MANIPULATED REGENERATION STUDIES
ON THREE
INDIGENOUS TREE AND ONE SHRUB SPECIES
ON A DEGRADED LAND IN WELLO, ETHIOPIA.

A Thesis
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By
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ABSTRACT

This thesis presents comparative responses in germination, growth, survival, and establishment of the following four woody indigenous plant species; *Acacia abyssinica* , Hochest. ex Benth, *Juniperus procera* Hochest ex Endl., *Olea europaea* L. subsp. *cuspidata* (Wall. ex DC.) Ciffieri (synonym: *Olea africana* Mill.) and the shrub *Euclea schimperi* Dandy on a degraded land at Aluma, southern Wello. The study includes an investigation of the plant species regenerated from the local soil seed bank of this degraded area.

The highest germination was obtained under various treatments for the four species: scarification (82.9%) and hot water treatment (85%) *Acacia abyssinica*; removal of the hard seed coat (82.7%) (*Olea europaea*); removal of the fleshy seed coat (72.5%) and the control (68.8%) *Euclea schimperi.* No germination obtained in *Juniperus procera* under laboratory conditions, but showed a response when sown in flower pots filled with nursery soil (41.7%).

Thirty two small quadrats (0.7m x 0.5m) in four study plots were established. Eight small quadrats in each plot were randomly allotted for each of the four principal investigations (i.e, for sowing of treated seeds, sowing of untreated seeds, transplanting of seedlings, and local soil seed bank investigation). Eight soil treatments that include artificial gap, fertilizer, mulch and all the possible combinations of these including the control were used in the study.

Seed manipulations and treatments under field conditions such as scarification, removal of the hard seed coat, and hot water treatment enhanced germination with a higher response from *A. abyssinica* (77.3 %) followed by *E. schimperi* (67.2%) and *O. europaea* (60.2 %). The lowest response from seed treatments was obtained in *J. procera* (13.6%). Among the untreated seeds, germination results were obtained from seeds of *E. schimperi*(60.6 %) and *O. europaea* (33.6 %) only, while the seeds of *A. abyissinica* and *J. procera* failed to germinate. Seed dormancy is attributed as a possible cause for the failure in germination. Significantly higher percent germination obtained in soils treated with mulch and its combination with either artificial gap, fertilizer or both.

A significantly higher percent survival of seedlings was recorded in *O. europaea* and *E. schimperi*, *A. abyssinica*, and *J. procera* respectively. Percent survival significantly increased in mulched soils and its combination either with artificial gap or fertilizer. Seedlings from treated seeds of *J. procera* showed 100% mortality about one month after germination. Mortality was increased starting at the end of the rainy season, which is primarily correlated with hot period season.

A total of 1679 seedlings were recorded from the local soil seed bank, of which 890 were dicotyledons and 789 monocotyledons with large number of herbaceous species. Among the dicotyledons, 4 *Acacia*, 13 *Dodonia* and 9 *Olea* individuals were obtained. In artificial gap treated soils and its combination either with mulch, fertilizer or both higher number of seedlings recorded.

Based on the results, some recommendations are made on possible treatments and manipulations that enhance the successful germination, growth and establishment of the study species.

1. INTRODUCTION

1.1. Scope of the problem

Although the forest history of Ethiopia is not well documented, it is generally believed that much of the country may have been covered by extensive forests (FaWCDA, 1982; Uhling, 1988; Berhane Habte & Mebrate Mihertu, 1990; Tamrat Bekele, 1993). According to some reports (Pollisco & Aklog Lake, 1991; FAO, 1981; Bendz, 1990) state closed forest and dense woodlands once covered 40% of the country before man started to clear the vegetation. However, this figure was reduced to 15% by 1955 (FaWCDA, 1982); to 3.6% in the early 1980's and an estimated of 2.7% in 1989 (IUCN, 1990). At present these forests are restricted to scattered remnants in the northwest and southeast highlands. Some old trees and remnant vegetation currently surviving around the churches and religious burial grounds are indicators of what sort of forest covered that part of Ethiopia (Tamrat Bekele, 1993).

The main reasons for this ruthless destruction of forests are increasing population growth of both human and livestock that increase the demands for agricultural lands, timber, fuel wood and pasture. As the population grew more land came under cultivation and more pressure was applied to the remaining forests to provide the range of products needed for domestic purposes (Tadesse Asres, 1989). The impact of livestock, through their browsing and compaction of the heavier soils has also created conditions which favour the maintenance of pasture rather than the regeneration of trees in areas abandoned for cultivation (IUCN, 1986). These activities facilitate the disappearance of most valuable indigenous plant species and caused a serious ecological imbalance. As a result to day we are facing the effects of environmental degradation, problems of fuel wood, timber and other forest products. The use of crop residues and dung in place of fuel wood led to soil deterioration (FAO, 1985; Hurni, 1988; Bendz, 1990); consequently minimized land productivity (Berhane Habte & Mebrate Mihertu, 1990). Thus degradation is making increasing numbers of the population vulnerable to the effects of drought. At present this serious problem of natural degradation is the true picture of eastern, northern and central highlands of Ethiopia.

Realizing this serious problem the government of Ethiopia and some non-governmental organizations have launched a number of programs to conserve the remnant forests and rehabilitate degraded areas. Exotic tree species notably, *Eucalyptus*, *Pines* and *Cupressus* have been used. The use of exotic species, however, poses some problems (Demel Tektay, 1993a). The wide spread die-backs of *Pines* and *Cypresses,* the biodegrading and erosion effect of *Eucalyptus* are some of the drawbacks of exotics that are not ecologically acceptable (Legesse Negash, 1994). Due to this the extent of rehabilitation of degraded areas and restoration of new plantations have been far below the targets (Pollisco & Aklog Lake, 1991). As a result the rate of land degradation still outweighs the rate of conservation and rehabilitation. In awareness of the problem there are efforts towards the development of different methods to increase the germination and growth capacity of some of the indigenous tree species in the Biology department of Addis Ababa University (see Legesse Negash, 1995)

Ethiopia possesses several plant species. About 12% of the total flora are endemic to the country (Tewelde Berhan Gebre Egziabher, 1991). Selecting these plant species, matching the species to their ecological zones within the area being restored and designing improved methods for their growth and establishment are prerequisites in programmes dealing with rehabilitating degraded lands. One of the possibilities towards this end could be to carry out manipulation studies on these indigenous plant species as set in their ecological zones and under natural environmental conditions. Manipulation of the seeds or vegetative organs (and their sowing or plantation sites) using different treatments is essential and this approach may facilitate their regeneration potential in degraded areas. In addition manipulation of the soil environment and investigation of the local seed bank can provide useful information to manage the species that are possibly locally best adapted in these degraded areas.

The present manipulation study conducted on a degraded land at Aluma (Wello, northern Ethiopia) compares the germination, growth and establishment of four indigenous plant species as well as it evaluates those plant species that can regenerate from the local seed bank under natural conditions.

The objectives of this study, therefore, are:

1. To investigate the germination of seeds and establishment of seedlings of four indigenous plant species on a degraded area.
2. To assess the effect of manipulation of the soil environment on the germination and growth of these indigenous plant species.
3. To investigate those plant species that can regenerate from the local soil seed bank.
4. To give some recommendations on the rehabilitation of degraded areas and provide background information for future research.

2. LITERATURE REVIEW.

2.1. Rehabilitating degraded areas.

The problems of environmental degradation is growing rapidly proceeding at a faster rate in many tropical regions. There is a large amount of degraded tropical forest land in relatively high rainfall areas and it continues to increase (Lovejoy, 1985). This is related to rapid population increase in many countries of the tropics which resulted in extensive clearing of forested land for fuelwood, agriculture and livestock. According to the estimate of the 1990 Tropical Forest Resource Assessment Project of FAO for the period 1981-90, 16.9 million hectare forest and woodland are converted to none forested lands per year (Lanly, 1992). As a result the long term productivity of land resources in the tropics are continually reduced from time to time.

Degraded lands are characterized by impoverished or eroded soils, hydrologic instability, reduced primary productivity and diminished biological recovery (Parrotta, 1992). These generally occurs when any one of the ecosystem storage (such as soil organic matter, soil nutrients, seed pool and bio-mass) have been reduced to the point that natural inputs cannot replenish them to their original state (Brown & Lugo, 1994).

The most common response to land degradation has been abandonment (Parrotta, 1992). After forests have been cleared and the land cropped for a few years, it is then abandoned, to regenerate,and regain its fertility before being cropped again. However under conditions of increasing population growth and intensified land use the period of fallow are often shortened or eliminated (Grainger, 1988). Degradation is thus likely to continue and is now one of the greatest conservation problem facing many tropical countries of the world. As a result, the rehabilitation or restoration of disturbed and degraded lands has become an important activity in many countries supported by both governmental and non governmental organizations' finance.

Ecological rehabilitation or biological recovery is proposed as a management strategy to reverse any converted ecosystem, damaged or degraded, to a fully functional ecosystem, irrespective of its original state (Brown & Lugo, 1994). This may be attained in various complementary ways under natural, semi-natural or artificial conditions. However, some times natural or semi-natural successional processes are insufficient or too slow (occurring over more than several decades) to rehabilitate lands to productive systems or they may be arrested at undesirable end point (Bradshaw, 1987; Brown & Lugo, 1994). In this case intervention by humans is required to speed up artificial measures of rehabilitation. The involvement of man during rehabilitation is important in the management of successional processes and selection of appropriate methods. This can accelerate natural successional processes and the final outcome will be reduced rate of soil erosion and increased biotic activity within the recovered ecosystem (Lugo, 1988; Parrotta, 1992). The idea behind rehabilitation is therefore to manipulate successional processes so that the end product of successional change will be useful.

One means that should be considered in rehabilitation or restoration of degraded lands is improved plantation of native or exotic species and extension of forest boundaries by means of artificial regeneration (Demel Tektay, 1993a). Experience of planting different species in degraded areas suggest that there is the possibility of reversing degradation processes. This has been achieved in a degraded land in Thailand using the plant *Eucalyptus camaldulensis* (Sakuri *et al.,* 1991); in a degraded costal pasture site in Puerto Rico by planting *Albizia lebbik* (Parrotta, 1992).

Successful rehabilitation requires manipulation of degraded lands as well as the plant species by physical, chemical, or biological means (Bradshaw, 1983 & 1987) to accelerate successional processes. Moreover experimental trails should be conducted using a wide range of plant species particularly on sites with problems of degradation. When this is combined with different treatments and manipulation, it enables to select appropriate plant species that can play an important role in the rehabilitation of degraded lands.

Rehabilitation techniques which intend to establish vegetation cover need some basic requirements as a pre-requisite. Some of these ecological requirements that should be considered in the rehabilitation of degraded lands include the following:

i. Strategies targeted at the soil (Bradshaw, 1983; Lugo, 1988).

- Manipulate the soil as needed either physically or biotically (ex. rip the soil, introduce soil fauna, Mycorrhizae etc.).

- Fertilize and irrigate when absolutely necessary.
- Keep top soil moist, cool and shaded.
- Use of fallow to do most of the forest rehabilitation.

ii. Strategies targeted at the flora (Lugo, 1988), include;

- Maximize vegetation cover.
- Restore tree cover.
- Manipulate the existing vegetation before attempting substitution.
- Use multiple seeding technique when in doubt as to what to plant.

This shows that the initial conditions of degraded lands as well as the species of plants used for rehabilitation purposes should be manipulated. Thus great human effort is needed for rehabilitation because natural ecosystem recovery processes are extremely slow.

2.1.1. Manipulation of the soil environment

The germination of seeds and establishment of seedlings depends on the presence of suitable environmental conditions in the soil. This has been shown by Harper *et al.*(1965), Sheldon (1974), and Rusch (1993). Harper *et al.*(1965) have drawn attention on the potential importance of different requirements for the germination and establishment of plants. They stated that different conditions in the soil micro-topography and micro-environment have selective effects on the germination of seeds and establishment of seedlings. In a crude sense, the number of seeds emerged and seedlings established is a function of the number of suitable conditions offered by the environment of the soil. This indicates that effective rehabilitation of a degraded land requires comprehensive and careful manipulation of the soil to create suitable micro-environment. As Harcharik & Kunkule (1978) pointed out that manipulation involves the improvement of moisture holding capacity, chemical status, soil depth and other physical characteristics of the soil. These can create detailed micro-topography that will be useful in regulating the regeneration potential of plants during rehabilitation efforts.

The effect of soil manipulation on the establishment of vegetation cover has long been recognized. Some of these manipulations are, addition of nutrients (Bradshaw, 1983; Lugo, 1988); use of mulch (Bradshaw, 1983; Lugo, 1988; Fisher *et al.*, 1986; Sakuri *et al.*, 1991) and creation of gaps or openings (Fenner, 1985; Rucsh, 1993).

A - Addition of Nutrients

The common feature of a degraded land is the absence of its original soil. This makes the soil to be deficient in some essential plant nutrients, thus creating a situation which is probably the single most important constraint on vegetation establishment (Johanson & Bradshaw, 1979). Nevertheless, deficiency of essential nutrients can be easily remedied by the addition of either commercial or natural fertilizers. This has been shown by different investigators. Luken (1990), for example, reported the dominance of grasses on highly disturbed lands when higher levels of nitrogen containing fertilizers are applied. In addition, he pointed out that the use of perennial grasses and legume plants during rehabilitation of disturbed lands, especially when coupled with fertilizers, may lead to productive plant communities that successfully inhibit soil erosion. Kadeba (1978) conducted fertilizer experiments in the savanna region of Nigeria with some *Pine and Eucalyptus* tree species, his results showed that fertilizing with phosphorus and nitrogen improves the survival and growth of these tree species. Similar results were obtained in Sudan and North Guinea with various *Eucalyptus, Pine* and *Teak* plant species (FAO, 1974). These investigations suggest that degraded lands which are exposed to extremes of nutrient deficiency require extensive nutrient treatments to ensure high rates of survival and establishment of plants.

B - Use of Mulches

One of the essential conditions for the germination of seeds and establishment of seedlings is improved moisture in the soil. However, the shallowness nature of the soil makes degraded lands to have a deficiency of optimum moisture conditions. As it was pointed out by different authors (Springfeild, 1978; Bradshaw, 1983; Lugo, 1988; Sakuri *et al*., 1991), this situation can be corrected by the addition of mulches.

Mulching is one of the several means of modifying the micro environment of the soil to meet the needs of seed germination, seedling survival and establishment (springfield, 1978). Mulching materials can be either natural or synthetic (manufactured) products. The most common natural mulches are straw, hay, wood chips, manure, sawdust (springfeild, 1978 ; Luken, 1990), and synthetic products like organic and inorganic liquids such as asphalt emulsions and latex (Springfeild, 1978).

Experimental studies conducted by different investigators confirms mulch as the best treatment for the survival and growth of plants in degraded areas. Fisher *et al.* (1986) found mulch as one effective treatment for the survival of *Juniper* species in surface mined lands in Mexico. The survival rates of these species were better than unmulched ones, and often equivalent to those of irrigated trees. A similar study in a degraded land of Thailand by Sakuri *et al.* (1991) showed mulch as the best treatment for the survival and establishment of different plant species.

The positive effect of mulch on the survival and growth of plants have been shown to be due to the following; a lowering of maximum soil temperature (Fenner, 1985; Sakuri, *et al.*, 1991); improving the moisture condition (Evans, 1986; Springfeild, 1978; Sakuri *et al.*, 1991; Luken, 1990); serving as a source of nutrients to plants and facilitating biological activity (Evans, 1986; Sakuri *et al.*, 1991); and control wind and water erosion (Fisher *et al.*, 1986).

