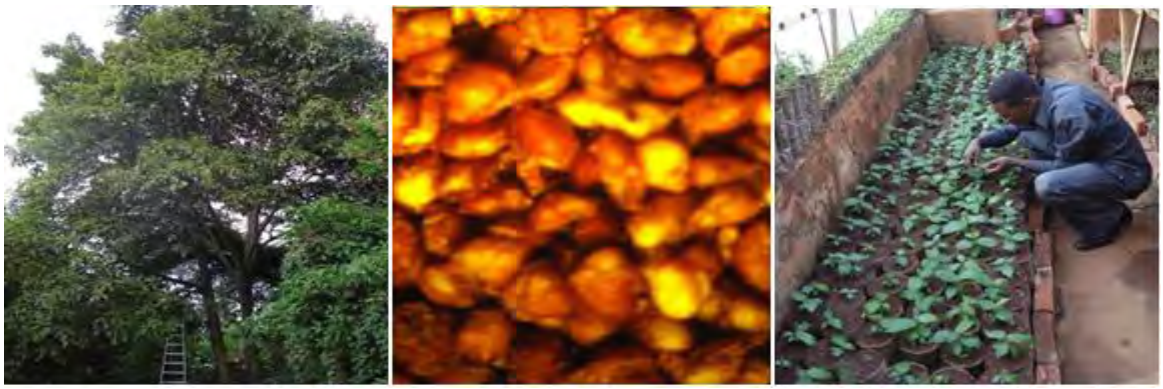
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

PLANT BIOLOGY AND BIODIVERSITY MANAGEMENT

PROGRAM UNIT

Germination Physiology, Germinant Establishment and Growth Performance Studies of *Ficus sycomorus* L. (Moraceae)



By

Wondye Kebede Mohammed

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Addis Ababa

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A thesis submitted to the School of Graduate Studies of Addis Ababa University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Biology and Biodiversity Management Program Unit.

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LIST OF ABBREVIATIONS

Am. Amharic

AOSN Association of Official Seed Analysis

Ar. Arabic

Eng. English

GA_3 Gibberellic Acid

ISTA International Seed Testing Association

KNO_3 Potassium Nitrate

MGR Mean Germination Rate

MGT Mean Germination Time

MGV Mean Germination Vigor

A. Or. Afaan Oromiffa

R^2 Coefficient of determination

Tg. Tigrign

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ABSTRACT

Ficus sycomorus *L. (Moraceae) is a tree indigenous to Ethiopia which possesses useful agro-forestry, medicinal, ecological and fodder importance. The tree is found scattered in many parts of the country mainly as a result of widespread deforestation and also lack of knowledge in the propagation techniques of the species. The current study focuses on germination physiology, germinant establishment and growth performances of tree's seedlings in the glasshouse. Figs of the tree were collected and dried for a week for various studies on the species. Germination of seeds in the laboratory was tested by using plant-derived aqueous smoke extracts,* GA_3 *and* KNO_3 *solutions at various concentrations. Double distilled water was used as a control. Germinant establishment and growth performances of young seedlings at various soil mixtures were examined. The results of seed count on the sample figs yielded between 168 to 465 seeds per fruit. The majority of seeds (73.5%) were found damaged by wasps and the balance (26.5%) were found to be sound and thus used for germination studies of the species. In the laboratory experiments a relative concentration of 100% plant-derived aqueous smoke extracts,* $10^{-6}M$ GA_3 *and* $10^{-3}M$ KNO_3 *yielded maximum germination of 92, 83 and 88%, respectively. The results of seed germination studies under laboratory conditions revealed significant differences* ($p<0.05$). *Among the various treatments administered germination studies conducted in polyethylene plastic pots under glasshouse conditions resulted in mean percentage germination of 57%. Extent of germinant establishment was studied using soil mixes of 4:3:2, 2:1:1, 4:1:3, 4:3:1, 1:1:1 and 1:1:0 of red soil, compost and sand, respectively. The study found 100% survival of seedlings in all the treatments and the control. Growth performance of seedlings tested in the above soil mixtures revealed that the 4:3:2 soil mixture resulted in significant* ($p<0.01$) *difference in growth compared to all the other treatments and the control. The overall results showed that F. sycomorus can efficiently be propagated through seeds in a wide range of soil types.*

Key words/phrases: *Ficus sycomorus*, fig, propagation, smoke extracts, seedling establishment.

1. INTRODUCTION

1.1 Background of the study

Ficus sycomorus is a multipurpose indigenous tree in Ethiopia. It is one of the forest trees with giant canopy layer. The current conditions of the species indicate that it was distributed far apart in many parts of the country as a result of forest depletion. In general, the depletion of such forest cover of indigenous tree in many regions of the country were observed from time to time with faster rate due to lack of knowledge for their conservation and propagation. According to Legesse Negash (1995), the main reasons for forest depletion in Ethiopia are summarized into two (a) for public economic importance (i.e. land clearing for farming, tree felling for fuel, commercial loggings for timber, tree cutting for construction of house, forest fire); and (b) difficulty in propagating indigenous forest species through the conventional tree propagation techniques. All cause deforestation and land degradation. Thus, the widespread deforestation and increased land degradation causes scarcity of the forest tree especially in the highland areas of Ethiopia (Badege Bishaw, 2001). As a result, litter decomposition and existence of microorganisms which are essential for soil fertility become doubtful and nutrients were lost. This in turn creates reduction of crop production.

Forest depletion also has great effect on carbon consumption globally and reduces the contribution for the sequestration of carbon from the atmosphere and its effect on global warming. Thus, optimize the appropriate seed germination enhancement procedures and propagation technique is very essential. Plant propagation can be defined as the duplication of plants from the mother plant either sexually through seeds or asexually by vegetative parts (Hartmann and Kester, 1975). Specifically, *F. sycomorus* can be propagated through seeds and by vegetative means. Thus, the ultimate goal of such plant propagation techniques is to produce large amount of plants which are similar to the parent. Therefore, in order to resolve such existing problems appropriate method of plant propagation should be used depending on the biological need of the species.

For this reason, matured and viable seeds are efficient for mass propagation, domestication and cultivation of useful tree species (Legesse Negash, 2002a; 2010). Every species of plant can be regenerated from seeds or through vegetative

propagation techniques under controlled environment and later transferred to the degraded areas. In order to perform such useful restoration activities of indigenous trees of Ethiopia, lack of scientific knowledge on their propagation biology and integrated physiological response of the plants complicate the problem (Legesse Negash, 2010). Many researches conducted in the past two decades proved the denigration of indigenous trees of Ethiopia was not true (Legesse Negash, 2010). Those findings set easy propagation techniques, developed successful methods to establish better germinant in glasshouse and nursery conditions.

Ficus sycomorus is one of the fast growing and easily propagated indigenous tree species of Ethiopia. As a result, obtaining satisfactory seed germination and achieving successful germinant establishment for better growth of many plant species were the most important procedures for the flourishing and propagation of indigenous tree species in Ethiopia (Kebebew Wakjira, 2007; Legesse Negash, 1995; 2010).

1.2 Brief description of *F. sycomorus* L.

Ficus sycomorus is commonly known as Biblical fig or fig mulberry. The tree is a member of family of plants called Moraceae. The family consists of 53 genera and 1400 species that are distributed in tropical, subtropical and warm temperate regions of the world (Friis, 1989). The tree is a medium size, decidious plant with large spreading crown (Friis, 1989). *Ficus sycomorus* is native to the Middle East and Eastern Africa. In Ethiopia, the species is distributed in river and lake margins, woodlands, wooded grasslands, evergreen bushlands, forest edges and coffee forests in moist to wet mid highlands between 500 to 2000 m a.s.l (Friis, 1989; Azene Bekele, 2007).

The tree offers unique ecological, aesthetic, and commercial values. The species requires wasp in order to reproduce sexually and the process of pollination commonly depends on specific wasp species (Wiebes, 1979; Weiblen, 2002). The wasp needs *F. sycomorus* as a place to lay its eggs while the tree needs the wasp to pollinate its flowers.

Ficus sycomorus figs are edible and the tree is recognized as a keystone species in tropical regions. The stems and branches serve as source of firewood and are used to produce charcoal; leaves are used as fodder. In addition, stems are used for timber

production. The timber has a fairly uniform structure, is light, soft to moderately hard, easy to work and finishes smoothly and holds nails firmly (Orwa *et al.,* 2009). However, its durability is low, and being easily attacked by termites. Unfortunately, these diverse uses of the tree have contributed to the destruction of the species by the local people from many areas of Ethiopia. *Ficus sycomorus* has diverse ecological importance, including control of erosion, provision of shade or shelter, improvement of soil organic matter and nutrient status, and water holding capacity of the soil (Azene Bekele, 2007).

Ficus sycomorus was a sacred tree in various communities (Azene Bekele, 2007; Orwa *et al.,* 2009; Legesse Negash, 2010). This has been associated with the tree believed to be a place of worship as „*Adbar*", under which various religious ceremonies are conducted by a variety of communities. In addition, the tree canopy provides shelter in various communities for many social purposes including for community meeting and social justice.

1.3 Propagation challenges of *F. sycomorus* L

Ficus sycomorus does not produce viable seeds in areas other than tropical Africa. According to Brown and Walsingham (1917), *F. sycomorus* did not produce viable seeds in Egypt. As a result the peasants propagated the plant by cuttings. Since the legitimate pollinators are absent from the Mediterranean countries, the pollination ecology and seed germination test of this tree cannot be studied in such geographical regions. The tree produces seeds in the tropical and subtropical areas such as Ethiopia, but not all the seeds obtained are good enough for germination (Orwa *et al.,* 2009). This has been attributed to various reasons such as pollination failures, environmental and predation problems; including feeding of the seeds by many species of insects (Legesse Negash, 2010). Such pollination and seed viability problems contribute to the scarcity of the species in various parts of the world.

In Ethiopia, the tree is found extremely scattered in farmlands, river and lake margins, woodlands, wooded grasslands, evergreen bush-lands, forest edges and clearings, and in coffee forests ranging from moist to wet mid highlands of the country. The scarcity of other forest trees due to forest destruction has great impact to the increased destruction of the *F. sycomorus* trees for various purposes including for fuel wood.

On top of this, cultivation of the species has never been undertaken, thus putting the survival of the species in danger.

In areas other than tropical Africa, the tree can be propagated by vegetative means through rooting of cutting. Propagation through seeds can be tested in tropical, subtropical and warm temperate areas of the world. These are areas where the specific pollinator wasp species are found, and where viable seeds are produced. The syconium of the species may contain numerous seeds, although, the viability of the seeds are quite low.

Previous studies conducted on Ethiopian *Ficus*, have mainly emphasized on checklist (Friis, 1990), or taxonomy and species descriptions (Friis, 1989; Azene Bekele, 2007). However, recent studies by Legesse Negash (2010) addressed the biology, uses and propagation techniques of *Ficus vasta.* The present study is a follow up of such studies, but specifically focusing on *F. sycomorus.*

For successful germplasm selection, domestication, propagation, cultivation and conservation of the species knowledge and understanding of the biology, germination physiology of the seeds, the conditions for germinant establishment and successful growth of the seedlings are very essential (Legesse Negash, 1995, 2010). However, little is known about seed germination physiology, germinant establishment and growth responses of seedlings to various soil mixtures.

The present study attempts to investigate the effect of plant-derived aqueous smoke extracts, GA_3 and KNO_3 at various dilution levels on germination responses of *F. sycomorus* seeds. Techniques for the transfer and establishment of germinant in optimal growth medium for better seedling growth under various soil mixtures has also been the subject of this study.

2. OBJECTIVES OF THE STUDY

2.1 General objective

The main objective of this study was to develop suitable seed pretreatment procedures for obtaining maximum germination percentage, describe techniques for establishing germinant, and assessing the impacts of growth media on growth performance of *F. sycomorus*.

2.2 Specific objectives

The specific objectives of the current study were to:

- determine seed developmental status of *F. sycomorus;*
- determine germination responses of *F. sycomorus* seeds under laboratory, and glasshouse conditions;
- study effects of phyto-hormones and plant-derived aqueous smoke extracts of various concentration levels on percentage germination, mean germination rate, mean germination time, and germination vigor of *F. sycomorus* seeds;
- establish the techniques for transfer of germinant of *F. sycomorus,* and
- examine growth potential of *F. sycomorus* seedlings under various soil mixture.

3. LITERATURE REVIEWS

3.1 Taxonomy and morphological features of *F. sycomorus*

Ficus sycomorus known variously as Shola, Bamba (Am); Akuku, Hagile, Huda, Lugo, Oda (A. Or); Shegla, Sagla (Tg); Subula (Ar); Faroh‟s tree, sycamore fig, or the fig-mulberry (Eng.), due to the similarity of leaves with those of the mulberry (Azene Bekele, 2007). The tree is a fig species of the mulberry family named Moraceae (Friis, 1989).

