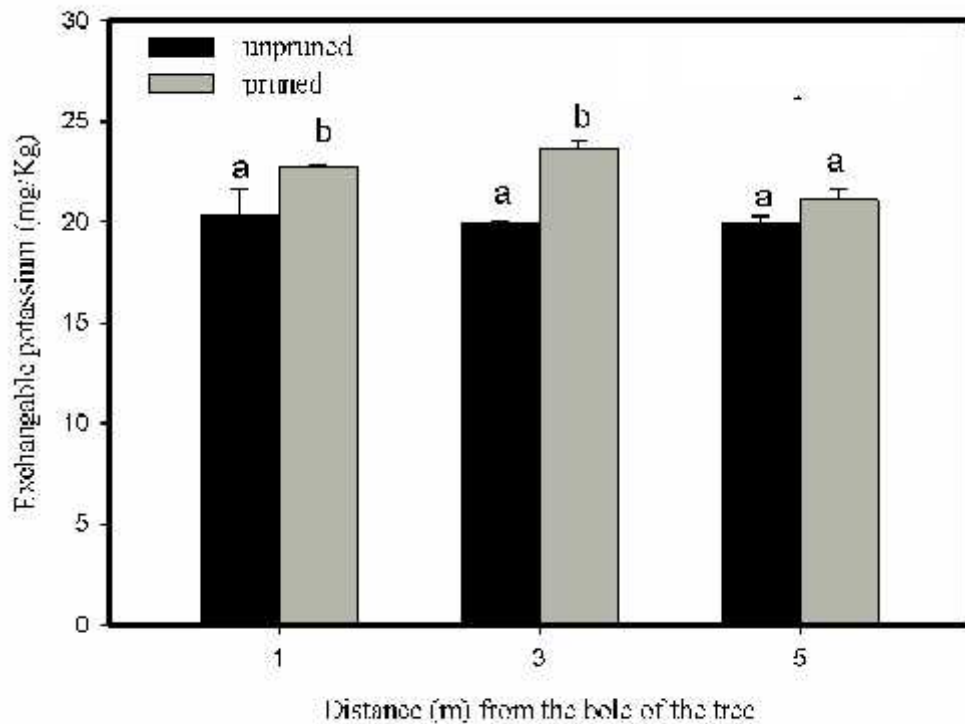


Figure 4.5.2.5 Exchangeable potassium of soil under unpruned and pruned *F.albida* tree from different radial distances from the trunk of the tree.

#### 4.5.2.6. Exchangeable sodium ( $\text{Na}^+$ )

Exchangeable sodium did not show significant differences within the different tree managements of tree as well as the different distances. The exchangeable sodium found under unpruned tree were  $38.0 \pm 2.9$ ,  $39.9 \pm 1.7$ ,  $41.6 \pm 0.2$  mg/Kg of soil obtained at 1 3 and 5 meter, respectively; whereas exchangeable sodium under pruned *F. albida* were  $42.3 \pm 1.5$ ,  $42.0 \pm 0.0$  and  $41.3 \pm 0.5$  mg/Kg of the soil measured at 1, 3 and 5 meter radial distances, respectively (Fig.4.5.2.6).

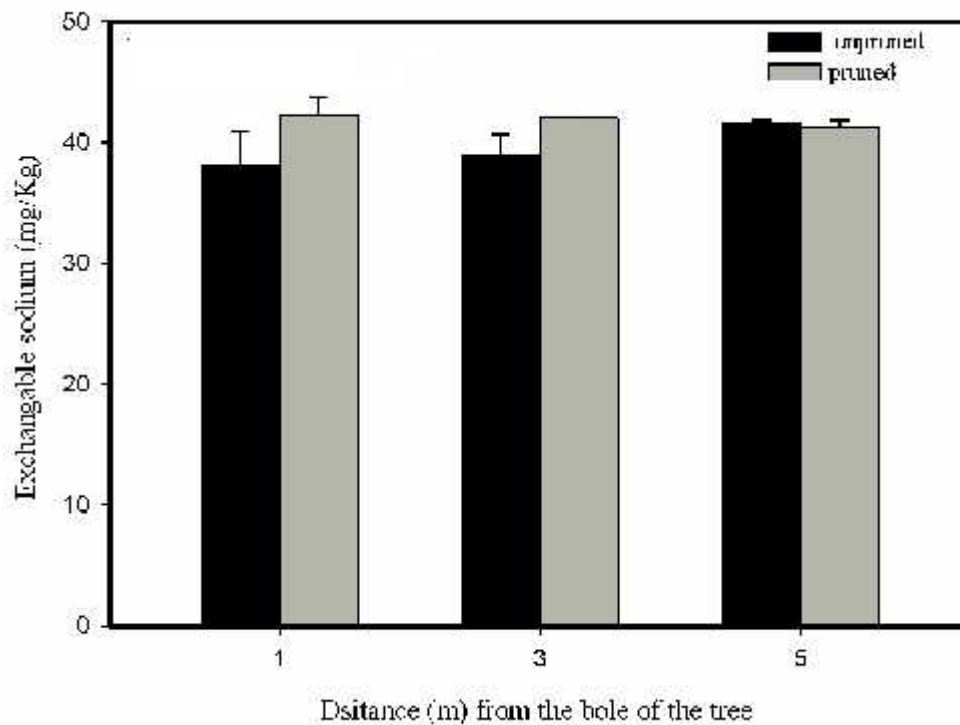


Figure 4.5.2.6 Exchangeable sodium of soil under unpruned and pruned *F. albida* tree from different distances from the tree trunk.

#### 4.6. Water relations of *F. albida*

##### 4.6.1. Stem water potential of unpruned and pruned *F. albida*

Stem water potential measured in midday was significantly ( $p < 0.05$ ) lower compared with the stem water potential measured during predawn between pruned and unpruned *F. albida*; however, the stem water potential measured in midday and predawn of the same tree management type were not significantly different. The mean midday and predawn stem water potential of unpruned *F. albida* were  $-0.86 \pm 0.04$  MPa and  $-0.54 \pm 0.04$  MPa, respectively; on the other hand, the mean midday and predawn stem water potential of pruned *F. albida* was  $-0.54 \pm 0.01$  MPa and  $-0.35 \pm 0.04$  MPa, respectively (Fig. 4.6.1).

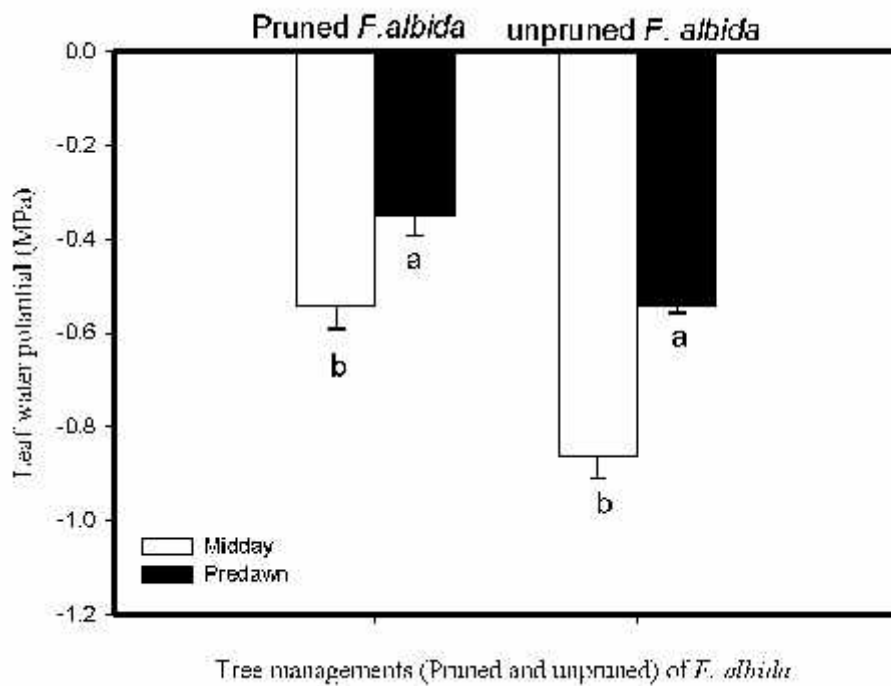


Figure 4.6.1 Midday and predawn stem water potential of pruned and unpruned *F. albida*, different letters showed that there is a significant difference between different tree management types); mean±S.E (n=5)

#### 4.6.2. Sap flow rate of unpruned and pruned *F. albida*

The highest and the lowest sap flow rate of both unpruned and pruned was observed in mid-day and from late evening to early morning, respectively. The highest (2100 cm<sup>3</sup> h<sup>-1</sup>) and the lowest (100 cm<sup>3</sup> h<sup>-1</sup>) sap flow rate were measured in unpruned tree (Fig.4.6.2a); whereas, the highest (900 cm<sup>3</sup> h<sup>-1</sup>) and the lowest (0-50 cm<sup>3</sup> h<sup>-1</sup>) sap flow rate were measured in pruned trees (Fig.4.6.2b).

Like the sap velocity observed in unpruned and pruned tree, there was a difference in sap flow rate across the sap wood depth, i.e., higher sap flow rate was observed from the inner sensor than the outer sensor in unpruned tree; whereas, sap flow rate was higher in the outer sensor than the inner one in pruned trees.

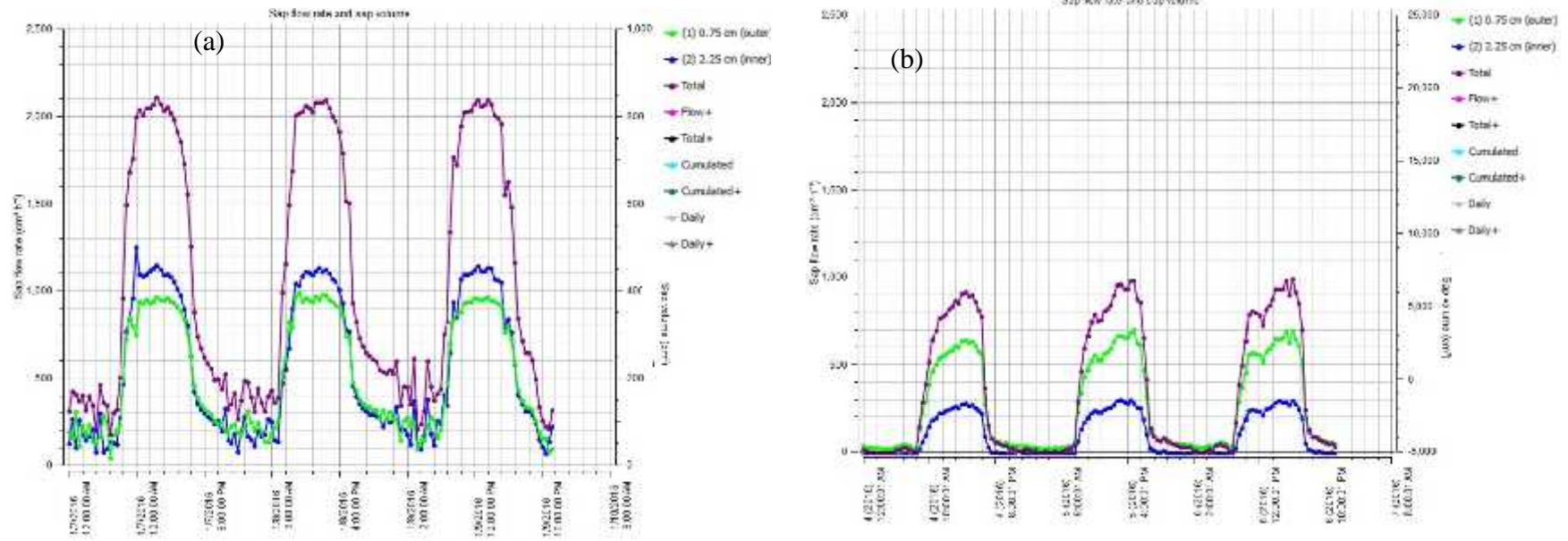


Figure 4.6.2 Three days maximum and minimum sap flow rate (cm<sup>3</sup> h<sup>-1</sup>) of unpruned (a) and pruned (b) *F. albida* in 2016 (different colors shows sap velocity in the inner and outer sensors)

#### **4.6.3. Diurnal sap flow rate of unpruned and pruned *F. albida***

The highest diurnal sap flow rate was measured in unpruned *F. albida* in mid-day (2:00 pm) in the dry period (January); whereas, the highest diurnal sap flow rate of pruned *F. albida* tree was recorded at 4:00 pm; on the contrary, the lowest diurnal sap flow rate of unpruned tree were recorded during late night (Fig.4.6.3a). The highest and the lowest diurnal sap flow rates were  $78.9 \text{ ms}^{-1}$  and  $3.5 \text{ ms}^{-1}$  recorded from unpruned and pruned *F. albida* were recorded at 2:00 pm and 4:00am, respectively in dry period (January) (Fig.4.7.3a); whereas, the highest and the lowest diurnal sap flow rate were 37 and  $1.2 \text{ ms}^{-1}$  recorded in pruned *F. albida*, respectively in wet period (August) (Fig. 4.6.3b). Generally pruning *F. albida* reduces diurnal sap flow rate in dry and wet period by 53.1 and 65.7%, during the dry and the wet season, respectively.