C - The role of gaps in regeneration

A gap is an opening that can be created by the removal of the above ground parts of plants (i.e shoots) (Rusch, 1993), together with or without their roots. It can be created naturally because of land slides, floods, fires, storms (Silvertown, 1982); by the activities of borrowing or trampling animals (Fenner, 1985); or due to human activities. Once formed it will have an effect on the regeneration potential of different plant species. In most plant communities for example, regeneration from seed is dependent upon the presence of gaps in the vegetation (Miles, 1974 ; Grubb, 1976).

According to Grubb's (1977) hypothesis, the presence of gaps would increase the existence of different plant species and provide suitable sites for their establishment. Therefore, it may accelerate the regeneration and colonization of different plant species. This has been reported in a tropical rain forest in Java (Kremer, 1933 as quoted by Fenner, 1985); in a heath land in Scotland (Miles, 1974); in limestone grassland communities in the Baltic island of Öland (Rusch, 1993). In these studies important observations were made that showed that the survival and emergence of seedlings is dependent upon the presence of gaps in the vegetation. However as Rusch (1993) indicated, the persistence of species in a community is possible when the dynamics of gap formation is matched with the occurrence of reproductive propagules.

2.1.2. Seed treatment

One means by which degraded lands can be rehabilitated through either planting of seedlings or direct sowing of different kinds of plant species. In particular, planting of native or exotic species by artificial regeneration depends upon the possibilities of raising seedlings either from seeds or vegetative propagules (Demel Tektay, 1993a).

This approach of rehabilitation requires among other things a higher percentage rate of germination in the sown seeds. However, seed germination can be inhibited by a variety of factors. These can be either biotic or abiotic, acting simultaneously in opposite directions and causes dormancy of the seed which may be either physical or physiological (Shehaghilo, 1987).

For example, as Legesse Negash (1992 & 1993) pointed out, seeds of many tropical plant species are covered by hard seed coats. These seed coats require suitable conditions for their degradation, otherwise they restrict imbibition and hence germination (Legesse Negash, 1994). Such a factor makes a number of plant species to require treatment and manipulation of the seed before sowing if satisfactory germination is to be obtained.

The effect of pre-sowing treatment of seeds on the rapid germination of tropical plant species has been shown by the work of Laurent & Chamshama (1987), Legesse Negash (1992 & 1993) and Demel Teketay (1993b, 1994, 1996). These kind of studies are suggestive of the fact that together with site manipulation the plants used for rehabilitating degraded lands require treatment and manipulation of their seeds or reproductive propagules. Some of these pre-sowing treatments include; soaking in water for varying lengths of time (FAO, 1974 ; Simmons, 1981; Laurent & chamshama, 1987; Demel Tektay, 1993b, 1994 & 1996); Scarifying or chipping the seed coat (FAO, 1974; Demel Tektay, 1993b & 1994; Legesse Negash, 1992 & 1993); alternate soaking and drying (FAO, 1974); plunging the seed into water or even boiling for a short time

(FAO, 1974; Laurent & Chamshama, 1987; Demel Teketay, 1993b, 1994 & 1996) Soaking in concentrated sulphuric acid (Laurent & Chamshama, 1987; Demel Teketay, 1993b, 1994 & 1996); and fire scorching (Laurent & Chamshama, 1987).

2.2. Rehabilitation from seed banks

The soil of most tropical and temperate habitats contains a reservoir of viable seeds of plants termed as the seed bank (Jefferson & Usher, 1987). Soil seed bank includes all seeds buried in the soil and those on the soil surface. These stored seeds in the soil are composed in part from seeds produced on the area and partly from seeds blown in from elsewhere (Harper, 1977; Thompson & Grime, 1979; Garwood, 1989). As a result the soil seed bank has a potential importance as a source of propagules of the original vegetation. The existence of these seeds in the soil seed bank is determined by their physiological properties (including germination, dormancy and viability), by the environmental conditions where they land and subsequent changes, and the presence of seed predators and pathogens (Garwood, 1989).

According to Grime (1979) seed banks can be differentiated into two fundamental types; transient and persistent seed banks. A transient seed bank is one in which none of the seed out put remains in the habitat in a viable condition for more than one year. On the other hand in persistent seed banks some of the components are at least one year old in the soil. In both cases the seeds remain buried in the soil and maintain their dormant state. If some disturbance brings them to the surface they will normally germinate and give rise to plants whose parents may have existed many generations before (Fenner, 1985). This knowledge of the seeds, whether seeds are transient or persistent, the nature of their germination cues and the environmental conditions suitable for establishment are fundamental to successful vegetation management (Van der valk & Pederson, 1989). For example, in the Netherlands (Van der valk & Verhoeven, 1988) seed banks are an important part in the conservation and management of high diversity communities in chalk grasslands and wetlands.

In areas where natural vegetation has been eliminated, the potential of reestablishing it from a relict seed bank is one possibility that is currently being investigated (Van der valk & Pederson, 1989). In view of this many plant ecologists have become increasingly aware of the importance of seed banks in maintaining species diversity. There have been a number of studies on the existence of viable seeds in the soil documented for different plant communities by Thompson & Grime (1979); Jefferson & Usher (1987); Dicke *et al.* (1988); and reviewed by Harper (1977); Grime (1979); Fenner (1985); Garwood (1989); and Van der valk & Pederson (1989).

An understanding of the population dynamics of viable seeds in the soil is useful in the management of a given area for different purposes. In agricultural activities if the species composition of the seed bank of an arable soil is determined, a knowledge of the long term viability of the species involved is clearly of value in providing a basis for control techniques. This enables to use selective chemical methods against the species known to be most persistent in the soil (Roberts, 1981 as quoted by Fenner, 1985).

The existence of viable seeds in the soil are potentially important in the restoration projects where plant cover is desired (Skoglund, 1992). The use of this seed source is particularly valuable in tropical forestry where planting as such is often omitted (Fenner, 1985).

The existence of viable seeds is valuable in the rapid colonization of a protective vegetation cover and helps to prevent further land degradation. This disposes many problems associated with collecting, storing and sowing, or transplanting individuals during the rehabilitation of degraded lands (Van der valk & Pederson, 1989). As a result the use of seed banks in rehabilitating degraded lands as well as to manage the existing vegetation is getting great attention in recent times.

Alternatively, there is the option of rehabilitating degraded lands by using donor soil seed banks from a nearby site with the appropriate vegetation. This is possible by moving an intact forest soil seed bank to the land which has been degraded (Skoglund, 1992). Such kind of approach was recognized and pioneered by workers interested in mine spoil reclamation. It involves the removal of top soil prior to mining, storing it and putting it back after the mineral has been removed, or alternatively, removing the top soil from an area to be mined and placing it to an area to be revegetated (Johanson & Bradshaw, 1979; Van der valk & Pederson, 1989). However donor seed banks will not produce vegetation identical to the native vegetation, because some native vegetation may not be present in the seed banks or their seeds may loose viability when the soil is stockpiled (Van der valk & Pederson, 1989). For this detailed knowledge should be present concerning the biological composition of the undisturbed environment and the seeds or vegetative materials before using the soil as a donor seed bank. If this is well understood, donor soils have a potential to establish rapidly a species rich vegetation dominated by native species adapted to local conditions. Seed banks, therefore, play an important role in the restoration and maintenance of degraded lands as well as to manage the existing vegetation and habitat creation.

3. MATERIALS AND METHODS

3.1. The study site

Wello region located in northern Ethiopia is a mountainous area with slope over 60% (ERCS, 1986). Due to high population density and unwise use of the natural vegetation, at present most of the lands in this region are exposed to erosion and degradation. One of the severely affected areas where the study was carried out is known as Aluma. It is situated 443 km north of Addis Ababa. In this area the average altitude is 2100 m above sea level with slope of 17%.

3.1.1. Population and land use

The majority of the people living around the study site are subsistence farmers. They also keep cattle in their surroundings. Because of scarcity of land, steep slopes and hill sides are cultivated by different crops and grazed by cattle continuously. This led the area to be over exploited, exposing to erosion and land degradation.

3.1.2. Vegetation

From many years back to the year 1980 the study site was used by the surrounding inhabitants for cultivating different kinds of crops. Starting from 1981, the area become under the ministry of Agriculture for plantation of different kinds of exotic and indigenous tree species. Thus until 1989 the area was covered by different kinds of plant species owned as a state forest. However starting from the beginning of 1990, the vegetation of the area was completely destroyed by the surrounding inhabitants as a result of clearance for domestic uses and overgrazing of their cattle (personal communication with the inhabitants). At present some remnant shrub and tree species are confined in the study site. Scattered species persisting in and adjacent to the study site are presented in appendix 1.

3.1.3. Climate

The rainfall in the region of wello is a bimodal divided in to two seasons locally referred as "Keremt" (big rains) and "Belg" (small rains). The keremt usually starts in June and it continues normally until the end of September. The Belg rains usually start in March/April and then continue until May.In favourable years these seasons merge, but in dry years the Belg may sometimes fail completely and the Keremt rains may end abruptly (SIDA, 1987).

There is no specific rainfall and temperature data for the study area. However the climatic conditions recorded by Ethiopian national meteorological service agency (ENMSA) at the nearby stations (Bistema and Haik) some what holds true for this area too (Tab. 1A & B).

Table - 1.A. Mean monthly temperature for locations near Aluma

Station name	Haiq		Bistema (Werebabo)	
Altitude	1900 m		2300 m	
Lat.	11.19		11.19	
Long.	39.40		39.45	
Temperature(°c)	Max.	Min.	Max.	Min
January	23.3	7.7	20.3	8.6
February	23.6	10.8	20.4	10.9
March	24.6	12.0	22.6	12.2
April	25.3	12.5	22.6	12.1
May	27.4	12.3	24.1	12.6
June	29.5	12.7	26.0	14.1
July	27.2	13.9	24.2	12.9
August	25.7	13.5	23.1	12.3
October	24.9	8.8	22.1	10.5
November	24.5	6.1	21.8	8.9
December	23.3	7.2	20.7	9.1

SOURCE: Ethiopian National Meteorological service agency.

(ENMSA)

Year of Records ; 1986 - 1995

Table - 1.B. Mean Monthly rainfall (in mm) for locations near Aluma.

Station name	Haiq	Bistema (Werebabo)
January	31.4	21.8
February	90.9	60.5
March	117.3	82.0
April	107.9	139.9
May	77.3	87.6
June	26.6	28.2
July	235.4	287.3
August	257.8	286.1
September	156.5	164.8
October	22.4	58.5
November	9.3	7.7
December	32.4	36.3

Source - ENMSA

Year of records: 1986 - 1995

3.1.4. Geology

The geological origin of the highlands of Wello is part of the trap series, which is the most prevailing formation of the tertiary period (65-2 million years ago). Petrographically they are basaltic alkaline rocks (Bechtold *et al.*, 1987). According to the description of Almaz Gezahegn and Kebede Tseayheu (1995) the rocks around Dessie belongs to the upper basic volcanite . Texturally, the basalt are scorinaceous basalt, fine gained relatively hard basalt and polyphyritic basalt with coarse grained phenocrysts. It appears, there fore, that the geological formation of the study site is not far from this description.

3.1.5. Soil

The soils of Wello are developed from trap series volcanics resulting in strong structural influence on land form and soil development. The outcome of this influence is accelerated erosion stoniness of the soil and mountainous topography (FAO, 1984). In addition to this the area has been cultivated intensively for a longer time which has added man made erosion. The general description of the soil near and around the study site shows that the most common types of soils are eutric regosols and eutric cambisols with lithic phases and lithosols occurring on steepest slopes (FAO, 1984). The steepest slopes around the study site are highly eroded, stoniness and rocks are the common features of the land.

.2. The study plants

The study includes four plant species which are indigenous to Ethiopia. The main reason for the choice of these particular indigenous plant species was based on the idea of their successional patterns. Two of the species, *A. abyssinica* and *E. schimperi* were considered and selected as pioneer stage species, where as *J. procera* and *O. europaea* as a representative of climax stage vegetation. A short description of each species is given below.

Acacia abyssinica Hochest. ex. Benth

A. abyssinica is also called umbrella thorn because it is typically crown shaped. It is a tree reaching up to heights of 20 m when mature. It usually grow at altitudes between 1500m-2800m above sea level, and occurs in areas with annual precipitation of 700-1600mm per year. The plant is commonly found in woodland, wooded grasslands, highland forest margins and along sides of rivers and streams (Dale & Greenway, 1961; Breitenbach, 1963).

It is drought tolerant and grow in degraded areas and along gullies. As with most other acacias it is used for fuel wood, charcoal, poles, tool handles, fodder, shade, apiculture, soil and water conservation and nitrogen-fixation of the soil (Azene Bekele *et al.*, 1993; Demel Teketay, 1993a). This plant is widely distributed in Ethiopia, Kenya, Malawi, Mozabique,Sudan, Tanzania, Uganda, Zaire and Zimbabwe (Demel Teketay, 1993a).

Seeds of *A. abyssinica* are usually brownish in colour; they are thick elliptical in shape and are compressed. They measure 7-10 x 4-6 mm and are covered with leathery seed coat which is impermeable to water. The seeds are susceptible to insect attack during their development in pods or even after they have been collected (Legesse Negash, 1995).

Euclea schimperi Dandy

It is a shrub or small tree 3-6 m high. It usually grows in dry woodland, bush land, riverine forest and marginal arid areas at altitudes between 1500 - 2300 m above sea level. It is traditionally used as a firewood, farm tools, food (fruit), ornamental, live fence and boundary marking (Azene Bekele *et al.*, 1993).

Fruits of *E. schimperi* are rounded in shape, green at first and upon ripening, become purple-black with soft and fleshy covering. The seeds are light-brownish in colour. The seed measures about 7-9 mm across and it has a thin seed coat covering.

Juniperus procera Hochest ex Endl.

J. procera also called African pencil cedar. The plant is an ever green tree reaching up to heights of 40 m (Dale & Greenway, 1961; Breitenbach, 1963). It is one of the endangered plant species found in Ethiopia, Kenya, Sudan, Zimbabwe, Zaire and Namibia (FAO, 1986). It usually occurs in highland and mountain areas, on rocks and on soils with good drainage, and is tolerant of widely varying soils. It is commonly found at altitudes between 1750 m - 2500 m with optimum rainfall laying between 400 - 1200 mm. Even though this plant does best in high rainfall areas, it can also survive quite dry conditions once established and adapted to less favourable conditions (FAO, 1986). The heart wood of this plant is extremely resistant to termites and is a very durable wood in the ground. It usually used for poles, timber (for floors, roof shingles, pencils), firewood, ornamental, shade, and windbreak (Dale & Greenway, 1961; Breitenbach, 1963).

J. procera has no woody cones but fleshy, berry-like fruits. The small male cones are solitary, rounded, terminal and are yellowish in colour. They occur in short axillary branchlets. The female cones are berry-like rounded and upon ripening, become fleshy and soft. They measure upto 8 mm across and may contain 1 to 4 seeds. Fresh seeds, obtained from ripe berries, are mucilaginous and some what tapered at one end (Legesse Negash, 1995).

Olea europaea L. subsp cuspidata (wall.ex DC.)
Cifferi(Synonym : *Olea africana* Mill.)

This plant is commonly known as wild olive. It is widely distributed in dry forests and forest margins often with *J. procera* in East Africa and Ethiopia (Dale & Greenway, 1961).

Wild olive is a handsome evergreen tree up to 15 m high with rounded crown and grey-green foliage. It is hard and drought resistant once established even in poor soils (Dale & Greenway, 1961). The plant is usually found at altitudes between 1500-2500m with average annual precipitation of 1000 mm. It is mainly used for furniture, cabinet work, ternary, firewood, charcoal and poles (Breitenbach, 1963; Azene Bekele *et al.*, 1993).This tree is much valued by the farmers of Ethiopia for making farm implements, houses and fences as well as for producing house hold furniture. The bark, the leaves and the wood are smoked as *matent* to ferment and flavour yogurt *Irgo or Tella* ,traditional Ethiopian beverage (Legesse Negash, 1993).

