115

ACACIA ABYSSINICA HOCHST. EX BENTH: POD AND SEED CHARACTERISTICS, GERMINATION PHYSIOLOGY AND POTENTIALS FOR SEEDLING ESTABLISHMENT ON DEGRADED LAND

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TABLE OF CONTENTS

List of tables

List of figures

List of Appendices

ABSTRACT

This study was conducted on pod and seed characteristics, germination physiology as well as the potentials of Acacia abyssinica Hochst. ex Benth ssp. abyssinica for growing on degraded land. Mature pods of A. abyssinica were collected from trees found in and around Addis Ababa (within a radius of 35 km). One hundred pods per tree were collected from 26 different trees. Comparison of the means of pod length, pod width and seed number per pod showed significant differences ($p < 0.05$) among samples obtained from the different localities. Pod length, pod width and number of seeds per pod ranged between 3.7 and 14.4 cm, 1.0 and 2.7 cm and 2 and 13 respectively. There was no significant correlation between pod length and width. Pod length and number of seeds per pod were significantly correlated ($p = 0.000$). On the other hand, pod width and number of seeds per pod were negatively correlated ($p = 0.000$). Seeds collected from 35 different trees were made into 17 bulks (each containing 1000 seeds). The weight of the bulks ranged from 74.01 to 116.11 g. There were significant differences ($p = 0.000$) among the mean weights of the 17 seed bulks.

Effects of gibberrelic acid (GA_3), indole-3-acectic acid (IAA) and kinetin with concentrations ranging from 10^{-3} M to 10^{-7} M on percentage germination and radicle length of chemically scarified seeds of A. abyssinica were examined. None of the plant growth regulators significantly increased the total percentage germination of seeds as compared to the control. Germination percentage decreased significantly at higher concentrations of IAA (10^{-3} M and 10^{-4} M) and kinetin (10^{-3} M). IAA at 10^{-3} M delayed germination for about a week as compared to the other concentrations of the same, though 63% of the seeds germinated within 10-15 days after incubation. GA_3 (at 10^{-3} M) significantly increased radicle length, while IAA at 10^{-4} M, 10^{-5} M and 10^{-7} M significantly decreased the radicle length as compared to the control.

The investigation on the potential of the species for growing on degraded land involved the growing of seedlings (GA_3 10^{-4} M treated and the control) in plastic bags in the greenhouse. Soil samples from degraded land were collected from geomorphically different locations from an area ca 4 km^2 along the road on the Modjo-Zeway road, at about 81 km south of Addis Ababa. Soil samples that served as a control were collected from places in and around Addis Ababa where A. abyssinica is currently found growing. Germinants from 10^{-4} M GA_3 and the control were planted in both types of soils and were left to grow in the greenhouse for 12 weeks. All the seedlings survived until harvest. Chemical and physical analyses of the soil samples were conducted in the National Soils Laboratory in Addis Ababa. The results of the analyses indicate that total nitrogen, organic carbon and available phosphorus were significantly higher ($p < 0.05$) in the soils collected from places where A. abyssinica is currently growing than those from the degraded land. On the other hand pH, Na, K, Ca, and CEC were found significantly

higher (p = 0.00) in the soils collected from degraded land. The mean values of plant height, number of branches, number of leaves, shoot dry weight and root dry weight were found to be significantly higher in the controls. From the results, it could be concluded that: (1) the presence of hard seed coats is the most important factor inhibiting germination in seeds of A. abyssinica; (2) provided that seeds are carefully scarified (chemically or mechanically), no germination stimulators are required for obtaining maximum percentage germination; and (3) the survival (until harvest) of the seedlings in soils collected from degraded land could indicate that A. abyssinica has the potentials for growing in degraded land provided that the minimum moisture requirements of the species is met.

1. INTRODUCTION

It has been reported by Davidson (1988), Evans (1989, 1992), EFAP (1992) and Fowlie (1996) that about a century ago closed forests covered 40 percent of Ethiopia and this has now been reduced to about 3.6 percent. But, Ethiopia's natural vegetation has been affected by agricultural activities for at least 5000 years. Though deforestation was accelerated towards the beginning of this century, widespread deforestation began around 2,500 years ago. It is, therefore, doubtful that forests covered 40 percent of Ethiopia (Tewolde Berhan Gebre Egziabher, 1986; Transitional Government of Ethiopia, 1992 in Marshal *et al.*, 1996; CSE, 1996).

Moisture, soil, topography, altitude, and human activities are some of the major environmental factors that determine variations in vegetation (Tewolde Berhan Gebre Egziabher, 1988). The various vegetation types of Ethiopia, have been grouped into nine major categories:

(1) Desert and Semi-Desert Scrubland; (2) *Acacia-Comiphora* (Small Leaved Deciduous) Woodland; (3) Lowland Semi-Evergreen Forest; (4) *Combretum-Terminalia* (Broad Leaved Deciduous) Woodland; (5) Moist Evergreen Forest; (6) Evergreen Scrub; (7) Dry Evergreen Montane Forest and Montane Grassland; (8) Afro-alpine and Sub-afroalpine Vegetation; and, (9) Riparian and Swamp Vegetation (CSE, 1996).

Acacia abyssinica Hochst. ex Benth. subsp. *abyssinica* belongs to the family Fabaceae (Leguminosae), sub-family Mimosoideae. This family is the third largest family of all the flowering plants and is commonly known as the pod-bearing family (Gunn, 1984).

Acacia abyssinica is a large tree which can attain a height of up to 20 m with branches ascending to form a very flat crown which can be up to 30 m wide (Fichtl and Admasu Adi, 1994; Legesse Negash, 1995). The bark is brown to almost black (dark green), rough and fissured. In younger trees, the bark is usually yellowish-white or cream in color and is parchment-like, but brittle which peels off readily (Legesse Negash, 1995; Bein *et al.*, 1996). The branchlets are longitudinally ridged; spines are straight, up to 4 cm long. Leaves are bipinnate, pinnae in up to 30 pairs; leaflets up to 40 pairs in a pinna. The flowers are sweet-scented, white or tinged red and are in round heads. They give rise to one chambered pods known as legumes. The flowering period spans over the period of October to May. The pods are somewhat thick and woody, straight or slightly curved, gray-brown or purplish-brown, up to 12 cm long and splitting on the tree or on the ground to release elliptic, compressed seeds (Thulin, 1983; Thulin, 1989; Friis, 1992, Fichtl and Admassu Adi 1994; Legesse Negash, 1995; Bein *et al.*, 1996).

In Ethiopia, *Acacia abyssinica* subsp. *abyssinica* occurs in woodland and wooded grassland, moist highland forest margins and along sides of streams and rivers with altitudinal range of 1500-2900 m above sea level and rainfall range of 1000-2000 mm/yr (Thulin, 1983, 1989; Friis 1992; Legesse Negash, 1995). It occurs in Tigray upland, Gondar, Gojjam, Shewa upland, Arsi, Bale upland, Illubabor, Keffa and Sidamo (Thulin 1983, 1989). It also occurs in Eritrea in wooded grassland, high forest edges, between 1,600 and 2,300 m above sea level (Bein *et al.*, 1996).

Acacia abyssinica is a superb source of fuel (fire wood and charcoal). Well formed stems are used for poles, posts and tool handles, building purposes, agricultural implements, railway sleepers, and heavy construction (Thirakul, undated; Legesse Negash, 1995; Bein *et al.*, 1996). The umbrella-

shaped crown, besides providing shade for animals and humans, is used for nesting by many birds. It is a beautiful ornamental tree for parks and sanctuaries. The thorny branches and twigs are commonly used for fencing fields of crops, the homestead and livestock enclosures (Fichtl and Admassu Adi, 1994; Legesse Negash, 1995; Wickens *et al.*, 1995; Bein *et el.*, 1996). The species is an important source of bee forage because its sweet-scented flowers produce abundant nectar and pollen (Azene *et al.*, 1993; Fichtl and Admassu Adi, 1994; Legesse Negash, 1995*). A. abyssinica* is also used in local medicine and the foliage and pods are eaten by camels and sheep (Wickens *et al.*, 1995; Bein *et al.*, 1996).

The current rate of deforestation in Ethiopia is estimated to be 200,000 hectares per year (Transitional Government of Ethiopia, 1992 cited in Marshal *et al.*, 1996). Land clearings for farming, tree fellings for fuel, commercial logging for timber, tree cutting for house construction, human settlement, population growth, accidental and intentional forest fires and difficulty in propagating indigenous forest species through the conventional (or adopted) tree propagation techniques are the major factors for the rapid depletion of native forests (Ensermu *et al.*, 1992; Evans, 1992; Legesse Negash, 1995). According to Tewolde Berhan Gebre Egziabiher (1986), the traditional attitude of the Ethiopian peasants to a forest has been that it is either a potential cropland, and hence its presence interferes with cultivation, or it is a source of fuel. This attitude together with lack of clearly defined ownership, and lack of authority of control over the forest, have been the major causes for heavy encroachment. Hence, the current use of trees for fuel nationally is exceeding incremental growth or reforestation in Ethiopia (EFAP, 1992, 1994a).

Deforestation has resulted in the loss of habitat for wildlife, the loss of reliable water supply, soil erosion and the loss of soil fertility and genetic resources of both plants and animals (EFAP, 1994b; CSE, 1996).

The Ethiopian highlands annually lose a total of 1.9 to 3.5 billion tons of soil as a result of erosion (EFAP, 1994b). As a consequence of this massive soil erosion, significant nutrient depletions have occurred resulting in widespread deficiency diseases in crop plants, animals, as well as in humans. In today's Ethiopia, there are fewer medicinal plant species, fewer nitrogen fixing species than there were some decades ago (Legesse Negash, 1995). The process of degradation, due to reckless destruction of vegetation, can be reversed by the re-establishment of vegetative cover which brings about slow but definite improvement in such inhospitable soils (Shukla and Misra, 1993).