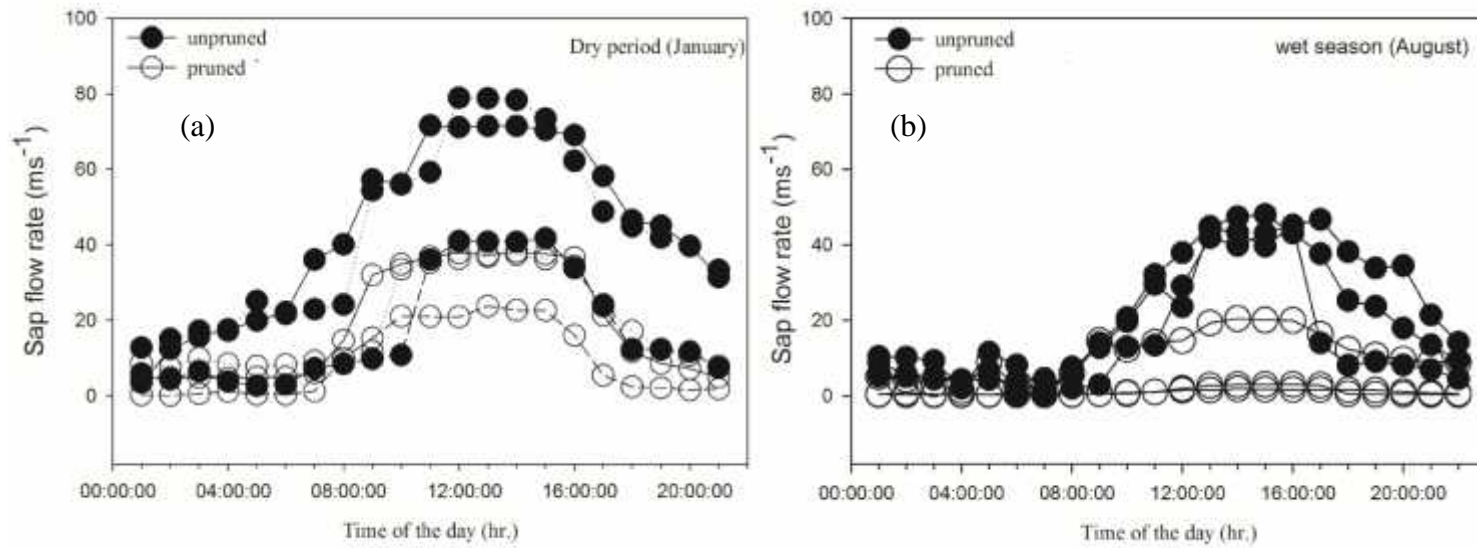


Figure 4.6.3 Diurnal sap flow rate (ms<sup>-1</sup>) of unpruned (●) and pruned (○) *F. albida* in dry period (January) (a) and in wet period (August) (b)

#### 4.6.4. Diurnal sap volume of unpruned and pruned *F. albida*

The highest sap volume of both unpruned and pruned trees was recorded in January 2015. Pruning the branches reduces diurnal sap volume by 89% in dry period and up to 98% during the wet period. The highest sap volume was measured in the dry period (January) when the tree crown was totally foliated with leaves. The highest diurnal sap volume in unpruned and pruned trees were 138.7 L day<sup>-1</sup> and 14 L day<sup>-1</sup>, respectively measured during the dry period and particularly in mid-day (Fig.4.6.4a); whereas, the highest (80 L day<sup>-1</sup>) and the lowest (1.6 L day<sup>-1</sup>) diurnal sap volume were measured during the wet period in unpruned and pruned *F. albida* tree at 12:00 and 16:00 pm, respectively (Fig.4.6.4b).

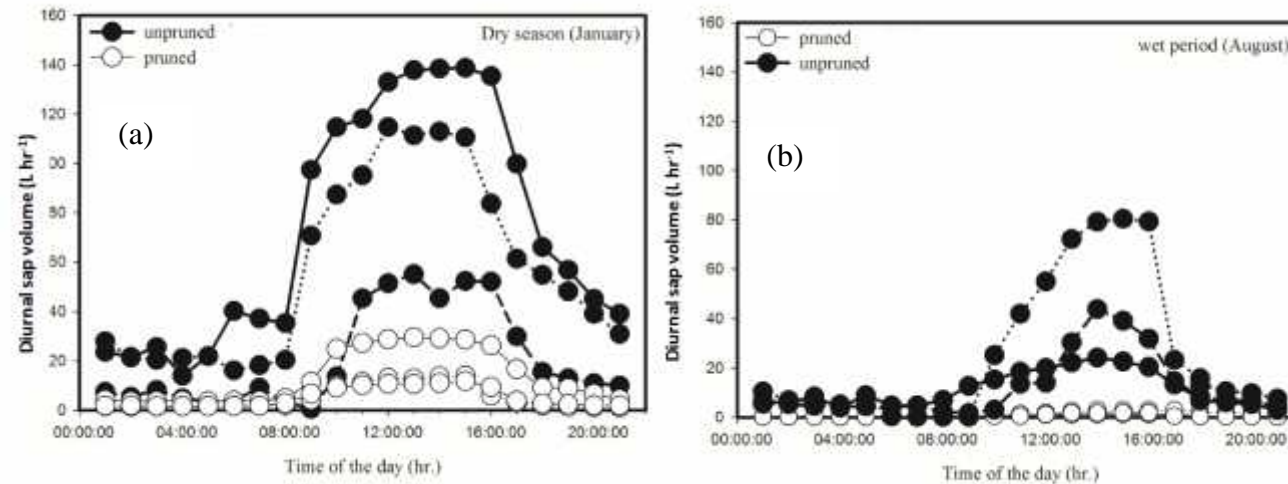


Figure 4.6.4 Diurnal sap volume (L hr<sup>-1</sup>) of unpruned ( ) and pruned ( ) *F. albida* tree in dry period (a) and wet period (b)

### 6.5. Monthly sap flow rate and sap volume of unpruned and pruned *F. albida*

Monthly maximum sap flow rate were  $55.6 \text{ ms}^{-1}$  and  $43.2 \text{ ms}^{-1}$  measured in unpruned and pruned *F. albida*, respectively around January and February in 2015. Sap flow rate was reduced to  $5.5$  and  $9.6 \text{ ms}^{-1}$  around April and May in 2015 due to leaf defoliation in unpruned and pruning effects in pruned trees, respectively. However, as the leaves started to flush and as the crown of the tree becomes fully foliated in unpruned trees, and when the leaves emerged and as the branches expanded in pruned trees towards the dry periods and as temperature increase, sap flow rate recovered and reached to  $41.6 \text{ ms}^{-1}$  in January and  $46.7 \text{ ms}^{-1}$  in October 2016 (Fig.4.6.5a).

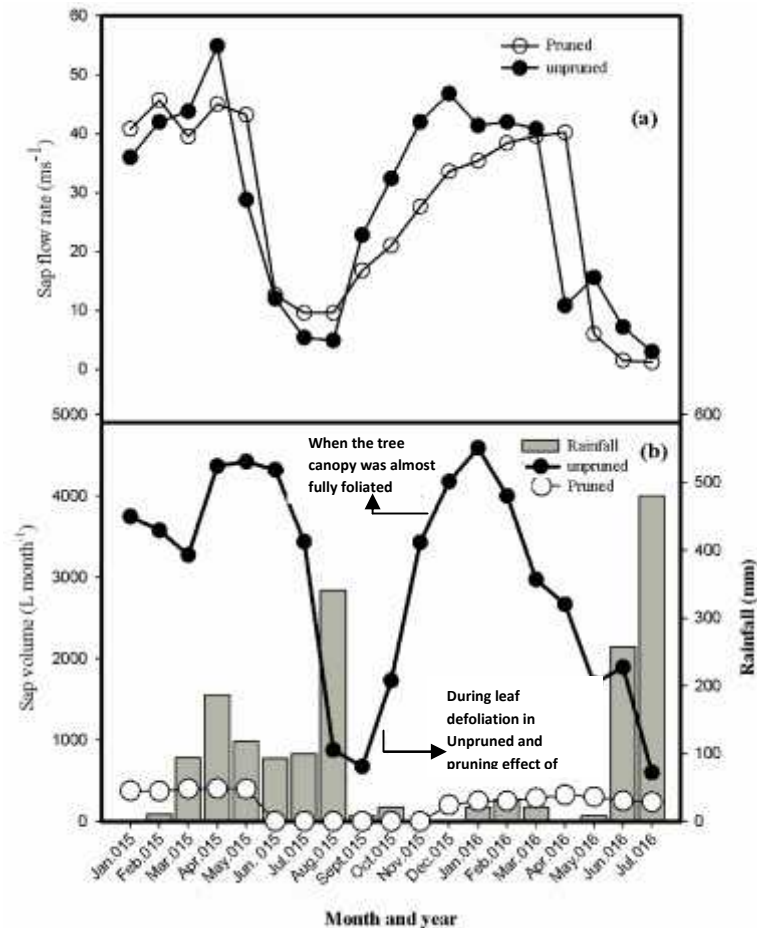


Figure 4.6.5 Monthly sap flow rate (a) sap volume and rainfall (b) of unpruned ( ) and pruned ( ) *F. albida*

Similarly, the sap flow rate, and volumetric water flow in xylem tissue measured from unpruned tree was significantly ( $P < 0.05$ ) higher compared with pruned *F. albida*. The highest ( $4590 \text{ L month}^{-1}$ ) sap volume was measured from unpruned *F. albida* tree in January 2016 (Dry period) and the lowest ( $599 \text{ L month}^{-1}$ ) sap volume was recorded in August 2015 (wet period) when the rainfall was highest; on the contrary, the highest ( $403 \text{ L month}^{-1}$ ) and the lowest ( $0.4\text{-}1.4\text{L}$ ) sap volume were recorded from June to September in 2015 and 2016, respectively (Fig.4.6.6b).

#### **4.7. Tree growth measurement**

##### **4.7.1. Cambium growth**

Mean monthly cambium growth of pruned *F. albida* tree was very slow from June to August 2015 during the rainy season and increased from September to November 2015 when soil moisture relatively high on the other hand, the average daily air temperature was higher than the main rainy season. The lowest cambium change was measured from December 2015 to March 2016; whereas, growth continued slowly in unpruned *F. albida* from April to July 2016. Cambium growth in pruned was slow from October 2015 to March 2016 and then declined from March 2016 to June 2016. (Fig. 4.4.1). Despite the difference observed in cambium growth between unpruned and pruned tree, the highest cambium growth change was observed during the dry periods particularly in 2016, when the tree canopy was fully foliated and when there is high transpiration. In general, the cambium growths in pruned and unpruned trees were very slow from during the main rainy seasons.

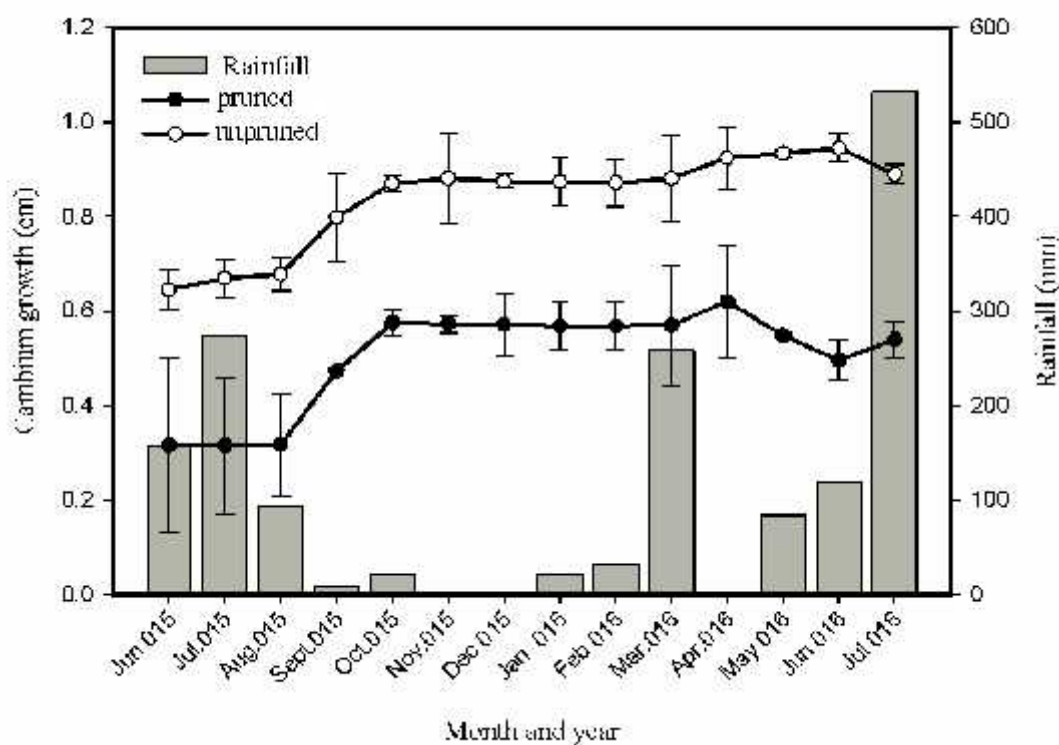


Figure 4.7.1 Monthly cambium growth of pruned ( ) and unpruned ( ) *F. albida* and rainfall (■) from January 2015 to July 2016

#### 4.7. 2. Tree characteristics

The heights of unpruned *F. albida* were 12.0, 10.0 and 8.5 m, respectively; whereas, the heights of pruned trees measured in June 2015 were 5.0, 6.0 and 5.5m. The crown diameters of unpruned trees were 4.1, 4.4, 4.6; whereas, the crown diameters of the pruned trees were 1.7, 2.3, and 1.8 m. The DBH of unpruned trees were 42.2, 61.1 and 45.7 cm; whereas, the DBH of pruned trees measured in June 2015 were 35.6, 57.3 and 38.2 cm, respectively.