The fleshy fruits (the drupes) of *O. europaea* are approximately oval in shape and, as they mature, their colour changes from light-green to purple. They usually measure 8-14 mm in length and 5-10 mm in diameter. The flesh is much liked by birds and seeds without flesh (i.e, those covered only with endocarp or stone) are common underneath trees of wild olive. The stone (the endocarp and the seed within it) ranges in shape from ovoid to somewhat spheroid. Normally, each stone yields a single seed. However, twin seeds may occur in some fruits or provenances. The seeds are somewhat brownish and decorated with branched lines that appear to have drawn all over their seed coats. In shape, they look much like a Rugby ball but range from ovoid to somewhat ventrally flattened seeds. The brownish seed coat covers the endosperm and embryo (Legesse Negash, 1995).

Diagrammatical representation of pods, fruits, and seeds of each of the study species is presented in appendix 3.

3.3. Seed collection and storage.

Ripe berries of *J. procera,* pods of *A. abyssinca*, fruits of *O. europaea* subsp. *cuspidata* and *E. schimperi* were collected from southern Wello (northern Ethiopia) within 10 to 35 Km. radius of Dessie town, in January and March 1995. They were collected from the plants before they have been dropped onto the ground. Immediately following collection, the fleshy part and pods were removed, and the resulting seeds were washed in tap water (except, for those seeds used for the untreated experiment). All seeds were then allowed to sun dry for 5-10 days in the greenhouse and placed in a refrigerator in plastic containers.

3.4. Laboratory and greenhouse studies

The relative germination capacity of each species were investigated using different treatments and manipulations:

Olea europaea subsp. *cuspidata.* - Manipulation and treatment of the seeds were done based on the work of Legesse Negash (1993). The seeds were removed from their hard seed coats by crashing in-between a piece of clean basalt rock and smooth concrete surface. They were then washed with a soapy detergent and surface disinfected with

0.15% $HgCl_2$ for 15 minutes. The disinfected seeds were rinsed using distilled water and arranged in rows onto a double layered tissue paper in a glass petri dish (diameter 9 cm; height, 1.5 cm). The total number of seeds arranged per petri dish was 40. Then the seeds were irrigated with distilled water until germination was completed.

Acacia abyssinica - Scarification and hot water treatment, as recommended for seeds of different *Acacia* species (Simmons, 1981) were used for the seeds of this species. Scarification was done by rubbing the seed using sand paper until a small portion of the seed coat was removed. During scarification care was taken not to damage the embryo. Hot water treatment involved immersing the seeds into boiled water immediately upon its removal from the heat source and then left to cool gradually. The seeds were left in the water for 24 hr until they imbibe and swell. Following these treatments the seeds were arranged onto a double layered tissue paper in separate glass petri dishes (diameter 9 cm; height 1.5 cm) and supplied with distilled water until germination was completed. The number of seeds arranged per petri dish was 30.

Euclea schimperi and Juniperus procera

A total of 11 treatments for *E. schimperi* (Table 2) and 7 treatments for *J. procera* (Table 3) were used.

For seeds of *E. schimperi*, scarification was done by rubbing the seeds with sand paper until some part of the seed coat is removed. In addition, the seeds of this species were treated with 0.15% $HgCl_2$ for 25 minutes to prevent fungal attack as a preliminary observation has shown that untreated seeds were attacked by fungal growth.

The effect of hot water treatment was investigated by immersing seeds in separate beakers containing 200 ml of boiled water which was immediately removed from the heat source. Then, the seeds were left to soak for different lengths of time (i.e. for 12 hrs and 24 hrs) in the water.

The effect of chemical treatment was tested by placing the seeds in beakers containing 100 ml of concentrated sulfuric acid and left to soak for different lengths of time (i.e 5, 10, 15 and 20 minutes). After these periods seeds were washed and rinsed in distilled water.

In each treatment 30 seeds of *E. schimperi* and 50 seeds of *J. procera* were arranged onto a double layered tissue paper in separate glass petri dishes (diameter 9 cm; height 1.5 cm) moistened with distilled water. Then the seeds of both species were periodically supplied with distilled water. However, seeds of *E. schimperi* under treatment 4 (Table 2) were supplied with GA_3 (10^{-4} M) (Gibberllic acid) until germination was completed.

All petri dishes were then placed in a germination incubator in the tissue culture room (Biology Department, Addis Ababa University) maintained at 25 ± 1^0 C until germination was completed.

In addition, seeds of *E. schimperi* and *J. procera* were sown in separate flower pots filled with nursery soil. Seed treatment 3 for *E. schimperi* (see Table 2), and treatment 1 and 2 for *J. procera* (see Table 3) were used during sowing. The pots were kept in the greenhouse, watering twice a day until germination was completed.

Assessment: Observations on germinating seeds were made daily. Germination was considered when the radicles were about 2 to 3 mm long. For pot experiments, germination in *E. schimperi* and *J. procera* was considered when the cotyledons were fully emerged. This observation continued until no more seeds had germinated for at least a week.

After the germinated seeds were counted, the germinants were transferred to small plastic tubes (Diameter 8 cm, length 12 cm) that have been filled with nursery soil. The tubes were arranged on flat wooden benches in rows in the greenhouse. They were regularly watered twice a day until they were transferred to the study site.

Table 2. List of treatments applied to seeds of *E. schimperi*.

Treatment number	Treatment
1	Scarification.
2	Scarification; Surface disinfection with 0.15% $HgCl_2$ for 25 min. and rinsed with distilled water.
3	Removal of the fleshy coat; surface disinfection with 0.15% $HgCl_2$ for 25 min. and rinsed with distilled water.
4	Surface disinfection with 0.15% $HgCl_2$ for 25 min., rinsed with distilled water, and periodically supplied with GA_3 (10^{-4} M).
5	Immersing seeds in boiled water immediately after removing from the heat source and left soaking for 12 hrs.
6	Immersing seeds in boiled water immediately after removing from the heat source and left soaking for 24 hrs.
7	Soaking in concentrated sulfuric acid for 5 minutes.
8	Soaking in concentrated sulfuric acid for 10 minutes.
9	Soaking in concentrated sulfuric acid for 15 minutes.
10	Soaking in concentrated sulfuric acid for 20 minutes.
11	Control.

Table 3. List of treatments applied to seeds of *J. procera*

Treatment number	Treatment
1	Immersing seeds in boiled water immediately after removing from the heat source and seeds left soaking for 12 hrs.
2	Immersing seeds in boiled water immediately after removing from the heat source and seeds left soaking for 24 hrs.
3	Soaking in concentrated sulfuric acid for 5 minutes.
4	Soaking in concentrated sulfuric acid for 10 minutes.
5	Soaking in concentrated sulfuric acid for 15 minutes.
6	Soaking in concentrated sulfuric acid for 20 minutes.
7	Control.

3.5. Field study.

3.5.1. Experimental design.

A reconnaissance survey was done on October 20 and 21, 1994 to locate the experimental plots. The study plots were situated in four already established sites (each 20 m X 20 m) within the frame work of the project of "Landscape Ecology and Ecological Restoration of Central Ethiopia". The four selected study plots were coded as plot I, II,III, and IV.

In each of the four study plots (10 m X 4.5 m), thirty two small quadrats (0.70 m X 0.50 m) were laid out arranged into four rows and eight columns. Each small quadrat were bounded out with wooden pegs and a rope. A 0.50 m wide gap around each small quadrat was left to avoid edge effects. Each of the four rows (with eight quadrats) within a study plot, was randomly assigned to one of the four principal investigations (i.e, plantation of seedlings, sowing of treated seeds, sowing of untreated seeds and seed bank investigation). Within each row, eight different soil treatments were randomly assigned to the eight quadrats. The same procedure was followed in all of the four plots and the experimental set-up resulted in a randomized complete block design.

3.5.2. Soil treatment.

The above-ground vegetation on each study plot was mowed before the onset of the rainy season. Then, during planting and sowing each quadrat within each row was subjected to different soil treatments and manipulations. The following eight treatments and manipulations either in isolation or in combination were used during the study.

1. Artificial Gap (AG): Both the above-ground plant material (shoots) and their underground parts (roots) were manually removed.
2. Mulch (M): Dried hay from *Hyparrhenia rufa* was over laid (2-3 cm thick) after planting and sowing to cover the ground surface.
3. Commercial Fertilizer (F): A combination of diammonum phosphate and urea (2:1 ratio) was applied at a rate of 125 kg per hectare during planting and sowing. Although the specific amount of fertilizer required by these study species and the study site is not yet known, this amount (125 Kg/ha) was considered from recommendations of fuel wood plantation in Ethiopia (Pohjonen, 1987).
4. A combination of mulch and artificial gap (M + AG).
5. A combination of fertilizer and artificial gap (F + AG).
6. A combination of mulch and fertilizer (M + F)
7. A combination of fertilizer, mulch and artificial gap (F + M + AG).
8. Control.

3.5.3. Seed treatment

Seed treatments and manipulations which resulted in maximum germination (Table 4) for each species during laboratory investigation, were applied to seeds of each species before the actual field experiment started.

Table 4. Seed treatments and manipulations used in the field.

Species	Seed treatment and manipulations.
Acacia abyssinica	Immersing seeds in boiled water immediately after removing from the heat source and the seeds left soaking for 24 hrs.
Euclea schimperi	Removal of the fleshy coat; surface disinfection with 0.15% $HgCl_2$ for 25 minutes, and rinsing with distilled water.
Juniperus procera	Removing the berries from the seeds; immersing the seeds in boiled water immediately after removing from the heat source, and the seeds left soaking for 24 hrs.
Olea europaea subsp. *cuspidata*	Removal of the hard seed coat; surface disinfection of the seeds with 0.15% $HgCl_2$ for 15 minutes and rinsing with distilled water.

3.5.4. Sowing and planting.

Sowing: After manipulation and treatment of the soil, eighty (80) treated and untreated seeds for each (20 seeds per species) were sown in each of the respective experimental quadrat. Seeds were uniformly sown in rows with 5 cm spacing in-between. During sowing an attempt was made to incorporate the seeds to a depth of 1.0 cm and then cover them with soil. Each sowing spot was then marked with a tooth pick to enable a close follow up latter on. In addition, the location of each seed was mapped on a graph paper to facilitate identification during each observation. Sowing was done between July 1-3, 1995.

Planting: Seedlings raised in the greenhouse (Science Faculty, Addis Ababa University) were transported to the study site and transplanted on July 4 and 5, 1995. In each of the small quadrats 20 seedlings (5 seedlings per species) were planted with a spacing of 10 cm in-between. Each seedling was given its own code to identify them in subsequent observations. Seedlings which died within 15 days of transplantation were replaced by seedlings from the original batch.

After sowing and planting each plot was watered twice a day until the beginning of the first showers of the summer rains which began on the 5th day. The height and number of leaves of each seedling were recorded at the end of plantation.

Assessment: Emergence of germinating seeds was monitored every three days during the germination period which lasted between 1 -8 weeks. Germination was considered when the cotyledons were fully emerged.

Observations on seedlings were made every fifteen days for the first two months and monthly thereafter for five months. The following observations and measurements were made for each species:

A. The number of germinated seeds;

B. Height measurements on individuals;

C. Total leaf count per plant;

D. Total number of seedlings present and the condition of each seedling (i.e live, dead or browsed) were recorded.

During the course of the investigation few seedlings that were found browsed were measured but left out from subsequent statistical analysis.

3.5.5. Local soil seed bank investigation.

Emerging seedlings in quadrats allocated for soil seed bank investigation were counted every fifteen days for the first two months and monthly thereafter. During counting each small quadrat (0.70 m x 0.50 m) were further grided into smaller quadrat (0.35 m x 0.25 m) to facilitate monitoring. At each census seedlings were identified and recorded only as either monocots or dicots. The location of emerging seedlings in each plot were mapped on a graph paper and their survival was subsequently followed. During this investigation some of the species recorded were collected and identified latter on at the National Herbarium, Addis Ababa University.

3.3.6. Statistical treatment of data

Germination and survival percentages were arcsine transformed before analysis. The results from germination, growth, survival and seed bank investigation were analyzed separately by the analysis of variance (ANOVA). In all cases significant treatment means were compared by the least significance difference (LSD) method (Zar, 1974).

Mean relative growth rate

Relative growth rate can be computed from growth parameters of each component of a plant (eg. weight,number of leaves, height etc.) which are recorded between two time intervals during the active growing period of the plant (Hunt, 1978).

Mean relative growth rate was calculated for each species to compare their growth patterns. Mean relative growth rate ($\bar{R}$) is calculated as follows;

$$\bar{R} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

Where, $W_2 - W_1 =$ change in height or leaf number between time T_2 and T_1 respectively.

$T_2 - T_1$ = Time interval

e = the base of natural logarithm.

In the present study mean relative growth rate was estimated from parameters of leaf number count and height measurements recorded between 60th and 150th days after transplantation and sowing.

4. RESULTS

4.1. Laboratory result

The species investigated in the present study respond differentially to the various treatments used, and showed variations in total germination percentage.

Acacia abyssinica: There was no significant difference ($p > 0.05$) in the germination results obtained by sand paper scarification (82.9 ± 3.7%) and hot water treatment (85 ± 2.7%) (Figure 1). In both treatments germination started on the same day (i.e on the 4th day), but ended on the 7th (sand paper scarification) and on the 9th (hot water treatment) day after sowing. A very low germination percentage (8.8 ± 3.4%) was recorded in the control with germination commencing on the 15th day and ended on the 21st day after sowing.

Euclea schimperi: Higher germination percent (greater than 65%) was obtained in treatments 3, 4 (see Table 2 for type of treatments) and in the control, but with no significant difference among each other ($p > 0.05$). In the other treatments (i.e, 5,6,7, 8 & 9) low percent germination was recorded (less than 45%) when compared to the controls (Figure 2). In treatments 1, 2 and 10 there was no germination at all and the seeds were found infected by fungal growth. Percent germination in hot water treatments (5 & 6) was significantly lower than in the control, but without significant difference between each other. Between treatments, 7 and 8 no significant difference was observed, but treatment 9 was significantly lower than these treatments ($p < 0.05$). In these observation germination started on the 6th day and ended on the 13th day after sowing.

Juniperus procêra: Seeds of this species failed to germinate when treated with hot water, scarification and sulfuric acid treatments. Some of the seeds were enlarged after these treatments, but they were restricted to germinate.

Olea europaea: Decoated seeds of *O. europaea* started germination on the 6th day and completed on the 14th day after sowing with a germination percentage of 82.7 ± 3.1% (Figure 1). However, seeds incubated without removing the hard seed coat failed to germinate.

4.2. Greenhouse results

E. schimperi : Removal of the fleshy seed coat, surface disinfection of seeds with 0.15% $HgCl_2$, and sowing in flower pots resulted a gemination percentage of 57.7 ± 3.3%, with germination starting on the 6th day and completing on the 16th day after sowing. A germination percent 53.2 ± 2.6% was attained in the control that started on the 9th day and ended on the 18th day after sowing.

J. procera: Soaking seeds in boiled water for 12 hrs and 24 hrs resulted in a germination percent of 39.5 ± 2.7% and 43.2 ± 2.9% respectively. These showed no significant difference ($p > 0.05$) from the control (41.7 ± 3.3%) (Figure 1). During this observation, germination started on the average on the 40th day and ended on the 49th day after sowing.