Ethiopia is one of northeastern African countries badly struck by the environmental crisis (Michelsen *et al.*, 1993). To reverse the current degradation of natural forests, woodlands and shrublands in the tropics, a rapid production of tree seedlings in nurseries and high survival rate after planting is important (Michelsen, 1992).

Plantation of native or exotic species that are adapted to the stressful conditions characteristic of degraded landscapes reverse degradation process by stabilizing soils (through the development of both extensive and intensive root systems), by increasing soil organic matter (through the enhancement of the above ground litter production, fine-root turnover and decomposition rates), through the moderation of soil pH and through the improvement of nutrient status (Parotta, 1992).

From the point of their fast growth and meeting the demands of people for fuelwood and construction materials in relatively shorter period of time, plantations such as *Eucalyptus* are common in Ethiopia (Pohjonen and Pukkula, 1990). But these plants have a high demand for water and nutrients, and also release allelopathic substances from leaves, bark and roots discouraging understorey vegetation and thus enhancing soil erosion (Michelsen *et al.*, 1993; Legesse Negash, 1995). Therefore, priority should be given to the cultivation of the local trees and shrubs because this involves less risks, local trees are known and traditionally accepted by the people whom they will have to serve, they have already been shown to grow and yield timber and other products under prevailing site conditions, seeds are readily available including a choice of varieties and site-provenance. Replacement of local trees by exotics may also impair or may even threaten the survival of man and his livestock. Hence, *in situ* germplasm conservation deserves special attention. Also, at last, the African forester should feel a high degree of responsibility for maintaining and improving the indigenous vegetation of his home region (von Maydell, 1990).

Fast growing leguminous trees are considered to be most suitable to form the last green line of defence or the first green line of attack in protecting the remaining forest cover and reforesting of the deforested regions (Vietmeyer, 1979).

Provided that soil moisture level is optimal during the initial stages of seedling establishment, some observations indicate that *Acacia abyssinica* is capable of growing on degraded land. It has the potential to grow relatively fast (Michelsen, 1993; Michelsen and Sprent, 1994). It has also been noted that the species is capable of tolerating drought (Legesse Negash, 1995). Consequently it has been suggested that the species is useful for improving soil N through N_2 fixation and for

conserving and improving degraded soils and landscapes (Azene *et al.*, 1993; Michelsen *et al.*, 1993; Legesse Negash, 1995). Fassil Assefa (1993) reported that, compared to *Acacia etbaica, A. seyal, A. tortilis, A. nilotica,* and *A. prasinata, A. abyssinica* and *A. negrii* accumulated higher percentage nitrogen through the symbiotic relationship they made with the two groups of nitrogen fixing bacteria, viz., *Rhizobia* and *Bradyrhizobia.*

There is lack of detailed data on the biology and germination physiology of seeds of *A. abyssinica.* There is also a need for quantitative data on the potentials of the species to establish and grow on degraded land. Also, quantitative data on the beneficial effects of the species in restoring degraded soils are lacking. The objective of this work was, therefore, to assess the potentials of the species for rapid seed germination, germinant and seedling establishment, growth performance, as well as the potential of the seedlings for growing on degraded land.

2. LITERATURE REVIEW

2.1 The role of *Acacia* spp in soil fertility

The direct contribution of *Acacia* species to soil fertility is two-fold. The first is through nitrogen fixation and the second one is due to litter fall which results from the recycling of minerals from the soil by root systems (Radwanski and Wickens, 1967 cited in Wickens *et al.*, 1995). The contribution in terms of nitrogen is probably minimal because the foliage in the ground undergoes two periods of rapid degeneration: the rapid litter dehydration and loss of any volatile compounds, and the decomposition of the remaining fibrous mass and minerals by the end of the long dry season. The

decomposition of the dung from the livestock browsing on the fallen litter is also an indirect contribution, following similar cycles to that of the litter (Wickens *et al.*, 1995).

Abebe, T (1994) reported that in a study of the growth performance of 13 multipurpose trees and shrubs at two locations in the semi-arid areas of southern Ethiopia, the best performance in terms of survival and growth rates (height and diameter growth) was attained by *Acacia nilotica*, *Acacia saligna* (syn. *Acacia calophyla*), *Acacia seyal* and *Prosopis juliflora* and stated that given the ecological limitations of semi-desert areas, the growth rates of these species are promising. This indicates that a sustainable production system can be realized using proper agroforestry technologies in Ethiopia.

In a study of nutrient cycling by litterfall, carried out in semi-arid environment, in a native *Acacia seyal* and a planted *Eucalyptus* stand grown on a poor soil, Bernhard-Reversat (1987) found that tree litterfall increased the soil N, P, K, Ca and Mg in the native vegetation. A field study conducted to investigate the litter production and nutrient recycling behaviour of young *Acacia* and *Eucalyptus* plantations raised on a highly alkaline soil showed that the litter production in an *Acacia* plantation was significantly higher than in a *Eucalyptus* plantation of the same age and stocking rate during all the six years of study (Gill *et al*, 1987). In *in vitro* and *in situ* Nitrogen mineralization studies in a natural *Acacia seyal* stand and in a *Eucalyptus camadulensis* plantation in Senegal mineralizable N measured by 20 days *in vitro* incubations, was higher in *Acacia* soil than in *Eucalyptus* soil (Bernhard-Reversat, 1988). In a nitrogen-fixing capacity assessment of nine legume species, Roskoski *et al.* (1981) suggest that Nitrogen fixation by tree legumes could make a significant N input to tropical agro-ecosystems. Bernhard-Reversat (1993) found that the litter fall under *Acacia*

was twice as much as that under *Eucalyptus* plantations which also decomposed slower than *Acacia* litter. Thatoi *et al.* (1995) studied the comparative growth, nodulation and total N contents of six tree legume species in pots with iron mine waste to select plant species for reclamation of mine waste soils. In this study, *A. nilotica* showed the best response in iron mine waste soils.

2.2 The seed and its role

The seed is the product of a fertilized ovule. In gymnosperms, the seed is naked and is borne on the surface of scales comprising the cone, whereas it is formed within the ovary in gymnosperms (Bradbeer, 1988). At the separation from the parent plant it consists of an embryo and stored food supply, both of which are incased in a protective covering (Hartmann *et al.*, 1990).

The seed is usually comprised of: the embryo, the endosperm, the perisperm, and the testa or seed coat (Mayer and Poljakoff-Mayber, 1975; Bewley and Black 1985, 1994). The endosperm may persist as a storage organ or, it may degenerate, particularly in those cases where the cotyledons serve as storage organs and may be fused to the seed or fruit coat (Mayer and Poljakoff-Mayber, 1975; Tran and Cavanagh, 1984). A whole series of polymers and substances required for re-establishing physiological activity during the process of germination are accumulated in the reserve tissues during seed embryogenesis (Colorado *et al.*, 1994).

Seeds vary extremely in size and shape depending on the form of the ovary, the conditions under which the parent plant grows during seed formation, and on the species. They also vary in the size of their embryo, the amount of the endosperm they posses and the extent to which other tissues

participate in the seed structure. Variability within a given species also exists and is often referred to as seed polymorphism (Mayer and Poljakoff-Mayber, 1975).

The seed can be viewed as the culmination of the activities of one plant generation and the start of a new generation. It contains with it a plant in miniature, with the potential for growth and development into an adult plant. In many species, the seed is shed in a dehydrated state from the plant to become a unit of dispersal and eventually, under appropriate conditions, to resume growth (Wareing and Phillips, 1970; Bryant, 1985; Bradbeer, 1988). The seed, therefore, occupies a critical position in the life history of higher plants (Bewley and Black, 1985, 1994).

According to Bradbeer (1988), plants by producing seeds may be regarded as achieving the following main objectives: (1) restoring their genetic materials; (2) a dispersal mechanism; (3) a multiplication mechanism, and, (4) a survival mechanism.

2.3 Dormancy in seeds

Dormancy is an intrinsic block to germination (Bewley and Black, 1985). Mature, healthy looking, viable seeds of numerous trees and shrubs fail to germinate even when moisture, temperature and light conditions are optimal for germination. Such seeds are said to be **dormant** (Roberts, 1972; Bryant 1985; Legesse Negash 1995). The condition is caused by the existence, within the seed itself, of a block(s) to germination (Bewley and Black, 1982). Dormancy offers considerable benefits to the seed by serving as a means whereby distribution of germination in time can be achieved (Tran and Cavanagh, 1984; Bewley and Black, 1985). In this way, the emerging seedling is guaranteed for a continued survival after germination. However, it is often considered as a problem by practising

foresters since in the absence of appropriate pre-treatment(s), seeds possessing in-built dormancy mechanisms often germinate irregularly, extending from several months to several years (Legesse Negash, 1995).

2.4 Causes of dormancy

The causes of dormancy are many and varied and may be due to: impermeability of the seed coat to water and gases, immaturity of the embryo, special requirements for temperature or light, presence of inhibitors, and mechanical restriction to radicle extension in germination operating alone or in combination according to species (Roberts, 1972; Mayer and Poljakoff-Mayber, 1975; Copeland, 1976). These mechanisms may be grouped into two broad categories, namely, embryo dormancy, in which some factor(s) (biochemical conditions or presence of chemical inhibitors) in the embryo itself prevents germination; and coat imposed dormancy, in which the presence of an impermeable, leathery or hard seed-coat prevents the embryo from germinating and so removal of the seed coat, followed by incubation, will result in embryo growth, as in various *Acacia* species (Bryant, 1985; Bradbeer 1988; Legesse Negash, 1995).