The tree height, crown diameter and DBH of both pruned and unpruned *F. albida* measured in 2016 are summarized in Table 11. The mean annual change of DBH in unpruned tree was 24%; whereas, the change of DBH in pruned tree was 12%, indicating that, pruning the branches of the tree reduced the DBH by 50%.

Table 7 Tree growth parameters in 2016 (at the end of the study period)

Tree characteristics in July 2016				
Tree management types	BD (cm)	Height (m)	DBH (cm)	CD (m)
Pruned	0.9±0.08	6.5	42.4±2.0	2.5±0.4
Pruned	2.1±0.01	7.5	60.2±2.7	2.8±0.2
Pruned	0.9±0.08	6.5	42.4±2.0	2.5±0.4
unpruned	0.8±0.02	15	65.3±2.1	8.5±1.8
Unpruned	1.0±0.02	16	61.0±1.8	9.5±2.5
Unpruned	2.2±0.2	12	68.1±2.3	9.5±0.3

Where BD is bark depth, DBH is diameter at breast height and CD is crown diameter (mean; n=10±SE.)

#### 4.8. Leafing phenology

The number of leaflets per twig varied not only within the study trees but also across the agricultural landscape in the Great Rift Valley area and variation among trees were the most prominent phenomena observed in unpruned *F. albida* in the study area. The highest leaflets (up to 40 leaflets per twig) were recorded during the dry period (October–February) when the tree crown was fully foliated. However, the highest (25) leaflets per twig was scored from tree number 2 and 8 from 2015 to March 2016. The maximum leaflets, were 14 were scored from tree number 1 and 5 from October to January 2015; whereas, the lowest leaflets per twigs (0-2) were scored around the onset of the rain season (May-July) in 2015 and 2016 when most of unpruned trees defoliated and later the leaf flushes starting from mid of June and the tree crown become gradually fully foliated until the onset of the next rain season (Fig.4.8a).

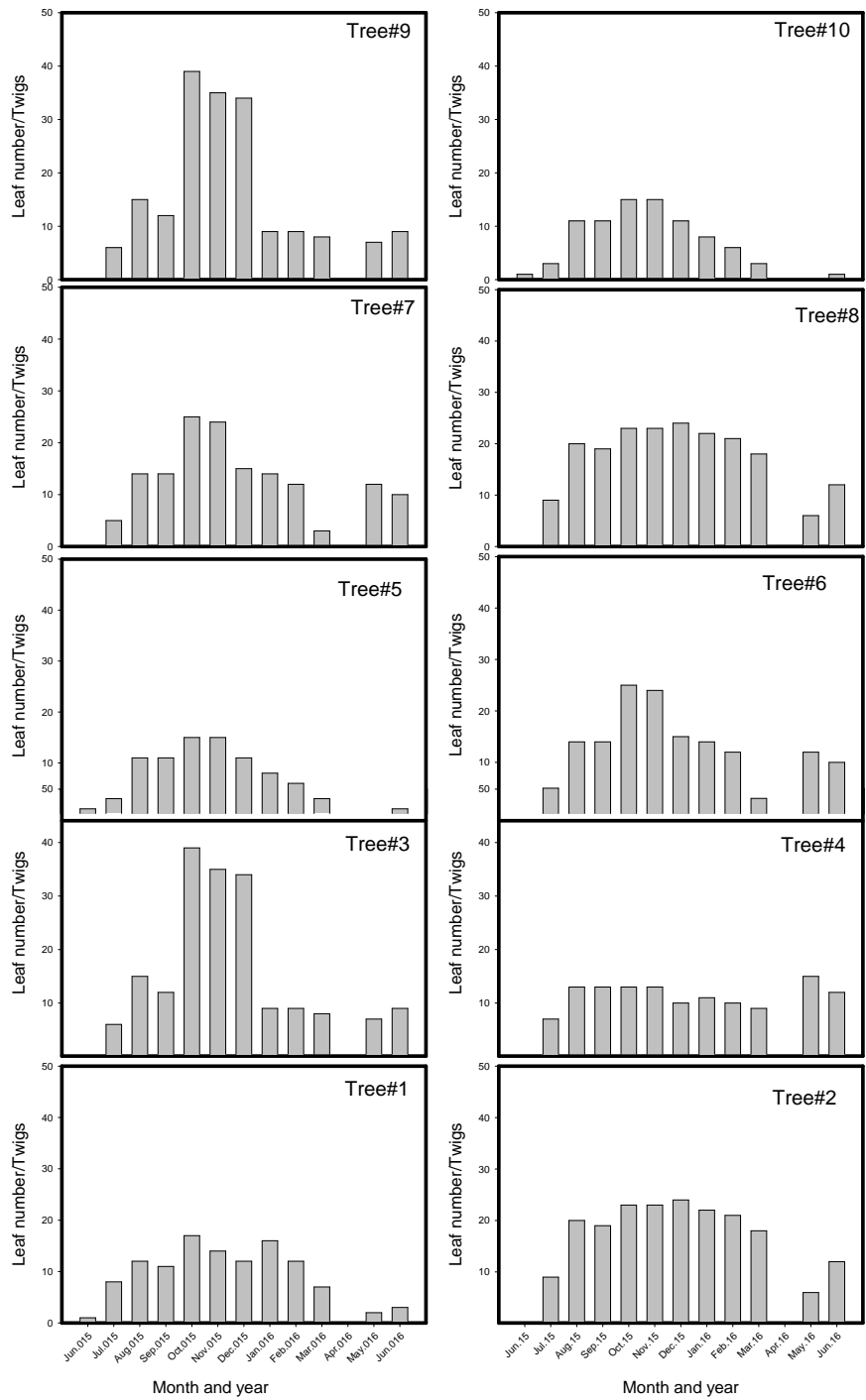


Figure 4.8a Leaflet numbers per twig in different months from June 2015-June 2016.

The mean leaflets remaining per twig of the above ten trees showed temporal and spatial variation. The highest mean leaflet per twig remaining was 23 during the dry

period (October–November) when the tree crown was fully foliated and then the number of leaflet per twig declined towards March and May each year and complete defoliation was observed in June both in 2015 and 2016 (Fig.4.8b). Leaflet remaining per twigs in October, November and December 2015 were significantly ( $p<0.05$ ) higher compared with the rest of the study periods except in August and September 2015; however, there was no data scored in April 2016 due to some security issue in the study area.

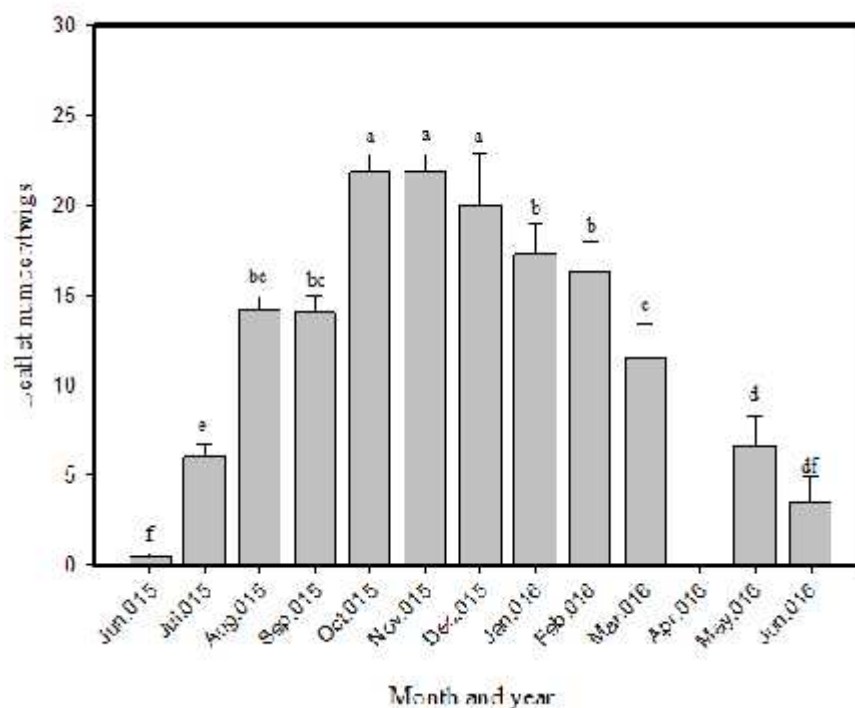


Figure 4.8b Monthly mean leaflets per twig of unpruned trees from June 2015 to June 2016; mean±SE (n=5).

#### 4.8.1. Relationship between leafing phenology and sap volume of unpruned *F. albida*

Sap volume in unpruned trees increased when the tree canopy was almost fully foliated and when the maximum leaflet was recorded (23 leaves let/twig) (Fig. 4.8b). However, the minimum sap volume was recorded from August-January each year

due to complete leaf foliation in unpruned trees (Fig. 3.2.1a); however, the sap volume in 2016 of same tree was higher in 2015 (Fig. 3.2.1b), since the branches from pruned trees were not pruned in 2016 to simulate the farmer's practice in the study area, since farmers prune the branches every 2-3 years.

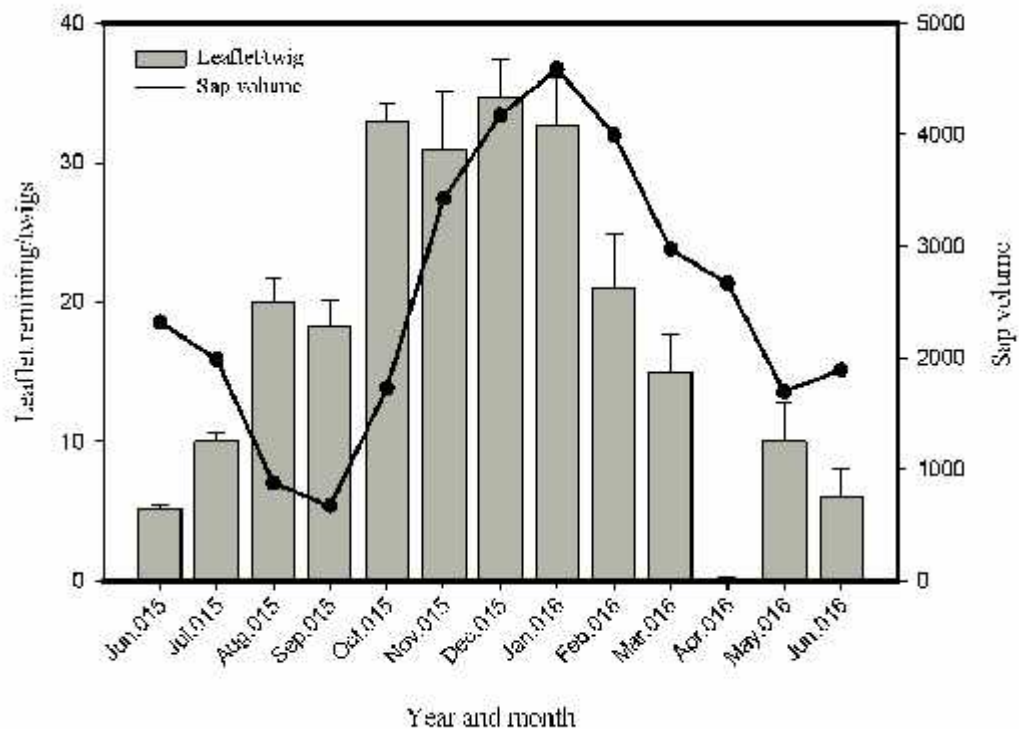


Figure 4.8.1 Relationship between monthly leaflet per twig remaining and sap volume of unpruned *F. albida* between June 2015-June 2016

#### 4.9. Physiological measurement of the wheat

##### 4.9.1. Relative water content (RWC) of the wheat

Relative water content (RWC) of the wheat showed slight difference as we go from the bole of the tree to the edge of the tree crown under unpruned and pruned trees. The mean relative water content of the wheat leaves obtained under unpruned *F. albida* at 1, 3 and 5m distance were  $85.1 \pm 2.3\%$ ,  $82.4 \pm 2.6\%$  and  $81.6 \pm 1.5\%$ , respectively; on the other hand, the highest mean relative water content of the wheat

recorded under pruned *F. albida* trees were  $80.1\pm 1.6\%$ ,  $78.2\pm 1.5\%$  and  $79.5\pm 1.6\%$  at 1, 3 and 5m distances, respectively.