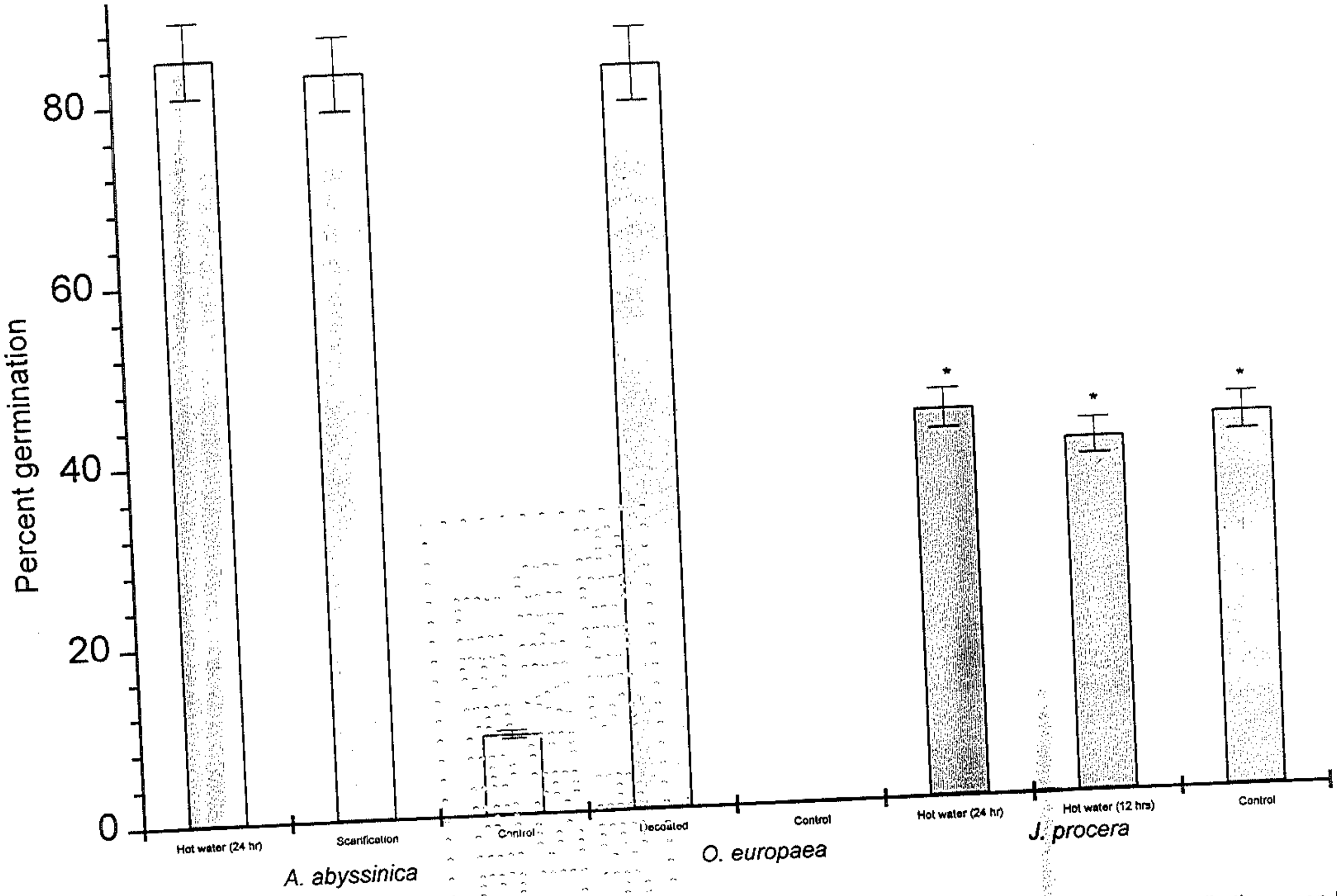

Fig. 1 Cumulative percent germination of *A. abyssinica*, *O. europaea* (in the laboratory) and *J. procera* (in the green house)

*: Pot experiment

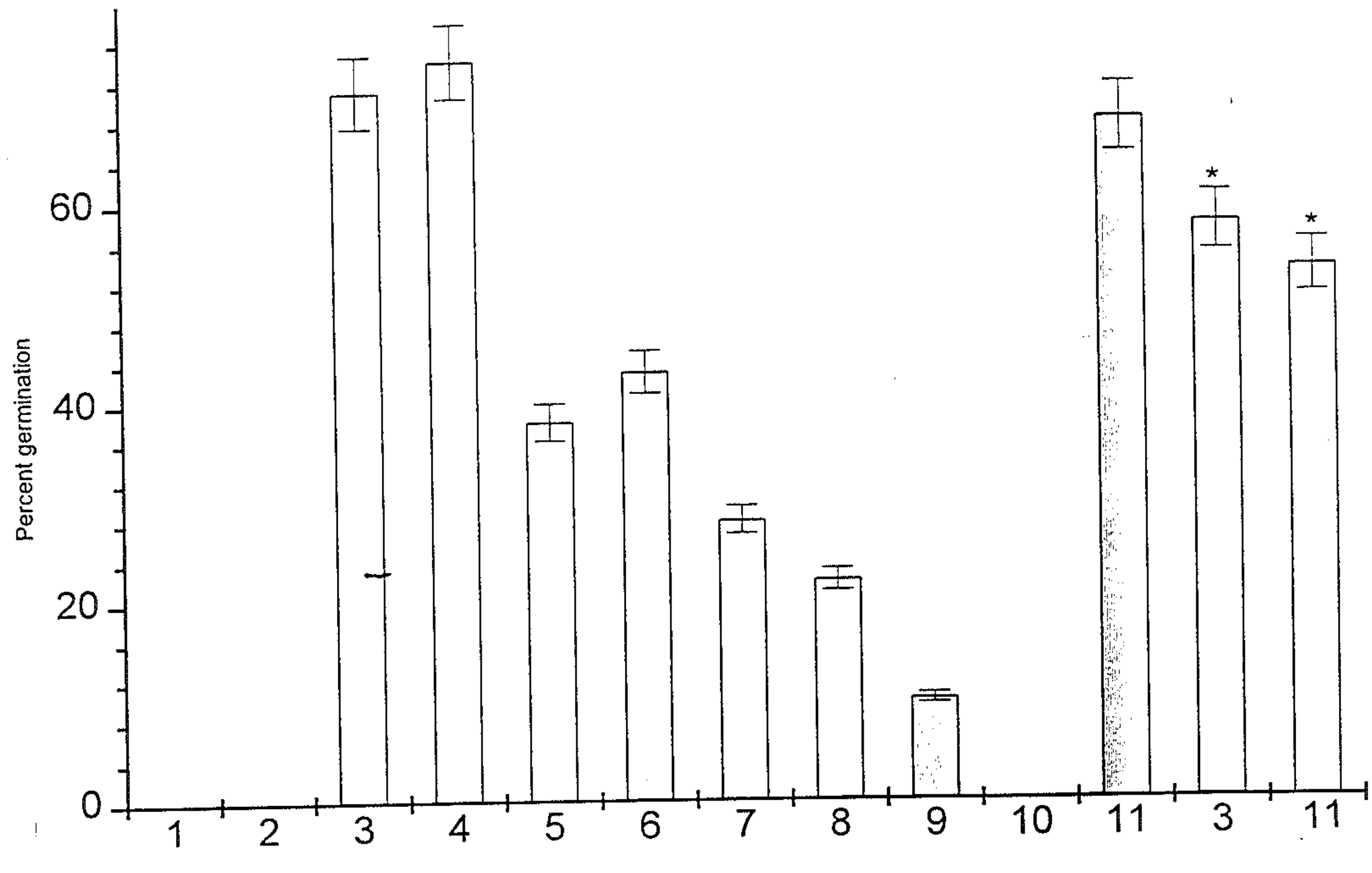

Fig. 2 Percent germination in *E. schimperi* under different treatments in the laboratory and greenhouse condition (see table 2 for type of treatments)

*: Pot experiment.

4.3. Field result

4.3.1. Germination study

Germination in both the treated and untreated seeds was completed in the first two months after sowing. Higher Percent germination was obtained from treated seeds (Figure 3). Here germination was relatively faster and higher than for untreated seeds of *A. abyssinica, J. procera and O. europaea*. However, there was no significant difference in percent germination between treated and untreated sown seeds for *E. schimperi*.

A significantly higher ($p < 0.05$) percent germination obtained from treated seeds of *A. abyssinica* (77.3 ± 1.8%) and *E. schimperi* (67.5 ± 1.2%) with no significant difference between each other. This was followed by treated seeds of *O. europaea* (60.2 ± 1.8%) with significant difference from *J. procera* which resulted the lowest percent germination (13.6 ± 1.1%).

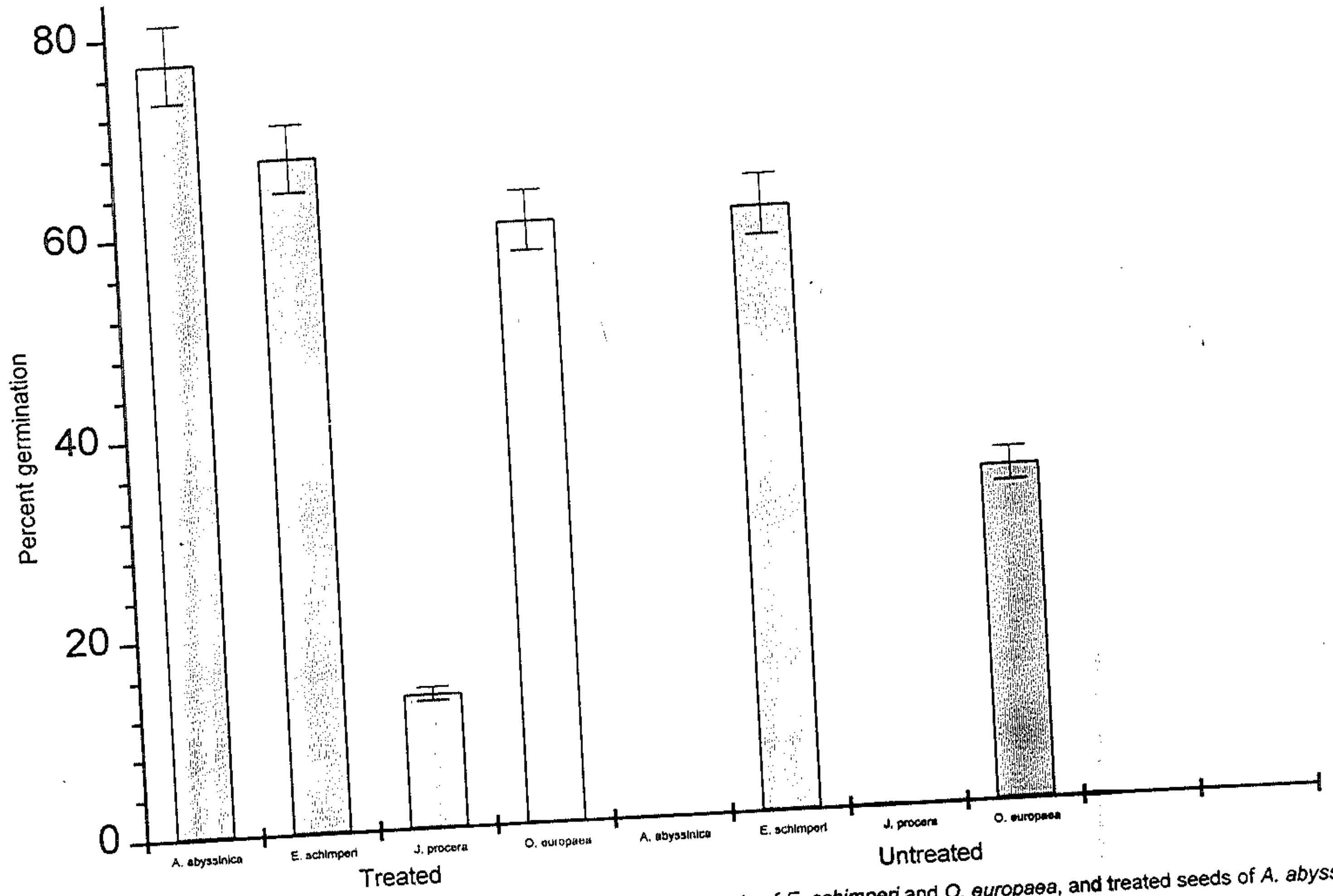

Fig. 3 Cumulative percent germination of treated and untreated seeds of *E. schimperi* and *O. europaea*, and treated seeds of *A. abyssinica* and *J. procera* in the study site

Comparative responses of germination within species, under the various soil treatments is shown in Table 5.

A. abyssinica: Germination of treated seeds started on the 6th day after sowing and was completed on the 12th day. A significantly higher percent germination was obtained in soils treated with Mulch, Fertilizer + Mulch, Mulch + Artificial gap, and Fertilizer + Mulch + Artificial gap (hereafter referred to as M, FM, MAG and FMAG, respectively) with no significant difference among each other. These showed significantly higher differences ($p < 0.05$) to the germination results obtained from soils treated with Artificial gap, Fertilizer, and Fertilizer + Artificial gap (hereafter referred as AG, F, and FAG, respectively). While there was no significant difference between results from AG, F, and FAG treated soils, and all showed a significantly higher percent germination than in the control ($p < 0.05$).

E. schimperi: Germination from the treated seeds started on 9th day and ended on the 15th day after sowing. Percent germination was significantly higher ($p < 0.05$) in M, FM, MAG and FMAG treated soils, but with no significant difference among each other. There was no significant difference in percent germination obtained from the other soil treatments (i.e, AG, F, and FAG) and the control.

J. procera: Germination in the treated seeds of *J. procera* started on the 48th day and ended on the 62nd day after sowing. A significantly higher ($p < 0.05$) percent germination obtained in soils treated with MAG. The lowest percent germination was recorded in soils treated with AG, F, FM, and FAG without significant difference among each other and the control. Percent germination obtained from soils treated with M and FMAG was significantly lower than in MAG treated soils, but higher than the remaining soil treatments and the control.

O. europaea: The treated seeds of this species started to germinate on 9th day and ended on the 18th day after sowing. The highest percent germination was recorded in MAG and FMAG treated soils without significant difference between each other. These showed a higher significant difference from M, FAG and FM treated soils, which in turn were significantly higher than the germination results obtained from AG and F treated soils and the control ($p < 0.05$).

Table 5. Effect of soil treatments on the cumulative germination percentage of treated untreated seeds of the study species, with ± SE (Standard error).

Soil treatment	Treated seeds				Untreated seeds	
	A.abyssinica	*E.schimperi*	*J. procera*	*O.europaea*	*E.schimperi*	*O.europaea*
Artificial gap (AG)	76.3±5.5 b*	65.0±3.5 b	12.5±3.2 c	52.5±5.2 c	57.5±4.3 d	27.5±5.2 d
Fertilizer (F)	72.5±4.3 b	62.5±3.2 b	11.3±1.3 c	53.8±1.3 c	55.0±7.4 d	32.7±7.5 c
Mulch (M)	83.8±4.3 a	71.3±4.3 a	15.0±2.1 b	62.5±3.2 b	66.3±2.4 b	40.0±4.1 a
F + M	82.5±1.4 a	70.0±2.2 a	10.0±2.1 c	61.3±5.5 b	58.3±2.4 d	33.8±5.5 cb
F + AG	76.3±6.6 b	63.8±2.4 b	10.0±3.5 c	58.8±3.1 b	60.0±2.4 cd	35.0±3.5 cb
M + AG	85.0±4.1 a	73.8±2.4 a	22.5±3.2 a	71.3±2.4 a	75.0±2.9 a	40.0±9.4 a
F+M+AG	81.3±1.3 a	71.3±2.4 a	17.5±3.2 b	71.3±4.3 a	65.0±7.4 bc	38.8±2.4 ba
Control	61.3±3.1 c	62.5±3.2 b	10.0±2.1 c	50.0±2.1 c	47.5±3.2 e	22.5±3.2 d

* For each species, means within the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

In the investigation of untreated seeds germination was found only in *E. schimperi* (60.6 ± 1.76%) and *O. europaea* (33.6 ± 2.0%) (Figure 3). The untreated seeds of *A. abyssinica* and *J. procera* failed to germinate during the study period.