2.5 Seed coat dormancy in *Acacia* species

Water impermeable coat protects the embryo from adverse storage and environmental conditions and actively promotes seed longevity. The major factors which control coat imposed dormancy are the structure and nature of the testa or seed coat (Tran and Cavanagh, 1984). The seed coats influence the ability of many seeds to germinate, most of their effects attributed to the preservation of seed dormancy. They may regulate germination by establishing a permeability barrier and interfering with the uptake of water, gaseous exchange and the outward diffusion of indigenous

germination inhibitors (Mayer and Shain, 1974). Although many *Acacia* species are good seeders, good germination response is prevented by the presence of tough seed coat (Legesse Negash, 1995). Viable seeds with hard seed coat will not imbibe water and therefore fail to germinate, even when conditions are apparently favourable for germination. Seeds that are unable to imbibe water are commonly termed impermeable or hard seeds; they remain hard compared to imbibed seeds. Impermeable seeds are common in many species of Fabaceae, as well as in some species of other families (Quinlivan, 1971; Mayer and Shain, 1974). The water impermeability of the testa of hard seeds is a physical exogenous dormancy, which may or may not be combined with other dormancy mechanisms (Nikolaev, 1969 cited in Rolston, 1978). Seeds become impermeable in the last stages of maturation and the degree of impermeability is related to the moisture content of the seed (Quinlivan, 1971; Mayer and Shain, 1974). The hydrophobic substances assumed to produce impermeability include cutin, pectin, suberin, and perhaps callose and hemicellulose (Tran and Cavanagh, 1984).

A palisade layer of macrosclerid cells, also called epidermal, prism, or malphigian cells is a common feature of water impermeable cells. The testa and its structures, the hilum, micropyle, strophiole, and chalaza all have been implicated as barriers to water or as areas where imbibition occurs. The ecological significance of hard seeds includes the ability to rapidly recolonize burnt areas after fire and to withstand ingestion by animals and birds (Rolston, 1978). In trees like *Acacia abyssinica*, the outer seed coat becomes hardened and suberized (i.e. converted into fatty substances) and therefore impervious to water (Rolston, 1978; Legesse Negash, 1995).

2.6 Softening of hard seeds to promote germination

Seed dormancy caused by the seed coat is the main problem to overcome if planting programs of *Acacia* species are to be successful (Masamba, 1994). Dormancy and factors that lead to the release from dormancy also play an important role in controlling the correct time and place for germination to take place (Al- Helal, 1996). The factors involved in breakage of hard seed dormancy are diverse. In nature, microbial attack and damage by fungi break hard seed dormancy (Mayer and Poljakoff-Mayber 1975; Bewley and Black 1985; Legesse Negash, 1995). Mechanical abrasion especially during cultivation, passage through the digestive tract of animals and birds, fire, extremes of temperature also may brake down or puncture the hard seed coats of *Acacia* seeds (Quinlivan, 1971; Rolston, 1978; Bewley and Black, 1985; Legesse Negash 1995). Artificially, the use of chemicals, enzymes, pressure, scarification, freezing heating and radiation are recommended (Rolston, 1978). Of these acid scarification is a common and effective method of treating *Acacia* seeds. Practices which weaken or damage the coat will also bring about other changes like increased sensitivity to light and temperature, permeability to gases and the removal of inhibitors (Khan, 1977 cited in Tran and Cavanagh, 1984).

2.7 Seed Germination

Seed germination is a phase in the life cycle of higher plants preceded by embryogenesis and seed development and followed by seedling growth and development (Lewak, 1985). Germination, the activation of the metabolic machinery of the embryo leading to the emergence of a new plant is the eventual function of the surviving seed followed by the growth of the embryo to give a mature plant (Bradbeer, 1988; Hartmann *et al.*, 1990). It is the resumption of active growth of the embryo that results in the rupture of the seed coat and the emergence of the young plant (Copeland, 1976).

Seed germination is a complex process which depends on the genetic constituents of the seeds and on several environmental factors such as the availability of optimal oxygen level, temperature, light and osmoticum (Al-Helal *et al.*, 1989 cited in Al-Helal, 1996) and is an important determinant for the population of a species (Mehta and Sen, 1991 cited in Krishan and Toky, 1994).

Arousing a dry seed to start growth into a new plant involves four groups of processes: the imbibition of water; the reactivation of existing enzymes and formation new ones; the commencement of growth and radicle emergence and finally the growth of the seedling with the characteristic features associated with the subterranean plant up to the time of emergence from the soil (Copeland, 1976; Leopold and Kriedemann, 1975; Lewak, 1985; Hartmann *et al.*, 1990).

The germination process commences with a sequence of events at the molecular and cellular levels which precede visible growth of the embryo (Bradbeer, 1988). It begins with the water uptake by the seed (imbibition), the hydration of colloids of plant cells, and ends with the start of the elongation by the embryonic axis, usually the radicle (Goss, 1985; Hartmann *et al.*, 1990). It therefore includes numerous events, e.g., protein hydration, subcellular structural changes, respiration, macromolecular syntheses, and cell elongation. But their combined effect is to transform a dehydrated, resting embryo with a barely detectable metabolism into one that has a vigorous metabolism culminating in growth.

The only stage of germination that can be timed fairly precisely is its termination. Emergence of the axis (usually the radicle) from the seed normally indicates that germination has gone to completion, though in those cases where the axis may grow before it penetrates the surrounding tissues, the completion of germination can be determined as the time when a sustained rise in fresh weight begins (Bewley and Black, 1985, 1994).

2.8 The conditions for germination

For germination to occur seeds require moisture, a suitable temperature, and in most cases an aerobic atmosphere (Wareing and Phillips, 1970; Bradbeer, 1988, Hartmann *et al.*, 1990) and sometimes light (Hartmann *et al.*, 1990). If one of these requirements is not met, germination will fail to occur (Bradbeer, 1988).

2.9 Plant hormones

Plant hormones are organic compounds which are synthesized in one part of the plant and translocated to another part, where they cause physiological response in very low concentrations (Salisbury and Ross, 1992). They are involved in the regulation of many aspects of plant growth and development and can influence the rates at which physiological processes occur (Bryant, 1985; Bradford and Trewavas, 1994).

Auxins, gibberellins and cytokinins interact in their influences on plant growth and growth differentiation, and it is highly likely that abscisic acid and ethylene also interact with other growth hormones (Wareing and Phillips, 1970). There are at least three major classes of growth promoting hormones, namely, Auxins, Gibberellins and Cytokinins (Wareing and Phillips, 1970). Auxins, mainly indole-3- acetic acid (IAA), kinetin, zeatin and GA_3 all promote seed germination of many species including of witchweed seeds (Lewak, 1985; Hsiao *et al.*, 1988).

The general role of plant hormones seem to lie in shifting a tissue from one physiological state to another one. The entrance to a new development phase, therefore, is supposed to be triggered by a hormonal factor (Lewak, 1985). The growth of a plant is a strictly controlled, dynamic and complex,

integrated and co-ordinated process. Genotype and environmental factors determine the rate of growth and the pattern of development of a plant which include the participation of growth hormone (Wareing and Phillips, 1970).

The mechanisms of hormone action rely upon their control of differential gene activation (transcriptional or translational control) or in alternation of the properties of cell membrane (Lewak, 1985). Plant growth regulators are involved in major developmental transitions, such as flowering, embryogenesis, or dormancy, and in real-time responses to environmental conditions, such as adjustments in growth rates or stomatal conductance (Bradford and Trewavas, 1994). Growth regulators can also synchronize all-or-none developmental processes. For example, gibberellic acid (GA) treatments can synchronize seed germination (Ni and Bradford, 1993). The variation among cells and tissues in their sensitivities and response times is an integral component of hormonal regulation of plant development (Bradford and Trewavas, 1994).

Plant hormones have commonly been used to influence the germination process (Bell *et al.*, 1993; Lewak, 1985). Some plant hormones are generally associated with other germination promoting factors. For example, in light requiring seeds, germination is enhanced by red light or sunlight, in the presence of GA and Ethylene, whereas, the dormancy-inducing system responds to far red light, high temperature, water stress and ABA (Bell *et al.*, 1993). It is known that there is a relationship between the magnitude of the induced response and the concentration of the regulating substance (Firn, 1986). Hormone effects on protein synthesis are generally achieved through enhanced RNA synthesis, formation of polyribosomes or through an interaction with the t-RNA and ribosomes as in the case of cytokinins (Sen, 1985).

2.9.1 Auxins

Auxins are of fundamental importance in the physiology of growth and differentiation. They appear to be mainly synthesized in meristematic tissues such as those of the stem and root apex, young developing leaves, flowers and fruits. The concentration of auxin available to tissues can have a determining effect on growth and differentiation. Factors which limit the IAA concentration in plant tissues include IAA synthesis, IAA destruction and IAA inactivation (Wareing and Phillips, 1970).

The best known growth stimulations by applied auxin are the elongation of stems and coleoptiles. The concentrations of applied auxin which stimulate growth are in the same range as the endogenous auxin concentrations. Auxin also participates widely in the overall organization processes, including the regulation of different growth rates, i.e. the tropisms and apical dominance (Wareing and Phillips, 1970). In addition to stem elongation, IAA is also assumed to contribute to the growth of leaves, flowers, fruits and stems of grasses and conifers. Auxin affects roots and root formation and lateral bud development (Salisbury and Ross, 1992).

Auxins and other growth regulators are a universal component of plants and a common constituent of seeds. High concentration of auxin inhibit germination, while low concentrations are generally promotive. IAA interacts with light in influencing germination (Copeland, 1976).