The relative water content of the leaves of the wheat measured in unpruned and pruned trees were insignificant between the different tree management and across the different distances (Fig.4.9.1).

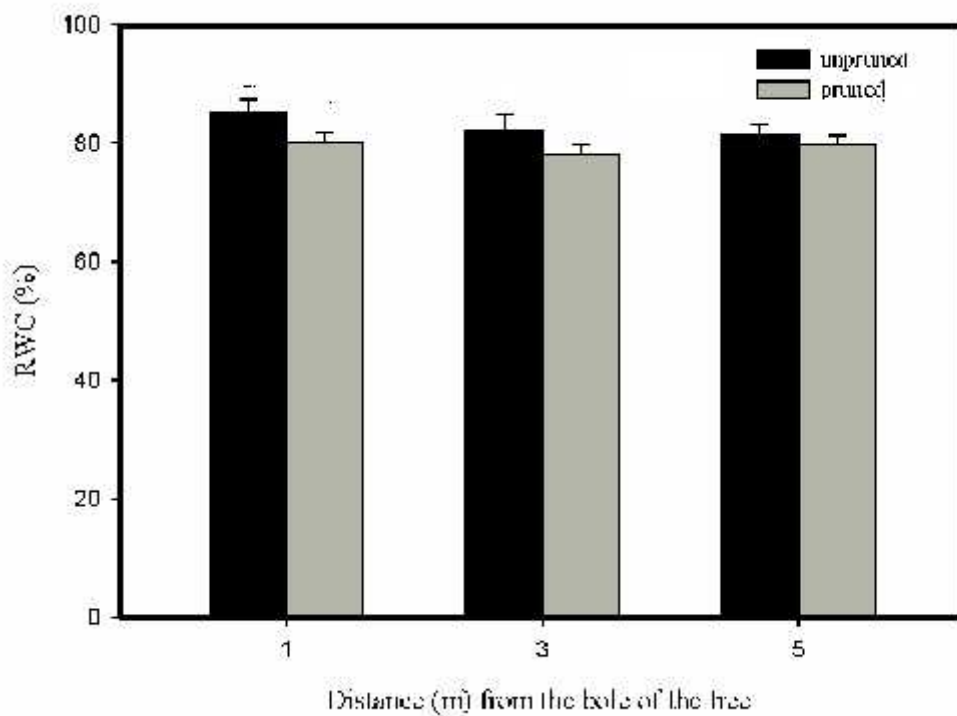


Figure 4.9.1 Relative water content (RWC) of the wheat under unpruned and under pruned tree (same letters showed there is no significant difference between different tree managements); mean  $\pm$ SE (n=18)

#### 4.9.2. Relative chlorophyll content (SPAD)

The SPAD reading of the wheat showed variation under unpruned and pruned trees as well as in different distances from the bole of the tree. The mean SPAD readings of the wheat under unpruned tree were  $45\pm 0.08$ ,  $46.6\pm 1.4$  and  $41.7\pm 2.0$  measured at 1, 3 and 5 meter distances, respectively; whereas, the mean SPAD readings of the

wheat under pruned tree were  $41.2 \pm 1.2$ ,  $39.7 \pm 2.3$  and  $37.7 \pm 1.1$  measured at 1, 3 and 5 m distances, respectively.

There was a significant ( $p < 0.05$ ) difference in SPAD reading between unpruned and pruned tree at 3 meter distance; whereas, the SPAD values between pruned and unpruned measured at 1 and 5 m distance from the tree trunk were statistically insignificant (Fig. 4.9.2).

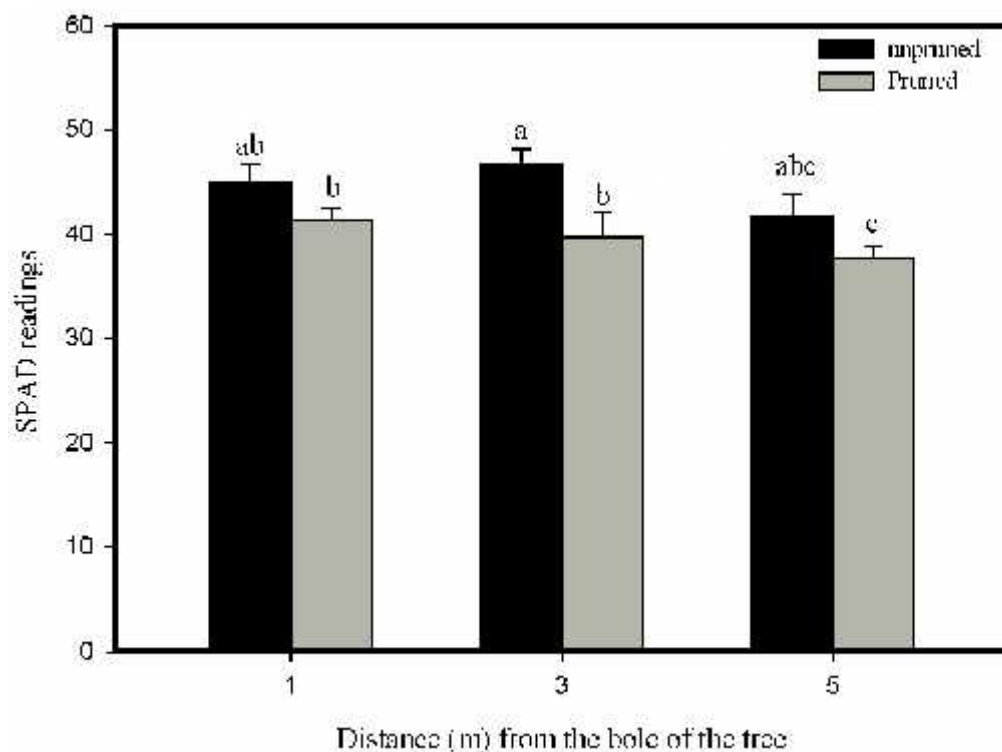


Figure 4.9.2 Total chlorophyll content (SPAD reading) of the wheat under unpruned and under pruned tree (different letters showed that there is a significant difference between different tree managements at different distances); mean  $\pm$ SE (n=18)

#### 4.9.3. Wheat gas exchange measurement

Figure 4.9.3 shows average CO<sub>2</sub> assimilation rates (c), transpiration rate (b) and instantaneous water use efficiency (WUE<sub>i</sub>) (a) of wheat at different distances from unpruned and pruned *F. albida*. The mean CO<sub>2</sub> assimilation rate of the wheat under

unpruned were  $5.6\pm0.3$ ,  $3.9\pm1.3$  and  $4.8\pm0.8 \mu\text{molm}^{-2}\text{s}^{-1}$  measured at 1m, 3m and 5m distance, respectively; on the other hand, the mean  $\text{CO}_2$  assimilation rate of the wheat under pruned *F. albida* were  $3.2\pm0.1$ ,  $4.1\pm0.2$  and  $5.3\pm0.4\mu\text{molm}^{-2}\text{s}^{-1}$  at 1m, 3 m and 5 m distance, respectively. However,  $\text{CO}_2$  assimilation rate of the wheat measured under unpruned and pruned trees were insignificant across the distances and within the different tree management types (Fig.4.9.3c).

The lowest transpiration rate (E) of the wheat under unpruned *F. albida* was  $1.2 \text{mmolm}^{-2}\text{s}^{-1}$  at 1m distance and showed an increment with distance from the bole of the tree. The highest mean transpiration rate was  $3.34 \text{mmolm}^{-2}\text{s}^{-1}$  measured at 3 meter under pruned *F. albida* and which was significantly ( $p<0.05$ ) higher compared with transpiration rate recorded at 1 and 5 meter distances of same tree as well as that of wheat under unpruned tree (Fig.4.9.3b). The mean transpiration rates of the wheat under unpruned trees were  $0.9\pm0.1$ ,  $1.6\pm0.1$  and  $1.3\pm0.1 \text{mmolm}^{-2}\text{s}^{-1}$  at 1, 3 and 5 m distance, respectively. On the other hand, the mean  $\text{WUE}_i$  of the wheat under pruned *F. albida* were  $1.1\pm0.03$ ,  $3.3\pm0.2$  and  $1.0\pm0.07 \mu\text{molm}^{-2}\text{S}^{-1}/\text{mmolm}^{-2}\text{S}^{-1}$ , at 1m, 3m and 5m distance, respectively.

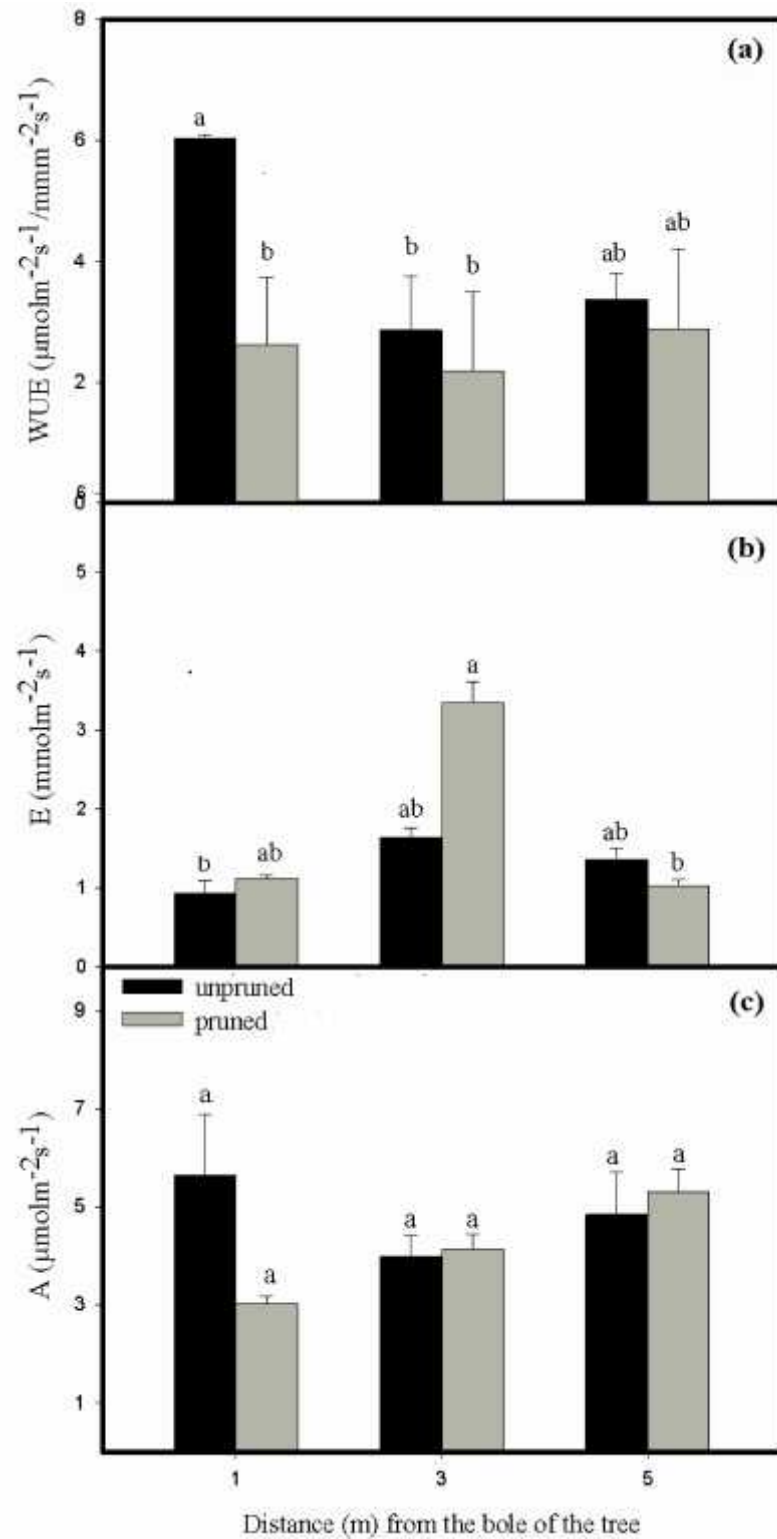


Figure 4.9.3 Mean  $\text{CO}_2$  assimilation rates (c) mean transpiration rate (b) and mean instantaneous water use efficiency ( $\text{WUE}_i$ ) (a) of the wheat from different distances under unpruned and pruned *F. albida*.