The taxonomy of the fig is in kingdom of plantae, division Magnoliophyta, class Magnoliopsida, order Urticales, family Moraceae, genus *Ficus,* subgenus Sycomorus, and species Ficus *sycomorus*. The genus has 1400 species in the tropical and sub-tropical regions of the world with a wide range of habit from tree to shrub, lianas and epiphytes (Friis, 1989; Legesse Negash, 2010). According to Friis (1990), about 20 species were recorded in Ethiopia. These are, *F. palmata* Forssk*., F. capreifolia* Del*., F. exasperata* Vahl., *F. asperifolia* Miq., *F. sycomorus* L*., F. mucoso* Welw. ex Ficalho*, F. sur* Forssk*., F. vallis-choudae* Del*., F. dicranostyla* Mildbr*., F. ingens* Miq*., F. salicifolia* Vahl*., F. lutea* Vahl*., F. platyphylla* Del*., F. vasta* Forssk*., F. glumosa* Del*., F. abutilifolia* Miq*., F. populifolia* Vahl*., F. rokko* Warb. & Schweinf*, F. umbellate* Vahl., and *F. ovata* Vahl.

The tree may reach to 30 m tall, buttressed, with a trunk up to 3.5 m diameter and with spreading crown (Friis, 1989). Bark is grey in the early seedlings and later becomes grayish brown in young seedlings; yellowish in saplings and the tree. The slash of the tree is pale brown, yellowish or pinkish. The young branches are with brown bark, puberulous to pubescent and scaly. Leaves are almost leathery and broadly ovate; base rounded to narrowly cordate; margin sub-entire to crenulate; apex rounded, acute to short acuminate; lamina dull, slightly scabrous or smooth above, scabrous or smooth, often pubescent bellow; midrib with 4-8 pairs of lateral nerves.

The stipules covering buds are scarious, lanate to hirsute. It has grey or brown scales, falling quickly, leaving a circular fringe or whitish or brownish hairs. Figs on special leafless, clustered, pendent branches on the trunk or older branches on panicles up to 1.7 cm long, basal bracts ovate to triangular, ostiole permanent (Friis, 1989).

3.2 Ecological and geographical distribution of *F. sycomorus*

The natural distribution area of the species extends from the west of Middle East to Cape Verde Islands and south to South Africa, Namibia and the Comoro Islands up to Sudan and Ethiopia in the north (Azene Bekele, 2007; Orwa *et al.,* 2009). It also grows naturally in the southern Arabian Peninsula (Muscher, 1912 *cited* in Taylor, 1918). Yemen in the south western part of the Arabian peninsula (Galil and Eisikowitch, 1968) and in very localized areas in Madagascar, and has been naturalized in Israel, Egypt (Galil and Eisikowitch, 1968; Friis, 1989; Azene Bekele, 2007). In its local habitats, the tree was usually found in rich soils along rivers and higher water table areas, but also in mixed woodlands (Orwa *et al.,* 2009). In Ethiopia, it is found in river and lake margins, woodlands, wooded grasslands, evergreen bush-lands, forest edges and coffee forests in moist to wet mid highlands between 500 to 2000 meters above sea level (Friis, 1989).

3.3 Uses of *F. sycomorus*

The individual tree has the highest fruit bearing capability in the plant kingdom, and the rich figs are present all year round (Da Rong *et al*., 2002; Legesse Negash, 2010). Thus, they can afford food and habitats for mammals, birds, insects, soil animals and micro-organisms (Azene Bekele, 2007; Orwa *et al.,* 2009; Legesse Negash, 2010).These kinds of habitats are also good for saprophytes, epiphytes, parasitic plants and shade enduring plants (Da Rong *et al.,* 2002). For this reason, many species of *Ficus* are internationally recognized as keystone species in the tropical rainforests and subtropical areas of the world (Da Rong *et al.,* 2002; Legesse Negash, 2010). Figs are eaten by livestock, birds and wild animals, which can also be dried, and have a good flavor and high food value (Azene Bekele, 2007; Orwa *et al.,* 2009; Legesse Negash, 2010).

Makishima (2005) reported that *F. sycomorus* is the most abundant fruit supplier for frugivorous animals in the riverine forest in the semi-arid land. Dharani (2002) reported that, chimpanzees use *Ficus* spp. as a fallback and/or food during the period of fruit scarcity. This suggests that *Ficus* could have been a keystone or staple food of many animals.

In addition, the species were used for firewood, construction of beehives, ornamentals, soil conservation and improvement, providing shade and protection of soil erosion (Azene Bekele, 2007; Orwa *et al*., 2009), and is an indicator of the accessible water table in the low land areas (Coppock, 1994; Orwa *et al*., 2009).

3.4 Medicinal importance of *F. sycomorus*

The tree has medicinal importance from latex, leaf, and bark extracts (Sofowara, 1993; Azene Bekele, 2007; Endalew Amenu, 2007; Orwa *et al.,* 2009; Olusesan *et al.,* 2010). In Ethiopian context, the medicinal uses of the species studied were sap of *F. sycomorus* is creamed directly on dermal layer of the skin to treat hepatitis; bark of *F. sycomorus* and root of *Prunus africana* are powdered together and backed with „teff" flour and eaten orally to treat rabies; and bark of *F. sycomorus* is dried powdered and mixed with butter and creamed directly and taken as anal medicine to treat hemorrhoid as recorded by (Endalew Amenu, 2007). In addition, in low land areas of Borena seed and root extracts have medicinal value for women after they have given birth (Coppock, 1994).

In many African countries, the leaves are used to treat snake bites; the latex is effective for chest diseases, colds, and dysentery; the bark is used to treat coughs, throat infections and chest pains (Sofowara, 1993; Orwa *et al.,* 2009).

3.5 Pollination biology and seed development in *F. sycomorus*

The fruits of *F. sycomorus* mainly called syconia or figs are the reproductive parts of the species in the genus *Ficus*. *Ficus* species can only be pollinated by their associated family Agaonidae (Hymenoptera: Chalcidoidea) wasps (Compton *et al.,* 1991; Joussulin *et al.,* 2001; Weiblen, 2001; Molbo *et al.,* 2003; Starr *et al.,* 2003; Machado *et al.,* 2001). Such pollinator agents includes several hundred wasp species that are closely associated with the flower structure of *Ficus* species (Boucek, 1988).

Ficus species are mainly monoecious as a result of the arrangement of the unisexual flowers in the enclosed inflorescence, or syconium (Kjellberg *et al.,* 1987; Berg and Wiebes, 1992; Weiblen, 2001; Legesse Negash, 2010). In monoecious species, all figs contain both staminate and pistillate flowers (Weiblen, 2001). The pollen laden female wasp enters in to the syconium in the receptive stage. The syconium lined internally with dozens or hundreds of the receptive female flowers and few immature

male flowers. The wasp lays the egg through the styles into some of the ovaries, thus pollination takes place in the process (Legesse Negash, 2010). On the other hand, dioecious species have two kinds of figs on separate plants. The male tree is monoecious that contains both staminate and pistillate flowers with short style, and the female tree has pistillate flowers only which produce seeds (Nadel *et al.,* 1992; Weiblen, 2001).

The wasps can only lay eggs within their associated *Ficus* fruit (Starr *et al*., 2003). For successful pollination and reproduction of *Ficus* species to occur, its associated pollinator wasp species must be present. Conversely, for successful reproduction of Agaonidae wasps to occur, their associated *Ficus* species must be present (Janzen, 1979). Pollination of all fig species has been done by fig wasps, which have their unique symbiotic associates. In *F. sycomorus*, the most common and possible pollinator wasps are *Ceratosolen arabicus* and *C. galili* (Wiebes, 1964; Berg and Wiebes, 1992; Weiblen, 2001; Orwa *et al.,* 2009).

All fig wasps complete growth and development within the fig inflorescence, and their interactions with hosts may be obligatory mutualistic (Ramirez, 1976; Janzen, 1979; Wiebes, 1979; Nadel *et al.,* 1992; Herre *et al*., 1996; Herre, 1999; Molbo *et al.,* 2003) that is populations of the figs or the wasps cannot persist without the other. On the other side, non-pollinating wasps was found together with the pollinators in a syconium of a fig, which have negative impacts on their hosts, either as gallers of figs or as parasitoids of pollinators (Nadel *et al.,* 1992; Legesse Negash, 2010). The pollinator larvae feed on endosperm, which is accessible only to offspring deposited between the ovary layers of short styled flowers in gall figs (Da Rong *et al.,* 2002)..

The maturation of pollinator offspring is associated with the release of pollen from staminate flowers, which the female wasps deliver to both kinds of figs. In seed figs, the pollinator ovipositors fail to penetrate the ovary layers of the long styled flowers. The number of female wasp species which enters a syconium has close relation with the seed bearing rate of female flowers, as well as the oviposition and reproduction rate of the fig wasps themselves (Da Rong *et al.,* 2002).

3.6 Seed germination

Seed germination is sequences of complex processes that lead to the initiation of growth in the quiescent embryo in the seeds (Bewley, 1997; Hadas, 2004). Hence the process incorporates those events that begin with the uptake of water by the quiescent dry seed and terminate with the elongation of the embryonic axis (Bewley and Black, 1994). During seed germination, various stored substrates are reactivated, repaired if damaged, and transformed into new building materials necessary for the initial growth of the embryo, its subsequent growth, and seedling establishment in its natural habitat (Koller and Hadas, 1982). To initiate the collection of processes, the condensed, insoluble stored substrates must first be hydrated and then hydrolyzed to their basic forms before they can be reprocessed.

The processes necessary to hydrate and reactivate enzymes, cell membranes, and cell organelles require much more respiratory energy that is used to maintain the dry seed (Bewley and Black, 1994).

The visible sign that germination completes is usually the penetration of the structures surrounding the embryo by the radicle; the result is often called visible germination. Subsequent events, including the mobilization of the major storage reserves, are associated with growth of the seedling. Practically all of the cellular and metabolic events that are known to occur before the completion of germination of non-dormant seeds also occur in imbibed dormant seeds. In fact, the metabolic activities of the latter are normally different from those of the former. Hence, a dormant seed may achieve practically all of the metabolic steps required to complete germination, yet for some unknown reason, the embryonic axis (i.e. the radicle) fails to elongate.

The variable germination potential of seeds in plant is mainly due to different fruits developing at different times and positions, but may be also a result of different seed positions in the same fruit as reported in cucumber (Jing *et al*., 2000). Successful seed germination following some period of dormancy results from an interaction between physiological and genetic factors and environmental factors, including sediment, light, and temperature (Baskin and Baskin, 1998).

However, this critical environmental cues that influence germination can vary over short horizontal and vertical distances as characteristics of the physical environment

(e.g. sediment type, pH, organic matter) and biological environment (e.g. abundance and type of sediment dwelling animals, physical arrangement of plant and animals in space and time) interact to create a variety of microclimates (Hamrick and Lee, 1987).

3.7 Factors affecting seed germination

Germination potential of seeds of many plants can be influenced by various environmental and the seed internal factors. Without understanding of such factors and appropriate knowledge of plant propagation techniques and their seed biology of indigenous trees, production of seedlings from seeds would be difficult (Legesse Negash, 1995; 2010). This is due to the existence of unique survival and developmental strategy of each indigenous tree species through long time of evolutionary processes. One of the major strategies in seed physiology is: some seeds of indigenous tree species undergo the period of dormancy to pass unfavorable environmental or internal situations. The germination of seeds in a particular situation and season is determined by the interaction between the dormancy releasing factors (Demel Teketay, 2005), which influence on the termination of dormancy or initiation of germination and seedling growth in many plant species like phyto-hormones, light (photoperiod), temperature, water (e.g. imbibition, osmotic changes, salinity), nutrients, moisture or mechanical cues (Hilhorst and Karssen, 1992). However, factors critical to this process can be seed specific.

3.7.1 Temperature

Temperature is most likely the main limiting environmental factor for seed germination and each species has its characteristic requirements (Nerson, 2007). Optimal temperature for germination may vary from species to species (Khurana and Singh, 2001). As a result of great inconsistency in heat capacity and heat conduction between soil and air, maximum fluctuation in temperature occurs at the surface in gaps away from the insulating effect of vegetation cover. Several tropical species require alternating or high temperatures to break dormancy and a high amplitude of alternating temperatures may certainly signal for the formation of a gap to the seeds (Khurana and Singh, 2001).

In this respect, an increase in temperature may trigger germination in many species of plants. This is due to changing the internal enzymatic kinetics and thus the

biochemistry of seed cells or by melting the suberized layer in seed coat sclerenchyma or at micropyle, allowing the seed to take up water (Vazquez-Yanes and Orozco-Segovia, 1992). Seeds of certain species require a brief period of chilling and subsequent higher temperature for accelerated germination and seedling growth (Hartmann and Kester, 1975).