The classical effect of auxin is to promote growth by stimulating the elongation of cells constituting a given tissue. However as the concentration of IAA increases the stimulatory effect on growth becomes inhibitory. Moreover, the concentration of IAA at which there is maximum stimulation of growth is different for different tissues (Goodwin and Mercer, 1983).

The regulation of growth by an auxin may involve a regulation of RNA synthesis and hence of RNA-directed protein synthesis. An auxin regulation of the DNA-directed RNA synthesis might take place via an increase in the template activity of DNA or, alternatively, via an increase in the effectiveness of RNA polymerase. The auxin stimulus could involve an enhancement of more RNA, or of a qualitatively different RNA (Wareing and Phillips, 1970).

Cell wall growth is stimulated by auxin, and can occur even when cell enlargement is completely suppressed by various means. During cell enlargement, the cell wall not only stretches, but it also increases in thickness by the deposition of new cell materials (Wareing and Phillips, 1970).

2.9.2 Gibberellins

The gibberellins are a large family of diterpene acids and are known to be of widespread, and probably universal, occurrence in higher plants where they are generally accepted to function as hormones (Jones and MacMillan, 1984). They exert profound and diverse effects on plant growth and development (Hooley, 1994). Gibberellins are known for promoting stem and germination of seeds (Hartmann and Kester, 1975; Hsiao *et al.*, 1988; Hartmann *et al.*, 1990).

GA initiates the synthesis of enzymes and this is associated with stimulations of RNA synthesis (Leopold and Kriedemann, 1975). Gibberellic acid when applied to many species of intact growing plants induces abnormally great extension of stems and leaves, but the response is greatest when genetically dwarf plants are treated with GA. The treated plants assume the appearance of normal, tall plants (due to increased elongation of the internodes) from which the mutants have arisen (Devlin, 1966; Wareing and Phillips, 1970; Harada and Veraga, 1972; Goodwin and Mercer, 1983;

Salisbury and Ross, 1992). Moreover, GA deficient mutants never germinate without applied GA (Groot and Karssen, 1992).

Dwarf mutants of maize and pea lack endogenous gibberellin but become phenotypically normal with exogenous application of this hormone. These plants are generally only about 20% of the height of normal plants in the absence of GA, but grow to full height following GA application. The result of GA application to dwarf plants is enhanced cell division and cell elongation (Chory *et al.*, 1987).

Application of gibberellin to dwarf pea seedling increases the levels of tryptophan, an important auxin precursor, and diffusable auxin (Valdovinos *et al.*, 1967). Dwarf pea plants, normal pea plants and sunflower treated with gibberellin yielded 3, 2 and 10 times auxin, respectively than untreated plants (Kuraishi and Muir, 1962).

In addition to the powerful effects of GA on stem growth, it has many regulatory effects on development. Frequently dormancy of buds and seeds can be relieved by GA, and some germination processes, e.g., the synthesis of hydrolytic enzymes for digestion of the endosperm reserves, are driven by GA (Leopold and Kriedemann, 1975).

Gibberellins are successful in breaking dormancy in seeds of numerous species of plants and also in accelerating germination of non-dormant seeds. Gibberellins are believed to be important in controlling the germination of seeds in nature and appear to have a major role both during seed development and seed germination (Copeland, 1976). Effective concentrations lie within the range

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10^{-5}-10^{-3} M. Of the gibberellins which have been widely tested, mixtures of GA_4 and GA_7 are effective at lower concentrations than GA_3 (Bewley and Black, 1982).

Gibberellins overcome seed and bud dormancy in many species, acting as a substitute for low temperature, long days or red light. In seeds, gibberellin enhances cell elongation so that the radicle can push through the endosperm, seed coat or fruit coat that restricts its growth (Hartmann *et al.*, 1990; Salisbury and Ross, 1992).

Gibberellic acid is essential for seed germination and, almost universally, stimulates germination. It is frequently associated with the mobilization of endosperm reserves and growth of embryonic tissues (Jones and Stoddard, 1977 cited in Bell *et al.*, 1993). Gibberellins appear to play a role in two different stages of germination. One occurs at the initial enzyme induction in their transcription from the chromosomes. The second is in the activation of reserve food mobilizing systems (Hartmann *et al.*, 1990).

GA induces germination of many dormant seeds; at low GA concentration few seeds germinate, but with increasing concentration more and more seeds are capable of initiating radicle growth (i.e. additional seeds are induced to germinate as the GA concentration increases). Individual seeds posses base GA values, or sensitivity thresholds, which set the minimum GA concentrations required to induce radicle emergence (Bradford and Trewavas, 1994).

GA_3 is as active as light in breaking dormancy of seeds of `Grand Rapids´ (Bryant, 1985). Light and GA promote germination of several *Eucalyptus* species held at 30° C or under conditions of water

stress (Zohar *et al.*, 1975 cited in Bell *et al.*, 1993). GA has also shown to overcome the requirements for after-ripening in many species of Poaceae (Don, 1979 cited in Bell *et al.*, 1993).

Gibberellins stimulate the mobilization of foods and mineral elements in seed storage cells; cause parthenocarpic (seedless) fruit development in some species; delay ageing (senescence) in leaves and citrus fruits and effects on leaf shape (Salisbury and Ross, 1992).

Barley seeds respond to exogenously applied GA_3 by the release of soluble N and loss of dry weight. This response is dependent on the GA_3 concentration. Gibberellic acid controls the synthesis of α-amylase in the aleurone layer which leads to the hydrolysis of starch in the endosperm. In cereal seeds (barley and wheat principally), surrounding the starchy endosperm are a few cells constituting the so called aleurone cells which, upon the addition of gibberellic acid, synthesize and release several hydrolytic enzymes such as α-amylase, phosphatase and β-glucanase (Penel *et al.*, 1985). It is shown that the α-amylase formed in the aleurone cell arise by *de novo* synthesis of protein. This protein synthesis is dependent on the synthesis of new mRNA and can be prevented by inhibitors of DNA dependent RNA synthesis (Varner *et al.*, 1965 cited in Mayer and Poljakoff-Mayber, 1975).

2.9.3 Cytokinins

The generic name cytokinin is used for chemical substances which can stimulate cell division, or cytokinesis (Leopold and Kriedemann, 1975; Salisbury and Ross, 1992). Cytokinins have been implicated in many aspects of plant growth and development such as cell division, cell enlargement, differentiation and morphogenesis and delaying senescence (Wareing and Phillips, 1970; Goodwin and Mercer, 1983; Horgan 1984; Salisbury and Ross, 1992). Cytokinins promote expansion of

cotyledons detached from seedling of more than a dozen species (Ross and Rayle, 1982; Salisbury and Ross, 1992). They also affect germination of seeds (Copeland, 1966; Mayer and Poljakoff-Mayber, 1975; Goodwin and Mercer, 1983). Since cytokinins are necessary for cell growth and differentiation, their influence on promoting seed germination appears to be natural. They have also been shown to inhibit senescence in leaves and to regulate the flow of chemicals through the plant system (Copeland, 1966). Cytokinins occur in high level in meristematic tissues (Torrey, 1976). Root tips synthesize cytokinins and export them to all parts of the plant (Salisbury and Ross, 1992).

The known natural cytokinins are substituted adenine compounds. Most available evidence suggests that naturally occurring cytokinins are purine, particularly adenine derivatives. Kinetin (6-furfurylaminopurine) was prepared from degraded deoxyribonucleic acid (DNA). Kinetin has never been shown to be present normally in plants, but substances which produce similar physiological and morphological effects have been found in various organs of many plants species (Wareing and Phillips, 1970).

Although kinetin does not occur in plant tissues, substances with a similar biological activity were shown to be widely distributed in plants. These substances were initially called kinins but this name has now been replaced by the generally accepted term 'ctyokinin' (Goodwin and Mercer, 1983).

Cytokinin activity tends to be high in developing fruits and seeds, but decreases and becomes difficult to detect as the seeds mature. In seed germination, cytokinin is believed to offset the effect of inhibitors, notably ABA and as playing a "permissive" role in germination in allowing gibberellic acid to function (Khan, 1971; Bewley and Black, 1982; Hartmann *et al*, 1990).

Kinetin is effective only in the presence of low level of light, which by itself is inadequate in promoting germination. In complete darkness kinetin, as well as other cytokinins, break the dormancy of only a small percentage of lettuce seeds (Bewley and Black, 1982).

Like auxin and GA, kinetin causes an increase in nuclear RNA synthesis and may regulate the release of RNA to the cytoplasm (Wareing and Phillips, 1970; Leopold and Kriedemann, 1975). The effectiveness of cytokinins in promoting germination and other growth processes seems to be related to their action of stimulating cell division as well as cell elongation (Copeland, 1966).

Kinetin is the best known cytokinin. According to Koller *et al.* (1962) the effect of kinetin seems to differ from gibberellin in that: 1) kinetin affects germination only in combination with light, while gibberellin may do so both light and darkness; 2) in the presence of kinetin, red light effects are reversed by far-red light but not in the presence of saturating concentrations of gibberellic acid; 3) kinetin increases germination only in combination with light of longer wavelength while gibberellic acid may do so over the range 400-700 nm; and, 4) they have different ranges of temperature activity.

3. MATERIALS AND METHODS

3.1 Pod/Seed collection

Mature pods of *Acacia abyssinica* were collected from trees growing in and around Addis Ababa (i.e. within a radius of 35 km) using long handled pruning shear. Collection sheet was spread on the ground under the branches. Maturity of seeds is indicated by the cracking of the dark coloured pods

containing seeds that are dark in colour as described by Doran *et al.* (1983). Pod length was measured from the apex to the base of the stipe and the width at the widest part as indicated by Gunn (1984).