Instantaneous water use efficiency is the ratio of CO<sub>2</sub> assimilation to transpiration rate. WUE<sub>i</sub> of the wheat under unpruned *F. albida* tree was higher at 1m distance followed by 3 and 5 m distances of same tree (Fig.4.10.3a). The mean WUE<sub>i</sub> of the wheat under unpruned were  $6.2 \pm 0.04 \mu\text{mol m}^{-2} \text{s}^{-1} / \text{mm}^{-2} \text{s}^{-1}$ ,  $2.8 \pm 0.8 \mu\text{mol m}^{-2} \text{s}^{-1} / \text{mm}^{-2} \text{s}^{-1}$  and  $3.36 \pm 0.4$  at 1, 3 and 5m distances, respectively. On the other hand, the mean WUE<sub>i</sub> of the wheat under pruned *F. albida* were  $2.6 \pm 1.1$ ,  $2.18 \pm 1.2$  and  $2.8 \pm 1.3 \mu\text{mol m}^{-2} \text{s}^{-1} / \text{mm}^{-2} \text{s}^{-1}$ , respectively. WUE<sub>i</sub> of wheat under unpruned trees at 1m distance was significantly ( $p < 0.05$ ) higher compared with WUE<sub>i</sub> found at 3m distance of same tree and with wheat found under pruned trees at 1 and 3 meter distances. However, there was no significant difference in WUE<sub>i</sub> recorded at 5 meter distances under pruned and unpruned trees (Fig.4.9.3a).

#### **4.9.4. Light response of the wheat to different light sources**

The highest rates of carbon dioxide assimilation of the wheat were 17 and 13  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , within and outside of the canopy of unpruned tree at the PAR level of 700; however, as the PAR level increased, rate of photosynthesis declined to 3-5 and 0.5-5  $\mu\text{mol m}^{-2} \text{s}^{-1}$  from inside and outside of unpruned tree, respectively as the PAR level reached to 1500  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . Similarly, the highest rates of carbon dioxide assimilation measured from inside and outside of the canopy of pruned tree were 14.8 and 11  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , respectively; however, as the PAR level increased to 1800  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , carbon dioxide assimilation rate of the wheat under pruned trees were higher compared with outside of same trees (Fig 4.9.4a).

In general carbon dioxide assimilation of wheat under unpruned tree both from inside and outside of the tree canopy was higher compared with wheat under pruned tree of same distances and same PAR levels.

The highest rate of transpiration of wheat under and outside of unpruned tree were 4.1 and 3.3  $\text{mmol m}^{-2}\text{s}^{-1}$ , respectively between the PAR level of 500-800  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , as the PAR level increases and reached to 1500  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , transpiration rate of the wheat under unpruned tree decreased below 2  $\text{mmol m}^{-2}\text{s}^{-1}$  especially under unpruned tree (Fig. 4.9.4c). On the other hand, transpiration rate of the wheat measured outside pruned tree was higher compared with inside of pruned tree at the PAR level around 150  $\mu\text{mol m}^{-2}\text{s}^{-1}$ . However, as the PAR level increased to 1500  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , rate of transpiration of the wheat was found below 2  $\text{mmol m}^{-2}\text{s}^{-1}$  (Fig. 4.9.4d).

Wheat stomatal conductance showed a similar pattern with that of transpiration rate under and outside of the two tree management types. The stomatal conductance under (1 and 3m from the tree trunk) unpruned tree was higher between the PAR levels of 500-800 and declined as the PAR level reaches to 1500  $\mu\text{mol m}^{-2}\text{s}^{-1}$  (Fig. 4.10.4e), on the contrary, the stomatal conductance of the wheat were below 0.1  $\text{mol m}^{-2}\text{s}^{-1}$  under (1 and 3m from the tree trunk) pruned tree both under and outside of the tree canopy (Fig. 4.9.4f).

In general, variation in physiological indices such as carbon dioxide assimilation rate, transpiration rate and stomatal conductance of the wheat were observed under unpruned tree were higher as compared with under pruned tree of similar distances and similar PAR levels.

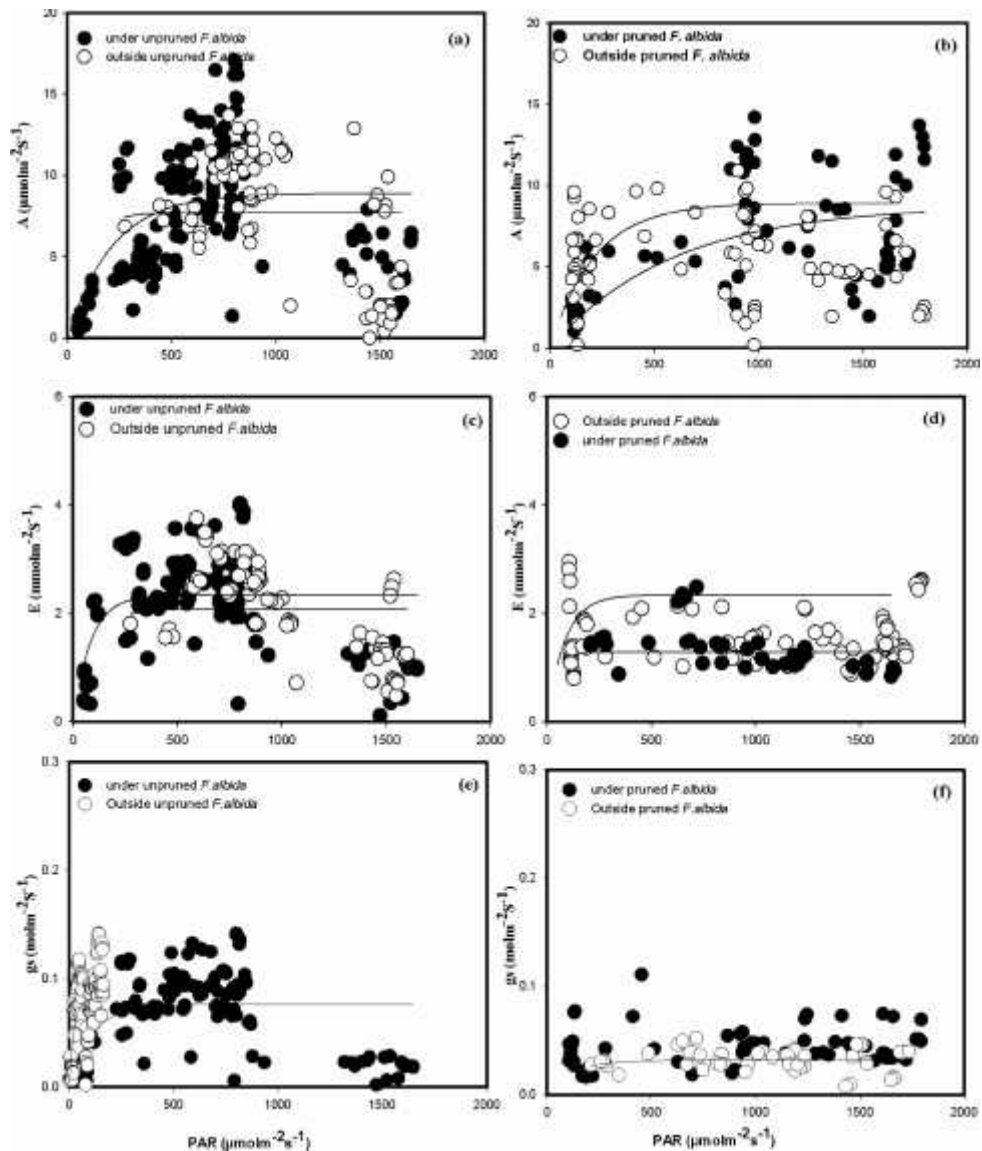


Figure 4.9.4 CO<sub>2</sub> assimilation rate (a&b), transpiration rate (c&d) and stomatal conductance (d&f) of the wheat under unpruned and pruned trees to different light levels, where closed circle represent inside ( ) and open circle represent ( ) outside of both unpruned and pruned trees.

## 4.10. Wheat growth measurement

### 4.10.1. Shoot height

Differences were observed in shoot height of the wheat under different distances from the bole the tree as well as between the tree management types. The shoot

height of the wheat declined as we go away from the tree trunk to the edge of the tree crown. The mean shoot height under unpruned *F. albida* tree were  $49.6 \pm 1.5$ ,  $48.1 \pm 1.4$  and  $43.4 \pm 2.4$  cm at 1, 3 and 5 m distance, respectively; whereas, the mean shoot height of the wheat measured under pruned tree were  $47.4 \pm 1.6$ ,  $46.2 \pm 1.5$  and  $37.1 \pm 2.7$  cm from 1, 3 and 5m distances, respectively. There was significant ( $p < 0.05$ ) difference in shoot height under unpruned tree at 1 m distance compared with at 3 and 5m distances of the same tree as well as across the distances under pruned (Fig. 4.10.1).

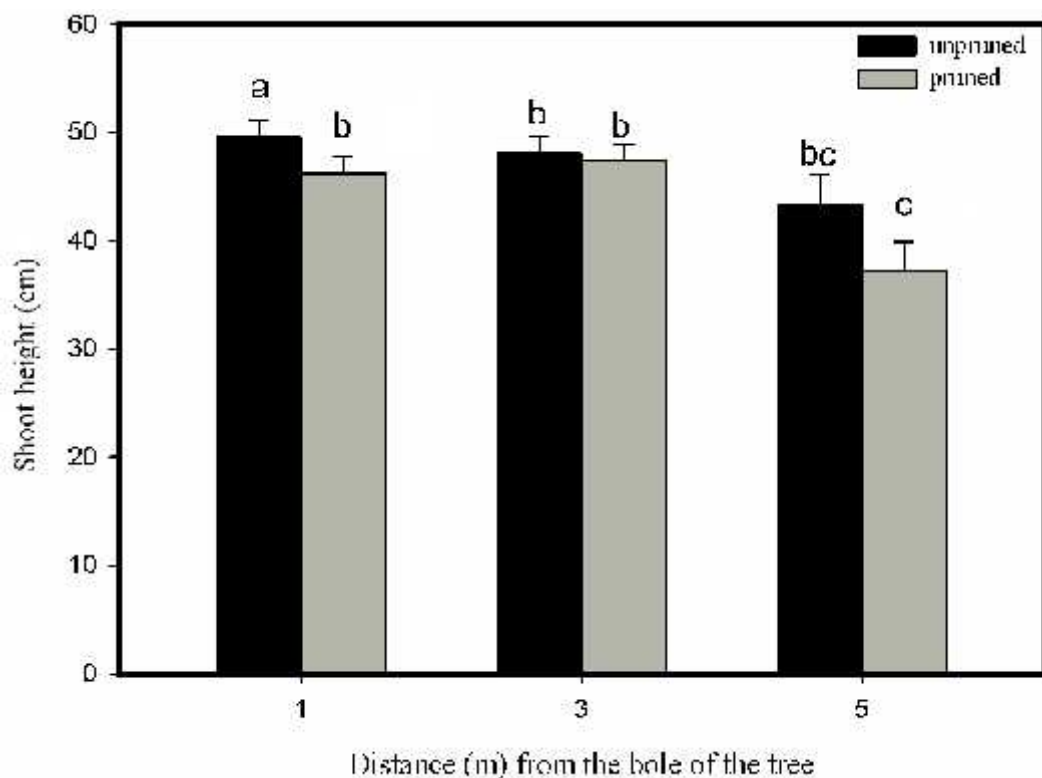


Figure 4.10.1 Mean shoot height of the wheat under unpruned and pruned *F. albida* from different distances, (different letters showed that there is a significant difference between different tree managements across different distances) from the bole of the tree; mean  $\pm$  S.E (n=45)

#### 4.10.2. Wheat tiller number

The number of tillers under unpruned tree was higher compared with under pruned tree of same distance. The mean tiller number scored under unpruned tree were  $8.7 \pm 0.7$ ,  $7.5 \pm 0.2$  and  $7.1 \pm 0.2$  at 1, 3 and 5m distance, respectively from the bole of the tree; whereas, the mean tiller number measured under pruned *F. albida* were  $6.3 \pm 0.3$ ,  $5.6 \pm 0.2$  and  $6.3 \pm 0.2$  m obtained from 1, 3 and 5m distance, respectively. There was significant ( $p < 0.05$ ) difference of tiller number scored from unpruned tree at 1 compared with 3 m distances of same tree as well as under 3 m distance under pruned tree, but not with 5 m distance of same tree as well as at 1, and 5 m distances of under pruned trees; however, the number of tillers scored under pruned tree at 1, and 5 meter distances of pruned trees were insignificant (Fig.4.10.2).