3.7.2 Seed maturity and dormancy

Seed is a miniature tree because it is responsible for its regeneration and ultimately for its reproductive success (Khurana and Singh, 2001). Following fertilization, growth sets in various parts of the ovule resulting into a seed; the zygote develops into the embryo, the primary endosperm nucleus gives rise to endosperm and the integuments form the protective seed coat, which is the seeds primary defense against adverse environmental conditions (Legesse Negash, 1993, 1995; Khurana and Singh, 2001). The dormant seeds readily germinate under favorable conditions, while others may possess primary dormancy or develop secondary dormancy that may require treatments to shift the seed again from the dormant to the quiescent state (Khurana and Singh, 2001).

Dormancy defined as, the state of reduced metabolic activity adopted by many organisms under conditions of environmental stress or the failure of an intact viable seed to complete germination under favorable conditions (Nerson, 2007). This inhibition of germination is caused by one or more of the following mechanisms: (a) Chemical inhibitors that prevent growth (b) Physical barriers that prevent the uptake or the movement of water, gases or chemicals within the seed (c) The embryo of the seed is not fully developed and needs time after dispersal to ripen (Bewley and Black, 1994; Baskin and Baskin, 1998; Legesse Negash, 1993, 1995, 2010).

Species of plants differ in their seed dormancy and requirements for seed germination (Demel Teketay, 2005). The seeds of some species are prevented from completing germination because the embryo is constrained by its surrounding structures. This phenomenon is known as seed coat dormancy (Legesse Negash, 1993) even though; embryos isolated from these seeds are not dormant. The other type of dormancy is found when the embryos of the seeds are dormant, known as embryo dormancy. The third type of dormancy regulates seed germination by the inner tissue of the seed,

which is the embryo, the enclosing endosperm and inner integument layer or both (Hartmann and Kester, 1975). Thus, dormancy must be broken to induce germination and various methods are used for this depending on the plant species and type of dormancy.

3.7.3 Seed treatment related to fire

Smoke from burning various parts of plants through distilled water created an aqueous smoke extract that was then used to treat seeds. Smoke treatment of seeds should take some points in to consideration. This may include traditional seed pretreatments, the kind of plant material burned, combustion temperature, response of treated species, and commercial availability of smoke products (Adkins and Peters, 2001; Sparg *et al.,* 2006). The chemical compositions of smoke are not clearly identified (Adkins and Peters, 2001). Even though, the possible chemicals which enhance germination predicted as nitrogenous compounds (Black and Young, 1998; Keely and Fotheringham, 1998).

However, the chemical composition of smoke varies with temperature but tests indicate that activating compounds produced between 160 to 200 °C are the most active (Jager *et al.,* 1996). In fact, the stimulatory chemicals are lost through volatilization at higher temperatures. As a result, on a practical basis, a slow flaming fire was most effective (Brown and Van Staden, 1997).

Periodic fire is known to influence the survival of seed, the timing of germination event and the survival of established seedlings (Bell *et al*., 1995).

Seeds which are released from dormancy by heat shock or chemicals leached from burnt wood as a result of wild fire are called refractory seeds or fire recruiters, and species that are flexible to frequent fire but require fire free periods for enrollment, possess non-refractory or fire resister seed syndrome. Species in which seedling recruitment does not occur after fire, but establishment and potential population expansion occur only under fire free condition are called fire persister or obligate resprouter (Keeley, 1991). A rainforest gap tree, *Ochroma lagopus,* showed enhanced germination when exposed to superficial fire (Vazquez-Yanes, 1974).

The hard seeded fire responding taxa generally have thick testa which is scarified by the heat from fire (Khurana and Singh, 2001). Heat shock induces imbibition by loosening cells in localized regions or possibly by denaturing inhibitors (Bell *et al,* 1995). Heat shock might induce production of chemicals that cause changes in the seed coat or other external layers to overcome water impermeability barriers. Thus, act as internal signals and mediate germination by induction of enzymes or growth regulators (Keely and Fotheringham, 1998). However, most of the rainforest seeds, especially those in the top few centimeters of soil were killed due to fire (Baskin and Baskin, 1998).

3.7.4 Gibberellic acid (GA_3)

Gibberellins are a group of plant growth regulators which play an important role in the regulation of seed germination and breaking dormancy. According to Taiz and Zeiger (2002), seed germination may require gibberellins for one of several possible steps: the activation of vegetative growth of the embryo, the weakening of a growth constraining endosperm layer surrounding the embryo, and the mobilization of stored food reserves of the endosperm. Seed germination can be stimulated by applying artificially produced phyto-hormones or by natural means. In a natural means of breaking dormancy, the gibberellin synthesizing mechanism is activated and the actual synthesis of gibberellins takes place when the seeds are transferred to a suitably higher temperature (Chen and Change, 1972).

Consequently, accumulation of GA results in germination of seeds. Gibberellins promote growth by increasing plasticity of the cell wall followed by the hydrolysis of starch to sugar which reduces the potential in the cell, resulting in the entry of water into the cell causing elongation (Arteca, 1996), hence, causing germination of seeds.

Releasing from dormancy can be affected by a variety of environmental and chemical stimuli. It is mediated through a common signal transduction chain that coordinates diverse cellular responses but that may differ between the seeds of different species and dormancy types. According to Vleeshouwers *et al.* (1995), there are common receptors for dormancy breaking agents within the plasma membrane of the responsive embryonic cells. When triggered, these receptors then initiate a signal transduction cascade, perhaps involving synthesis of or sensitization to germination

promoting gibberellins (GAs), that leads to the completion of germination. Changes in the phosphorylating activity of membrane associated, Ca^{2+} dependent protein kinases that lead to dormancy or germination have been proposed as well (Trewavas, 1988).

Thus, gibberellic acid is known to break dormancy of several types of plant seeds: these are (a) light promoted seeds, such as grand rapids lettuce seed (*Lactuca sativa* L. var. Grand Rapids); (b) light inhibited seeds, such as the seed of the honey bee plant (*Phacelia tanacetifolia* Benth); (c) seeds requiring stratification (storage at low temperatures in a moist condition), such as the hazel nut (*Corylus avellana* L.); (d) seeds requiring after ripening (storage at room temperature in dry condition), such as the wild oat (*Avena fatua* L.) as reported by Chen and Change (1972).

3.7.5 Potassium nitrate (KNO_3)

Nitrogenous compounds, especially nitrates promote the seed germination of a wide range of plant species. The effect of such a nitrate compounds on promotion of seed germination is best realized in combination with other factors such as temperature manipulations or light (Saini *et al.,* 1984).

In assessment of the interaction of nitrate with growth regulators, the phenomena initiated by many environmental factors, that interacts through altering the availability of endogenous hormones (Saini *et al.,* 1984). Plant hormones and environmental factors can often bring out identical responses in seeds, but a causal relationship between the two remains a matter of much controversy.

However, potassium nitrate (KNO_3) was most widely used chemical for promoting germination and for breaking seed dormancy. For this purpose solutions of 0.1 to 0.2 % KNO_3 were common in usual germination testing and are recommended by the Association of Official Seed Analysts (AOSA) and the International Seed Testing Association (ISTA) for germination tests of many species (Basra, 1994).

Both higher and lower concentration of KNO_3 has effect on germination of seeds of many plants. Yucel and Yilmaz, (2009), reported that lower concentration of KNO_3 (<1%) inhibit germination of *Salvia cyanescens* seeds.

The optimum germination rate was better in 1% concentration series and when KNO_3 exceeds 2% in concentration, it becomes a germination inhibitor (Yucel, 2000; Yucel

and Yilmaz, 2009). According to Sarihan *et al.* (2005), KNO_3 treated seeds of *Plantago lanceolata* showed germination frequency range of 84.3-95.3, 85.0-96.0 and 88.3-94.8 % from 1000, 2000 and 4000 ppm KNO_3 treatments, respectively, and all concentration levels of KNO_3 improve germination frequency over control. Even though improvement in the germination of KNO_3 treated seeds was not consistent. Yet, 2000 ppm KNO_3 treated seeds showed the highest germination percentage over the control in *Plantago lanceolata* seeds.

3.8 Growth response parameters

The term growth is applied to quantitative changes occurring during development, and it may be defined as an irreversible change in the size of cell, organ, or whole plant. Plant development also defined as the sequence of ontogenetic events, involving both growth and differentiation, leading to changes in function and morphology. This growth response can be expressed in various parameters of plant growth measurements. Some of these growth measurement parameters were the increment of the plant height, leaf number and leaf area.

Leaf is an important plant organ that is associated with photosynthesis and evapo-transpiration. The number of leaves have great influence on growth performance studies of many plant species. Leaf initiation is regulated by the environment during the early growth of seedlings (Humphries, 1966) and was influenced both by temperature and by the supply of assimilates from upper leaves. In addition, light and availability of water is considered a major determinant factor of leaf growth (Dale, 1988). However, smaller rates of leaf expansion were associated to increased competition for available nutrients.

Leaf area is similarly the most determinant factor in radiation interception, photosynthesis, biomass accumulation, transpiration and energy transfer by canopies of many plant species (Akram-Ghaderi and Soltani, 2007; Mokhtarpour *et al.,* 2010). Leaf area is an indicator of crop growth and productivity (Kurt *et al.,* 2005; Blanco and Folegatti, 2003). As a result this has great influence in final crop yields and total growth of the plant. For this reason, better growth and larger yields in productivity of many plant species obtained was due to the existence of optimal leaf area that attained earlier in the season (Watson, 1952). The leaf area at any time depends on the

numbers and sizes of leaves, both of which are influenced by effects of environment on leaf initiation and rate of expansion (Bull, 1968). For measurement of leaf area, many methods have been developed. Direct methods for determining leaf area are restricted to the use of an automatic area integrating meter, which is classified as destructive (Pyne *et al.,* 1991; Blanco and Folegatti, 2003; Kurt *et al.,* 2005). Tracing, shadow graphing or the use of a planimeter to measure the leaf area of leaves attached to shoots was time consuming and tedious. Other methods were also used, such as hand scanners and laser optic apparatuses were developed for leaf area measurements (Kurt *et al.,* 2005).

On the other hand, leaf area of plants can be measured by indirect methods. This method of measuring leaf area can be classified as non-destructive. In non-destructive methods, leaf area was usually estimated by measuring the number, width or length of plant parts or whole plant (i.e. leaf width, length, number, branch length, branch number, and plant height). These measurements can be undertaken without cutting the plants. Non-destructive methods have been successfully applied for various crops such as sorghum, pearl millet (Pyne *et al.,* 1991), sunflower (Bange *et al.,* 2000). In some cases, these methods (except for plant height) were also time consuming and labor intensive because they include many measurements.

4. MATERIAL AND METHODS

4.1 Fig collection and seed extraction

Ficus sycomorus can produce many figs on the upper parts of the branches or on stems of the tree (Figure 1A, B). For this study, mature figs of *F. sycomorus* were collected from the major branches of a tree planted by the "Rapid Propagation of Indigenous Trees Project" in 1995 within the College of Natural Sciences, Addis Ababa University. Polyethylene plastic bags were used to collect the figs (Figure 1C), which were dried for a week under laboratory conditions (Figure 1D).

Immature figs of *F. sycomorus* are green in color, and change to redish-orange when they get ripe. These ripe figs were collected to quantify seed number from each of the sampled fig, and in order to use for further experiments. The diameter of each fig was also measured with caliper to observe the effect on seed number (Appendix 1).

Seed numbers were determined on 125 randomly taken samples. Seeds which were damaged by the pollinator wasp species or other insects were manually separated from healthy seeds using an inverted microscope set at a magnification of 20x (Figure 1E).

Figure 1. Seed collection, drying and extraction with the aid of an inverted microscope.

4.2 Petri dish experiments for seed germination tests of *F. sycomorus*

Germination tests of *F. sycomorus* were conducted in Plant Physiology Laboratory of PBBMU (Plant Biology and Biodiversity Management Program Unit). The seeds were presoaked in a 250 ml Erlenmeyer flask (E-flask) containing 25 ml of the respective germination stimulators (i.e. GA_3, KNO_3, and plant-derived aqueous smoke extract solutions). Double distilled water was used as a control. The seeds soaked in the treatment solutions were aerated for six hours (Figure 2) before setting these in the respective Petri dishes. Only seeds which sank to the bottom of E-flasks were used for the germination experiments. The dilution levels used were 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} moles for GA_3 and KNO_3 treatments; and 10, 25, 50, 75, and 100% extracts for plant-derived aqueous smoke extract treatments.

Figure 2. Aeration of *F. sycomorus* seeds for six-hours.

Preparation of plant-derived aqueous smoke extracts was made by burning 200 gm of small branches and leaves of various plants. The plant species used for the generation of smoke were *Juniperus procera* Hochst. ex Endl., *Hagenia abyssinica* (Bruce) J. F. Gmel, *Olea europaea* subsp. *cuspidata* (Wall ex G. Don) Cif., and *Ficus sur* Forssk. Part of these plants were burned in a beekeeper's smoker (Figure 3) having a diameter of 100 mm and a depth of 200 mm. The generated smoke was forced into a 500 ml E-flask (containing 500 ml of double distilled water) through plastic hose fitted to the mouth of the smoker by applying pressure to the air sack of the smoker. The mouth of the E-flask was plugged with a smoke-tight rubber material whose center has been hollowed out to allow for the entry of the plastic hose to the E-flask. The smoke was pumped into the E-flask for 45 minutes. The resulting smoke water was maintained as

a stock solution in a refrigerator at 4°C, and later used to prepare cold aqueous smoke extracts of different dilution levels. The active principles in the smoke are reported to be water soluble (Brown and Van Staden, 1997). The method of smoke extraction was adopted from Keeley and Fotheringham (1998).