One hundred pods per tree were collected from 26 different trees located in different localities for pod measurements. Seed collected from 35 trees were made into 17 bulks. Seeds from trees that are more than 100 m apart were taken separately while seeds from trees that are less than 100 m apart were considered as a population and equal volumes of their seeds were mixed to make a bulk (Doran *et al.*, 1983). The seeds were extracted manually and were dried in the sun for about 30 days.

3.2 Soil collection and preparation

After several reconnaissance trips, sites for soil collection were selected. Soil samples from degraded land were collected from an area of about 4 km^2 on the Modjo-Zeway road (Kurmana Fatole *Kebele*, Lume *Wereda*, Nazareth *Zone*, east Shoa) about 81 km south of Addis Ababa. Nine geomorphically different locations, were selected. From each site four 50 x 50 x 50 cm holes were dug and the soil from each hole was thoroughly mixed. Equal volumes from each hole were taken and these were mixed to make a bulk for each sample.

Nine soil samples from places where *A. abyssinica* is currently growing were also collected from underneath trees growing in and around Addis Ababa: One sample was collected from Addis Ababa, from a site located along Gerji-Bole road; another from Burayu *Kebele* Welmera *Woreda* at ca 16 km west of Addis Ababa, on the road to Menagesha. The remaining 7 samples were collected from

Menagesha Kolobo *Kebele*, ca 33 km on the same route, near a small stream called Jiga. The same collection method as the one used for soils from degraded land was applied.

The soil samples were brought to the greenhouse of the Biology Department, Arat Kilo Campus, Addis Ababa University and each sample was thoroughly mixed. About 1.5 kg of soil from each sample was taken for the physical and chemical analyses.

For the plant growth experiments, soil from each sample was filled into eight plastic bags, 15 cm diameter and 25 cm height, whose bottom was cut open to allow free drainage of water. This gave a total of 18 x 8 = 174 plastic bags, 72 of which were filled with soils from degraded land and the remaining 72 with soils collected from places where *A. abyssinica* is currently growing.

3.3 Soil physical and chemical analyses

Soil samples collected from degraded land and from places where *A. abyssinica* is currently growing were taken to the National Soils Laboratory in Addis Ababa for chemical and physical analyses. In the laboratory, the soils were air dried at room temperature by spreading on plastic trays. After drying, they were sieved through a 2 mm sieve. The particle size distribution was determined by modified Bouyoucos method. Determination of organic C and total N was done using the Walkley and Black, and Kdjeldal methods, respectively. Available P was extracted using the Oslen method. Soil pH was determined in 1:2.5 soil/water suspension. After stirring, reading was made using Corning 140 pH Meter with a combined electrode. Exchangeable base-forming cations were determined a mixture of 5 g of soil and 5 g acid washed sand percolated with 250 ml 1M ammonium acetate. Sodium and potassium were determined by flame photometer, while calcium

and magnesium were determined by atomic absorption spectro-photometer using an air-acetylene flame.

To determine the Cation Exchange Capacity (CEC) soil previously leached with 1M ammonium acetate was successively washed with 25 ml portion of 95% ethanol using a total of 100 ml of ethanol. Absorbed ammonia was determined after distilling in 0.2N sulphuric acid and titrating the excess acid by 0.1 sodium hydroxide. CEC was then determined from a standard graph.

DTPA (Diethylenetriaminepentaacetic acid) extractant was used in determining the available micronutrients (Fe, Cu, Zn and Mn) and the reading was taken using Atomic Absorption Spectrometer.

3.4 Plant growth regulators

Indole-3-acetic acid (IAA), gibberellic acid (GA_3) and kinetin were tested for their influence on germination stimulation or inhibition of *A. abyssinica* seeds. The chemicals were purchased from Sigma Chemical Company, St. Louis, MO, USA, and were of standard "tissue culture tested" quality. Each chemical was dissolved in 1N NaOH and diluted with distilled water to prepare 10^{-3} M stock solution. The pH of the stock solutions was adjusted to 7.0 ± 0.1 using 1N HCl. Using the proper dilution factor, solutions of 10^{-4} M to 10^{-7} M were prepared from the stock solutions.

3.5 Seed scarification

Mechanical or chemical scarification of seeds would overcome coat imposed dormancy. Chemical scarification employing concentrated sulphuric acid is quite simple and effective, except for the cost

of the acid (Sur *et al.*, 1987; Legesse Negash, 1995). Seeds collected from one mother tree were thoroughly washed, placed in a glass beaker and were covered with concentrated sulphuric acid. The seeds and the sulphuric acid were continuously stirred to ensure equal exposure of the seed surfaces to the acid. Soaking in concentrated sulphuric acid lasted ninety minutes as recommended by Legesse Negash (1995). The acid was then decanted off and the seeds were thoroughly rinsed with tap water. The pre-treated seeds were then put in Petri dishes that were covered by ordinary soft paper.

3.6 Seed germination

To determine the influence of IAA, GA_3 and kinetin on the germination response of the seeds of *A. abyssinica*, 100 chemically scarified seeds (10 seeds per Petri dish) were used for each concentration of the corresponding germination stimulators. The control was to provide 100 chemically scarified seeds with distilled water. About 5 ml of the corresponding test solution (or distilled water) was poured onto the seeds which were then incubated by randomly placing the Petri dishes in a culture room kept at 26-28° C. The room was lit with fluorescent lamps at a quantum flux density of ca 40 μ mol m^{-2} s^{-1}. Periodic additions of 2 ml of the respective solutions was made as these were depleted through imbibition.

Seeds are said to have germinated when the radicle length equals the seed length. Germinated seeds were counted for 5 consecutive days after the appearance of the first germinant. The length of the radicle of the germinants was measured 7 days after incubation.

To obtain germinants for planting in the soils brought from the degraded land and from places where *A. abyssinica* is currently growing, ca 500 seeds collected from a single mother tree were chemically scarified using conc. H_2SO_4. Two hundred fifty of the scarified seeds, 10 per Petri dish, were made to germinate in 10^{-4} M of GA_3; and the remaining 250 seeds were germinated in distilled water (control).

3.7 Planting out the germinant

Seven days after incubation (sowing) 72 well developed germinants were selected from the GA_3 treated group and 36 of them were planted out, in 36 of the bottomless transparent polythene pots filled with the soils obtained from degraded land. The remaining 36 germinants were planted out in similar plastic bags filled with soils collected from places where *A. abyssinica* is currently growing. Similarly, 72 well developed germinants from the control were selected and were planted out following a similar design for the GA_3 group.

The planted germinants were then placed in the greenhouse in a completely randomised block pattern and were covered with thin polythene plastic sheets (supported by a wooden scaffolding, ca 50 cm from the surface of the pots) so as to protect them from desiccation. This was kept in place for ten days.

3.8 Growth performance of plants

The growth and investigation of the growth performances of the seedlings was carried out in a greenhouse (area 6.6 m^2 and height 2.9 m.) which is located within the Science Faculty Campus of the Addis Ababa University, from January to March 1997. The mean minimum and maximum

temperatures of the greenhouse during the investigation period were 13.4 ± 0.1° C and 31.7 ± 0.3° C respectively and the relative humidity was 70-80% (measured using MK 3 Automatic Porometer, Delta-T Device Cambridge CB5 OEJ, England). The mean quantum flux density during the investigation was 692 ± 109 μ mol m^{-2} s^{-1} (measured using LI-189, LI-COR, Lincoln, Nebraska, USA).

Plants were watered twice daily with 30 ml of tap water, until they were harvested. Two weeks after planting, 30 ml of 10^{-4} M GA_3 was added to the plants obtained from the GA_3 treated seeds. The height, number of branches and leaves of each seedling was recorded weekly for ten weeks starting from the third week after planting.

Plants were harvested 12 weeks after planting by cutting the stem at the soil level. The roots were carefully separated from the soil by mixing the soil and root mass with a volume of water which is five-fold larger than the soil volume, and was shaken for about 20 minutes as described by Kirchmann (1988). The soil-root-water suspension was then passed through sieves with 0.5 mm mesh size. Root pieces collected from the sieve were cleaned of the soil. The root nodules were carefully removed from the roots.

The above ground biomass production and the root masses were separately oven dried at 80° C for 24-48 hrs. The dry weight was recorded after constant weight was achieved.

3.9 Statistical analyses

The statistical analysis was carried out using the software package Statistica for Windows Release 4.0 (Statsoft Inc., 1993). The significance of the means of the plant growth variables were subjected to analysis of variance (ANOVA) at 5% level of significance and Newman-Keuls test was run to compare differences in means within the experiment.

4. RESULTS

4.1 Pod length, pod width, number of seeds per pod and seed weight

Comparison of the means of pod length, pod width and the number of seeds per pod showed significant differences among samples obtained from different localities ($p<0.05$). Pod length and width were insignificantly correlated; pod length and number of seeds per pod were significantly correlated ($r = 0.11$; $p=0.000$) while the pod width and the number of seeds per pod were significantly inversely correlated ($r = -0.05$; $p = 0.006$). The pod length ranged between 3.7 and 14.4 cm with a mean ± SE of 8.05 ± 0.03 cm. The pod width ranged between 1.0 and 2.7 cm with a mean ± SE of 1.87 ± 0.001 cm. The number of seeds per pod also varied significantly ($p=0.000$) ranging between 2 and 13 seeds per pod with a mean ± SE of 7.30 ± 0.04 seeds.

The comparison of the mean weights of the seventeen seed bulks, each bulk containing 1000 seeds (100 seeds weighed at a time) showed that there were significant differences ($p=0.000$) among the 17 seed bulks. The weight of 1000 seeds ranged from 74.01 to 116.11 g with mean ± SE weight of 91.11 ± 0.85 g.