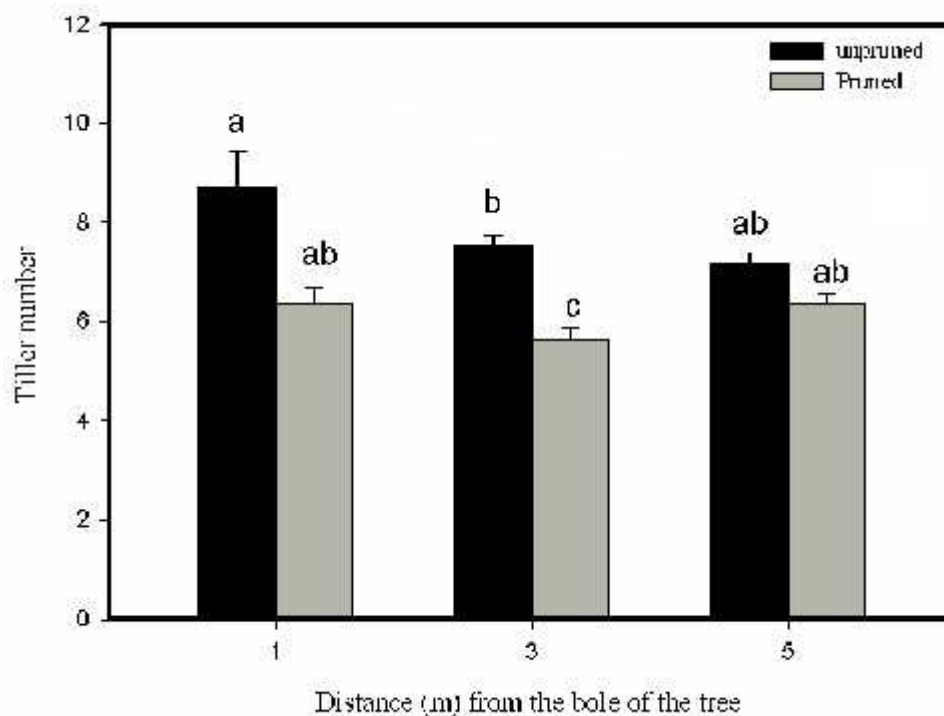


Figure 4.10.2 Mean number of tiller under unpruned and under pruned *F. albida* trees, (different letters showed that there is a significant difference between different tree managements and between different distances); mean $\pm$ S.E (n=45)

## 4.11. Wheat biomass measurement

### 4.11.1. Aboveground biomass of the wheat under pruned and unpruned *F. albida*

Aboveground biomass of the wheat showed a decreasing trend as we go from the bole of the tree under the two management types. The mean aboveground biomass of the wheat under unpruned *F. albida* were  $3.3\pm 0.2$ ,  $2.8\pm 0.2$  and  $2.6\pm 0.2$  t ha<sup>-1</sup> found from 1m<sup>2</sup> at 1, 3 and 5 m distances, respectively; whereas, the mean aboveground biomasses of the wheat under pruned tree were  $2.9\pm 0.2$ ,  $2.5\pm 0.2$  and  $2.3\pm 0.2$  t ha<sup>-1</sup> found at 1, 3 and 5 meter distances, respectively. Aboveground biomass of the wheat under unpruned tree at 1m distance was significantly ( $p<0.05$ ) higher compared with under pruned tree of same distance; however, no significant ( $p>0.05$ ) difference of wheat aboveground biomass were observed under unpruned and pruned tree at 3 and 5 m distances (Fig. 4.11.1). In general aboveground biomass of the wheat under unpruned *F. albida* tree were higher by 28, 17 and 11% compared with aboveground biomass of the wheat found under pruned tree of same distances from the tree trunk.

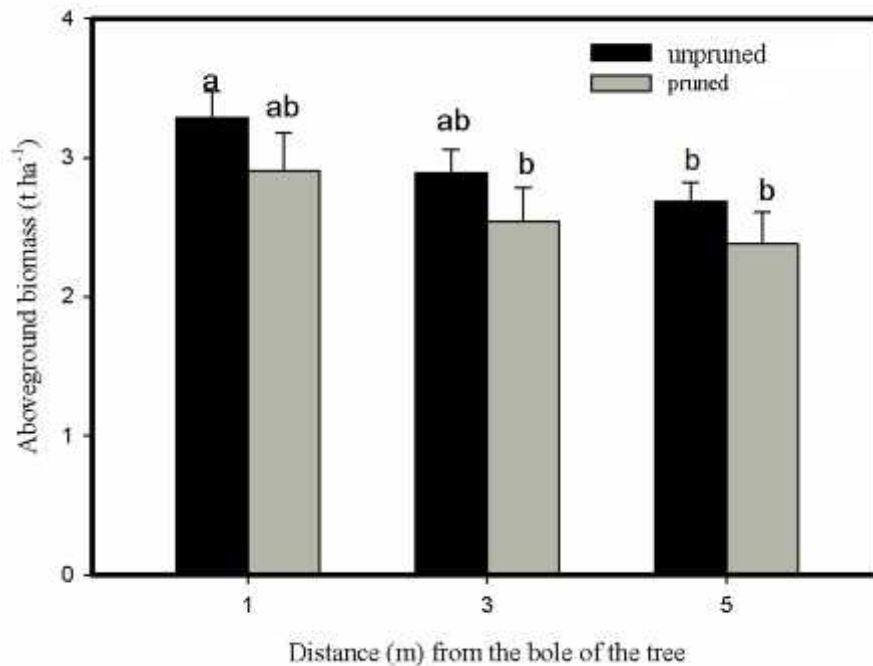


Figure 4.11.1 Wheat aboveground biomass (t ha<sup>-1</sup>) under unpruned and pruned *F. albida* at different distances (different letters showed that there is a significant difference between different tree managements and distances); mean±S.E (n=27)

#### 4.11.2. Grain weight of wheat

The grain yield of wheat showed a decreasing trend as we go from the tree trunk under the two tree management types in similar trend with that of aboveground biomass. The mean grain yield obtained under unpruned tree were 2.9±0.2, 2.5±0.0.2 and 2.38±0.2 t ha<sup>-1</sup> from 1m<sup>2</sup> at 1, 3 and 5m distances, respectively; whereas, the mean grain yield obtained under pruned *F. albida* tree were 2.2±0.2, 2.3±0.2 and 2.3±0.1 t ha<sup>-1</sup> from 1, 3 and 5m distances, respectively. The grain yield found at 1m distance was significantly (p<0.05) higher compared with the grain yield measured under 5 m distance of same tree as well as the grain yield found under 3 and 5m distances under pruned tree; however, no significance (p>0.05) difference of grain yield was observed under unpruned and pruned tree at 3 m

distance (Fig.4.11.2). Grain yield of the wheat obtained under unpruned *F. albida* was higher by 27, 23 and 23% at 1, 3 and 5m distances compared to pruned *F. albida* tree of similar distances from the tree trunk.

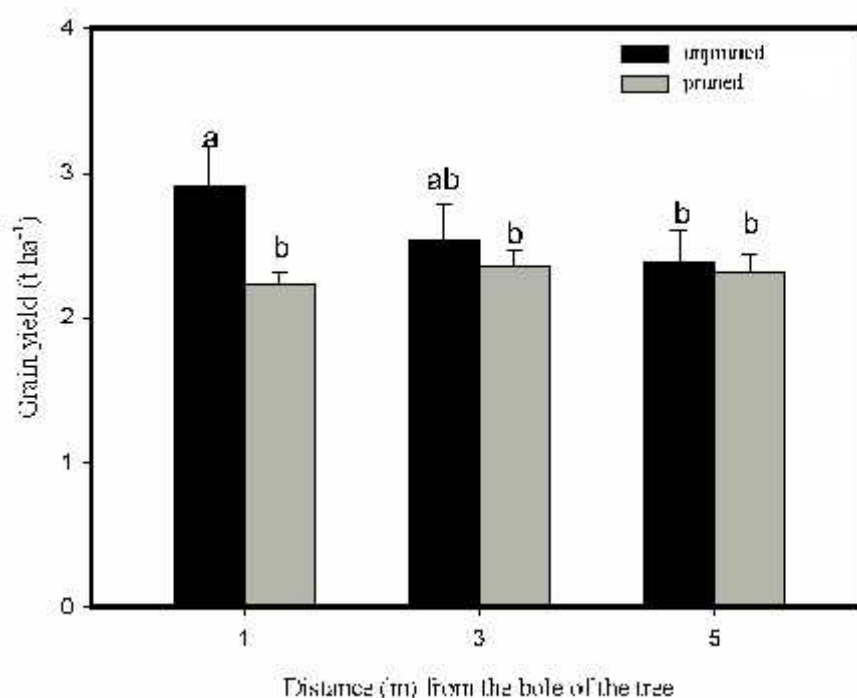


Figure 4.11.2 Wheat grain yield under unpruned and pruned *F. albida* at different distances (different letters showed that there is a significant difference between different tree managements and distances); mean±S.E (n=27).

Table 8. Mean aboveground biomass and the grain yield of the wheat under (1 and 3 m) and outside (5 m) from the tree trunk

Tree management	Location from the tree	Aboveground biomass (t ha <sup>-1</sup> )	Grin yield (t ha <sup>-1</sup> )
Pruned	Under	2.3±0.18 <sup>ab</sup>	1.51±0.12 <sup>a</sup>
Pruned	Outside	2.1±0.24 <sup>b</sup>	1.29±0.28 <sup>a</sup>
Unpruned	Under	3.3±0.21 <sup>a</sup>	2.07±0.29 <sup>b</sup>
Unpruned	Outside	2.7±0.31 <sup>a</sup>	1.82±0.264 <sup>ab</sup>

Aboveground biomass of the wheat found under and outside of unpruned tree was significantly ( $p < 0.05$ ) higher compared with outside of the pruned tree. However, aboveground biomasses of the wheat found under and outside of same tree management were insignificant (Table 8).

Aboveground biomass found under pruned tree was lower up to 30% as compared with aboveground biomass of the wheat found under unpruned tree of similar distance. The grain yield obtained under unpruned *F. albida* was significantly ( $p < 0.05$ ) higher compared with the grain yield obtained outside of same tree as well as both under and outside of pruned tree. However, the grain yield obtained under and outside of the pruned tree was insignificant. The average grain yield of wheat obtained in the study area was  $1.6 \text{ t ha}^{-1}$  (personal communication with the farmers); however, the mean grain yield obtained under and outside of unpruned *F. albida* tree was  $1.9 \text{ t ha}^{-1}$ , the effect of intercropping unpruned *F. albida* increases the grain yield by 18.2% as compared with average yield found in Ejerssa Joro Kebele, Lome woreda, Oromia Oregional State.

## CHAPTER FIVE

### 5.0. DISCUSSION

#### 5.1. The use of *F. albida* on soil moisture beneath the tree

The present study aimed at understanding the influence of intercropped *F. albida* tree on microclimate of understorey crops, as well as the impact of pruning *F. albida* on soil nutrient status, tree water use, leaf foliation/defoliation pattern and understorey wheat productivity. Differences both in spatial and temporal soil moisture were observed under unpruned and pruned *F. albida* tree; however, Soil moisture found under (at 1 and 3 m) unpruned tree was significant higher ( $p < 0.05$ ) as compared with the soil moisture under pruned tree of similar distances. This might be due to the higher interception of high light intensity by the tree canopy in unpruned tree (Photo. 3.2.1a) could reduce evapotranspiration and the canopy could also enhances rate of rain water infiltration.

The scattered trees on the agricultural landscape as “nurse trees” due to their pronounced nursing effect to the underneath crops, where water and nutrient availability are found in most critical condition but also govern crops productivity (De Boever, 2015). *F. albida* is considered as an important tree that used to modifies microclimate, such as reducing high light intensity and optimizing the temperature for the accompanying crops (Jones *et al.*, 1997; Ong and Swallow, 2003; Sida *et al.*, 2018). For instance, the PAR levels measured under unpruned *F. albida* at 1m distance was significantly ( $p < 0.05$ ) lower compared with same tree at 5 meter distances as well as under pruned tree at 1, 3 and 5 m distances (Fig. 4.2). *F. albida* is a source of shade to the accompanying crops and reduce high temperature and desiccation (Dechasa Jiru, 2004; Sida *et al.*, 2018). *F. albida* plays vital role to

the underneath crops to improve the environment for better utilization of resources such as water and nutrients (Jerneck and Olsen, 2013). Previous studies indicated that microclimate created by the stand of *F. albida* improves various climatic conditions such as reducing evapotranspiration; lessen air and soil temperature as well as solar radiation (Barnes and Fagg, 2003). In the present study, the PAR level was reduced by 77% under unpruned *F. albida* particularly at 1m distance due to the light interception by the branches of the tree (Fig. 4.2); interestingly, there is a minimum competition of the tree on soil moisture and nutrients with the underneath crops as it enters into physiological dormancy during the crop season (Dangasuk *et al.*, 1999).

Higher light intensity brings about an increase in temperature which affects tree and crop productivities through accelerating phenology (Asseng *et al.*, 2015). High light intensity and low soil moisture content found under pruned *F. albida* become the root cause for reduction in crop productivity (Dilla *et al.*, 2018). Reproductive stages of crops and plant are more sensitive to extreme temperature which may reduce grain yield by 80-90% as compared to the normal temperature regime (Hatfield and Prueger, 2015). Both evapotranspiration and low soil water content limit both plant water relations and gas exchange (Zha *et al.*, 2017).

The highest soil moisture percentage was recorded during the main rain season (July-September 2015 and 2016) which declined towards the dry periods (November 2015 to May 2016) under both tree management types. The higher soil moisture under unpruned tree might be due to the highest organic matter content found as the result the litterfall incorporated beneath the tree (Fig. 4.5.2.3). Intercropping of perennial tree may help in retaining soil moisture and delaying the onset of water stress

condition (Siqueira *et al.*, 2008); not only by alleviating water stress condition but also by enhancing nutrient availability for under canopy crops (Bayala *et al.*, 2008). Several reports have been shown that high organic carbon improves the soil texture and contributes to improve water retention up to 10-20% higher compared with low organic carbon content of sandy soil (Rawls *et al.*, 2003). The tree is also known with hydraulic pump and redistributing of moisture and nutrients to the upper soil surface which improves crop productivities to the vicinity of the tree trunk (Alexandre and Ouedraogo, 1992). The persistent foliage of *F. albida* in the dry season is an important option for mulching (Jones *et al.*, 1997; Dangasuk *et al.*, 1999a; Ong and Swallow, 2003; Iiyama *et al.*, 2017; Sida *et al.*, 2018). Similarly the moisture residual from mature trees ease competition with the understorey crops (Schoonmaker *et al.*, 2008).