Figure 3. Setup of the bee keeper"s smoker for the preparation of plant-derived aqueous smoke extracts.

The germination tests were conducted in plastic Petri dishes with a diameter of 90 mm and depth of 15 mm. For all the germination tests conducted, 50 seeds were placed on each Petri dish which was overlaid with a single layer of Whatmann No.1 filter paper. Each treatment had three replicates. Thus, a total of 54 Petri dishes were used for the first series of experiments, and the experiment repeated once. The Petri dishes were covered with the corresponding lids and placed over benches of the Plant Tissue Culture Laboratory maintained at a temperature of 26.25 ± 2.95 ^{o}C and relative humidity of 43.95 ± 6.15 %. After the start of the experiment, just enough double distilled water was added twice a day (i.e. in the mornings and evenings) depending on the moisture levels of tiny seeds as judged usually; and this was continued up to the end of the experiment.

Seed germination counts were made every two days after the start of seed germination. To facilitate counting, germinated seeds were separated from the non-germinated after recording. The experiments were sustained until at least 80% of the replication from each treatment showed no new germination for two successive counts.

A seed was considered germinated at the emergence of the radicle. Germination responses were expressed in terms of mean percentage germination, mean germination time, mean germination rate, and mean germination vigor.

4.3 Pot experiments

Pot experiments were conducted within the glasshouse of "Rapid Propagation of Indigenous Trees Project" (College of Natural Sciences, Addis Ababa University). Seeds were grown in 15 conical pots (mouth diameter 14 cm, depth 5 cm) filled with a mixture of red soil, compost and sand in equal proportions (Figure 4). In each pot, 50 seeds were sown and were covered by a thin layer (0.1 to 0.2 cm depth) of the same soil mixture. The pots were placed in the glasshouse and watered once a day.

Figure 4. Pot experments in glasshouse germinated *F. sycomorus* seeds.

A single layer of thin polyethylene plastic sheet was used to cover the pots for conserving moisture. The polyethylene plastic sheets were removed when the seeds germinated and cotyledons emerged to the soil mixtures. But watering of the pots continued until the end of the experiment.

Data on germination responses were collected every two days after the first day of seed germination. To facilitate further counts, germinants were placed on one side of the pot after recording. Counting of germinants was extended until at least 80% of the pots showed no new germination for at least two consecutive counts. The final germination responses of seeds in glasshouse pot experiments were expressed in terms of mean percentage germination.

4.4 Seedling establishment and growth performance studies on germinants of *F. sycomorus*

For growth performance studies on germinants of *F. sycomorus,* six different soil mixtures were prepared in a ratio of 4:3:2, 4:3:1, 4:1:3, 2:1:1, 1:1:1, and 1:1:0 of red soil, compost and sand, respectively. From these soil mixtures, five of them were used as treatments and 1:1:0 was used as a control. In this experiment, seeds were soaked in double distilled water in a 250 ml beaker for 6 hours. A total of 1000 seeds which sank to the bottom of the beaker were removed and sown in 5 pots (diameter, 16 cm depth, 16 cm) filled with sand (Figure 5). Germinants were then transplanted to 100 polyethylene plastic sleeves of diameter 5 cm and length 10 cm for each soil mixture. Thus, a total of 600 polyethylene plastic sleeves were prepared, in which 30 randomly selected seedlings were planted in their respective soil mixtures for the study of growth performances.

Figure 5. Germination response of *F. sycomorus* seeds in clean river sand.

The five treatments and the control were labeled and arranged in a glasshouse at random and were watered daily with tap water. Seedling transfer and subsequent establishment were performed following the procedures by Legesse Negash (1995; 2010). Transplantation of the small seedlings was performed after they produced four leaves. The small seedlings were separated from the soil and were kept in a 500 ml beaker containing tap water until transplantation was done.

To facilitate transplantation, a hole was made in the middle of the soil of each plastic sleeves. For all treatments, whole root system of the small seedlings was inserted into the prepared hole, leaving the shoot part above the surface of the potted soil mixtures. The remaining space of the hole was filled with the same mixture of the soil that was used for potting.

The transplanted seedlings were maintained in the glasshouse and covered with thin plastic sheet lifted up by using wooden frames of each 30 cm long. Between 4 and 5 weeks after transplanting, the thin plastic sheet was removed, and the seedlings were watered using sprinkling irrigation once a day.

To compare growth responses of the seedlings under glasshouse conditions, height increment and leaf number of each seedling were measured by using a ruler (mm) at two weeks interval on 30 sampled seedlings. Sample seedlings were transferred into polyethylene bags of diameter 20 cm and length of 30 cm at week eight and the height increment and leaf number were measured every two weeks.

The width (W) and length (L) of the lamina from the top, middle and bottom parts of the plant were measured with a simple millimeter ruler. Length of the lamina was measured from lamina tip to the point of connection of the lamina and petiole, and width was measured across the widest parts of the lamina lobes from each sample seedlings to calculate the leaf area. The map of lamina from the sample seedlings was taken on graph paper to calculate the actual leaf area. Seedlings were watered once a day by sprinkling irrigation.

4.5 Germination parameters and statistical analyses

Germination response of *F. sycomorus* was computed using the formula:

$$\text{Percentage germination} = (n/N) \times 100 \quad \text{---------- (1)}$$

Where, n=total number of germinated seeds; N=total number of seeds in the sample.

The mean germination time (MGT), mean germination rate (MGR), and germination vigor were determined according to Labouriau and Agudo (1987) as follow:

$$MGT = \Sigma(ni \times ti)/ n \quad \text{---------- (2)}$$

Where, ni= percentage of seeds germinated between two consecutive counts; ti= time taken since germination experiment started; n= total percentage of seeds germinated.

$$MGR = (1/MGT) \quad \text{---------- (3)}$$

Where, MGT= mean germination time, which was calculated according to the equation provided in (2).

$$\text{Germination vigor (\%)} = \Sigma \frac{(Gi \times ti)}{N} \times 100 \quad \text{---------- (4)}$$

Where, Gi= number of seeds germinated up to the day under consideration; ti= time taken since the first day of incubation; N= total number of seeds.

Leaf area was calculated according to Montagomery (1911 *cited* in Bhatt and Chanda, 2003; Mokhtarpour *et al.,* 2010) by the formula as follows:

$$\text{Leaf area} = L \times W \times A \quad \text{---------- (5)}$$

$$A = \text{Actual leaf area}/ L \times W \quad \text{---------- (6)}$$

Where, L= length of the lamina, W= width of the lamina, A= constant

Statistical analyses were performed according to the following procedures. The effects of GA_3, KNO_3, plant-derived aqueous smoke extracts and distilled water (control), germinant establishment, and growth performance of seedlings were analyzed by a one way ANOVA using SPSS for windows version 17.0 with treatments as factors. Duncan‟s Multiple Range Test was used for the determination of significant differences among mean values of treatments. The same test was employed for the determination of significant differences between mean values studies conducted in the glasshouse. Graphs and correlation of leaf area with length and width parameters were generated using sigma plot 10.0 (Systat Software, Inc.). Statistically significant differences among treatments were determined at a 5% significance level.

5. RESULTS

5.1 Number and status of *F. sycomorus* seeds

It was found that the total number of seeds per fig of *F. sycomorus* ranged from a minimum of 168 in the smallest fig to a maximum of 465 seeds in the largest fig. The average number of seeds for 125 figs was 301.76. But, more than half of the seeds were found damaged by the pollinator wasp species or other insects. Generally, the percentage of normal seeds was much lower (26.5%) than the damaged ones (73.5%). The individual seeds of *F. sycomorus* were found tiny and very light, with the weight of 1000 individual seeds being 0.2888 grams.

5.2. Petri dish experiments

Germination responses of *F. sycomorus* seeds to various concentrations of plant-derived aqueous smoke extracts, GA_3 and KNO_3 are provided in Figure 6A, B, and C, respectively. Germination started at day four and completed at day sixteen of the incubation period. In all treatments, rate of germination was fastest between days four and eight. Except for 10^{-3} M GA_3 treatment, all seeds germinated better when treated with various concentrations of plant-derived aqueous smoke extracts, GA_3, and KNO_3 compared to the control. Maximum percentage germination was attained within fourteen days after treatment of the seeds with the respective germination stimulator and was found to be 92, 83, and 88 percent for 100% plant-derived aqueous smoke extracts, GA_3 (10^{-6} M), and KNO_3 (10^{-3} M), respectively. From the treatments, plant-derived aqueous smoke extracts in all dilution levels were preferred and showed a significance difference ($p<0.05$) from the control.

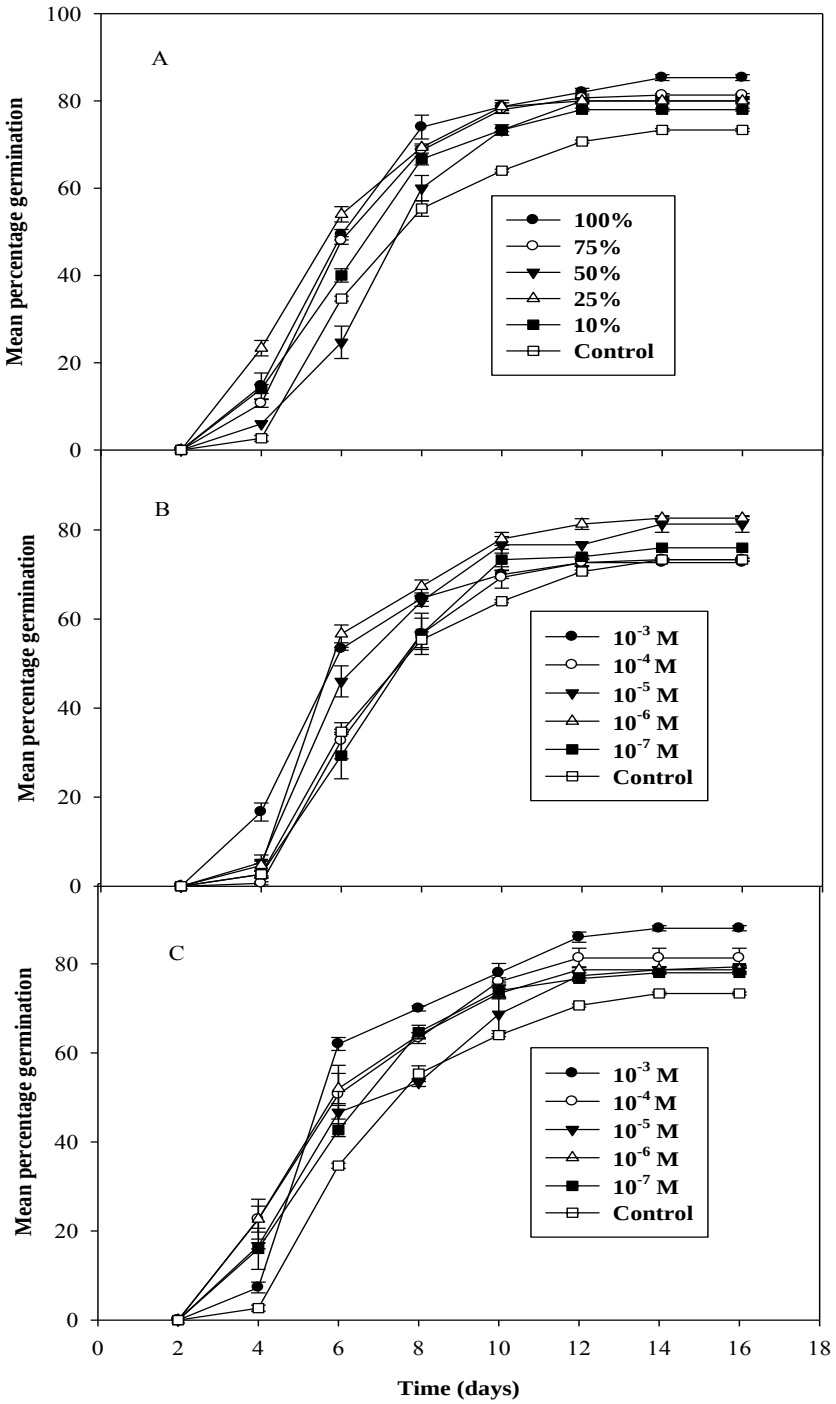

Figure 6. Effects of various concentrations of plant-derived aqueous smoke extracts (A), GA_3 (B), and KNO_3 (C) on mean percentage germination of *F. sycomorus* seeds. The Control was double distilled water. The data line represents mean germination percentage with respective concentrations ± SE. [n=3 randomly placed replicate Petri dishes each with 50 seeds per treatment].

