1 Introduction

1.1 Overview of forest resources in Ethiopia

Ethiopia is an agrarian country in sub-Saharan Africa with a land area of approximately 1.1 million km^2. It possesses varied ecological conditions ranging from lowlands of below 1500m to highlands of 4620m asl. The present population of Ethiopia is estimated to be 73 million with annual growth rate of 2.36% (CIA 2005). More than 85% of the people live in rural areas and make their living from various types of subsistence agriculture. Agriculture accounts for 52% of the GDP (World Bank 2002), and 90% of the total export revenue (IMF 2002).

Ethiopia is rich in its flora. The forests and woody vegetation of Ethiopia are complex and diverse. It is estimated to contain 6500-7000 species of higher plants of which about 125 are endemic (Tewolde 1991). They comprise natural high forests, open woodlands, bush lands, trees on farms and plantations. Forestry is one of the indispensable chain links of the national economy. Forest products contribute 2.5% of Ethiopia GDP (Georg and Mutch 2001). The production of wood for various purposes, soil protection, the maintenance of a balanced water regime, are among the goods and services provided from these resource. The major source of energy consumption in Ethiopia was made up of biomass fuels, in which fuel wood makes up 81.8% (EFAP 1993). Forestry also creates employment opportunities for a significant number of people.

However, Ethiopian forests have been changing substantially during the last four decades. The closed forests, according to historical sources (e.g. Davidson 1988; EFAP 1994), once covered more than 40% of the total land area in the country. As a result of deforestation, which was estimated at 150,000 to 200,000 ha per year, the natural forest cover has been reduced substantially to less than 3% (EFAP 1994) with most of the remaining forests, nowadays, being located in remote areas in the west and southern part of the country.

The arid, semi arid and dry sub humid areas of Ethiopia account for about 70% of the total land mass and 46% of the total arable land (Anonymous 1998). The open savanna woodlands in Ethiopia, with arid or semiarid type vegetation are distributed over very large areas of the Rift Valley, northern, southern, eastern, and western parts of the country. These woodlands, which were estimated to cover 371 900 km², 30% of the total land area of the country (FAO 1981), have also suffered from deforestation. FAO/UNEP (1981) estimates indicated that the remaining woodlands cover approximately 20% of the total land area, with most of them being already heavily disturbed.

1.2 Deforestation, dryland degradation and its impacts

The major environmental and natural resources management issues that Ethiopia is currently faced with are problems related to deforestation, soil erosion and degradation, loss of biodiversity and energy related problems. Around 15% of the total energy consumption in Ethiopia is covered by agricultural residues and dung which otherwise could have been used to maintain soil fertility (Davidson 1988). According to the FAO (1993), fuelwood demand in Ethiopia will outstrip current vegetation resources by the year 2010. As a result of erosion, an estimated 1.5-2.0 billion tons of soil are lost annually (Chadhokar 1988) and around two million hectares of land in Ethiopia has become irreversibly barren (WIC 2002). Agricultural expansion, heavy grazing, the losses of vegetation cover due to uncontrolled felling and fire (e.g Figure 1.1) are among the main factors which have contributed to this negative trend. In this connection, there are many visible symptoms of the adverse effects on the livelihood of the local population today. Scarcity of fuelwood, fodder and construction materials and a decline in crop yield due to loss of fertile topsoil are among the common problems encountered by the current generation (Getachew 1999). Particularly the threats to the arid and semi arid zones are exacerbated by low and erratic rainfall, high temperature, overgrazing and salinity problems.

Figure 1.1. Extensive tree cutting for fuelwood and charcoal selling is very common in *Acacia* woodlands (Abernosa, the present study area).