E. schimperi: The untreated seeds of this species started germinating on the 10th day and ended on the 17th day after sowing. A significantly higher ($p < 0.05$) percent germination was obtained from soils treated with MAG than in the other treatments (Table 5). In M and FMAG treated soils percent germination was significantly higher than those obtained in treatments AG, F, FM, and FAG. The lowest response in percent germination was obtained in the control which was significantly lower than the other soil treatments ($P \leq 0.05$).

O. europaea: Germination in the untreated seeds of *O. europaea* started on the 34th day and ended on the 45th day after sowing. A higher percent germination was obtained in M, MAG and FMAG treated soils which were without significant difference among each other. Soils treated with F, FAG and FM there was no significant difference ($p > 0.05$) between each other. These however showed a significantly higher percent germination than AG treated soils and the control (Table 5).

Comparison of percent germination of treated seeds among species under the various soil treatments is indicated in Table 6. The treated seeds of *A. abyssinica* and *E. schimperi* showed no significant difference between each other under all soil treatments.

In *J. procera,* percent germination was significantly lower ($p < 0.05$) than all the three species, under each soil treatment.

Percent germination in *O. europaea* and *E. schimperi* showed no significant difference under MAG and FMAG treated soils, while in the remaining soil treatments, *O. europaea* showed significantly lower percent germination than *A. abyssinica* and *E. schimperi* ($p < 0.05$).

Table 6. Comparison of percent germination of treated seeds between species under different soil treatments, with ± standard error.

SOil treatment	Species			
	A. abyssinica	*E. schimperi*	*J. procera*	*O. europaea*
Artificial gap (AG)	76.3 ± 5.5 a*	65.0 ± 3.5 a	12.5 ± 3.2 c	52.5 ± 5.2 b
Fertilizer (F)	72.5 ± 4.3 a	62.5 ± 3.2 a	11.3 ± 1.3 c	53.8 ± 1.3 b
Mulch (M)	83.8 ± 4.3 a	71.3 ± 4.3 a	15.0 ± 2.1 c	62.5 ± 3.2 b
F + M	82.5 ± 1.4 a	70.0 ± 2.2 a	10.0 ± 2.1 c	61.3 ± 5.5 b
F + AG	76.3 ± 6.6 a	63.8 ± 2.4 a	10.0 ± 3.5 c	58.8 ± 3.1 b
M + AG	85.0 ± 4.1 a	73.8 ± 2.4 ab	22.5 ± 3.2 c	71.3 ± 2.4 b
F + M + AG	81.3 ± 1.3 a	71.3 ± 2.4 ab	17.5 ± 3.2 c	71.3 ± 4.3 b
Control	61.3 ± 3.1	62.5 ± 3.2	10.0 ± 2.1	50.0 ± 2.1

* For each soil treatment means within the same row followed by the same letter don't differ significantly at 5% level of probability (LSD test).

4.3.2. Growth performance

Comparisons of growth rates as computed from periodical measurements of plant height and leaf number, revealed differences within each species. Significantly higher changes ($p < 0.01$) in height within species of transplanted seedlings (Figure 4) and seedlings from sown seeds (Figure 5), occurred between 60 to 150 days and almost levelled upto 180 days after sowing.

4.3.2.1. Transplanted seedlings.

The effect of soil treatments within species mean height and mean leaf number is shown in Table 7. The comparisons are based on height measurements and leaf counts made 210 days after sowing.

A. abyssinica: Mean height and mean leaf number were significantly higher ($p < 0.05$) from seedlings grown in FAG and FMAG treated soils than in the other soil treatments. These measured characters showed no significant differences from seedlings grown under F, FM and MAG treated soils , but with significantly higher difference ($p < 0.05$) from those seedlings grown in AG and M treated soils. In soils treated with AG and M significantly lower mean height and mean leaf number were obtained than in the other soil treatments, without significant difference from the control.

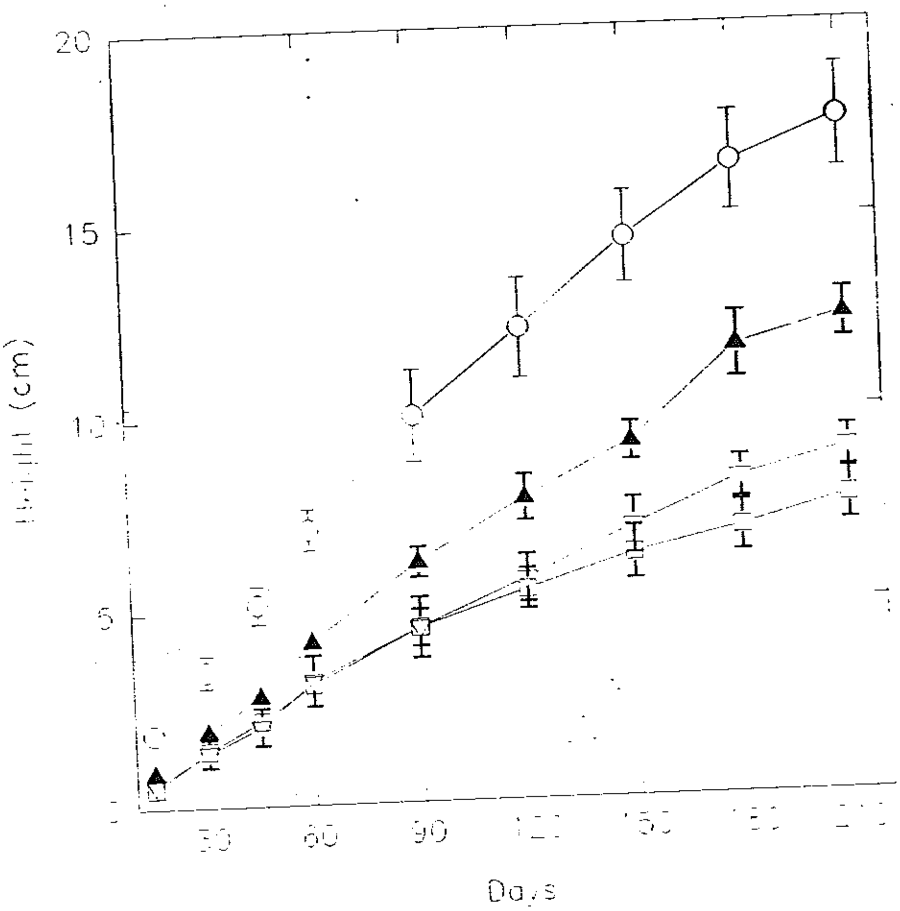

Fig 4. **Mean** height increments (cm) of transplanted seedlings upto 210 days atfer planting

○ A. abyssinica
▲ O. europaea
△ E. shimperi
□ J. procera

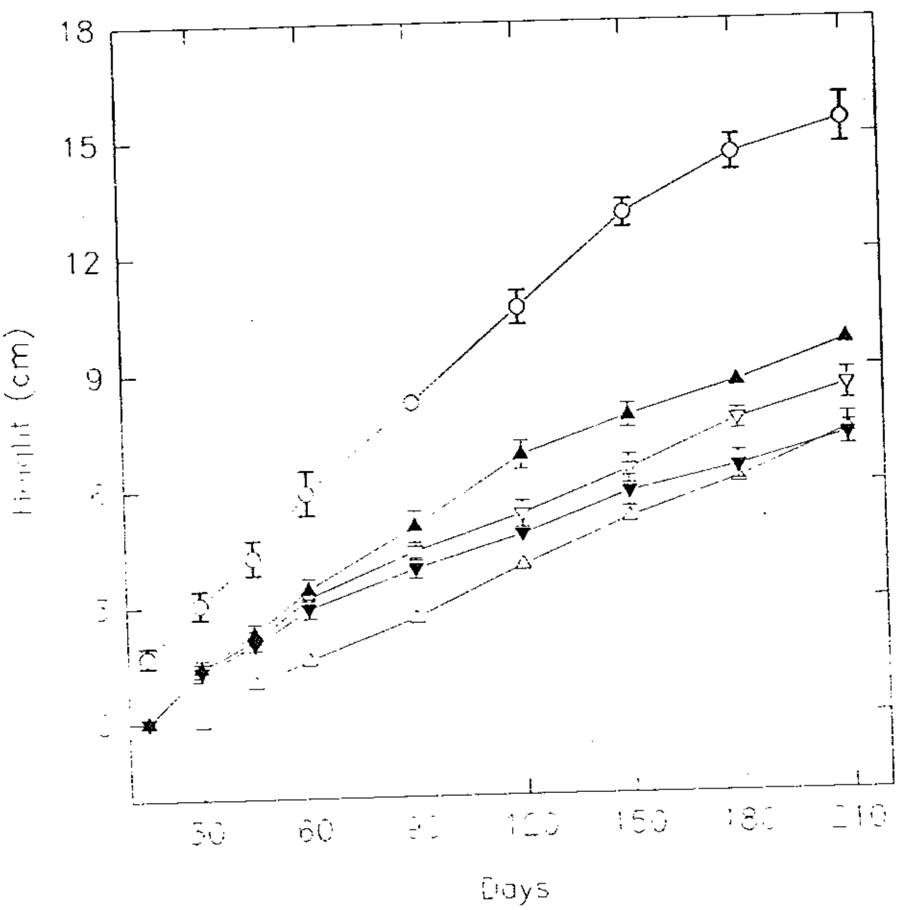

Fig 5. Mean height increments (cm) of seedlings from treated (*) and untreated (**) seeds upto 210 days after sowing

o A. abyssinica *.
▽ E. shimperi *
▲ O. europaea *
△ O. europaea **
▼ E. shimperi **

E. schimperi: Significantly higher ($p < 0.05$) mean height and mean leaf number were 3obtained in soils treated with MAG and FMAG, but with no significant difference between each other. In soils treated with FM and FAG no significant differences in mean height and mean leaf number obtained, but they showed significantly higher difference ($p < 0.05$) from AG, F and M treated soils. In soil treatments AG, F and M no significant differences in mean height and mean leaf number obtained between each other and the control.

J. procera: Significantly higher ($p < 0.05$) mean height and mean leaf number were obtained in FM, FAG, MAG and FMAG treated soils, but without significant difference among each other. In these treatments mean height and mean leaf number were significantly higher ($p < 0.05$) than those seedlings grown in AG, F and M treated soils and the control. In F and M treated soils no significant differences obtained, but in each of these treatments mean height and mean leaf number showed significantly higher difference from AG treated soils and the control ($p < 0.05$).

O. europaea: Mean height obtained in F, FAG and FMAG treated soils was significantly higher ($p < 0.05$) than in the other soil treatments, but with no significant difference among each other. In soils treated with M, MAG and FM no significant differences in mean height obtained among each other, but seedlings grown in each of these treatments showed significantly higher mean height than in AG treated soils and in the control. Mean leaf number in FAG and FMAG treated soils showed significantly higher difference ($p < 0.05$) from the other soil treatments. In F, M, FM and FAG treated soils mean leaf number showed no significant difference among each treatment, but it was significantly higher ($p < 0.05$) than in AG treated soils and in the control.

Table 7. Effect of soil treatments on mean height (cm) and mean leaf number of transplanted seedlings 210 days after planting, with ± standard error. H - mean height (cm) L - mean leaf number

Soil Treatment	Species							
	A. abyssinica		*E. schimperi*		*J. procera*		*O. europaea*	
	H	L	H	L	H	L	H	L
Artificial gap(AG)	15.2 ± 2.0 c	16.1 ± 1.0 c	7.7 ± 0.1 c	7.1 ± 0.2 c	6.3 ± 0.3 c	49.7 ± 3.8 c	10.0 ± 0.7 c	19.3 ± 2.3 c
Fertilizer (F)	18.2 ± 0.4 b	19.4 ± 1.1 b	8.0 ± 0.3 c	7.1 ± 0.2 c	7.3 ± 0.3 b	55.1 ± 3.3 b	13.8 ± 0.7 a	22.6 ± 2.1 c
Mulch (M)	16.0 ± 1.5 c	17.6 ± 0.6 c	7.7 ± 0.2 c	7.3 ± 0.3 c	7.2 ± 0.4 b	54.2 ± 3.4 b	10.5 ± 0.9bc	21.8 ± 2.5 c
F + M	20.7 ± 1.8 b	25.5 ± 3.3 b	9.0 ± 0.3 b	8.4 ± 0.4 b	8.2 ± 0.3 a	58.0 ± 2.0 a	10.6 ± 3.6 bc	22.5 ± 2.1 c
F + AG	26.5 ± 1.3 a	26.7 ± 3.2 ab	8.8 ± 0.3 b	8.4 ± 0.4 b	8.2 ± 0.2 a	57.9 ± 3.6 a	14.4 ± 0.5 a	24.8 ± 3.1 a
M + AG	18.6 ± 1.6 b	19.7 ± 1.2 b	9.9 ± 0.2 a	9.9 ± 0.2 a	8.0 ± 0.2 a	58.1 ± 4.2 a	11.7 ± 0.4 b	23.2 ± 1.2 b
F + M + AG	27.9 ± 1.9 a	28.3 ± 4.1 a	10.3 ± 0.3a	9.8 ± 0.4 a	8.8 ± 0.1 a	59.9 ± 0.9 a	15.0 ± 0.6 a	26.0 ± 3.1 a
Control	14.2 ± 0.9 c	15.1 ± 1.4 c	7.8 ± 0.1 c	6.6 ± 0.2 c	5.9 ± 0.2 c	48.2 ± 2.9 c	8.3 ± 0.3 d	16.1 ± 1.2 d

* For each species, means within the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

Comparative mean relative growth rate (RGR) between transplanted seedlings is shown in Table 8. Seedlings of *E. schimperi* had a significantly higher ($p < 0.05$) mean RGR in height than all the other three species. This was followed by the mean RGR of *J. procera* which was significantly higher than those of *A. abyssinica* and *O. europaea*. The latter two species showed no significant difference between each other. RGR in mean leaf number however, showed no significant differences among the four species ($p > 0.05$).

Comparisons in mean RGR within species under different soil treatments showed no significant difference ($p > 0.05$). However although statistically non-significant, the following trends were observed between some soil treatments. *A. abyssinica* showed relatively higher mean RGR in soils treated with FAG and FMAG ; *E. schimperi* in FAG, FMAG, and MAG treated soils and in *O. europaea* it was relatively higher in FM, MAG and FMAG treated soils.

Table 8. Mean Relative Growth rate of transplanted seedlings as percent per week between 60 and 150 days after planting.