In all treatments of plant-derived aqueous smoke extracts, GA_3, and KNO_3 mean germination time of *F. sycomorus* seeds was found between days six to eight (Figure 7). Except for a treatment of GA_3 at 10^{-6} M, other treatments did not reveal a significant difference at ($p<0.05$).

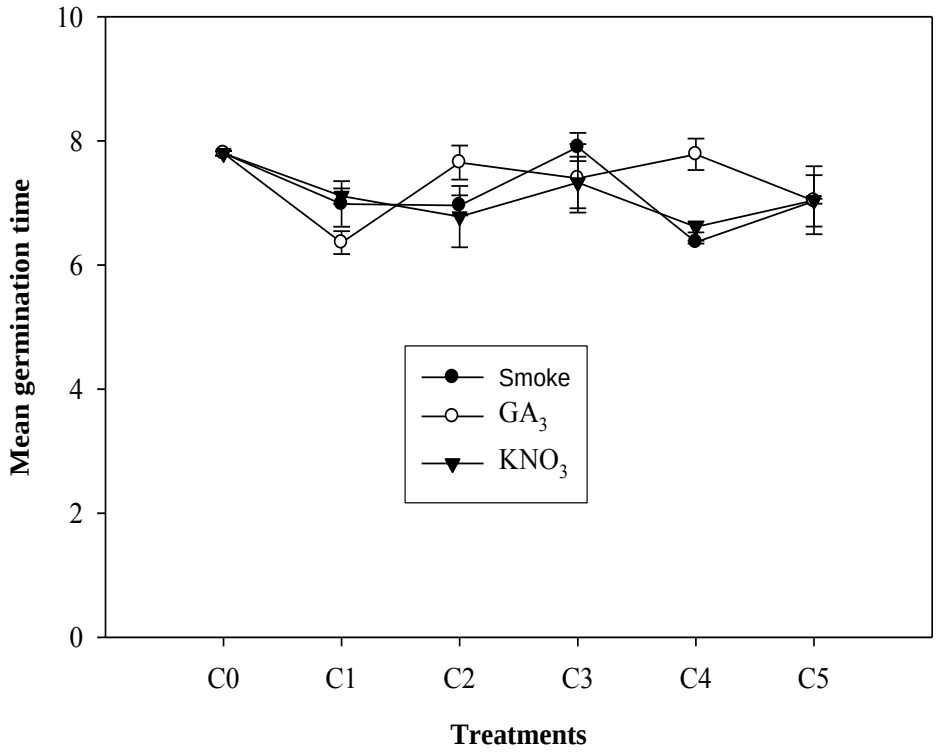

Figure 7. Effects of various concentrations of plant-derived aqueous smoke extracts (—●—), GA_3 (—○—), and KNO_3 (—▼—) on mean germination time of *F. sycomorus* seeds. C1= 100, C2= 75, C3= 50, C4= 25, C5= 10 % for plant-derived aqueous smoke extracts and 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} moles for GA_3 and KNO_3 treatments, respectively. The control (C0) was double distilled water. The data points represents mean germination time with respective concentrations ± SE. [n=3 randomly placed replicate Petri dishes each with 50 seeds per treatment].

In all treatment concentrations of plant-derived aqueous smoke extracts, GA_3 and KNO_3 the mean germination rate was found fluctuated. Generally, the mean germination rate was fast in all treatments. The peak germination rate (0.157±0.000) was found at 75% of plant-derived aqueous smoke extract and followed by (0.157± 0.004) in 10^{-3} M GA_3. Even though, all treatments did not revealed a significance difference (Figure 8).

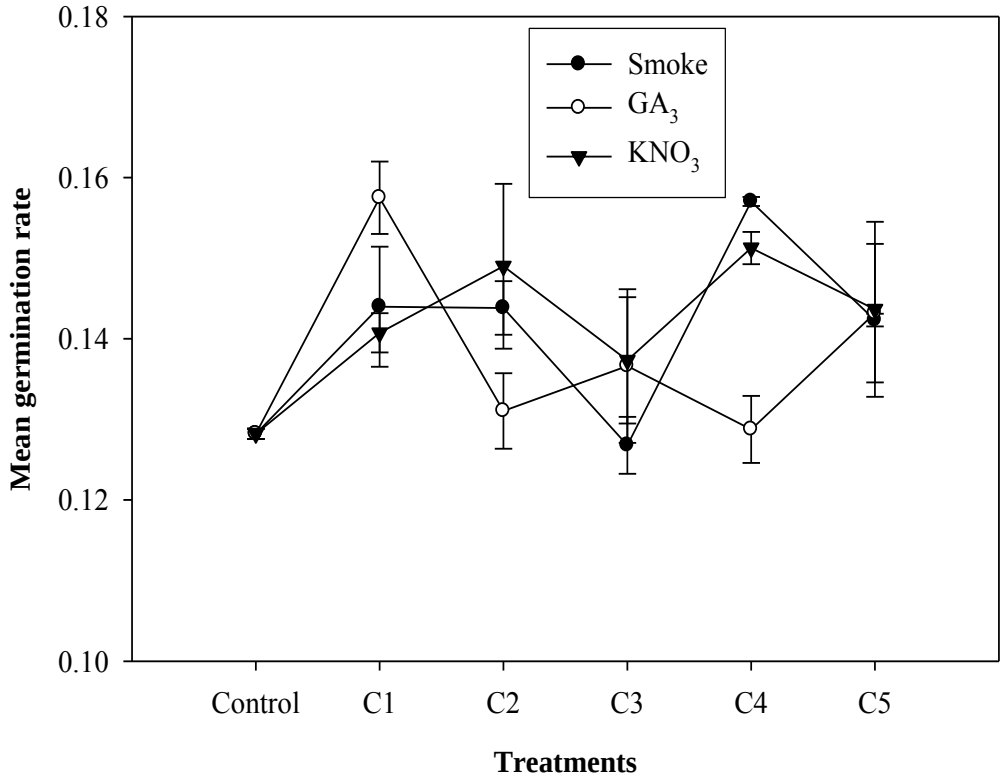

Figure 8. Effects of various concentration levels of plant-derived aqueous smoke extracts (—●—), GA_3 (—○—), and KNO_3 (—▼—) on mean germination rate of *F. sycomorus* seeds. C1= 100, C2= 75, C3= 50, C4= 25, C5= 10% for plant-derived aqueous smoke extract treatments and 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} moles for GA_3 and KNO_3 treatments, respectively. The control (C0) was double distilled water. The data points represents mean germination rate with respective concentrations ± SE. [n=3 randomly placed replicate Petri dishes each with 50nseeds per treatment].

The mean germination vigor in all treatment solutions of plant-derived aqueous smoke extracts, GA_3, and KNO_3 are provided in (Figure 9). Compared to the control, all the treatment solutions respond good germination vigor. However, with in all concentrations of plant-derived aqueous smoke extracts and KNO_3 treatments the mean germination vigor was almost closer to each other. In general, GA_3 treatments showed lower mean germination vigor than plant-derived aqueous smoke extracts and KNO_3. GA_3 treatments of 10^{-3} M and 10^{-5} M revealed significantly lower ($p<0.05$) than the rest concentrations of GA_3, plant-derived aqueous smoke extracts and KNO_3.

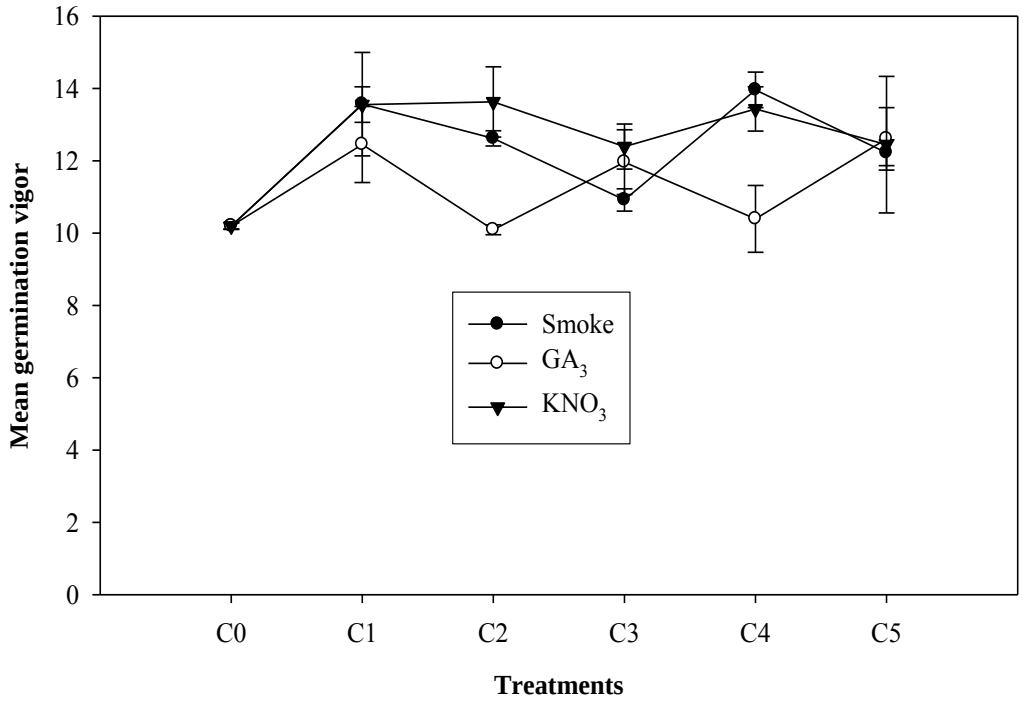

Figure 9. Effects of various concentration levels of plant-derived aqueous smoke extracts (—●—), GA_3 (—○—), and KNO_3 (—▼—) on mean germination vigor of *F. sycomorus* seeds. C1= 100, C2= 75, C3= 50, C4= 25, C5= 10% for plant-derived aqueous smoke treatments and 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} moles for GA_3 and KNO_3 treatments, respectively. The control (C0) was double distilled water. The data points represents mean germination vigour with respective concentrations ± SE. [n=3 randomly placed replicate Petri dishes each with 50 seeds per treatment].

5.3 Pot experiments

Germination responses of seeds of *F. sycomorus* treated with double distilled water is provided in (Figure 10), germination of seeds started on the eleventh day and completed on the twenty ninth day after sowing. Faster germination rate were observed between days nine to twenty three. Maximun germination percentage of seeds (57%) was attained within twenty nine days. On the over all germination process under glasshouse condition, four trends were observed: (a) the day for the starting of radicle emergence takes relatively longer time (b) the initial rate of increase was approximately constant (c) the final rate of decrease was again constant for the whole pots in the experment (d) the final date that germination of seeds observed was two fold longer than the laboratory germinated seeds.

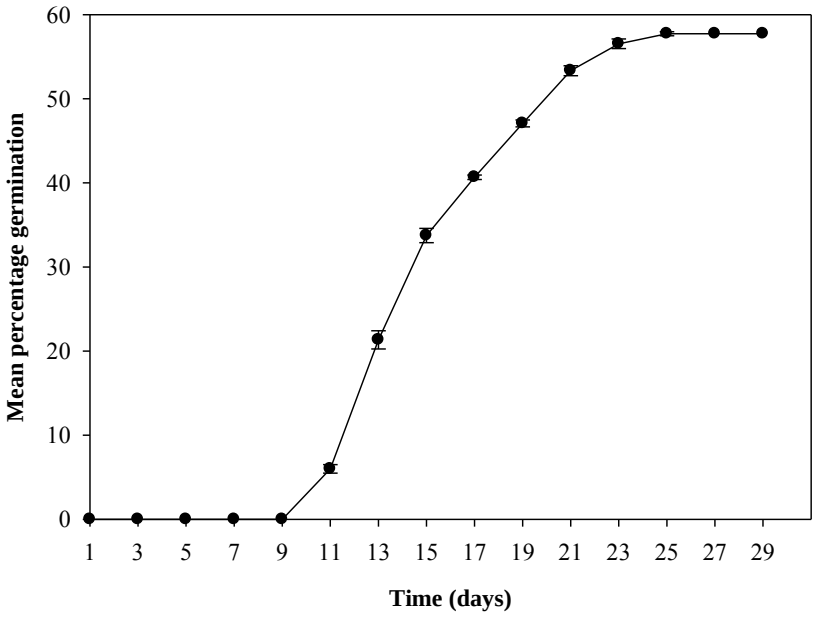

Figure 10. Germination pattern of *F. sycomorus* seeds in pots under glasshouse conditions. Data points represent the mean percentage germination on the respective days. Vertical bars indicate ± SE [n=15 randomly placed replicate pots each with 50 seeds].