Dryland degradation, which when it becomes severe, can be referred to as desertification. Desertification is the result of a combination of climatic factors (primarily drought) and anthropogenic factors (primarily over utilization). Land degradation via soil erosion begins with degradation of the protective vegetation cover. Land degradation via salinization becomes a problem when arid areas with poorly drained clay soils are irrigated for cultivation. Soluble salts have a tendency to accumulate under such conditions, resulting in severe inhibition of plant growth. A good example is the Amibara project where 4700 ha of land has been lost through salinity by 1988/89. Land degradation via soil crusting and compaction also occurs following vegetation loss as a result of excessive livestock trampling. These activities have brought about increases in undesirable tree and shrub species at the expense of desirable species. For instance, encroachment of woody plants has been shown to reduce production of grass biomass and decrease potential grazing capacity (Richter et al. 2001; Gemedo 2004) thereby negatively affecting the socio-economic conditions of the pastoral system (Abule 2002; Gemedo 2004). However, the woody species should not be regarded as the cause of the problem but as one of the probable symptoms of poor land management.

The effect of land degradation and desertification are compounded by recurrent droughts. For instance an estimated 30-35 million people in 21 African countries were seriously affected by drought notably in 1984 and 1985. About 10 million of those were displaced and became known as “environmental refugees” (Anonymous 1998). Ethiopia has been affected by several periods of severe drought during this century. The recent extreme drought severity during 1973-1986 and its political and economic consequences were reported by different authors (Kiros 1991; Adana 1991; Cutler 1991). The drought of 1984-85 alone had claimed the lives of above 500,000 people. Droughts in Ethiopia were related with El Niño Southern Oscillation (ENSO) (Haile 1988; Bekele 1993). It is clear that drought alone does not necessarily lead to famine. Of course, the risk of famine during times of drought is high in poor countries like Ethiopia, which often have inadequate food reserves and poor transportation networks. In one way or another, environmental degradation would also contribute its toll to the severity of drought effects.

In fact, degradation of lands and natural resources is a major global challenge. Hence, in recent years, a number of international initiatives have focused on strategies to improve the sustainable management of these resources. As a result, during the Earth Summit in Rio de Janeiro in 1992, forestry was accepted as an integral part of the agenda of sustainable development. Restoration/rehabilitation of degraded lands is a subject that is receiving considerable attention in many parts of the world. Restoration is a necessity and not an option in Ethiopia (Kebrom 1998) and restoration of the degraded landscapes will play a vital role in harnessing sustainable development (Mulgeta 2004). However, management of woodlands on a sustainable basis is a challenge for people living in many arid and semi arid areas of the world. This is also true for people in Ethiopia, where the efforts that have been made so far in this regard, are quite inadequate. Hence, vast areas of the open woodlands and savanna type vegetation in Ethiopia are being further destroyed (Getachew 1999). From the above brief analysis of the problem, it is apparent that the situation is critical, that it requires a systematic approach to restore, the indigenous woodland species of the country.

As mentioned in the Ethiopian Forestry Action Program, lack of appropriate information has been a major problem faced when attempting to manage natural resources. The woodland and savanna type vegetation are much less documented even than the closed forests (Getachew 1999). Unlike the closed forest area, the government (forestry service) has not yet actively intervened in the management and administration of the woodlands and bushlands. The lowland woodlands are intensively used by nomadic tribes and some settled communities/pastoralists for grazing and cultivation. Fire used in pastoral land management, and an open access to tree felling for fuelwood and charcoal production, have led to a drastic degradation of the natural vegetation. Therefore, the sustainable management and restoration of these woodlands, which has so far been neglected, should be among the priorities for the country. Hence, the present study was undertaken in the savanna woodlands in the Rift Valley of Ethiopia where deforestation and dryland degradation have become a serious problem.