Soil treatment	Parameter							
	Mean height (cm)				Mean leaf number			
	A.abys	*E.schi.*	*J.pro.*	*O.eur.*	*A.abys*	*E.schi.*	*J.pro.*	*O.eur.*
Artificial gap (AG)	2.96 c*	4.68 a	3.77 b	2.82 c	2.72 ns	2.75 ns	2.97 ns	3.02 ns
Fertilizer (F)	3.05 c	5.08 a	4.19 b	2.98 c	3.28 ns	3.37 ns	3.56 ns	3.64 ns
Mulch (M)	2.54 c	4.63 a	4.36 b	2.54 c	3.14 ns	3.31 ns	3.69 ns	3.32 ns
F + M	2.97 c	5.0 a	4.28 b	2.97 c	3.18 ns	3.36 ns	3.77 ns	3.63 ns
F + AG	3.61 c	5.47 a	4.45 b	3.25 c	3.60 ns	3.37 ns	3.73 ns	3.51 ns
M + AG	2.76 c	5.48 a	4.40 b	2.87 c	2.99 ns	3.39 ns	3.90 ns	3.60 ns
F + M + AG	3.31bc	5.42 a	3.98 b	2.98 c	3.42 ns	3.98 ns	3.99 ns	3.72 ns
Control	2.92	4.66	4.22	2.83	2.42	2.84	3.22	3.05

* For each species (in character height), means in the same row followed by the same letter donot differ significantly at 5% level of probability (LSD test).

ns = Non significant. *A. abys.* = *A. abyssinica; E. schi.* = *E. schimperi.*
J. pro. = *J. procera; O. eur.* = *O. europaea*

4.3.2.2. Seedlings from treated seeds.

The effect of each soil treatment on mean height and mean leaf number of individual species is shown in Table 9.

A. abyssinica: Mean height and mean leaf number were significantly higher ($p < 0.05$) in soils treated with FAG, FMAG than in the other soil treatments, but with no significant difference among each other. In F and FM treated soils mean height and mean leaf number showed higher significant difference from AG, M and MAG soil treatments. In M and MAG treated soils non-significant differences in mean height and mean leaf number obtained, which in turn significantly higher than in AG treated soils and in the control ($p < 0.05$).

E. schimperi: Significantly higher ($p < 0.05$) mean height obtained in FMAG treated soils. This measured character in AG treated soils and in the control was significantly lower than in all the other soil treatments ($p < 0.05$). In F, FM, FAG and MAG treated soils differences in mean height was non-significant among each other, but significantly higher than in AG treated soils and in the control. In soils treated with M mean height showed non-significant difference ($p > 0.05$) with F and FAG treated soils, but remained significantly lower from the others except from AG treated soils and the control. Mean leaf number was significantly higher ($p < 0.05$) in FMAG and FM treated soils. Seedlings grown in each of these treatments showed significantly higher difference from all the other soil treatments. In soils treated with FAG and

MAG no significant differences obtained, but showed significantly higher ($p < 0.05$) mean leaf number than in AG, F, M treated soils and in the control. In AG, F, M treated soils and the control no significant difference in mean leaf number obtained among each other.

O. europaea: In soils treated with FM, FAG and FMAG significantly higher ($p < 0.05$) mean height and mean leaf number obtained than in the other soil treatments, with no significant difference among each other. In treatments AG, F, M and MAG no significant differences observed between each other, but showed significantly higher mean height and mean leaf number ($p < 0.05$) than in the control.

The mean relative growth rate of each species under the various soil treatments is shown in Table 10. A significantly higher ($p < 0.05$) mean RGR obtained in *E. schimperi* than in *A. abyssinica* and *O. europaea*. The latter two species showed no significant difference ($p > 0.05$) in mean RGR under all soil treatments.

Mean RGR within species showed non-significant differences under the various soil treatments (Table 10). Although statistically non-significant still variations are observed under some soil treatments. In *A. abyssinica* relatively higher mean RGR are shown in FAG and FMAG; in *E. schimperi* in MAG and FMAG and in *O. europaea* in FM and FMAG treated soils.

Table 9. Effect of soil treatments on mean height (cm) and mean leaf number of seedlings from treated seeds 210 days after sowing, with ± standard error in brackets. H - Mean height (cm); L -Mean leaf number

Soil treatment	Species					
	A. abyssinica		*E. schimperi*		*O. europaea*	
	H	L	H	L	H	L
Artificial gap (AG)	11.8± 0.8 d*	15.1± 0.9 d	6.9± 0.1 d	6.4 ± 0.2 c	8.0 ± 0.2 b	12.9 ± 0.5b
Fertilizer (F)	16.6± 1.0 b	20.0± 1.1 b	8.2± 0.1 bc	7.0± 0.2 c	8.4± 0.3 b	13.5 ± 0.4b
Mulch (M)	13.3± 0.7 c	17.7± 0.8 c	7.8± 0.1 c	7.1± 0.1 c	8.6± 0.2 b	12.3± 0.3 b
F + M	17.0± 0.6 b	20.4± 1.6 b	9.0± 0.2 b	8.9± 0.2 ab	10.1± 0.1 a	16.6± 0.4 a
F + AG	18.2±0.6 a	22.8±1.5 a	8.2± 0.2 bc	8.0± 0.3 b	9.7± 0.1 a	16.2± 0.4 a
M + AG	15.1± 0.4 c	18.4± 0.7c	8.8± 0.3 b	8.3± 0.2 b	8.9± 0.2 b	13.8± 0.7 b
F + M + AG	18.0± 0.4 a	23.9± 1.1 a	10.1± 0.1 a	9.6± 0.2 a	10.5± 0.2 a	16.8± 0.3 a
Control	10.8± 0.4 d	14.8± 0.8 d	6.8± 0.2 d	6.0± 0.2 c	7.2± 0.1 c	11.2± 0.4 c

* For each species means in the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

Table 10. Mean relative growth rates of seedlings from treated seed as percent per week between 60 and 150 days after sowing.

Soil treatment	Parameter					
	Mean height (cm)			Mean leaf number		
	A. abys.	*E. schi.*	*O. eur.*	*A. abys.*	*E. schi.*	*O. eur.*
Artificial gap(AG)	5.0 b*	6.95 a	4.79 b	3.05 b	4.38 a	2.70 b
Fertilizer (F)	5.28 b	7.29 a	4.92 b	3.43 b	5.12 a	2.84 b
Mulch(M)	5.18 b	6.88 a	4.86 b	3.43 b	4.66 a	2.74 b
F + M	5.31 ab	7.26 a	5.25 b	3.56 b	5.0 a	3.21 b
F + AG	5.47 ab	7.12 a	5.0 b	3.60 ab	5.23 a	2.92 b
M + AG	5.22 ab	7.43 a	5.15 b	3.38 b	5.49 a	3.10 b
F + M + AG	5.60 a	7.45 a	5.76 a	3.81 b	5.79 a	3.15 b
Control	4.97	6.89	4.38	2.58	4.28	2.39

* For each species, means in the same row followed by the same letter don't differ significantly at 5% level of probability (LSD test). A. abys. = A. abyssinica; E. schi. E. schimperi; O. eur. = O. europaea.

4.3.2.3. Seedlings from untreated seeds.

The effect of application of different soil treatments on mean height and mean leaf number of *E. schimperi* and *O. europaea* is shown in Table 11.

E. schimperi: In soil treatments FM and FMAG mean height and mean leaf number recorded were significantly higher ($p < 0.05$) than in the other soil treatments. In F, M, FAG and FMAG treated soils no significant differences obtained, but each of them showed significantly higher mean height and mean leaf number than in AG treated soils and in the control.

O. europaea: Mean height and mean leaf number was significantly higher ($p < 0.05$) in FMAG and FM treated soils. These measured characters were significantly low in AG treated soils and in the control. In F, M, FAG and MAG treated soils non-significant differences ($p > 0.05$) were observed, but showed significantly higher mean height and leaf number than in AG treated soils and in the control.

Mean RGR within species of *E. schimperi* and *O. europaea* showed significant differences under the various soil treatments. In both species RGR in height was significantly higher ($p < 0.05$) in FMAG treated soils, than in the other soil treatments. In FM and MAG treated soils, it showed non significant differences, but significantly higher than ($p < 0.05$) AG, F, M, and FAG treated soils. In soils treated with F, M, FAG no significant differences in mean RGR obtained, which in turn significantly higher than in AG treated soils and in the control. Mean RGR in leaf number was significantly higher in FMAG treated soils than in the other soil treatments. In soils treated with F, FM, FAG and MAG no significant difference obtained between each other, but showed significantly higher mean RGR than in M, AG treated soils and in the control (Table 12).

Table 11. Effect of soil treatments on mean height (cm) and mean leaf number of seedlings from untreated seeds 210 days after sowing , ± standard error.

H - Height (cm) ; L - Leaf number.

Soil treatment	Species			
	E. schimperi		*O. europaea*	
	H	L	H	L
Artificial gap(AG)	5.7± 0.2 c*	6.2± 0.4 c	5.5± 0.2 d	8.6± 0.2 c
Fertilizer (F)	6.7± 0.2 b	7.3± 0.3 b	7.2± 0.1 b	10.8± 0.1 b
Mulch (M)	6.6± 0.2 b	6.5± 0.3 c	6.6± 0.1 b	9.6± 0.3 c
F + M	8.5± 0.2 a	8.6± 0.4 a	8.0± 0.2 a	12.1± 0.2 a
F + AG	7.5± 0.2 b	7.3± 0.3 b	7.6± 0.2 bc	11.2± 0.4 b
M + AG	7.4± 0.2 b	7.0± 0.4 b	7.1± 0.1 b	10.5± 0.3 b
F + M + AG	9.0± 0.2 a	9.2±1 0.2 a	8.5± 0.1 a	12.7± 0.3 a
Control	5.4± 0.3 c	5.7± 0.3 c	5.1± 0.1 d	8.6± 0.4 c

* For each species, means in the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

Table 12. Mean relative growth rate of seedlings from untreated seeds as percent per week between 60 and 150 days after sowing.

H - mean height ; L - mean leaf number

Soil treatment	Species			
	E.schimperi		*O. europaea*	
	H	L	H	L
Artificial gap (AG)	6.52 d*	4.49 d	5.93 d	4.49 d
Fertilizer(F)	7.37 c	5.65 b	7.50 c	5.14 c
Mulch(M)	7.15 c	5.07 c	7.42 c	4.87 c
F + M	7.87 b	5.63 b	7.92 b	5.55 b
F + AG	7.39 c	5.81 b	7.37 c	4.62 c
M + AG	7.97 b	5.95 b	7.71 b	5.49 b
F + M + AG	8.60 a	6.23 a	8.77 a	5.76 a
Control	6.31 d	4.45 d	5.31 d	4.36 d

* For each species means in the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

4.3.3. Survival of seedlings.

The survival of each species was expressed as the number of individuals surviving out of the total, expressed in percent.

4.3.3.1. Transplanted seedlings.

Significantly higher percent survival ($p < 0.05$) obtained from seedlings of *O. europaea* (92.5%) and *E. schimperi* (88.6%) with no significant difference to each other. These showed significantly higher difference from *A. abyssinica* (80.6%) and *J. procera* (70%). *A. abyssinica* showed significantly higher difference from *J. procera*. Comparison of survival within species of transplanted seedlings is shown in Table 13. Each of the four species from transplanted seedlings showed significantly higher ($p < 0.05$) percent survival in soils treated with mulch and its combination with either fertilizer, artificial gap or both (i.e FM, MAG and FAG) than in the other soil treatments (i.e AG, F and FAG and the control). Within species of *A. abyssinica* percent survival showed no significant difference in F and FAG treated soils, but it was significantly higher than in AG treated soils and in the control. The same trend was observed in *O. europaea*. *E. schimperi* showed significantly higher survival in AG than in FAG treated soils and in the control. Percent survival in *J. procera* significantly lower in soils treated with AG, F and FAG than in the control ($P < 0.05$).

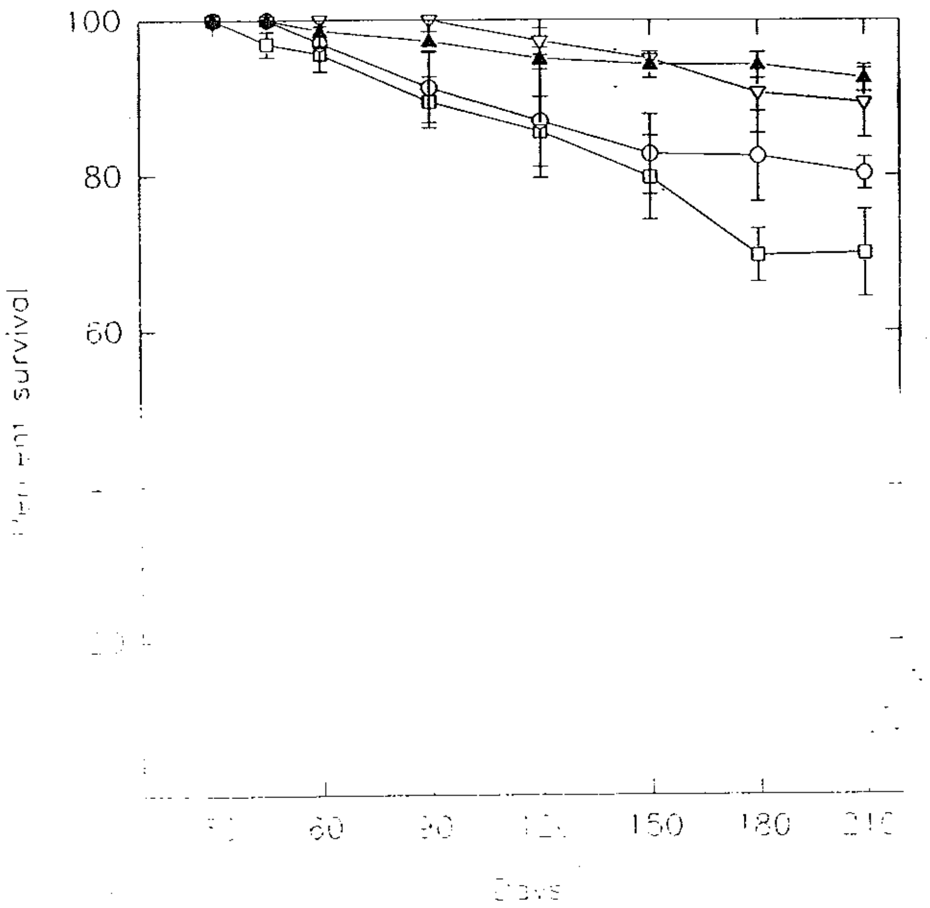

Fig 6 Percent survival of transplanted seedlings in the study site 210 days after sowing

▲ O. europaea

▽ E. shimperi

○ A. abyssinica

□ J. procera

Table 13. Percent survival of seedlings from transplanted seedlings under different soil treatments, 210 days after transplanting.

Soil treatment	Species			
	A. abyssinica	E. schimperi	J. procera	O. europaea
Artificial gap (AG)	70 d*	85 c	60 c	90 b
Fertilizer (F)	80 bc	90 b	65 c	90 b
Mulch (M)	85 ab	95 a	75 a	95 a
F+M	85 ab	95 a	75 a	95 a
F+AG	75 c	80 d	65 c	90 b
M+AG	85 ab	90 b	75 a	95 a
F+M+AG	90 a	95 a	75 a	95 a
Control	75 c	80 d	70 b	90 b

* For each species values in the same column followed by the same letter don't differ significantly at 5% level of probability.

4.3.3.2. Seedlings from treated seeds.

Percent survival in *O. europaea* (78.5%) and *E. schimperi* (74.8%) was significantly higher ($p < 0.05$) than in *A. abyssinica* (65.2%), with no significant difference between them. Seeds of *J. procera* germinated and grew a few centimetres, but all died about one month after germination (Figure 7).

In each species, a significantly higher percent survival was observed in soils treated with M, FM, MAG and FMAG (Table 14). These were significantly higher ($p < 0.05$) than in treatments AG, F, FAG and the control. The latter group was not significantly different from one another.