The highest soil moisture percentage was measured in July 2016 at 1m distance under unpruned (41.3%) and pruned (23.5%) *F. albida*, this might be due to the higher rainfall in July (Fig. 4.1) and maybe due to the tree canopy was foliated with leaves that reduce high light intensity and ease evapotranspiration (Fig.3.2.1.a). The lowest soil moisture records were 5.7 and 4.5% measured in June 2015 and 2016 outside unpruned and pruned tree. Soil moisture measured under unpruned tree was significantly ( $p < 0.05$ ) higher compared with the moisture content under pruned tree across the different soil depths; similar result was reported by Siddique *et al.* (1990); who reported, the branches from unpruned tree enhanced rate of percolation into the soil pores which is important to enhance soil moisture and to recharged ground water table. However, soil moisture measured under pruned tree from different

depths (10-100cm) do not have not have much difference between 1 and 6 m distances from the tree trunk (Fig. 4.4.2.).

### **5.2. The influences of *F. albida* on soil nutrient**

The tree in the study area defoliates the leaves around mid of June each year which is the onset of the main rain season (Fig.3.21b); when the land is under preparation for the planting period which offers an opportunity to incorporate the litter in the soil and improve soil nutrient content. However, the type of nutrients released from the litter depends on time of leaf phenophase, litter types and rate of decomposition (Rhoades, 1996). One of the advantages of intercropping deep rooting perennial trees such as *F. albida* is taking up water and nutrient which is far beyond the crop root zone (Richards and Caldwell, 1987).

*F. albida* is known for fixing atmospheric nitrogen as well as adding litterfall to the soil which improves major soil nutrients such as nitrogen, phosphorous and potassium (Gajaseni and Gajaseni, 1999; Bonkougou, 2001; Fadl, 2010; Luvanda *et al.*, 2016). On the other hand, the tree does not compete with the underneath crops for soil nutrients since it enters into physiological dormancy during the crop season (Dangasuk *et al.*, 1999). The reverse leaf phenology of the tree makes it, the most compatible tree in agroforestry systems in improving soil nutrient (Boffa, 1994; Orwa *et al.*, 2009).

The tree adds high organic carbon to the soil from its litterfall which is crucial to improve crop productivity (Kalinda *et al.*, 2015). Similar report showed that an increase in grain yield close to *F. albida* tree could be due to high accumulation of soil organic matter, nitrogen fixation and nutrient recycling at the rhizosphere (Komicha Negeyo , 2018)

*F. albida* has an extended lateral root system which plays significant role in soil stabilization as well as in improving chemical properties of the soil beneath the tree canopy especially for the most essential nutrients such as nitrogen, phosphorous and potassium (Dangasuk *et al.*, 1999; Thakur and Singh, 2008; Sanda and Atiku, 2013; Umar *et al.*, 2013). The litterfall has a significant role for soil organic matter to the accompanying crops and it is important in soil stabilization as well as in improving chemical properties of the soil under the tree canopy especially for the most essential nutrient such as NPK (Mokgolodi *et al.*, 2011; Sanda and Atiku, 2013); soil organic carbon (Fig. 4.5.2.3); total nitrogen (Fig. 4.5.2.2) and available phosphorous in the present study (Fig. 4.5.2.4) were significantly ( $p < 0.05$ ) higher under unpruned at 1m distance compared with pruned tree of similar distances. The result concurred with Aseferachew Abate *et al.* (1998), who reported that soil organic carbon, total nitrogen and available phosphorous of the soil were higher under the tree canopy of *A. senegal* and *A. tortilis*. Total nitrogen and organic carbon of the soil were higher close to *F. albida* tree compared with open area (Umar *et al.*, 2013; Getahun Haile *et al.*, 2014; Dilla *et al.*, 2018; Sida *et al.*, 2018). Similar result was reported by different authors where nitrogen percentage was reported to be higher by 33-35% close to *F. albida* tree compared to the crop without tree (Sida *et al.*, 2018); and soil carbon was significantly higher close to *F. albida* tree (Dilla *et al.*, 2018). The soil particle size found from inside and outside of both tree managements and from different distances from the bole of the tree were fine loamy sand (Table 3). This is in agreement with Zeleke Asaye (2017), who reported, soil particle size was independent with the distance from the tree trunk.

### 5.3. Impact of pruning on stem water potential and sap volume of *F. albida*

Information related to water use efficiency and leaf phenophase of different agroforestry trees are important in understanding tree-crop interactions particularly in semi-arid tropics as difference within the extent of competition or complementarity between trees and crops (Muthuri *et al.*, 2009). Trees with larger crowns facilitate percolation of rain water into the soil pores and recharge ground water table (Ilstedt *et al.*, 2016). Predawn stem water potential was higher than midday both in unpruned and pruned *F. albida*. Similar findings are reported by different scholars, the lower leaf water potential during the midday might be due to high temperature and evaporation causing stress on the tree (Intrigliolo and Castel, 2006; Agele and Cohen, 2007; David *et al.*, 2007; Aster Gebrekirstos *et al.*, 2011); however, both predawn and midday stem water potential was higher in pruned *F. albida* compared to unpruned *F. albida* (Fig.4.6.1); perhaps be due to the lower canopy area in pruned trees reduces canopy evapotranspiration demand (Table 1).

Intrigliolo and Castel (2006) reported that significant difference between midday and predawn leaf water potential was due to the response to the soil moisture status caused by different irrigation management (Nortes *et al.*, 2005). Rouspard *et al.* (1999) reported; midday leaf water potential of *F. albida* dropped up to -0.5MPa when soil moisture was low in the sub soil surface; indicating the tree was under moderate stress condition. Predawn leaf water potential of *B. aegyptica* and *A. tortilis* were -2.36MPa and -1.89 MPa, respectively, while midday water potential of same trees were -4.61MPa and -3.05MPa, respectively (Aster Gebrekirstos *et al.*, 2006). Stem water potential of *F. albida* in the present study indicated that both midday and predawn leaf water potential was higher than the value of *B. aegyptiaca*

and *A. tortilis* reported from the same region. The finding indicates that *F. albida* tree is possibly using deeper water sources and is less stressed to water deficit condition compared to the co-occurring species of *B. aegyptica* and *A. tortilis*.

Ground water sources are used as sources of transpiration of plants up to 70% during the dry season (David *et al.*, 2007). Water absorption by the tap root system enhances plant hydraulic lift which helps to reduce the demand of transpiration by 25-50% in dry periods and has a significant role for soil moisture and nutrient uptake to the accompanying crops and the neighboring shrubs and herbs in arid areas (Caldwell and Richards, 1989).

Sap flow rate and sap volume of *F. albida* tree varied between different management types, season and leaf foliation and defoliation patten (Photo 3.3.1b). Tree water use is reduced by a decrease in photosynthetic performance of the plant, plant architecture as well as the change in leaf area (Thakur and Singh, 2008; Alcorn *et al.*, 2013). The highest sap flow rate and sap volume were recorded from unpruned *F. albida* tree in dry period (January) when the tree crown become fully foliated (Photo 3.3.1a).

The daily maximum and minimum sap flow rates of unpruned *F. albida* during the dry period (January) were 78.9 and 3.5 ms<sup>-1</sup> recorded at 01:00 and 04:00 hours, respectively (Fig.4.6.5a); whereas, the daily maximum and daily minimum of sap flow rate of pruned *F. albida* were 51.2 and 1.2 ms<sup>-1</sup> recorded at 3:00 pm and 7:00 am (Fig.4.6.5b). The higher temperature during the dry period induces a higher sap flow rate in unpruned and pruned tree (Fig.4.1); whereas, the lowest diurnal sap flow

rates of unpruned and pruned tree were recorded late in the evening and early in the morning, when evapotranspiration becomes very low.

Monthly maximum sap flow rate  $55.6 \text{ ms}^{-1}$  and  $43.2 \text{ ms}^{-1}$  were recorded in unpruned and pruned *F. albida*, respectively around January and February in 2015. However, sap flow rate was reduced to  $5.5$  and  $9.6 \text{ ms}^{-1}$  in May 2015, this might be due to leaf defoliation in unpruned tree (Fig.3.3.2a) and pruning the branches in pruned tree in June (Fig.3.3.2b). The result concurred with the report by Alcorn *et al.* (2013), who reported that pollarding the tree reduce transpiration rate by 39% and 59% in *Eucalyptus pilularis* and *Eucalyptus cloeziana*, respectively compared to the non-pollarded one.

Monthly sap flow rate recovers around September when the leaf start to flushes in unpruned tree (Fig.3.3.1a) and as the braches expand from pruned trees (Fig.3.3.2b) and reached to  $41.6 \text{ ms}^{-1}$  in January and  $46.7 \text{ ms}^{-1}$  in October 2016 towards the dry periods. *F. albida* is known with deep and tap root system extend to the depth of 40 m which might help the tree to explore more water especially during the dry season (Boffa, 1994; Orwa *et al.*, 2009). The higher sap volume in unpruned tree might be due to the higher canopy area and sap wood depth compared with the pruned one (Table 1). Similar result was reported by Oren *et al.* (1999), where sap flux was directly proportional with sap wood area.

Sap volume recorded from unpruned tree was significantly ( $P < 0.05$ ) higher compared with pruned *F. albida*. The highest sap volume from unpruned and pruned trees were  $4590$  and  $599 \text{ L month}^{-1}$ , which means  $153$  and  $16.9 \text{ L day}^{-1}$ , respectively recorded in January 2016. The low relative humidity (45%) and higher temperature (Fig.4.1) might have exacerbated the rate of transpiration. Sap flow rate is correlated

positively with high light intensity, air temperature and water vapor pressure deficit (Zha *et al.*, 2017). On the contrary, the lowest sap volume was 403 and 0.4-1.4 L month<sup>-1</sup>, measured in September 2015 in unpruned and pruned tree, respectively. This might be possibly due to the low relatively higher mean relative humidity (47%) and lower mean air temperature (22°C) (Fig.4.1) might have contributed to the low sap volume measured from both unpruned and pruned trees.

#### **5.4. The effect of pruning on leafing phenology of *F. albida***

The number of leaflets remaining per twig and within trees showed variation perhaps due to disturbances such as pruning and browsing by goats and camels. The branches were pruned around the onset of the rain season which has a pronounced effect altering the normal leafing phenology as well as flowering and fruit setting of *F. albida*. Pruning has a negative effect on the time of flowering and fruiting and even as pruning become more intense, fruit productivity will be severely affected (Jorquera-Fontena *et al.*, 2014). The highest and lowest leaflet scored per twig were 40 and 15 recorded in October from tree number 3 and tree number 5, respectively (Fig. 4.8a). Not only variations in leaflet number per twig within the trees, but also inconsistency was observed in leaf foliation/defoliation among trees in the study area, again as the result of extensive pruning of the branches of the tree (Fig. 3.3.2b). Pruning the branches of guava tree alters leafing phenology and, delays flower and fruit development (Singh *et al.*, 2015). In the present study leaf defoliation was observed from unpruned *F. albida* around the onset of the main rain season mainly in the first week of June of each year (Fig. 3.3.1b) and the leaf starts to flushes from beginning of July and the canopy gets foliated during the entire rain periods around the study area (Fig. 3.3.2a). In contrast to this finding; different information has been

documented about the nature of leafing phenology of *F. albida* that the tree is fully defoliated during the main raining season and the canopy of the tree becomes fully foliated during the entire dry period (Ismael, 1986; Roupsard *et al.*, 1999). Pruning the branches of *Citrus reticulata* tree affects shoot emergence as compared in unpruned tree and even it was recorded earliest in severely pruned trees (Dhaliwal *et al.*, 2014). Both aboveground and below ground biomass production were affected by pruning the trees and subsequently reduce below ground resources utilization due to limited root growth (Bayala *et al.*, 2004).