4.2 Percentage germination

Comparison of means of percentage germination of seeds treated with different concentrations of GA_3 and the control showed no significant difference (p=0.62). However, IAA and kinetin treatments significantly differed (p=0.000) from that of the control (Table 1).

Table 1. Mean percentage germination (± SE) of seeds of *A. abyssinica* treated with various concentrations of GA_3, IAA, kinetin and the control.

Concentration (M)	Plant growth regulators		
	GA_3	IAA	Kinetin
Dist. H_2O	93 ± 3.35a*	93 ± 3.35c	93 ± 3.35b
10^{-7}	98 ± 1.33a	98 ± 1.33c	97 ± 1.53b
10^{-6}	97 ± 1.53a	97 ± 1.53c	97 ± 2.13b
10^{-5}	97 ± 1.53a	100 ± 0.00c	97 ± 1.53b
10^{-4}	96 ± 1.63a	60 ± 5.77b	97 ± 1.53b
10^{-3}	96 ± 2.21a	0 ± 0.00a	70 ± 3.33a

***Means within the same column followed by different letters are significantly different from one another at $p < 0.05$**

None of the hormones significantly increased the total germination of seeds relative to the control. Germination percentage decreased significantly at higher concentrations of IAA (10^{-3} M and 10^{-4} M) and kinetin (10^{-3} M). IAA at 10^{-3} M delayed germination for about a week as compared to other concentrations of the same, though 63% of the seeds germinated 10-15 days after incubation (Figure 1). In the seeds treated with IAA 10^{-4} M germination started 4 days after incubation, whereas in the GA_3 treated, except for the 10^{-3} M, this was the period of the highest germination rate. For the control the highest germination rate was on the 5th day after incubation (Figure 1).

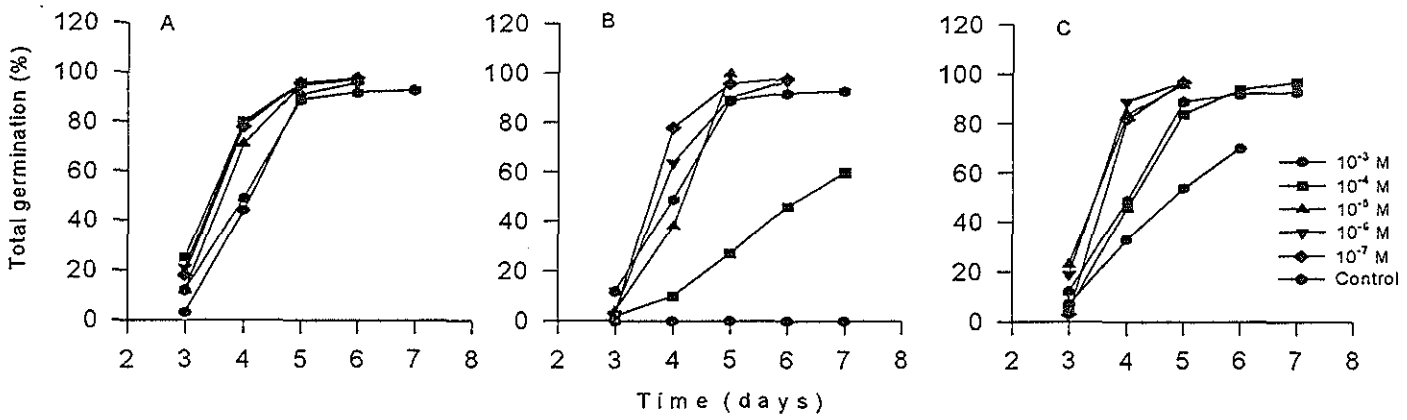

Figure 1. Mean germination percentage as a function of time of *A. abyssinica* seeds in different concentrations of GA_3 (A), IAA (B) and kinetin (C).

4.3 Radicle length

Radicle length of the germinants was measured 7 days after incubation and it was found that GA_3 concentration of 10^{-3} M significantly increased radicle length as compared to the control. On the other hand, IAA at 10^{-4} M, 10^{-5} M and 10^{-7} M significantly decreased the radicle length as compared to the control (Table 2). Kinetin at 10^{-3} M and 10^{-4} M decreased radicle length. However, at lower concentrations (10^{-5} M - 10^{-7} M), there was no significant difference as compared to the control.

Table 2. Mean (± SE) radicle length of germinants treated with various concentrations of GA_3, IAA, kinetin and the control.

Concentration (M)	Radicle length (cm)		
	GA_3	IAA	Kinetin
Dist. H_20	3.23 ± 0.12b*	3.23 ± 0.12 f	3.23 ± 0.12e
10^{-7}	3.11 ± 0.11b	2.55 ± 0.10e	2.91 ± 0.11c
10^{-6}	3.05 ± 0.10b	3.31 ± 0.12d	3.0 ± 0.10c
10^{-5}	2.86 ± 0.10b	2.50 ± 0.10e	2.96 ± 0.10c
10^{-4}	3.25 ± 0.12b	1.56 ± 0.06b	2.55 ± 0.12b
10^{-3}	3.62 ± 0.10a	0.00 ± 0.00a	1.73 ± 0.10a

***Means followed by different letters within the same column are significantly different from one another ($p < 0.05$).**

4.4 Physical and chemical analyses of soil

4.4.1 Soil texture

Textural analyses done on the textural condition of the sampled soils revealed that sand, silt and clay fractions in the soils collected from degraded land ranged from 39-49%, 18-30% and 26-35%, respectively. On the other hand, in the soils collected from places where *A. abyssinica* is currently growing the range was 29-35%, 28-40% and 26-35%, respectively. Comparison of the means

showed that both sand and silt percent in both types of soils differ significantly ($p<0.05$) while the difference in clay percent is insignificant. The mean (± SE) sand, silt and clay percentages of the soils obtained from degraded land were 43.0 ± 0.4, 26.0 ± 0.42 and 31.0 ± 0.42 respectively. On the other hand, in the soils collected from places where *A. abyssinica* is currently growing, the mean (± SE) sand, silt and clay percentages were 34.11 ± 0.49, 34.89 ± 0.42 and 29.89 ± 0.46 respectively. Analysis of variance showed that sand and silt mean percentages in both soil types differ significantly ($p<0.05$).

4.4.2 Soil pH

Mean soil pH values of the soils obtained from degraded land were found to be significantly higher ($p = 0.00$) as compared to those of the soils obtained from places where *A. abyssinica* is currently growing (Table 5).

4.4.3 Nitrogen, carbon, organic matter levels and C:N ratio

The minimum, maximum and mean (±SE) percentage of total nitrogen (N), organic carbon (C) and organic matter (OM) and carbon to nitrogen ratio of the soils collected from places where *A. abyssinica* is currently growing were significantly higher than those collected from degraded land. Except for C:N ratio, the minimum total nitrogen (N), organic carbon (C) and organic matter (OM) percentage values of the soils collected from places where *A. abyssinica* is currently growing were higher than the maximum values of the soils collected from degraded land (Table 3).

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Table 3. Mean (± SE), minimum and maximum total N, C, OM and C:N ratio in soils collected from degraded land (A) and soils collected from places where *A. abyssinica* is currently growing (B).

Soil type		Soil parameters			
		% N	% C	% OM	C:N
A	Mean	0.07 ± 0.03	0.63 ± 0.02	1.08 ± 0.03	9.67 ± 0.28
	Minimum	0.028	0.379	0.653	7.00
	Maximum	0.098	0.918	1.583	14.00
B	Mean	0.31 ± 0.01	3.38 ± 0.08	5.82 ± 0.13	10.89 ± 0.10
	Minimum	0.254	2.733	4.712	9.00
	Maximum	0.456	4.918	8.531	12.00

4.4.4 Available phosphorus, exchangeable bases, CEC and Base saturation (BS)

Mean available phosphorus was found to be significantly higher ($p = 0.00$) in soils obtained from places where *A. abyssinica* is currently growing whereas the mean concentrations of the exchangeable base forming cations: Na, K, and Ca were significantly higher ($p = 0.00$) in soils from degraded land. CEC and BS followed the same trend as available, Na, K and Ca with higher mean values in soils obtained from degraded land (Table 5). However, the level of Mg was higher in soils obtained from places where *A. abyssinica* is currently growing than the soils obtained from degraded land.

4.4.5 Soil micronutrients

The mean ± SE content of Fe, Mn, Zn and Cu is significantly higher ($p<0.05$) in the soils collected from places where *A. abyssinica* is currently growing as compared to that of the soils collected from degraded land (Table 7).

4.5 Growth performance of the seedlings

All the plants in the plastic pots filled with soils obtained from degraded land and from places where *A. abyssinica* is currently growing survived until harvest time, i.e., 12 weeks after planting. Regression analysis between percentage organic matter (% OM) percentage nitrogen (% N), available phosphorus (P) and micronutrients (Fe, Mn, Zn and Cu) and some of the plant growth parameters showed significant correlation (Table 4). It was also found that the mean values of plant height, number of branches and leaves, shoot and root dry weights were found to be significantly higher in the controls than the GA_3 treated ones (Table 6). The comparison of the height of seedlings from both treatments grown in soil samples collected from degraded land (Figure 2) and places where *A. abyssinica* is currently growing which contain the minimum and maximum amount of organic matter is shown in Figure 3.

Table 4. Correlation coefficient (r) values of soil and plant growth parameters (N.B. All correlation coefficients given below are significant at $p<0.05$).