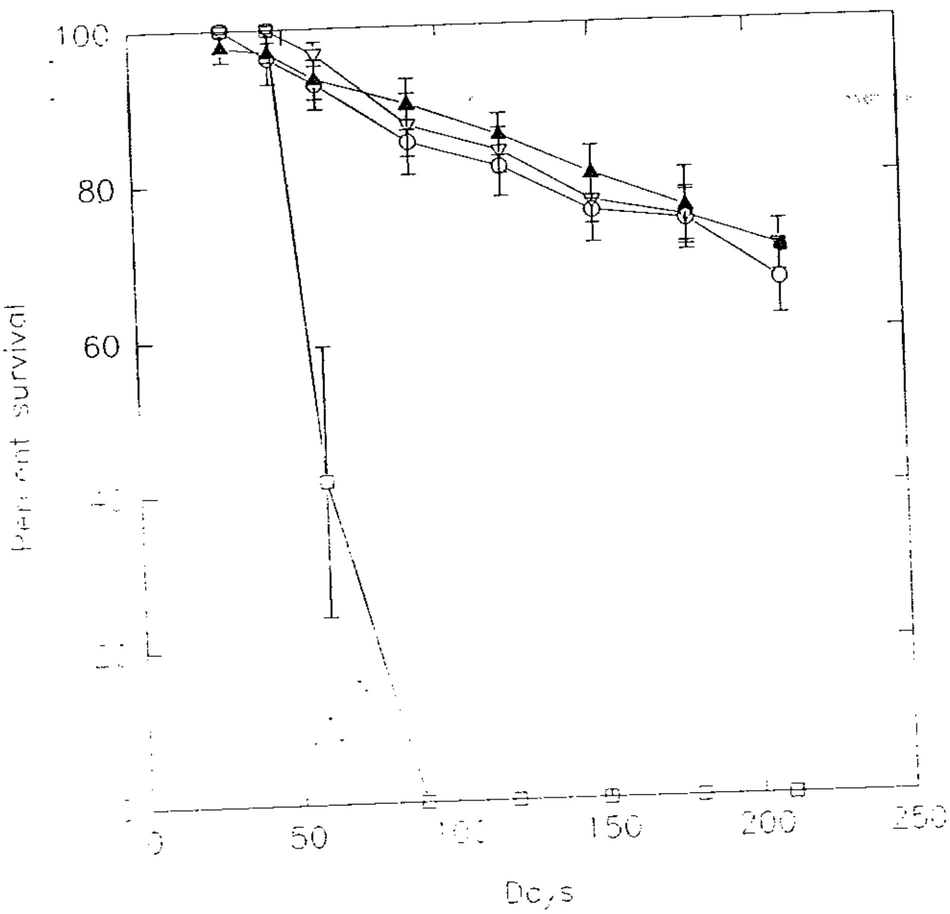

Fig 7 Percent survival of seedlings from treated seeds

in the study site 210 days after sowing

▲ O. europaea

▽ E. shimperi

○ A. abyssinica

□ J procera

Table 14. Percent survival of seedlings from treated and untreated seeds under different soil treatments, 210 days after sowing.

Species	Artificial gap (AG)	Fertilizer (F)	Mulch (M)	F + M	F + AG	M + AG	F + M + AG	Control
Treated seeds								
A.abyssinica	61.4 c	64.8 b	69 a	69 a	65.6 b	68.8 a	71.9 a	60.5 c
E. schimperi	70.5 b	72.8 b	79 a	78.4 a	72.3 b	78.9 a	79.4 a	66.7 d
O. europaea	75.6 c	80.0 b	82.6 a	82.3 a	72.4 c	82.8 a	83 a	72.4 c
Non treated seeds								
E. schimperi	68.6 c	70.8 b	76.6 a	76 a	67.2 c	73.2 a	75.8 a	66.3 c
O. europaea	72.7 b	73.6 b	80.7 a	81.3 a	71.8 b	79.1 a	80.9 a	72.3 b

* For each species means in the same row followed by the same letter don't differ significantly at 5% level of probability (LSD test).

4.3.3.3. Seedlings from untreated seeds.

Percent survival of seedlings from untreated seedlings was 76% in *O. europaea* and 71.3% in *E. schimperi* at the end of the study period (Figure 8). Soil treatment effect (Table 14) within species showed that, in M, FM, MAG and FMAG there was significantly higher ($p < 0.05$) percent survival than in the other soil treatments. In AG, F and FAG treated soils percent survival showed non significant differences among each other, but it was significantly higher than the control.

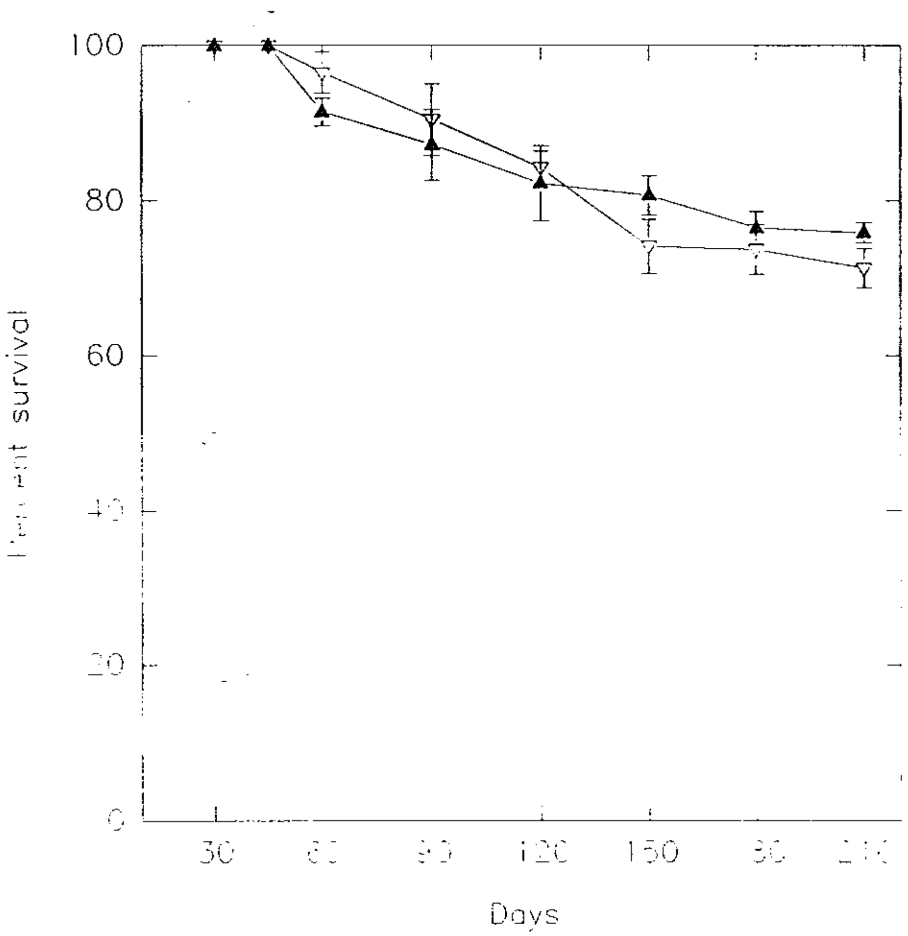

Fig 8 Pecent survival of seedlings from untreated seeds in the study site 210 days after sowing

▽ E. schimperi
▲ O. europaea

4.3.4. Seed bank results

A total of 1679 seedlings were recorded from the four plots. Out of these 890 were dicotyledons and 789 were monocotyledons (Figure 9). Within the dicotyledons 26 individuals were woody species, out of which 4 were *Acacia* 13 *Dodonia* and 9 *Olea* species. The monocotyledons mainly consisted of grasses. Some of the common species identified are presented in appendix 2.

The total number of seedlings that emerged under each soil treatment is shown in Table 15. Significantly higher number of seedlings were obtained in soils treated with FMAG, when compared to the other soil treatments. Although there was no significant difference between soils treated with FAG and MAG, these were significantly higher from AG, F, M and FM treated soils and the control. Among the latter, seedling number was significantly higher in soils treated with AG than F. A significantly higher number of seedlings obtained from soils treated with M, FM and the control. In both M and FM treated soils significantly lower number of seedlings obtained ($p < 0.05$) than in the other soil treatments and in the control.

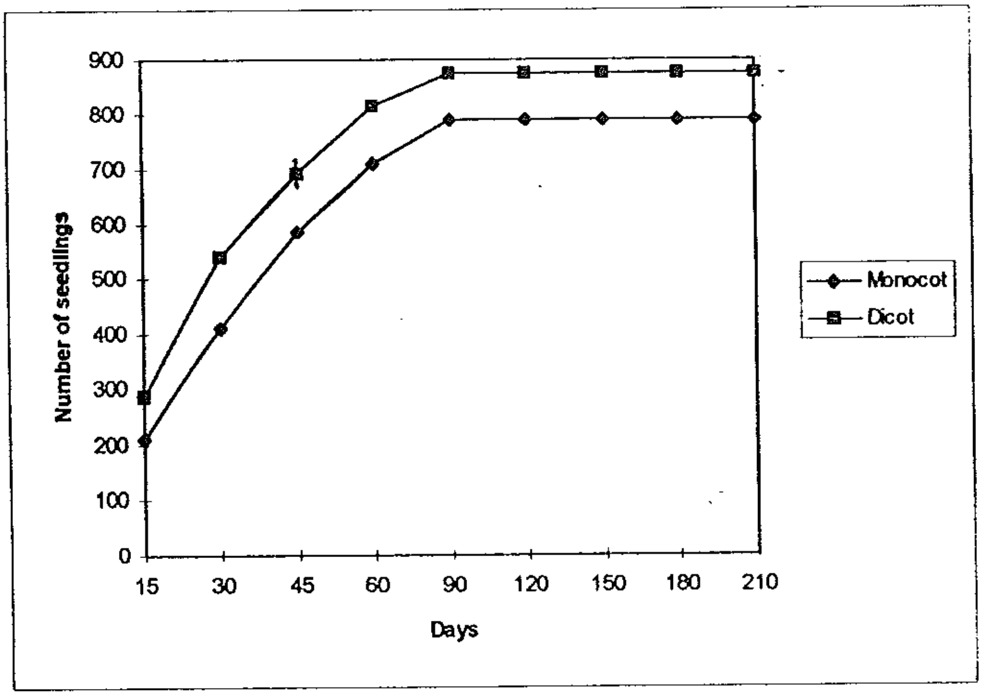

Fig. 9. Total number of monocot and dicot seedlings recorded in the local seed bank of the study site

Table 15. Effect of soil treatments on the total number of seedlings obtained from the local soil seed bank.

Soil treatment	Seedlings		
	Monocots	Dicots	Total
Artificial gap (AG)	106 b*	110 b	216 c
Fertilizer (F)	82 c	85 c	167 d
Mulch (M)	72 d	79 c	151 e
F + M	69 d	85 c	154 e
F + AG	112 b	146 a	242 b
M + AG	121 ab	146 a	267 b
F + M + AG	146 a	147 a	293 a
Control	81 c	92 c	173 d
Total	789	890	1679

* For each group values in the same column followed by the same letter don't differ significantly at 5% level of probability (LSD test).

5. DISCUSSION

Comparative percent germination in the species investigated showed that seed dormancy and accompanying environmental factors affected their performance. This was clearly observed in both the laboratory and field studies. However, it is not appropriate to make direct comparisons between laboratory and field results, since there were differences in the conditions to which the seeds were exposed. In the field the environmental conditions, specially climate factors, varied both daily and seasonally. The soils were also supplied with different treatments. This makes the field conditions more heterogeneous than the laboratory where conditions were maintained relatively constant.

Significantly higher percent germination were obtained from seeds of *Olea europaea* after removal of the hard seed coat, and in *Acacia abyssinica*, in both scarification and hot water treatment (Figure 1). These results indicate that dormancy caused by the hard seed coat in part restricts the germination of these two species. Similar investigations on *O. europaea* (Legesse Negash, 1993), and *A. abyssinica* (Legesse Negash, 1995) also demonstrated that these treatments are effective in improving seed germination of these species.

Seeds of *Juniperus procera* imbibed water but failed to germinate when scarified, and treated by hot water and sulphuric acid. This may be resulted due to damage of the embryo after these treatments. Similar observations were reported by (Demel Teketay, 1993a) who showed that seeds of this species gave no response to the pre-sowing treatments such as acid and hot water scarification. These results, however, differ from those of Laurent and Chamshama (1987), who found germination responses in this species by hot water (68-74%) and sulphuric acid (73-78%) treatments in Tanzania. This can be partly attributed to differences in provenances in seeds isolated from Tanzania and Ethiopia. Variations in geographical and climatic conditions may probably contribute to differences in the degree of dormancy between seeds. However, after removing seeds from their berries germination was possible in *J. procera* when sown in flower pots filled with nursery soil and in the field study. Earlier investigations by Legesse Negash (1995)showed that sowing either in flower pots or in a prepared seedbed to be effective methods that result in successful seed germination for this species. In the present investigation however, percent germination obtained was between 40%-45%. This low percent germination could result from the development of fruits without having an embryo. The development of such kind of fruit can also be associated with the absence of pollination, because of the dioecious nature of the species.

Inter treatment comparative performance in seeds of *E.schimperi* showed that higher percent germination was obtained either when the fleshy seed coat was removed or in the control. Significantly low percent germination obtained by hot water and sulphuric acid treatments, but it was nil in scarified seeds and in those treated with sulphuric acid for 20 minutes (Figure 2). Similar germination results were obtained in treated and untreated seeds in pot experiments and in the field study. Low percent germination probably associated with the thin and soft nature of the seed coat that can expose the embryo to extreme damages after these treatments. Mechanical scarification, sulphuric acid and hot water are known to be effective treatments resulting in rapid and high percent germination in different species with hard seed coat dormancy (Laurent & Chamshama, 1987; Legesse Negash, 1993; 1995; Demel Teketay, 1994, 1996). The fact that germination was either completely inhibited or poor by these treatments as evidenced from higher percent germination in the control is therefore, indicative that seeds of *E. schimperi* seems to have lower or no dormancy imposed by the hard seed coat.

Higher percent germination under field conditions was obtained from treated seeds of *A. abyssinica* and *O. europaea* (Figure 3). This suggests that seed manipulations such as scarification and removal of the hard seed coat, and hot water treatments are required to break dormancy and facilitate germination as concluded by different investigators (Laurent & Chamshama, 1987; Legesse Negash, 1992;1993;1995; Demel Teketay, 1994; 1996).

The presence of hard seed coat may have partly resulted in the failure of untreated seeds of *A. abyssinica* and *J. procera* to germinate. The existence of thick and impermeable seed coat have a profound effect on the passage of water and oxygen and thus restrict the germination potential of many plants (Mayer, 1974; Fenner, 1985). Therefore, seeds of these species require mechanisms which enables them to overcome this barrier. On the other hand, seed dormancy has an ecological and biological significance for the survival of many plant species during unpredictable environmental conditions (Fenner, 1985; Baskin & Baskin, 1989). Nevertheless, the germination capacity of *A. abyssinica* and *J. procera* under natural environmental conditions seems to require much time as none of the seeds of these species were observed to germinate under different soil treatments.

The untreated seeds of *O. europaea* germinated under field conditions, but failed to do so in the laboratory. Similar responses to germination were observed in treated seeds of *J. procera*. This may result from the influence of soil factors. Within the soil fluctuating temperature, soil organisms, soil acids and related factors enhance germination of seeds by increasing seed coat permeability (William & Elliot, 1960; Baskin & Baskin, 1989; Moreno-Casasola *et al.,* 1994). The application of different soil treatments, together with other interacting soil factors may provide conditions that can break seed dormancy of these species.

An increase in percent germination in the treated seeds of *A. abyssinica*, and *J. procera* and in both treated and untreated seeds of *E. schimperi* and *O. europaea* was obtained by the application of mulch alone or its combination with the other treatments (Table 5). Higher germination in mulched soils could result from the contribution of mulch in supplying favourable moisture by reducing evaporation, protecting seeds from run off during rainfall periods, and providing optimum temperature necessary for germination. As it was stated by different investigators (Springfield, 1978; Luken, 1990;

Sakuri *et al.,* 1991), mulching materials such as grass or hay are known to ameliorate the conditions of the soil and create favourable micro environment for germinating seeds. The increase in germination by this treatment is therefore, suggestive that mulching can facilitate seed germination of these study species.