5.4 Seedling transfer of *F. sycomorus*

Transfer of germinant to a smaller polyethylene plastic sleeves of diameter 5 cm and length 10 cm and seedlings from the smaller polyethylene plastic sleeves to the larger with diameter 20 cm and length of 30 cm containing their corresponding soil mixtures in *F. sycomorus* were successful at a survival rate of 100% (Figure 11).

Figure 11. *F. sycomorus* seedling growth in a glasshouse under various treatment soil mixtures of 4:3:1 (A), 4:3:2 (B), 2:1:1 (C), 4:1:3 (D), 1:1:1 (E) red soil, compost and sand, respectively. The control soil (F) was a mixture of red soil and compost at ratio of 1:1 at weeks 5, 8 and 11.

5.5 Effect of various soil mixtures for germinant establishment and growth performance of *F. sycomorus*

The growth pattern on seedlings of *F. sycomorus* varies depending on the type of the soil mixtures (Table 1). All soil mixtures were found better for height increment of *F. sycomorus* seedlings compared to the control in the first weeks of the experiment. From the tested soil mixtures for height increments of *F. sycomorus* seedlings, 4:3:2 was found to be the best soil mixture throughout the experiment except dominated by 2:1:1 soil mixture in the third week. Later, the soil mixture of 4:1:3 displayed

equivalent height with the control. At the end the soil mixture of 4:1:3 was dominated by all soil treatments including the control. All soil mixtures response to seedling growth pointed out a significant difference at ($p < 0.01$).

Table 1. Mean height (mm) increment of glasshouse grown *F. sycomorus* seedlings. Seedlings were grown in polyethylene plastic sleeves in various soil mixtures of red soil, compost and sand. The control was a soil mixture of red soil and compost at 1:1 ratio. Within a column, mean followed by various letters have significant difference. Number in parenthesis are standard deviations (n=30 samples per treatment).

Treatments	**Time (Weeks)**						
	1	3	5	7	9	11	13
(Red soil: Compost: Sand) 4:3:2	10.25^{a} (0.43)	16.70^{b} (0.62)	28.40^{a} (1.37)	33.20^{a} (1.18)	38.13^{a} (1.45)	47.87^{a} (1.59)	63.23^{a} (1.93)
(Red soil: Compost: Sand) 2:1:1	9.35^{ab} (0.29)	18.45^{a} (0.64)	27.25^{ab} (1.14)	32.10^{ab} (1.13)	35.50^{ab} (0.90)	45.37^{ab} (1.44)	61.57^{ab} (2.02)
(Red soil: Compost: Sand) 4:1:3	9.20^{ab} (0.25)	12.70^{c} (0.47)	19.35^{d} (0.86)	23.05^{d} (0.97)	24.63^{d} (0.90)	30.70^{d} (1.10)	42.43^{d} (1.78)
(Red soil: Compost: Sand) 4:3:1	9.65^{ab} (0.38)	13.60^{c} (0.60)	24.30^{bc} (1.11)	28.35^{c} (1.19)	33.20^{b} (1.19)	42.03^{b} (1.22)	56.67^{b} (1.99)
(Red soil: Compost: Sand) 1:1:1	9.00^{ab} (0.40)	13.75^{c} (0.63)	23.75^{c} (1.29)	29.00^{bc} (1.36)	34.97^{ab} (1.13)	42.37^{b} (1.59)	57.60^{ab} (2.26)
(Red soil: Compost) 1:1	8.90^{b} (0.57)	10.55^{d} (0.43)	15.60^{e} (0.99)	19.75^{d} (1.32)	28.33^{c} (1.21)	36.00^{c} (1.73)	48.83^{c} (2.76)

The leaf number in seedlings of *F. sycomorus* under various soil mixtures showed a visible difference (Table 2). The leaf number was found better in soil mixtures of 2:1:1 followed by 4:3:2 ratios of red soil, compost and sand. Between the seventh to ninth weeks the seedlings growth was found faster. The greater range of mean leaf number was found between eleventh to thirteenth weeks in all treatments and the control. After the eleventh week, the mean number of leaves in the control soil mixture (1:1) attained rapid increment than 4:1:3 and 1:1:1 ratios of treatment soil mixture. At the end of thirteenth week, the soil mixture at a ratio of 2:1:1 responded significant difference ($p < 0.01$) in leaf number compared to the rest of treatments and the control. The soil mixture at ratio of 4:1:3 revealed relatively low increment in leaf numbers.

Table 2. Mean leaf number of glasshouse grown *F. sycomorus* seedlings. Seedlings were grown in polyethylene plastic sleeves in various soil mixture ratios of red soil, compost and sand. The control was a soil mixture of red soil and compost at 1:1 ratio. Within a column, means followed by various letters have significant difference. Numbers in parenthesis are standard deviations (n=30 samples per treatment).

Treatments	**Time (Weeks)**						
	1	3	5	7	9	11	13
(Red soil: Compost: Sand) 4:3:2	4.00^{a} (0.00)	7.90^{bc} (0.34)	12.95^{ab} (0.61)	16.60^{a} (0.69)	20.27^{ab} (0.70)	23.00^{a} (0.85)	28.37^{ab} (0.97)
(Red soil: Compost: Sand) 2:1:1	4.00^{a} (0.00)	8.25^{a} (0.46)	13.25^{a} (0.81)	17.75^{a} (0.85)	21.40^{a} (0.66)	23.60^{a} (0.75)	30.37^{a} (0.82)
(Red soil: Compost: Sand) 4:1:3	4.00^{a} (0.00)	6.45^{bc} (0.29)	10.90^{b} (0.72)	13.30^{b} (0.71)	15.77^{c} (0.72)	18.83^{b} (0.78)	24.77^{cd} (0.96)
(Red soil: Compost: Sand) 4:3:1	4.00^{a} (0.00)	6.95^{abc} (0.39)	11.90^{ab} (0.69)	15.70^{a} (0.84)	19.33^{ab} (0.85)	22.53^{a} (0.82)	27.40^{abc} (1.06)
(Red soil: Compost: Sand) 1:1:1	4.00^{a} (0.00)	7.25^{abc} (0.35)	12.55^{ab} (0.65)	16.10^{a} (0.52)	18.60^{b} (0.78)	19.73^{b} (0.77)	26.70^{bc} (1.16)
(Red soil: Compost) 1:1	4.00^{a} (0.00)	5.90^{c} (0.35)	8.50^{c} (0.69)	12.30^{b} (0.83)	15.97^{c} (0.84)	19.00^{b} (0.88)	22.70^{d} (1.26)

In leaf area studies of *F. sycomorus,* the administered soil mixtures attained three different categories (Figure 12). The soil mixtures 2:1:1 and 4:3:2 attained leaf area of 3,518.4 ± 240.59, 3,483 ± 229.59 mm^2, respectively. The second categories of soil mixtures at ratio of 1:1:1 and 1:1 revealed 2,803.6 ± 163.98, 2,713.8 ± 121.75 mm^2, of leaf area. The third categories of soil mixtures 4:3:1 and 4:1:3 attained 2,364.3 ± 104.98, 2,186 ± 169.47 mm^2 of leaf area, respectively. From the tested soil mixtures 2:1:1 and 4:3:2 ratios produced better leaf area with visible ranges of differences compared to the rest of soil mixtures and the control. Even though, the soil mixture of 2:1:1 was the best of all the soil mixtures in leaf area of *F. sycomorus* seedlings until thirteenth week, the three groups of soil mixtures showed a significance difference in mean leaf area at ($p<0.01$).

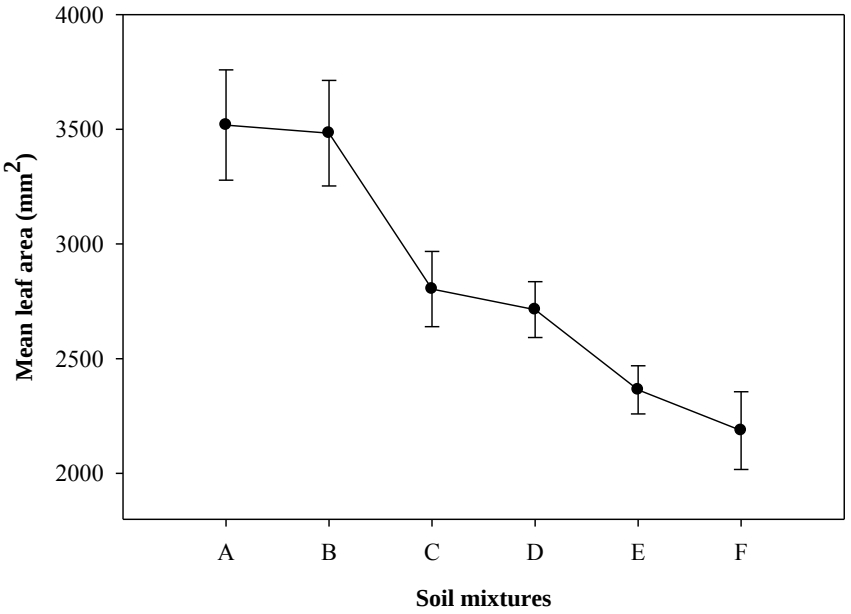

Figure 12. Effects of various soil mixtures on leaf area of *F. sycomorus* seedlings. A= 2:1:1, B= 4:3:2, C= 1:1:1, D= 1:1 (control), E= 4:3:1, F= 4:1:3 ratios of red soil, compost and sand respectively. Data line represents the mean leaf area of seedlings at respective soil mixtures. Vertical bars indicate standard error. [n=30, randomly taken sample seedlings per treatment].

The leaf area showed positive correlation with the square of leaf lamina length, square of leaf width, product of length and width, the sum of length and width (Figure 13). The highest correlation was found in the higher value of coefficient of determination, that was in parameter of the product of length and width (L*W). The soil mixtures of 2:1:1, 4:3:2, 1:1:1, 1:1:0, 4:3:1 and 4:1:3 attained R^2 of 0.99, 0.98, 0.92, 0.99, 0.98 and 0.99, respectively. All the soil mixtures displayed a significance difference ($p<0.0001$).

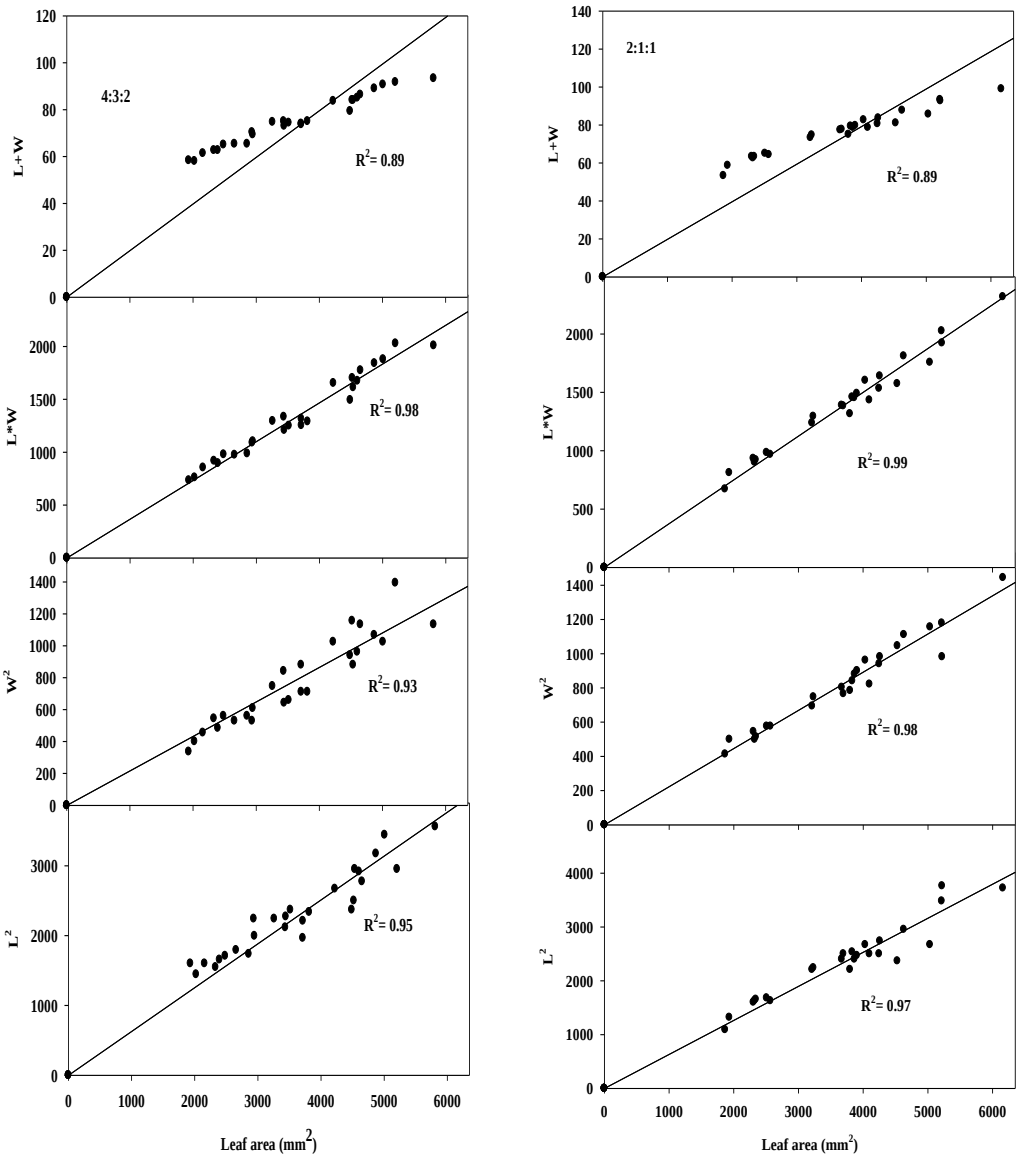

Figure 13. Correlation of leaf area (LA) with parameters of leaf length (L) and width (W) at 4:3:2, 2:1:1, 4:1:3, 4:3:1, 1:1:1 and 1:1:0 of soil mixes. (n=30 replicate seedlings per treatment, R^2=Coefficient of determination).