1.3 Savanna determinants and adaptive traits

Savannas are the most common vegetation type in the tropics and subtropics (Solbrig 1991). They are mainly found in Africa, Australia and South America where they make up 45-65% of the vegetation (Huntley and Walker 1982). They are defined as ecosystems with a continuous grass stratum a discontinuous layer of trees and shrubs of variable height and density, and where growth patterns are closely associated with alternating wet and dry season (Bourliere and Hadely 1983). Savannas can be subdivided into a number of savanna types based on rainfall, seasonality characteristics and density of woody vegetation. The main physiognomic types of savanna according to Sarmiento (1984) are: a) Grass savanna: when both trees and shrubs are absent; b) Shrub savanna: when trees are absent; c) Tree savanna: when trees and shrubs are scattered and d) Savanna wood land: when the trees and shrubs form a canopy which is generally light. Precipitation, which is the one constant climatic characteristic of tropical savannas, varies from about 300 mm/year to over 1600 mm/year, and there is dry season of between 2 and 10 months (Frost et al.1986). Temperature depends on the altitudinal and latitudinal position of the savanna (Nix 1983).

Savanna determinants: Savannas are heterogeneous ecosystems at different spatial and temporal scales. To explain some of the common features and differences in savanna structure and function, savanna ecologist postulated four principal selective forces, which were called determinants (Frost et al. 1986; Goldstein et al. 1988; Walker 1987; Medina 1993). These are: Plant -available moisture (PAM), Plant –available nutrients (PAN), fire and herbivory. These determinants are predicted to interact at all ecological scales but their relative importance differs with scale (Medina and Silva 1990; Solbrig 1991). However, PAM and PAN are principal determinants of savanna structure at the higher scales.

Adaptive traits: Though conditions in the savanna are harsh, over time, plants, animals and humans have adapted to the environment, and today savannas support a rich diversity of plant and animal species and human cultures (Mistry 2000). The significant plant life forms in savannas are grass and shrubs/trees. Many of these have particular characteristics and strategies with respect to the four main ecological determinants. Savanna grasses, for example have C4 photosynthetic path way as an adaptation to the limitation of PAM. Perennial grasses also survive the dry season by dying back and remaining dormant as underground structures. Attributes of savanna trees for reducing evapo-transpiration include sclerophyl, i.e hard leaves and being leaf less during the dry season. Many plants also store water in underground organs, and some may have extended root systems to allow greater foraging for moisture. With regard to PAN, plants adaptation includes internal recycling of limiting nutrients, especially just before leaf fall, and root mycorrhizal associations.

In response to herbivores, savanna plants have also physical, chemical and biological deterrents. These include thorns, the presence of allelo-chemicals which are either bad testing and the presence of mutualism, e.g ants living on savanna trees. The main protective mechanisms against fire seem to comprise features that enable species to resist the violent and dramatic high temperature stress, either by avoidance or tolerance. These include the development of thick and insulating corky barks around the trunks and branches, bud dormancy and burial of seeds under ground during the dry seasons (Coutinho 1982).

1.4 Rationale for the study of the savanna woodlands in the Rift Valley of Ethiopia

The woodlands and savanna were estimated to cover 30% of the total land of the country (FAO 1981). About 55% of the total *Acacia* woodlands and savanna region of the country are mainly concentrated in the lowlands of the Rift valley (Getachew 1999). Despite prevailing harsh environmental conditions, these woodlands are inhabited by economically, socially and environmentally valuable plant and animal species. They are important sources of fuelwood, construction materials, fruits, fodder, medicinal plants, and honey flora for local communities. They also provide a number of other valuable products for rural daily livelihood needs, and preserve the soil and local climate. The woodlands have great importance for production of gum arabic, incense and gum myrrh products (Mulugeta and Demel 2004a, b). Most of these minor forest products (natural gums) are exported while about 50 per cent of the incense products are consumed locally.