#### **5.5. The effect of pruning on cambium growth of *F. albida***

Dendrometer is one of nondestructive techniques to measure large scale tree growth and response to different environmental conditions (Wang and Sammis, 2008). The highest cambium growth was recorded in unpruned *F. albida* as compared to pruned one during the study period. The cambium dynamics was very slow around the onset of the main rainy season and declined towards the dry period (Fig.4.7.1); this might be due to the soil moisture in the beginning of the rainy period was very small to be absorbed by the tree since cambium increment is the difference between the swellings and shrinking of the stem. The highest amplitude and cambium growth was observed when the highest sap volume was recorded especially in unpruned tree from October to April 2015 and 2016 (Fig. 4.6.5) and when the crown of tree was fully foliated during the dry period (Fig. 4.8). This might be due to the tap rooting systems of the tree and probably can access water in the aquifer to respond to transpiration demand. This agreed with the report by Zweifel *et al.* (2001); stem growth change was determined by the daily course of transpiration during the day and the water stored in the tissue during the night. The highest fluctuation of the

stem change associated with water potential (Makinen *et al.*, 2003). Stem growth change is related to water status and bark hydration; however, the amplitude of shrinking and swelling was also affected by some climatic variables (Herrmann *et al.*, 2005). The lowest growth change was observed around the onset of the main rainy season (May- July); perhaps due to leaf fall in unpruned (Photo 3.3.1b) and the effect of pruning in pruned tree (Photo 3.3.2b). Contrary to the report by Aster Gebrekirstos *et al.* (2008), where the mean annual diameter increment of trees varied from species to species; but it was, positively correlated with external climatic factors such as precipitation. This differences might be attributed a peculiar reverse leafing phenology of the *F. albida*.

#### **5.6. The influences of *F. albida* on the understorey wheat Physiology**

In the present study, higher CO<sub>2</sub> assimilation rate (Fig.4.9.4a) and stomatal conductance (Fig.4.9.4e) were higher under unpruned *F. albida* at 1m distance as compared with same tree at 3 and 5m distances from the bole of tree. The higher CO<sub>2</sub> assimilation rate and stomatal conductance inside unpruned trees maybe due to higher soil moisture content (Fig.4.4.1); higher total nitrogen percentage of the soil beneath unpruned *F. albida* tree (Fig.4.5.2.2) and the higher chlorophyll content of the leaves under unpruned tree (Fig. 4.9.2). Higher SPAD reading is related to higher pigment values which are also an indicator of nitrogen contents as well as higher photosynthetic performance of the wheat (Shah *et al.*, 2017). On the contrary, the low wheat productivity under pruned *F. albida*, might be due to the higher PAR level (Fig. 4.2) and low soil moisture under the pruned tree canopy (Fig. 4.4.1). Carbon dioxide assimilation of the wheat under unpruned tree declined away from the bole of the tree. However, CO<sub>2</sub> assimilation rate (Fig. 4.9.4b) and stomatal

conductance (Fig.4.9.4f) of wheat did not show any clear trend with distance under pruned *F. albida*. Higher temperature outside the tree canopy may have reduced photosynthetic performance of the wheat. High temperature suppresses assimilation rate of photosynthesis of C3 plants (Neri *et al.*, 2003; Huett, 2004).

In the present study, transpiration rate of the wheat was lower under unpruned *F. albida* from 1m compared to 5m distance from the tree trunk (Fig.4.9.4c). The lowest in CO<sub>2</sub> assimilation of the wheat outside the crown of the tree might be due to high light intensities (Bote and Struik, 2011).

Rate of carbon dioxide assimilation of the wheat measured under pruned *F. albida* was 2.6  $\mu\text{molm}^{-2}\text{s}^{-1}$  which was lower by 60 percent compared with wheat carbon dioxide assimilation rate measured under unpruned tree. This might be due to the highest PAR level (Fig.4.2) measured under pruned tree; lower total nitrogen (Fig.4.5.2.2) and lower organic carbon (Fig.4.5.2.3) content of the soil as well as lower chlorophyll content (Fig.4.9.2) measured from the wheat under pruned tree of similar distance. The lower SPAD value of the wheat leaves measured under pruned tree might be due to the lower total nitrogen (Fig. 4.5.2.2), organic carbon (Fig. 4.5.2.3) and available phosphorous content beneath pruned tree (Fig. 4.5.2.4). This is in line with the report of Shah *et al.* (2017) who reported that, limited nutrient supply will be the cause for the decrease in chlorophyll pigment. Instantaneous water use efficiency of the wheat under unpruned *F. albida* was higher compared with the wheat under pruned tree (Fig.4.9.3a), reflecting the relationship between carbon dioxide assimilation and transpiration rates of the crop.

### **5.7. The influences of *F. albida* on understorey wheat productivity**

In the present study, aboveground biomass and grain yield of the wheat measured under unpruned *F. albida* was higher by 30% and 27%, respectively compared to under pruned *F. albida* of similar distance from the bole of the tree (Table 8). A higher aboveground biomass of wheat was found under unpruned *F. albida* (Fig. 4.11.1); reflected also higher shoot height (Fig. 4.10.1) and higher number of tillers (4.10.2) of the wheat found under unpruned tree as compared with under pruned *F. albida*. Significantly higher soil moisture recorded under unpruned tree (Fig. 4.4.1) could contribute for better biomass production close to *F. albida* trees. Integration of compatible agroforestry trees has a potential to enhance yield as compared with the monoculture systems (Reed *et al.*, 2017). The roots of *F. albida* is known for exploring larger volume of water and nutrient both laterally and vertically and supplying to the annual crops to improve biomass production (Aster Gebrekirstos *et al.*, 2011). Many reports have shown that the root of *F. albida* redistribute not only soil moisture but also nutrient redistribution is known with the root of *F. albida* which is found beyond the cropping root zone (Bayala *et al.*, 2008). Favorable environmental condition such as low temperature nutrient acquisition and soil moisture retained were vital for 9.8% increment of sorghum grain under *Balanites* canopy (Kassa *et al.*, 2010; Coulibaly *et al.*, 2014). Similar result was reported from the similar study area that both aboveground biomass and grain yield of the wheat were significantly higher under *F. albida* compared with the crop alone (Sida *et al.*, 2018).

The wheat grain yield found under unpruned *F. albida* was significantly higher as compared with under pruned tree of similar distance (Fig. 4.11.2). The grain yield of

barely recorded under the tree canopy of *F. albida* was also higher compared to outside of the tree canopy (Kiros Hadgu *et al.*, 2009). According to Horton and Hart (1998), soil moisture found under the tree significantly contribute for the net primary productivity of the plant.

## **6.0. SUMMARY AND RECOMMENDATIONS**

### **6.1. Summary**

This study address the impact of pruning on tree water relations and leaf foliation/defoliation pattern of *Faidherbia albida* as well as on the understorey wheat productivity. Extensive pruning the branches of *F. albida* is common in Great Rift System of Ethiopia in general and in the study area in particular. However, competition for water and light between the tree and the accompanying crops is minimal and positive.

The main findings of this study are summarized as follows:-

- The mean monthly soil moisture found under unpruned was higher particularly close to the tree trunk as compared to the pruned one. Pruning the branches of *F. albida* reduced soil moisture by 56% in August and 78% in June.
- *F. albida* tree modifies the temperature under its canopy. PAR level measured under unpruned tree was reduced by to 77% during the cropping season as compared with pruned tree of similar distance.
- Macronutrient such as total nitrogen (0.2-0.4%) and available phosphorous (10-25mg/Kg) of the soil were found to be moderate range; whereas, organic carbon (2.0-4.1%) content of the soil was found to be higher under unpruned tree compared

with the pruned one. However, the soil pH found under unpruned trees was slightly acidic as compared with pruned one.

- Mid-day and predawn stem water potentials of pruned *F. albida* tree were higher by 37% and 13%, respectively compared with unpruned one.
- The highest and the lowest diurnal sap flow rate in unpruned and pruned trees were 78.9 ms<sup>-1</sup> and 3.5 ms<sup>-1</sup>, in midday and early in the morning, respectively during in dry period (January); whereas, the highest and lowest diurnal sap flow rate in pruned trees were 37 ms<sup>-1</sup> and 1.2 ms<sup>-1</sup>, respectively, in mid-day and early in the morning in the wet period (July- September).
- Diurnal mid-day (13:00 PM) sap flow rate was reduced by 53.1% during the dry period (January) and 65.7% during the wet periods (July to September), respectively, compared with unpruned tree due to lower canopy area in the dry period and extensive pruning around the onset of the rainy period and when transpiration rate was low.
- Sap volume of unpruned tree was higher up to 52% during the main rainy season (July- September), and even much higher (91%) in the dry season (October-March) compared with the pruned one in same period.
- *F. albida* manifest reverse leafing phenology of in the study area. The tree dropped the leaves around the onset of the rainy season and the canopy was covered with leaves during the cropping period (July- October), but with different shed levels. Later the canopy was fully foliated during the dry season from October to January.

- The study found that physiological performance, aboveground biomass and grain yield of the wheat as well as soil nutrient were higher under unpruned tree compared to under pruned *F. albida* tree from similar distances.
- Cambium dynamics of unpruned and pruned *F. albida* trees increased from July to September in 2015, during the rainy season; however, monthly cambium growth change was slow from October 2015 to February 2016 (towards the onset of the dry period).
- Wheat gas exchange (photosynthesis rate and water use efficiency) measured under unpruned *F. albida* tree were higher by 50 and 55%, respectively compared with the wheat under pruned trees; however, transpiration rate of the wheat was lower as compared to under pruned tree of similar distance
- Pruning of the branches of *F. albida* reduced the complementarity benefit of the tree to the accompanying wheat as, the result, the wheat aboveground biomass and grain yield was reduced by 30 and 27%, respectively compared with wheat productivities under and outside of similar distance.

In general, from the above findings, we can conclude that heavy pruning of the branch of *F. albida* alters the microclimate beneath the tree, reduces tree water use, affects the normal leafing phenology of the tree and reduces and compromise complementarity benefit of the tree to the understorey wheat productivities.

## 6.2. Recommendations

Agroforestry system is a viable option in semi-arid regions to improve soil fertility and to improve agricultural productivity. The Great Rift Valley System of Ethiopia is known for an erratic rainfall pattern and for the highest mid-day air temperature which exacerbates evapotranspiration. Morphological plasticity and reverse leafing phenology of *F. albida* are taken as peculiar characteristics that make the tree to be the best tree for agroforestry uses. So considering the environmental condition of the Great Rift Valley Systems in general and the study area in particular, the tree contribute a paramount importance to improve microclimate condition beneath the tree and to improve soil nutrients due to great amount of litterfall incorporated in the soil around the onset of the main rainy season and which is important to improve the accompanying crop productivity:-

- It is recommended that awareness creation effort be promoted on farmers about the importance of *F. albida* tree to the accompanying crops and discourage pruning the branches in order to boost agricultural productivity.
- Alternative options must be considered for fencing and firewood to retain the branches of *F. albida*.
- The current research on management is inadequate, so wide scale promotion and more studies should be conducted to enhance the regeneration potential and to improve the economic and ecological benefits of the tree.
- It is recommended that litterfall analysis and rate of decomposability studied to provide important information on the time of nutrient release and litter quality.

- The population density of the tree is found at critical stage. It is expected to be reduced to 1-2 trees per ha in the coming decades, which requires immediate action.
- Free grazing is common especially after the crop is harvested. Seedling and sapling of the tree are exposed to grazing by Camels and other livestock from the nearby regions in the study area. As the result measures should be taken to improve the regeneration potential of the *F. albida* tree.

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**Declaration**

I, the undersigned declare that this dissertation is my original works and it has not been presented in other universities for a degree or other purposes. All sources of the materials used have been duly acknowledged.

Name: Awol Assefa Toib      Signature \_\_\_\_\_ Date \_\_\_\_\_

The thesis has been done under my supervision

Name: Prof. Masresha Fetene      Signature \_\_\_\_\_ Date \_\_\_\_\_

The thesis is prepared based on AAU's thesis writing guidelines.

## 8.0. LIST APPENDICES

The following papers are emanated from this PhD study:

**Appendix 1.** Paper submitted to agroforestry Systems journal entitled “*To prune or not to prune *Faidherbia albida*: competing needs for water, wheat and tree products in semi-arid Ethiopia*” currently under review

**Appendix 2.** Paper submitted to agroforestry Systems journal entitled “*Faidherbia albida improves microclimate and soil chemical property beneath the tree in semi-arid climatic region of Ethiopia*”. Currently under review

**Appendix 3.** Poster presented on the World Congress on Agroforestry in Montpellier, France, from 20 to 22 May 2019 entitled “*Pollarding *Faidherbia albida* tree reduces complementarily benefits of understorey wheat: Experience from Ejerssa Joro, Semi-arid Ethiopia*”

The following are some of the photos taken during the study periods in the field and in the laboratory.

**Appendix 4.** Installation of solar panel to charge internal battery of heat ratio data logger (a) and while downloading sap flow data (b)



**Appendix 5.** Coring of cylindrical wood using increment corer (a) and cylindrical wood stained using methyl orange (yellowish in color) and not stained (whitish in color) (b)



**Appendix 6.** Experimental set up for wheat physiological and biomass measurement under unpruned *F. albida* each arrow indicates where each quadrant laid at 1, 3 and 5 m distance from three directions



**Appendix 7. Soil texture analysis using hydrometer methods**



**Appendix 8. Total nitrogen % analysis using Kjeldhal methods: Digestion block (a), Distillation unit (b) and samples after titration (c)**



**Appendix 9.** Available phosphorous analysis of soil Bray II methods



**Appendix 10. Potassium and Sodium analysis using flamephotometer**



**Appendix 11.** Wheat gas exchange measurement using Li-cor 6400 photosynthesis systems



**Appendix 12.** Measuring PAR level using Ceptometer