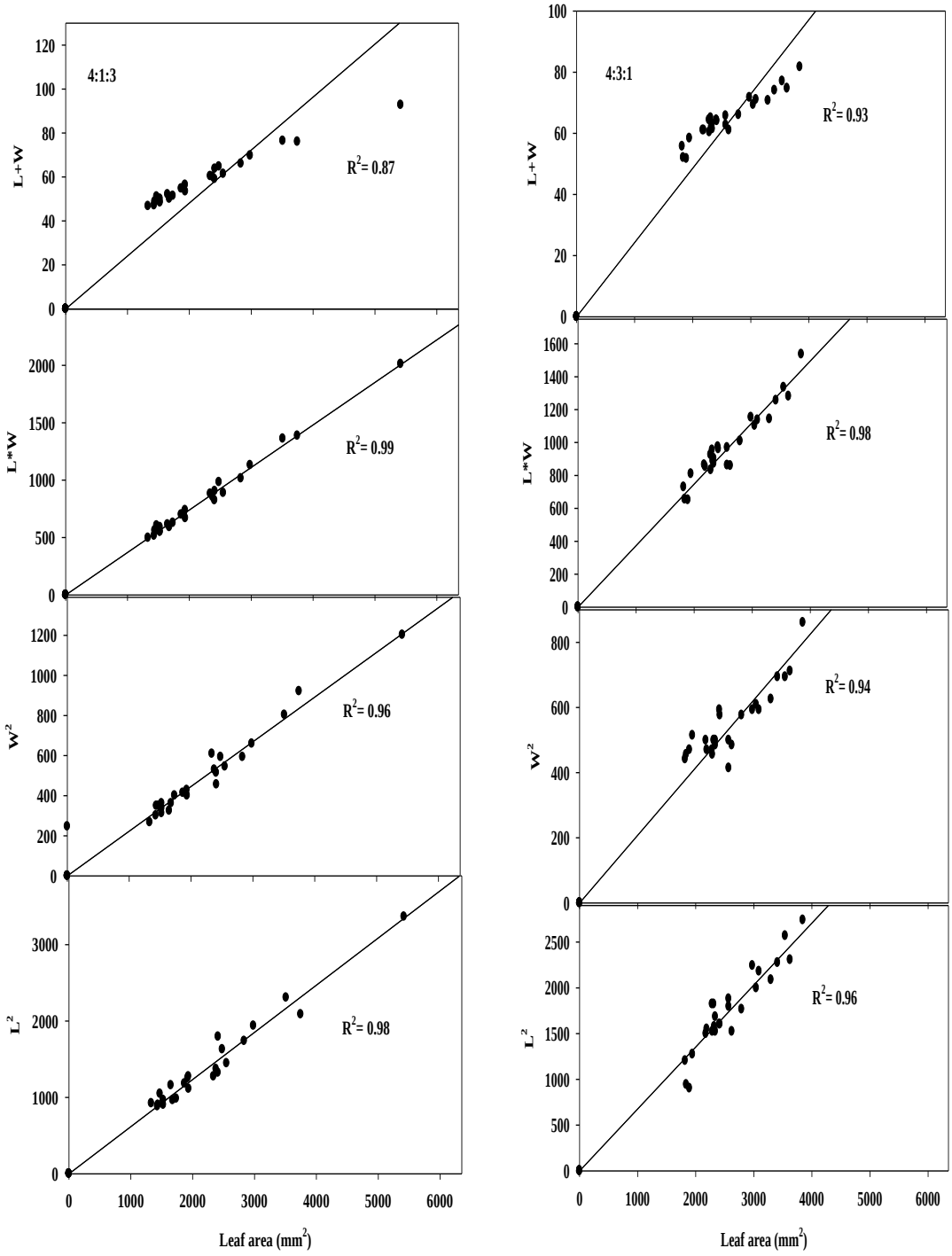

Figure 13 continued.

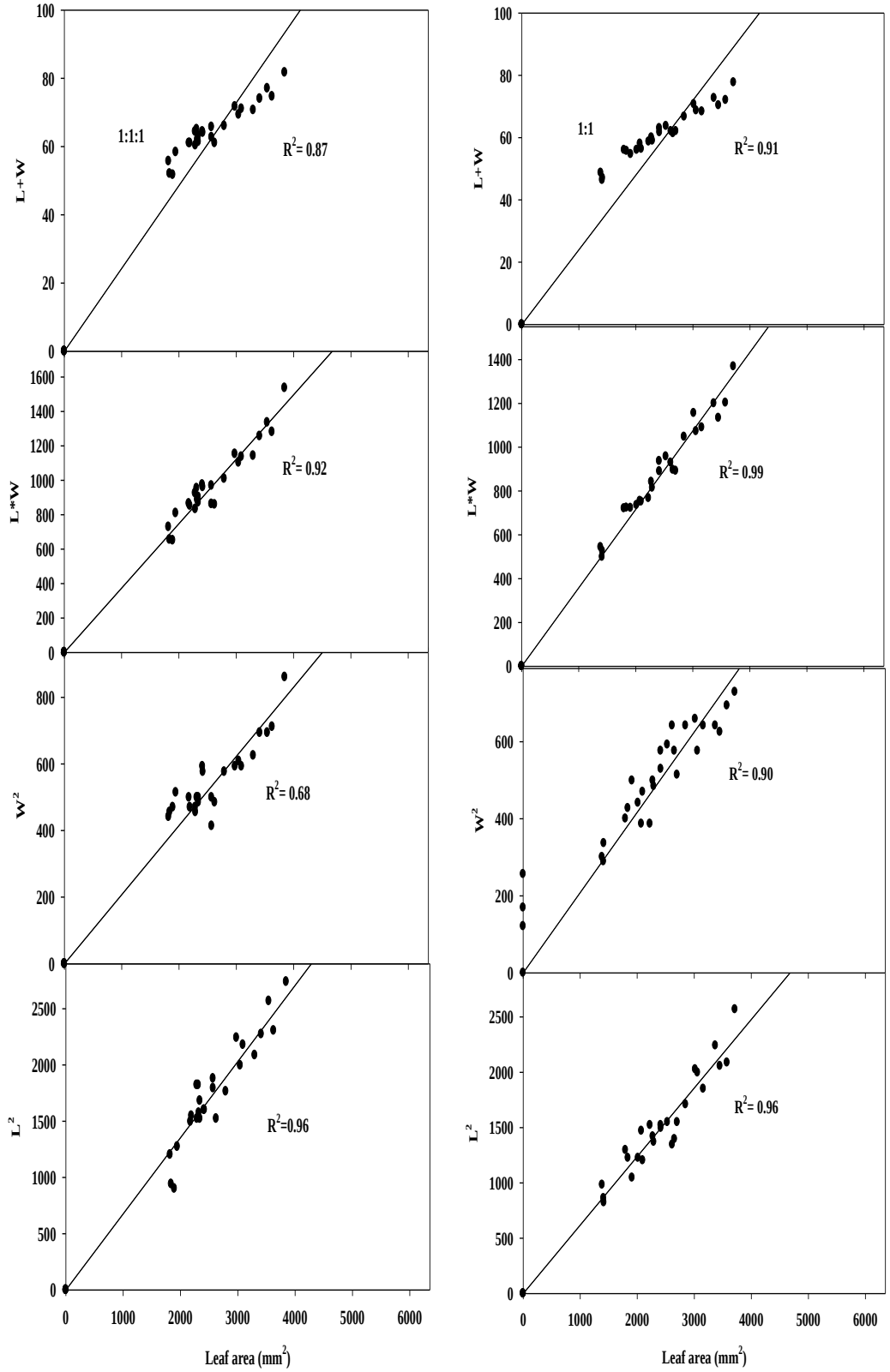

Figure 13 continued.

6. DISCUSSION

6.1 Status of seeds in figs of *F. sycomorus*

Microscopic examination of *F. sycomorus* seeds in the laboratory revealed that about 73.54% of the seeds were empty. This was due to the tiny wasp species inside the individual fig eating much of the embryos and the corresponding food reserve of the seeds. This observation is supported by the study of seed production in *F. vasta* (Legesse Negash, 2010). In addition, Da Rong *et al.* (2002) reported that when one pollinator wasp enters one female syconium, the number of seeds to total female florates was found to be 51.3%. When 2 or 3 wasps enter one female fig, the percent might be up to 86.5%. However, when the number of the fig wasps entering the syconium was up to 4 or more, the amount of seeds developed would decrease, with the percentage of 40.2% to 63.8%. In our study, the average number of normal seeds in the sample figs was much lower (26.5%) than the damaged seeds (73.5%) which may be associated with the presence of various wasp species in the syconium of each fig feeding on the latter.

The diameter of the fig also has contribution on the number of seeds. Seed number increases when the diameter becomes larger. The diameters of the figs in *F. sycomorus* ranged from 1.5 to 2.4 cm in the sample figs studied (Appendix 1). Kerdehue and Rasplus (1996) reported that, as the diameter of the figs increases the number of seeds and insects which enter the fig also increases in *Ficus sur* and *Ficus vallis-choudae*.

In some of the figs studied, from 8-14 gall flowers were found and all of them were found without seeds. Thus, presence of many gall flowers has contributed to the reduction of the total number of seeds in each sample fig.

The other reason that might contribute to the reduced number of seeds in the figs was the success of pollination. Successful pollination occurs when specific fig wasps enter figs of specific fig tree species (Janzen, 1979; Compton *et al.,* 1991; Joussulin *et al.,* 2001; Weiblen, 2001; Molbo *et al.,* 2003; Starr *et al.,* 2003; Machada *et al.,* 2010). *F. sycomorus* has specific mutualistic wasp species and the common ones are *Ceratosolen arabicus* and *C. galilii* (Wiebes, 1964; Berg and Wiebes, 1992; Weiblen, 2001; Orwa *et al.,* 2009). However, many wasp species and other insects were found

in the syconium, which probably act as gallers. In our study, two species of wasps were found in the sample figs that need later identification.

6.2 Effects of plant-derived aqueous smoke extracts, GA_3 and KNO_3 treatments on germination responses of *F. sycomorus* seeds

Treatments with plant-derived aqueous smoke extracts, GA_3, and KNO_3 have potential to enhance seed germination in *F. sycomorus,* compared to the control (Figure 6A, B, and C).

According to Roche *et al.* (1997), aqueous smoke extracts obtained from the combustion of plant materials have positive effects on germination of plant seeds. Similarly, Keeley and Fotheringham (1997) have also reported plant-derived aqueous smoke extracts have positive effect on 170 different native plant species. Keeley and Bond (1997) also reported that of the 57 species of South African native plant species from fire prone areas, 44% showed increased germination in response to being treated with smoke.

The present study showed that plant-derived aqueous smoke extracts at a relative concentration of 10% resulted in relatively lower percentage germination (78%), compared to a relative concentration of 100% which yielded 92% of germination. The result indicated that plant-derived aqueous smoke extracts stimulated germination of seeds of *F. sycomorus* (Figure 6A). All of the smoke treatments showed significance differences ($p<0.05$) from the control. Even though, a relative concentration of 100% plant derived aqueous smoke extract was the best solution to enhance germination of *F. sycomorus* seeds.

Blank and Young (1998) reported that grass seeds which were treated with smoke extracts grew better than the control and produced significantly greater biomass. Also, a commercial liquid smoke was found to stimulate germination in *Oryza sativa* (Dohery and Cohn, 2000).

Brown and Van Staden (1998) found out that plant-derived aqueous smoke extracts improved seed germination in lattice and celery. However, the strength of the response varies depending on the species, the variable chemical composition of wild fire which may produce carbon mono-oxide, nitrate, nitrogen dioxide, and various

acids (Black and Young, 1998). Based on the chemical composition of the fire, the effects of smoke are highly variable and affect species and ecotypes differently (Dixon and Roche, 1995). Also, highly concentrated smoke water solutions may inhibit germination of species like *Syncarpha xestita* (Brown and Van Staden, 1997).