Parameters				Micronutrients (ppm)			
	% OM	% N	Av. P (ppm)	Fe	Mn	Zn	Cu
Height	0.73	0.73	0.74	0.57	0.74	0.30	0.42
No. of Branches	0.60	0.58	0.58	0.46	0.59	0.23	0.26
No. of Leaves	0.67	0.65	0.65	0.52	0.65	0.19	0.30
Shoot dry weight	0.70	0.69	0.72	0.53	0.67	0.25	0.35
Root dry weight	0.57	0.56	0.61	0.46	0.55	0.20	0.28

Table 5. Mean (± SE) values of some chemical parameters for soils obtained from degraded land (A) and from places where *A. Abyssinica* is currently growing (B).

Soil Type		Available	Exchangeable bases (meq/100 g)				TEB	CEC	BS
	pH	P (ppm)	Na	K	Ca	Mg	meq/100 g	meq/100 g	meq/100 g
A	7.82 ± 0.03	2.45 ± 0.16	4.07 ± 0.20	2.61 ± 0.06	19.40 ± 0.43	2.04 ± 0.05	27.90 ± 0.65	30.69 ± 0.51	91.11 ± 1.01
B	5.58 ± 0.02	8.62 ± 0.30	0.46 ± 0.01	1.22 ± 0.05	11.53 ± 0.31	3.92 ± 0.11	17.13 ± 0.41	32.49 ± 0.40	52.44 ± 0.73

Table 6. Mean (± SE) values of some growth parameters of seedlings grown in soils collected from degraded land (A) and from places where *A. abyssinica* is currently growing.

Soil type	Treatment	Plant growth parameters				
		Height (cm)	No. of Branches	No. of Leaves	Shoot dry weight (g)	Root dry weight (g)
A	GA_3 10^{-4}M	30.03 ± 1.19	19.28 ± 0.99	102.94 ± 6.15	1.21 ± 0.11	0.56 ± 0.39
	Control	33.44 ± 1.17	25.03 ± 0.90	132.89 ± 5.67	1.66 ± 0.11	0.78 ± 0.46
B	GA_3 10^{-4}M	46.17 ± 1.22	31.44 ± 1.25	194.17 ± 8.35	3.09 ± 0.21	1.07 ± 0.07
	Control	52.95 ± 1.31	42.19 ± 2.45	263.38 ± 15.07	4.23 ± 0.24	1.40 ± 0.10

4.6 Effects of soil types and treatment on plant growth

Two way analysis of variance (ANOVA) showed that both treatment (10^{-4} M GA_3 and distilled water) and soil type (from degraded land and the natural habitat of *A. abyssinica*) separately have highly significant effect (p= 0.000) on the height, number of branches, number of leaves, shoot dry weight and dry weight of the seedlings, but the interaction between and soil type and treatment has no significant effect on these plant growth parameters.

Table 7. Mean (± SE) micronutrient content of the soils collected from degraded land (A) and soils obtained from palaces where *A. abyssinica* is currently growing (B).

Soil type	Micronutrient content (ppm)			
	Fe	Mn	Zn	Cu
A	5.26 ± 0.40	1.66 ± 0.08	0.27 ± 0.01	0.68 ± 0.03
B	13.94 ± 0.55	4.03 ± 0.07	0.42 ± 0.04	1.06 ± 0.05

5. DISCUSSION

5.1 Influence of growth regulators on percentage germination

The effect of GA_3 on the germination of seeds varies with the concentration applied and the plant species used. For example, Legesse Negash (1993) reported that 10^{-4} M was the optimal concentration of GA_3 which gave the maximum final percentage in wild olive seeds. However, test of the various GA_3 concentrations conducted on the seeds of *A. abyssinica* showed that there was no significant difference between the treated and the control seeds (Figure 1). Similarly, Legesse Negash (1992) reported similar trend in the effects of GA_3 on the final germination percent of

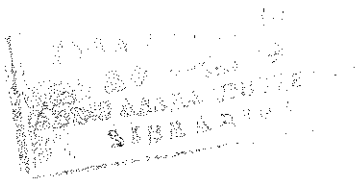
Podocarpus. According to Legesse Negash (1992), the absence of a significant response to the application of GA_3 on seeds of *Podocarpus* might indicate that germination of these seeds is not initiated by phytochrome, a plant pigment which mediates promotion of germination by light (MacDonald and Hart, 1981). Higher concentrations of IAA (10^{-3} M and 10^{-4} M treatments) significantly decreased the germination percentage as compared to the control since high concentrations of auxin inhibit germination (Khan, 1971; Copeland, 1976).

Cytokinins counteract inhibitors and allow gibberellic acid to function and only gibberellins and inhibitors are positively implicated in germination processes (Khan, 1971). Cytokinins were also found to be ineffective in stimulating germination in the seeds of witchweed (*Striga asiatca*) (Hsiao *et al.*, 1988).

Kinetin at higher concentration (10^{-3} M) significantly decreased the final germination percentage of the seeds of *A. abyssinica* as compared to the control. The results of this experiment suggest that the most important factor inhibiting the germination of the seeds of *A. abyssinica* is the presence of the hard seed coat since unscarified seeds didn't germinate for a period of over one month.

5.2 Soil pH

Though pH has little or no direct effect on plant growth, its most universal effect is through influence on the rate of plant nutrient release (Thompson and Troeh, 1978). The pH of soil solution is of fundamental importance in understanding nutrient availability since plants take up their nutrients from the soil solution (Ritchie, 1989). As a result it affects plant growth through control of nutrient availability. pH also influences the occurrence and the activity of soil micro-organisms (Mengel and



Kirkby, 1982). The pH of the soils from degraded land was significantly higher and ranged from 7.37 to 8.18 while that in the soils from places where *A. abyssinica* is currently growing ranged from 5.34 to 5.91.

5.3 Organic matter, nitrogen and phosphorus content of the soils

Growth of vegetation depends on the quantities of nutrients present in the soil in forms available to plants. Soil organic matter (OM) comprises an accumulation of partly disintegrated and decomposed plant and animal residues and other organic compounds synthesized by the soil microbes as the decay occurs. It binds mineral particles into granules that are largely responsible for the loose, easily managed condition of productive soils and increases the amount of water the soil can hold (Brady, 1990). OM influences physical and chemical properties of soils and commonly accounts for as much as one third or more of the cation exchange capacity of surface soils (Wilde *et al.,* 1979; Brady, 1990). It is responsible for the stability of soil aggregates (Brady, 1990). The OM in the soil serves as a living place for organisms, encourages the effects of mineral colloids, exerts a strong influence upon the formation of structural aggregates, retention of aggregates, retention of moisture and adsorption of nutrients ions. In many soils, OM is synonymous with soil fertility (Wilde *et al.,* 1979).

The mean (± SE) OM (Table 3) in the soils collected from places where *A. abyssinica* is currently growing (5.83 ± 0.13) was significantly higher than that of the soils collected from degraded land (1.08 ± 0.03). The mean (± SE) OM content of the soils from degraded land is far below the minimum (<2%) (Murphy, 1959). On the other hand the mean (±SE) of the soils collected from places where *A. abyssinica* is currently growing higher than the >3% value considered high by Murphy (1959). Similarly the total nitrogen level in the soils collected from degraded land (0.07 ±

0.003) is below the minimum value (0.10%) whereas the total nitrogen level of the soils obtained from places where *A. abyssinica* is currently growing (0.31 ± 0.01) is greater than the high value (>0.15%) assigned by Murphy (1959). Likewise, the organic carbon content of the soils from places where *A. abyssinica* is currently growing (3.38 ± 0.06) is significantly greater than that of the soils from degraded land (0.63 ± 0.02).

Phosphorus plays a critical role in the life cycle of plants and is the most critical essential element in influencing plant growth and seed production (Wilde *et al.*, 1979; Brady, 1990). The mean concentration of available phosphorus in both types of soil differ significantly, the highest being in the soils from places where *A. abyssinica* is currently growing. The available phosphorus content of the soils from degraded land (2.45 ± 0.16 ppm) is low, while that of the soils from places where *A. abyssinica* is currently growing (8.62 ± 0.3 ppm) is in the medium range according to Murphy (1959). According to Killham (1994), phosphorus availability in soils is reduced at low pH (<5.5) as well as at higher pH (>6.5), thus the higher amount of available phosphorus in the soil from places where *A. abyssinica* is currently growing (with mean pH = 5.6) may be attributed to the optimal pH. Significantly higher concentrations of phosphorus in soils under Faidherbia albida trees was reported by Kamara and Haque (1992).

Differences between the soils from degraded land and the soils from places where *A. abyssinica* is currently growing in organic matter, carbon, nitrogen and phosphorus may be attributed to the contribution by trees to the soil through litterfall in which the organic matter releases substantial quantities of nitrogen, phosphorus, and other stored nutrients needed by plants.

5.4 Growth performance of the seedlings

The growth performance parameters of the seedlings that were assessed were height, the number of branches, the number of leaves, shoot dry weight and root dry weight. The values of these parameters were found to be higher in the control than the GA_3 treated ones. GA_3 is known to induce stem elongation with the greatest response in genetic dwarfs (Devlin, 1966; Wareing and Phillips, 1970; Harada and Veraga, 1972; Goodwin and Mercer, 1983; Karssen and Groot, 1987 cited in Bell *et al.*, 1993). The shoot and root dry weight of the control and treatments was significantly lower for the seedlings grown in the soils from degraded land as compared to that of the soils from places where *A. abyssinica* is currently growing. The difference in root dry weight may be due to the difference in nutrient content of the soils since root growth, as a rule is not affected by external pH in the range of 5.0-7.5 (Marschener, 1995).