Though the importance of indigenous trees for the people living in these areas and for the national economy has been recognized in recent years, vast areas of the open woodlands and savanna type vegetation in Ethiopia are being further destroyed. Large areas of the woodlands especially in the Rift Valley have experienced population influx from the neighbouring highland areas by people looking for new agricultural and grazing lands (Getachew 1999). It must be noted that Ethiopia's indigenous forests are repositories of biodiversity. Hence, any degradation and or simplification of these resources results in immediate biodiversity losses (Legesse 1990). How to restore biodiversity over large areas of degraded lands is a major challenge faced in Ethiopia today. In many cases, natural recovery is either unlikely or slow because the degraded sites have become subject to further disturbances such as grazing or cultivation (Lamb 1998). Reforestation/ afforestation of degraded lands is often seen as the most sound rehabilitation technique (Lugo 1997; Parrrota et al. 1997; Lamb 1998; Mulugeta and Demel 2004).

To counteract the effects of deforestation, a number of exotic species have been introduced into Ethiopia since 1970's.. Impact of reforestation has not, however, been commensurate with the rate of deforestation. Lack of knowledge on site - species matching led to failure of most of the attempted reforestation programs (Aster 1998; Kindeya et al. 2005). Lack of knowledge on the ecology of indigenous species and their adaptation to environmental stress limited their use in the reforestation programs. In fact, natural forest management and establishment of plantations with indigenous species were not considered attractive due to the presumed slow growth of indigenous species. Management of plantations of exotic species such as *Eucalyptus* and *Cupressus* was considered to be easier and cheaper. However, the fast growing species such as *Cupressus* and *Pinus* spp seem to be ill adapted to the environment. *Eucalyptus* species seem to replace the indigenous forest species wherever they could survive, consequently undermining the diversity of the forest vegetation. In many arid and semi arid areas, however, for instance in Abernosa (the present study area), *Eucalyptus* woodlots have failed due to recurrent droughts (personal observation). This discouraged people from considering tree planting as a management option.

Taking the above savanna attributes into account it is clear that tree establishment in the savannas is even more challenging. However, naturally occurring tree and shrub species have survived with the help of adaptive traits, which they have acquired due to long term exposure to ecological stress. Hence, knowledge on their ecology, their adaptation to environmental stress, growth dynamics and climate growth relationships would help land managers for designing methods to restore these resources and to promote the propagation of important and well adapted savanna trees species as a potential reforestation species, particularly for drought prone degraded lands. It is prudent, therefore, to raise these questions: Could the adaptive traits be identified and manipulated to provide a basis for selecting important tree species suitable for mass restoration/ reforestation of degraded lands? Do some of these species compete favourably for scarce resources and grow well in mixed communities? To what extent does land degradation, disrupts ecophysiological stability and leads to poor adaptations, as a result of natural or anthropogenic interferences? As mentioned above, information on the woodland vegetation is scant. Therefore, the major themes of this study were ecophysiological (plant water potential and osmotic potential), dendroncronology (tree ring analysis) and stable carbon isotopes analysis.

1.5 Research objectives

In an attempt to address the above stated problems and make recommendations for future directions with regard to the restoration of the savanna woodlands, this study was initiated with the following specific objectives:

1. To compare the dominant tree and shrub species for their adaptation to water stress, using plant internal water potential measurements in arid and semi arid conditions and to determine the effect of land degradation on these adaptations.

2. To compare the dominant tree and shrub species for their adaptation to osmotic stress (salinity) in arid and semi arid conditions using plant osmotic potential measurements and determine the effect of land degradation on these adaptations.

3. To evaluate the invasion potential of co-occurring species using ecophysiological measurements, i.e. plant water and osmotic potentials.

4. To analyze the presence of annual tree rings and understand tree growth dynamics of four naturally co-occurring tree species, and evaluate the relationship between long term radial growth and climatic parameters, and evaluate the association of ENSO and drought/ famine years in Ethiopia with tree ring pointer years.

5. To explore whether there is a common pattern in stable carbon isotopes in tree rings of co-occurring tree species and determine the climatic content and strength of the stable carbon isotopes signal as a potential climate proxies.

6. To analyze the relationship among the stable carbon isotope, dendrochronological and ecophysiological measurements and evaluate their implication in reforestation.