Germination in soil treatments AG and FAG was significantly lower and increased when these treatments are in combination with mulch. It has been reported that the occurrence of gaps or openings provide suitable microenvironment for the rapid germination of seeds (Miles, 1974; Rusch, 1993). This effect of gaps on seed germination is associated with improvement of the light, temperature and moisture regimes in the soil. So the ability of any seed to respond to conditions found in the gap is a valuable asset to have maximum germination in their natural habitats (Fenner, 1985). However, the results from the present study differ from those reported by Miles (1974) and Rusch (1993) in different plant species. Some reasons may account to explain such cases. It was observed that the shallowness nature of the soil, and absence of protecting materials such as mulch exposed some seeds during rainfall periods. This partially contribute for few number of seeds to lose in viability before they germinate. Although the actual causes of loosing viability is not fully understood, it can be related to insufficient moisture condition resulting from the shallowness nature of the soil (Oomes & Elbrese, 1976 ; Fenner, 1985). This may cause dehydration of the seeds after they are exposed to the soil surface.

In addition, seed collecting ants were observed carrying some of these exposed seeds and storing it in their casts. Earlier observations reported by Gross *et al.,* (1991) in Northern Australia indicated that many ant species are seed harvesters and predators rather than dispensers of sown seeds. These factors in addition to seed dormancy may account for the reduction in the count of germinated seeds under field condition.

Growth performance of seedlings showed variation between different species and also between individuals of the same species growing under different soil treatments. The causes of these variations are probably a combination of different factors including differences in germination time, microhabitat differences, and genetical factors of the species.

Seedlings of *A. abyssinica, O. europaea* and *E. schimperi* showed better growth over the full range of all sites (Figures 4 & 5). Increase in growth may be attributable to the early start in seed germination. After seed treatment germination in these species completed within short periods both in the laboratory and in the field study. The untreated seeds of *E. schimperi* also showed similar responses. An early start in germination of a plant has the ecological advantage of enhancing its subsequent growth and enabling it to occupy suitable microsites (Ross & Harper, 1972). Thus, the immediate germination of seeds of these species seems to have an advantage allowing the seedlings to grow better during the study period.

Visual observations and growth measurements revealed that both transplanted seedlings (Table 7) and seedlings from sown seeds (Tables 8 & 11) showed good growth performances in mulched and fertilized soils with a higher response from *A. abyssinica* followed by *O. europaea*. Those seedlings grown with a combination of these treatments in particular were relatively of better stature, had deep green leaves, and visibilly healthier looking than seedlings with the other soil treatments. Placing a layer of mulch may protect these seedlings against high temperatures and loss of moisture from the soil, while fertilizers supply essential nutrients to sustain rapid growth.

The positive effects of mulch and fertilizer treatments on the growth of these indigenous species is similar to those documented for different species planted in the savanna regions of Nigeria (Kadeba, 1978) and in a degraded land of Thailand during rehabilitation programmes (Sakuri *et al.*, 1991). Therefore, this result suggest that maintaining the fertility status, moisture and optimum temperature of the soil using fertilizer and mulch treatments could be one effective means of making the growth and establishment of *A. abyssinica, E. schimperi, J. procera,* and *O.europaea* successful when rehabilitating degraded lands. However, the optimum amount of fertilizer required by these species in the study area needs to be tested by further field experiments.

Comparisons of mean relative growth rate (RGR) of each species showed some differences. Significantly higher mean RGR was recorded in seedlings of sown seeds than transplanted ones. This significantly higher RGR was obtained in *E. schimperi* than seedlings of the other species. Differences in RGR between species could be related to the size of the plant. According to Evans (1972) RGR is expected to decrease with age or size of a plant. The important reason for the lower value of RGR when the size of a plant increases is more elaborated by Hunt (1978). This author pointed out that the larger and more complex the living organism is, the lower will be the rate of dry weight increase possible on percentage basis, and this trend is generally held due to the increased morphological and anatomical differentiation which is necessary to sustain life in large systems. In addition, differences in RGR may also result from differences in genetic constitutions that causes physiological variations between species (Grime & Hunt, 1975).

Higher percentage in survival and establishment was observed among transplanted seedlings (Figure 6) than seedlings grown from sown seeds (Figures 7 & 8). This resulted from the fact that transplanted seedlings were already well developed and had functional root systems which enables them to grow and establish soon after transplanting.

Percent survival of many seedlings fell significantly at the end of the rainfall period and starting with the beginning of the dry season. This may be accounted for by the marked drying of the soil that can't enable it to hold enough moisture. This effect was specially severe among the transplanted seedlings of *J. procera* and some of the seedlings grown from sown seeds too. From seedlings of *J. procera* grown from sown seeds 100% mortality was recorded. To start with treated seeds of this species germinated during relatively low rainfall period (i.e, in mid September) and seedlings were exposed to strong sun light about one month after germination. This causes a drying out of seedlings. Relatively higher temperature during early stages of growth therefore, may be a factor contributing to higher mortality. Similar investigations on the survival and establishment of different plant species (Miles, 1972; Swaine & Hall, 1983; Blain & Kellman, 1991) showed that high temperature and drought appeared to be important factors of mortality at the early stages of growth.

During the hot and dry period seedlings of *E. schimperi* and *O. europaea* showed low percent mortality. This observation may suggest that these species can be tolerant to drought periods. One of the important characteristic of *O. europaea* is its potential of drought resistance and high longevity once established (Dale & Greenway, 1961). *E. schimperi* also known to grow well in degraded and arid areas under natural conditions (Azene Bekele *et al.*, 1993). With this potential for higher survival success, *O. europaea* and *E. schimperi* are likely to grow and establish well in the study area.

Higher percent survival in each species was recorded in mulched soils and its combination with either fertilizer or artificial gaps or a combination of these treatments (Table 13). In addition to its use in improving the conditions for germination and growth, mulch also increases the chances of survival of many seedlings by modifying the conditions locally and creating favourable microsites (Luken 1990). This observation is in conformation with most of the available information obtained in different plant species such as; *Atriplex canescens* and *Eurotia lanta* in New Mexico, U.S.A. (Springfield, 1978); *Juniperus monosperma* in surface mined lands in New

Mexico (Fisher *et al.*, 1986) and *Eucalyptus* species in a degraded land of Thailand (Sakuri *et al.*, 1991).

Percent survival of each species under artificial gap was significantly lower than in the other soil treatments. This can be the result of removal of the vegetation cover which may cause immediate loss of the moisture of the shallow soil. A similar effect was reported on the survival of seedlings of *Acacia tortilis* in semi-arid Africa (Smith & Schackleton, 1988). Dry periods therefore, together with poor water retention in the soil may result in the failure of seedling survival.

Another factor which was important in accounting for the mortality of seedlings of *A. abyssinica* and *O. europaea* was the presence of browsing herbivores. A few seedlings of these species were affected by rabbit and bush duckier browsing. The greater effect of these animals was preventing the continued growth and development of the seedlings. However, those that were browsed but not uprooted and killed were found to regenerate leaves from the branches cutoff point. In addition to browsing effect some seedlings of *A. abyssinica* were found to have been killed by termite attack. The effect of browsing and termite attack on the survival of different plant species during the early stages of growth has been emphasized by different authors (Harper, 1977; Auguspurger, 1984; Fenner, 1985). Therefore, large herbivores and termites are important factors that will have some impact on the survival of seedlings, and this must be taken into account and corrective measures should be planned during planting these species.

Following disturbance or destruction of a vegetation, seed banks can be one important source of reproductive propagules for the regeneration of different plant species. Due to this many authors stressed the potential importance of the soil seed bank as one means of rehabilitating the lost vegetation in degraded lands (Johanson & Bradshaw, 1979; Van der valk & Pederson, 1989; Skoglund, 1992). However, studies on this issue are limited in the tropics in general as seen from the review by Garwood (1989), and particularly in Ethiopia knowledge on soil seed banks is scarce and only one study has recently been reported on the subject (see Demel Teketay & Granstrom, 1995).

The total number of seedlings that emerged from the local seed bank in the present investigation showed variation during each census and appeared to be related to the rainfall pattern. The peak total seedling emergence was attained in July and August (Figure 9) seemingly the most favourable period for germination. The number of emerging seedlings, however declined during subsequent observations. This decrease may be attributed to either the induction of dormancy by high temperature (Thompson & Grime, 1979) or the presence of a low density of seeds due to the shallowness of the soil.

The dominant group of seedlings recorded from the local seed bank were dicotyledons, with a preponderance of herbaceous plants and very few woody species. Grasses were the dominant group among the monocotyledons. A higher number of herbaceous and grass species than woody species was reported from the seed bank study of four dry Afromontane forests elsewhere in Ethiopia (Gara Ades, Menagesha, Munessa-

Shashemene and Wof-Washa) (Demel Teketay & Granstrom, 1995). The increase in the number of herbaceous and grass seedlings can be attributed to a combination of factors; their short reproductive cycles, long distance dispersal and from their potential of accumulating large number of small viable but dormant seeds for a longer period in the soil seed bank (Harper, 1977). This small seed size is important because it enables them to infiltrate into cracks and thus incorporate deep in the soil (Fenner, 1985).

The total number of woody species obtained from the local seed bank were very low, among which were a few number of seedlings of *Olea* and *Acacia* individuals. This probably resulted from the existence of very few and scattered mature individuals of *Acacia* species and *O. europaea* subsp. *cuspidata* near the study plots thus, contributing little to the local seed bank. On the other hand the absence of seedlings of other woody species in the soil seed bank is due to the total disappearance of mature stands and individuals from the nearby areas and poor long distance dispersal of their large sized seeds (Demel Teketay & Granstrom, 1995). However, seedlings of the shrub species *Dodonia* were emerged with out the existence of mature stands in the surroundings. This may imply that the small sized seeds of this species either can survive in the soil for long or they have been carried-in as part of the seed rain from another area.

Observations on emergence of seedlings from the local seed bank revealed that a large number of seedlings were responded to gap creation and its combination either with fertilizer or mulch (Table 14). The use of mulch and fertilizer treatments as one management strategy in increasing the establishment of a vegetation from the local seed bank has also been reported by some authors (Johanson & Bradshaw, 1979; Van der Valk & Pederson, 1989).

Manipulation of the local soil seed bank can facilitate the potential of recolonizing species regenerated from buried reproductive propagules. The application of different soil treatments and manipulations therefore, could be one important strategy to increase the number of colonizing species from the soil seed bank. Some of these manipulations and treatments include maintaining soil moisture, addition of fertilizer (Van der valk & Pederson, 1989), and gap creation (Rusch, 1993). Gap creation exposes many buried seeds to light and daily fluctuating temperature that would increase the chances of germinating seeds (Fenner, 1985). It is therefore, likely that the combined effect of gap creation, fertilizer and mulch could increase the number of emerging seedlings from the local soil seed bank of the present investigation.

6. CONCLUSION AND RECOMMENDATION

Although the process of rehabilitation requires more time and effort to attain the definite target, the present study may give us an insight into the role of seed and soil manipulations in facilitating the growth and establishment of indigenous plant species. The results from the local seed bank study can also provide additional information about the importance of such manipulations in the management of successional process during rehabilitating degraded lands.

Successful rehabilitation requires manipulation of the soil as well as the plant species. Therefore, with careful species selection and management practices and understanding of their natural succession, planting indigenous plant species would be a promising tool for rehabilitating degraded lands.

The germination results obtained both in the laboratory and in the field studies are indicative of the fact that seed treatments are essential to effect maximum germination. Treatments used for seeds of *A. abyssinica* (scarification and hot water treatments) and *O. europaea* (removing the hard seed coat) have proved to be satisfactory in producing maximum germination. In *E. schimperi* , however good germination can be obtained without any seed treatment. In the present investigation direct sowing either on seed beds or in flower pots (filled with nursery soil) required more than 50 days for seeds of *J. procera* to germinate. Thus further investigations are required to obtain convenient methods that can increase the germination capacity of this species within a short time.

The germination capacity of seeds of the investigated species in the field was influenced by soil treatments such as mulch, and its combination either with fertilizer or artificial gap. Therefore, the application of mulching materials like hay or straw in combination with artificial gap together with seed treatments such as scarification and hot water, is recommended to obtain high percent in the species studied.

Higher growth response and survival rates for each species were observed in mulched and fertilized soils. However, in countries like Ethiopia where fertilizers are expensive and unavailable in large quantities, the use of fertilizers over a large scale is not feasible. Instead, soil treatments such as mulching in combination with the creation of artificial gaps could be enough for large scale rehabilitation of degraded lands.

Except in *J. procera*, a better performance growth and survival was observed in transplanted seedlings. Seedlings from sown seeds were sensitive to different factors such as drought, predation and other hazards of the environment than transplanted ones. Raising seedlings in the nursery and transplanting them therefore, may be an effective means for assuring successful seedling establishment during rehabilitation programmes. In this respect *E. schimperi* and *O. europaea* followed by *A. abyssinica* are recommendable for use in the study area because of their successful growth and establishment potential. Although the growth and survival responses of these species is encouraging, it can not be said however, whether their response would be sustained in subsequent seasons. This requires again looking for additional information from long term studies.

With regards to the soil seed bank, the creation of gaps together with the use of mulch are recommendable treatments to increase the recruitment of most of the grass and herbaceous species. The number of woody species emerged from the local seed bank however, were very low. Therefore, to rehabilitate this degraded land within short period planting raised seedlings would be a better alternative, to natural regeneration. It may also be still a good strategy to leave some land free of any interference so that it rehabilitates itself naturally, no matter how long time it takes. This helps to monitor the process of natural regeneration, and thereby find out the natural course of events which can in turn generate valuable knowledge that helps better cope with the problem of rehabilitation.

Finally to reach at definitive recommendations in rehabilitation efforts and to reclaim degraded lands with indigenous plant species. additional long term studies should be conducted in different agroclimatic zones of the country. If this effort is supported by public awareness and conservation of the remnant natural vegetation, the task of rehabilitating degraded lands in the country can be said to be in the right track to find lasting solutions.

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Appendix 1. List of plant species recorded in the study site.

Acacia spp.

Agrostis semiverticilla

Allophyllus abyssinica

Aloe spp

Bidens pilosa

Carissa edulis

Croton macrostachys

Coreopsis boraniana

Datura stramonium

Ehretia cymosa

Eucalyptus spp.

Ficus gnapolocarpa

Gravellia robusa

Grewia ferruginea

Guizotia scarbia

Hyparrhenia rufa

Jasmium abyssinicum

Juniperus procera

Kalonche spp.

Mythenus spp.

Olea europaea subsp. cuspidata

Osyris compressa

Rosa abyssinica

Rumex nervosus

Stephania abyssinica

Appendix 2. List of some species of plants emerged form the local seed bank.

Monocots

Bothriochloa insculpta

Hyparrhenia rufa

Kohautia coccinea

Hyparrhenia hirta

Linum spp.

Rhynchelytrum repens

Dicots

Acacia spp.

Bidens pilosa

Conyza schimperia

Crotalaria spp.

Dodonia spp.

Euphorbia schimperana

Guizotia obyssinica

Hypoestes forskali

Indigotera spp.

Justicia hetrocarpa

Lactuca inermis

Olea spp.

Polygala persicariifolia

Satureja punctata

Seneico lyratus

Solanum villosum

Vermifrux abysinica

Vernonia spp.

Appendix 3. Diagrammatical representation of pods, fruits, and seeds of the study species.