5.5 Soil micronutrients and seedling growth

The micronutrients iron, manganese, copper and zinc all form metallic cations that precipitate into low solubility compound at high pH (Thompson and Troeh, 1978). While there is a considerable variation in the specific roles of the specific micronutrients in plants, all commonly participate in enzyme systems (Brady, 1990). Deficiencies of these elements often limit plant growth in high lime or alkaline soils (Thompson and Troeh, 1978).

6. CONCLUSION AND RECOMMENDATIONS

Unscarified seeds of *A. abyssinica* failed to germinate while the scarified ones successfully germinated within 3 to 5 days after incubation. This indicates that germination of *A. abyssinica* seeds is controlled by the seed coat. The low and erratic seed germination of the species which could be an obstacle to establishment could be removed by chemical scarification using H_2SO_4, which is a successful means of breaking dormancy in the laboratory. However, studies should be made to develop a cheap, practical and convenient method of overcoming dormancy.

Application of plant hormones during germination had no significant effect in increasing percentage germination as compared to the control, indicating that no germination stimulators are required for obtaining maximum percentage germination provided that the seeds are carefully scarified.

Deforestation is a major contributing factor for land degradation and desertification since it affects both the quality of soil and environment and the availability of key natural resources. A dramatic increase in the rate of afforestation is needed to replenish immediate or imminent human needs and for the purposes of environmental protection and rehabilitation.

Overexploitation of the land in order to maximize production to feed the ever growing population is a major problem in the tropics. Therefore, reversing environmental degradation is a necessity if the sustainability of the resources is to be maintained.

N_2 fixation by tree legumes could make a significant N input to soils. Therefore, soils not found economical for regular farming, should be brought under legume tree cover since investigations have demonstrated the improvements of both physical and chemical properties of soils under tree cover.

Seedlings planted on degraded soils survived until harvest time (i.e. 12 weeks after planting) despite the low level of organic matter, total nitrogen and available phosphorus in these soils. The results indicate the potential of *A. abyssinica* for reforestation of degraded land.

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Appendix 1. Soil pH and texture of soil samples collected from degraded land (CL = Clay loam; SCL = Sandy clay loam).

Sample No.	Physiographic position	pH (H_2O 1:2.5)	Texture			Class
			% Sand	% Silt	% Clay	
1	Summit	7.63	49	24	27	SCL
2	Summit	7.93	39	30	31	CL
3	Summit	7.83	41	28	31	CL
4	Summit	8.10	41	26	33	CL
5	Shoulder	8.12	41	26	33	CL
6	Backslope	7.78	49	24	27	SCL
7	Footslope	7.43	43	28	29	CL
8	Toeslope	8.18	43	18	39	CL
9	Toeslope	7.37	41	30	29	CL

Appendix 2. Soil pH and texture of soil samples collected from places where *A. abyssinica* is currently growing (L = Loam; CL = Clay loam; SCL = Sandy clay loam; B = Backslope; S = Shoulder; T = Toeslope).

Sample No.	Physiographic position	pH (H_2O 1:2.5)	Texture			Class
			% Sand	% Silt	% Clay	
1	Addis Ababa (B)	5.47	37	32	21	CL
2	Burayu (T)	5.34	39	32	29	CL
3	Kolobo (T)	5.44	33	36	31	CL
4	Kolobo (T)	5.86	39	28	33	CL
5	Kolobo (T)	5.61	35	38	27	L
6	Kolobo (T)	5.91	35	34	31	CL
7	Kolobo (B)	5.63	31	36	33	CL
8	Kolobo (S)	5.48	33	38	29	CL
9	Kolobo(S)	5.50	25	40	35	CL

Appendix 1. Soil pH and texture of soil samples collected from degraded land (CL = Clay loam; SCL = Sandy clay loam).

Sample No.	Physiographic position	pH (H_2O 1:2.5)	Texture			Class
			% Sand	% Silt	% Clay	
1	Summit	7.63	49	24	27	SCL
2	Summit	7.93	39	30	31	CL
3	Summit	7.83	41	28	31	CL
4	Summit	8.10	41	26	33	CL
5	Shoulder	8.12	41	26	33	CL
6	Backslope	7.78	49	24	27	SCL
7	Footslope	7.43	43	28	29	CL
8	Toeslope	8.18	43	18	39	CL
9	Toeslope	7.37	41	30	29	CL

Appendix 2. Soil pH and texture of soil samples collected from places where *A. abyssinica* is currently growing (L = Loam; CL = Clay loam; SCL = Sandy clay loam; B = Backslope; S = Shoulder; T = Toeslope).

Sample No.	Physiographic position	pH (H_2O 1:2.5)	Texture			Class
			% Sand	% Silt	% Clay	
1	Addis Ababa (B)	5.47	37	32	21	CL
2	Burayu (T)	5.34	39	32	29	CL
3	Kolobo (T)	5.44	33	36	31	CL
4	Kolobo (T)	5.86	39	28	33	CL
5	Kolobo (T)	5.61	35	38	27	L
6	Kolobo (T)	5.91	35	34	31	CL
7	Kolobo (B)	5.63	31	36	33	CL
8	Kolobo (S)	5.48	33	38	29	CL
9	Kolobo(S)	5.50	25	40	35	CL

Appendix 3. Exchangeable bases and CEC of soil samples collected from degraded land.

Sample No.	Physiographic position	Exchangeable bases (Meq/100 g soil)				Sum	CEC	Base sat.(%)
		Na	K	Ca	Mg			
1	Summit	3.29	2.92	17.47	1.67	25.35	25.60	99
2	Summit	5.74	1.52	21.96	2.08	31.30	33.60	93
3	Summit	5.74	2.72	23.45	2.08	33.99	36.00	94
4	Summit	5.59	2.97	20.46	1.75	30.77	32.20	96
5	Shoulder	6.28	3.07	24.45	2.17	35.97	36.20	99
6	Backslope	1.92	2.62	15.47	2.42	22.43	26.00	86
7	Footslope	1.92	3.12	20.46	2.83	28.33	33.00	86
8	Toeslope	3.83	2.72	18.46	1.92	26.93	29.60	91
9	Toeslope	2.30	1.80	12.48	1.42	18.00	25.00	72

Appendix 4. Exchangeable bases and CEC of soil samples collected from places where *A. abyssinica* is currently growing (B = Backslope; S = Shoulder; T = Toeslope).

Sample No.	Physiographic position	Exchangeable bases (Meq/100 g soil)				Sum	CEC	Base sat.(%)
		Na	K	Ca	Mg			
1	Addis Ababa (B)	0.61	1.82	9.98	3.33	15.74	29.80	53
2	Burayu (T)	0.46	1.37	8.48	2.50	12.81	27.80	46
3	Kolobo (T)	0.39	0.78	9.98	3.25	14.40	28.80	50
4	Kolobo (T)	0.54	1.50	15.97	5.33	23.34	35.60	66
5	Kolobo (T)	0.39	0.65	16.47	5.50	23.01	39.40	58
6	Kolobo (T)	0.46	1.27	10.98	4.08	16.79	31.60	53
7	Kolobo (B)	0.39	1.30	9.98	3.25	14.92	33.00	55
8	Kolobo (S)	0.54	1.62	11.48	3.58	17.22	32.80	53
9	Kolobo(S)	0.39	0.63	10.48	4.50	16.00	33.60	48

Appendix 5. Data on the chemical properties of soil samples collected from degraded land

Sample No.	Physiographic position	$CaCO_3$ %	T.N %	O.C %	C/N	OM	Av. P (ppm)	Fe	Mn (DPTA)	Zn	Cu
1	Summit	1.9	0.056	0.519	9	0.9	1.92	14.28	2.26	0.4	1.38
2	Summit	6.3	0.084	0.638	8	1.1	0.96	3.8	1.04	0.2	0.54
3	Summit	8.6	0.049	0.539	11	0.92	1.54	3.92	0.8	0.2	0.56
4	Summit	5.6	0.077	0.539	7	0.93	1.10	3.06	1.34	0.4	0.76
5	Shoulder	8.0	0.028	0.379	14	0.65	2.28	4.5	0.82	0.2	0.7
6	Backslope	1.8	0.07	0.658	9	1.13	4.02	3.08	2.76	0.2	0.64
7	Footslope	2.4	0.056	0.738	13	1.27	2.40	6.44	2.14	0.4	0.48
8	Toeslope	2.5	0.098	0.718	7	1.24	2.34	3.86	1.4	0.2	0.56
9	Toeslope	1.5	0.098	0.918	9	1.58	5.46	4.36	2.36	0.2	0.46

Appendix 6. Data on the chemical properties of soil samples collected from places where *A. abyssinica* is currently growing (B = Backslope; S = Shoulder; T = Toeslope).

Sample No.	Physiographic position	T.N %	O.C %	C/N	OM	Av. P (ppm)	Fe	Mn (DTPA)	Zn	Cu
1	Addis Ababa (B)	0.28	2.97	11	5.126	8.28	8.54	4.3	1.4	1.98
2	Burayu (T)	0.266	2.89	11	4.988	13.20	16.84	3.14	0.4	0.78
3	Kolobo (T)	0.254	2.73	11	4.712	6.20	16.68	3.16	0.2	1.46
4	Kolobo (T)	0.317	3.81	12	6.569	8.80	14.82	4.52	0.2	0.96
5	Kolobo (T)	0.456	4.95	11	8.531	10.16	15.02	4.88	0.4	1.86
6	Kolobo (T)	0.271	3.19	12	5.503	8.44	19.38	4.06	0.6	0.82
7	Kolobo (B)	0.322	3.55	11	6.122	11.30	17.16	3.92	0.2	0.98
8	Kolobo (S)	0.341	3.07	9	5.297	6.50	13.24	3.78	0.2	0.94
9	Kolobo(S)	0.312	3.23	10	5.572	4.68	3.78	4.5	0.2	0.58