At concentration of 10^{-3} M GA_3 has reduced seed germination of *F. sycomorus* (72.6%), compared to other concentrations (i.e. 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} M) and the control (Figure 6B). When diluted to 10^{-6} M, it was found that germination improved to 83%. Induction of seed germination through GA_3 is due to the effect of gibberellins in promoting plasticity of the cell wall. The process is followed by the hydrolysis of starch to sugar which reduces water potential in the cell, hence resulting in the entrance of water into the cell and causing elongation (Arteca, 1996).

Similarly, a significant improvement in germination of GA_3 treated seeds of *Plantago lanceolata* from the untreated seeds was observed with a range of 86.3 to 94.8 % at 100 ppm, 87.5 to 93.3% at 200 ppm and 89.8 to 94.0% at 400 ppm treatments (Sarihan *et al.,* 2005). Similar effects were also reported for *Morus nigra (*Koyuncu, 2005); *Lycopersicum esculentum* (Bakrim *et al.,* 2007), *Prunus avium* (Cetinbas and Koyuncu, 2006) seeds.

On the other hand, germination test on *F. sycomorus* seeds using various concentrations of KNO_3 were found best (88%) at higher concentration (10^{-3} M) and decreased when the dilution level increased (Figure 6C). Similar results were obtained by other studies and on diverse plant species, including *Salvia cyanescens* (Yucel and Yilmaz, 2009); *Cucumis sativus* (Ghassemi-golezani and Esmaeilpour, 2008); *Ferula gumossa* and *Teucrium polium* (Parez-Fernandez *et al.,* 2006); *Avena fatua* (Nadjafi, *et al.,* 2006); *Cuscuta epithymum* and *Foeniculum vulgare* (Ali *et al.,* 2010). According to Basra (1994), KNO_3 has a positive effect to improve germination percentage and germination rate between concentration levels of 1 to 2% and even less, this was also supported by AOSN and ISTA. Again (Sarihan *et al.,* 2005) reported that, KNO_3 treatments fluctuates seed germination. In general, KNO_3 improved seed germination as compared to the control.

6.3 Pot experiment for germination studies of *F. sycomorus* under glasshouse conditions

The results in (Figure 10) indicated that, the percentage seed germination in glasshouse was 57%. The use of glasshouse was to maintain a less variable day and night temperatures which speed up seed germination of various indigenous trees of Ethiopia (Legesse Negash, 2010).

The first radicle emergence observed in the glasshouse was at the eleventh day but in the laboratory experiments was at the fourth day. The last radicle emerged on the twenty ninth day at the glasshouse but on fourteenth day in the laboratory after seeds were sown. The extended time observed was due to the thin layer of sand that may have reduced the temperature of the seed environment to some extent. The experiment was extended even after 45 days, and the remaining seeds did not germinate.

In this over all germination process three features were observed: (a) the initial rate of increased seed germination was approximately constant for all replicates under the glasshouse conditions (b) seeds attained the optimum point of germination period between the eleventh to fifteenth days after sowing (c) the final rate of seed germination decreased again at a constant manner for the whole replicate in pot experment.

6.4 Germinant establishment and seedling servival of *F. sycomorus*

Establishment of germinants were critically affected by the type of soil mixtures used as reported by Legesse Negash (1995; 2010). In the present study the establishment of *F. sycomorus* germinants on various soil mixtures were found in agreement with the previous report (Figure 11). The results of the study also revealed that seedling servival in all treatments and the control soil mixes were 100%. This was associated with the presence of compost in all treatments and control soil mixtures, that acts as a reservior for nitrogen, phosphorus, potassium and other organic matter. As a result, soil mixtures with sufficient nitrogen concentration tends to increase the allocation of carbon, that makes the species a better compititor for light (Gholami *et al.,* 2007). The existance of such nutrients affects the soil properties, survival of seedlings and growth in biomass.The same results were reported by Davis *et al.,* (2007) and Lopez *et al.,* (2010).

6.5 Growth performance studies of *F. sycomorus*

6.5.1 Height increment

The study showed that *F. sycomorus* seedlings attained maximum height in the soil mixture at ratio of 4:3:2 red soil, compost and sand, respectively. The seedlings of *F. sycomorus* that were grown in polyethylene plastic bags and after the seedlings were transferred to 20*30 cm polyethylene plastic pots, the height increment of the seedlings were found higher in the same soil mixtures as compared to the other treatments and the control (Table 1). Then followed by 2:1:1 soil mixture. This could be as a result of better composition of the compost, physical and chemical properties and ease of nutrient uptake by the seedlings through their roots. The reduction in height of seedlings in soil mixture of 4:1:3 was due to the higher proportion of sand soil, which increases the level of drainage and nutrient leaching, which could have led to low seedling growth and lower content of organic nutrients in the mixture. Contrary, in soil mixture of 4:3:1, relatively small proportion of sand were used that reduce aeration of the seedlings, which finally influence the growth of *F. sycomorus* seedlings.

The soil mixture of 1:1:1 have relatively low proportion of organic matter, and other nutrients that equivalent to the sand proportion reduce the growth of seedlings. Based on this fact, the control (1:1) ratio of red soil and compost respectively, revealed lower height increment due to low aeration of the roots of *F. sycomorus* seedlings.

According to Lopez *et al.* (2010), compost was the best reservoir for natural organic matter, nitrogen and phosphorus. In addition, red soil was a very important major component of the soil mixture in the germinant establishment of indigenous trees of Ethiopia (Legesse Negash, 1995, 2010). The two soil mixtures together were essential to hold moisture and reduce nutrient leaching.

Furthermore, the sand mixture of the soil used to provide good aeration for the roots of *F. sycomorus* seedlings. However, variation on the height increment of seedlings between treatments and the control was due to the composition of the soil, that have difference in the contents of organic nutrients, moisture, water holding capacity, and aeration of the root zone. However, all soil mixes used for the growth performance

studies, in terms of height, of *F. sycomorus* seedlings showed significant difference ($p<0.05$).

6.5.2 Leaf number

In the present study, in the data presented in table 2, leaf number was found higher in the soil mixture of 2:1:1 followed by 4:3:2, 1:1:1, 4:3:1 soil ratios. This was associated in response to the higher amount of compost from the mixture soils and the control. The soil mixture at ratio 4:1:3 of red soil, compost and sand, respectively exhibited the lowest number of leaves. This was associated to the presence of relatively high proportion of sand which influences the leaching of nutrients and lower composition of the compost. The results of 2:1:1, 4:3:2 and 4:3:1 soil mixtures attained better leaf number. However, the control soil mixture produced greater number of leaves than 1:1:1 and 4:1:3 of red soil, compost and sand, respectively. In our study, except the first week, leaf numbers of seedlings in all soil mixtures displayed a significant difference ($p<0.05$).

Seedlings grown in the soil mixture of 2:1:1 revealed better leaf number than other soil mixtures. These trends of increased number of leaves were due to increased application of compost. Hasanuzzaman *et al.* (2008) reported in *Aloe vera*, the application of organic matter increased the cell division and elongation without delaying the nutrient uptake process which provided better results due to better nutrition. The study was in agreement with Humphries (1966), leaf number highly influenced by the supply of assimilates from upper leaves and increased competition for available nutrients.

6.5.3 Leaf area

The present study confirmed that better leaf area (3,517± 240.59 mm^2) was found in the soil mixture of 2:1:1 which was followed by (3,483± 229.59 mm^2) in the soil mixture of 4:3:2 than the rest of the treatments and the control (Figure 12). The soil mixtures of 2:1:1 and 4:3:2 of red soil, compost and sand, respectively were used to increase assimilation of photosynthetic products slightly higher than other treatment soil mixtures for *F. sycomorus* seedlings. These also allow the measurement of leaf area on the same plant several times during the growing period. Thus, studies of leaf areas of *F. sycomorus* found a better growth measurement feature which indicates the

capacity of capturing light energy for the use of photosynthesis (Bhatt and Chanda, 2003). As a result, the presence of many carbohydrates in the plant seedlings may speed up the growth of the seedlings and the whole biomass. These results of the soil mixtures were followed by the 1:1:1, 1:1 (control), 4:3:1 and 4:1:3 of red soil compost and sand, respectively. Therefore, the two soil mixtures 2:1:1 and 4:3:2 revealed distinct growths in terms of leaf area as well as leaf number and plant height were considered as best soil mixes in the restoration and conservation activities on the species than the rest of treatments.

6.5.4 Correlation tests

Correlation coefficients under dependent variables of the squares of length, squares width, the product of length and width, the sum of length and width are found efficient methods to predict the leaf area of plants (Figure 13). The highest value of coefficient of determination (R^2) was the best parameter for prediction of leaf areas of plants. The study confirmed that L+W, W^2, L^2 of lamina in *F. sycmorus* showed lower coefficient of determination in all treatments. But, in all soil mixtures, the coefficients of determination were found best in the parameter of the product of length and width, which revealed highest positive correlation for the leaf area. Thus, the best correlation to predict leaf areas of *F. sycomorus* was found best with the product of length and width than other parameters. The result was found in agreement with Bange *et al.,* (2000), Bhatt and Chanda (2003), Blanco and Folegatti (2003), Pinto *et al.,* (2004), Ramesh, *et al,* (2007), Karimi *et al.,* (2009) and Mokhtarpour *et al.,* (2010).

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Figs of *F. sycomorus* produce numerous seeds, even though, the number of healthy and viable seeds was found very low (only 26.5%), compared to the damaged ones (73.5%).

Germination of *F. sycomorus* seeds improved after pretreatments with plant-derived aqueous smoke extracts, GA_3 and KNO_3 solutions. Except 10^{-3} M GA_3, other treatments improved germination of the seeds significantly better than the control. Seeds treated with a relative concentration of 100% plant-derived aqueous smoke extracts, 10^{-6} M GA_3 and 10^{-3} M KNO_3 attained the maximum percentage germination, which were 92, 83 and 88%, respectively.

Ficus sycomorus has excellent growth performance and seedling survival rate under a wide range of soil mixtures. The species showed better growth in terms of height in the soil mixture of 4:3:2 and in terms of leaf number and leaf area in the soil mixture of 2:1:1 red soil, compost and sand, respectively.

For the non-destructive method of leaf area measurement in *F. sycomorus* seedlings, the highest positive correlation was obtained in the parameters of the product of leaf length and width under all soil mixture conditions.

Planting of *F. sycomorus* provides guarantee for the sustainability of ground water, ecological services, fodder, as well as medicinal and litter production. It is also effective in restoring biodiversity and fertility of soils.

7.2 Recommendations

Similar to other indigenous trees of Ethiopia, *F. sycomorus* is an important tree which conserves water, has ecological, medicinal, and fodder values. It is a fast growing tree with a potential to convert solar radiation in to economically and environmentally useful biomass. The species is effective in CO_2 sequestration, hence protecting the environment from the current problem of global warming. However, the serious depletion of many indigenous trees including *F. sycomorus* in many landscapes of the country becomes dangerous due to various reasons. As a result, planting of the tree seedlings in many areas required to restore the degraded forest environment.

Regarding to this, conservation of the remaining trees of the species and restoring the deforested areas through mass propagation would be an essential procedure. As a result, the following recommendations are forwarded:

- Based on the present study, local farmers, forestry research centers, and other responsible bodies interested in propagating *F. sycomorus* are encouraged to use plant-derived aqueous smoke extracts, KNO_3 and GA_3 of appropriate concentrations for enhanced germination and subsequent growth of seedlings.
- The soil mixtures at 2:1:1 and 4:3:2 ratios of red soil, compost and sand, respectively are highly recommended for mass seedlings production in the nursery.
- Further studies are recommended for the identification of specific pollinator wasp species. Development of vegetative propagation techniques for *F. sycomorus* is highly recommended.
- Responsible authorities should give attention and priority for indigenous trees research and development.

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APPENDICES

Fig code	Diameter	Total number of seeds	Damaged seeds		Normal seeds		Remark
			Number	Percent	Number	Percent	
Sf1	2.1	296	252	85.14	44	14.86	
Sf2	2.2	304	256	84.21	48	15.79	
Sf3	1.7	247	197	79.76	50	20.24	
Sf4	1.8	279	232	83.15	47	16.85	
Sf5	2.4	348	296	85.06	52	14.94	
Sf6	2	310	253	81.61	57	18.39	
Sf7	2.4	369	318	86.18	51	13.82	
Sf8	2.1	323	277	85.76	54	16.72	
Sf9	1.8	201	113	56.22	88	43.78	
Sf10	1.8	243	112	46.09	131	53.91	8 gall flowers
Sf11	2.4	344	152	44.19	192	55.81	
Sf12	1.6	179	113	63.13	66	36.87	
Sf13	1.6	218	192	88.07	26	11.93	
Sf14	1.9	302	255	84.44	46	15.23	
Sf15	1.9	258	176	68.22	82	31.78	9 gall flowers
Sf16	2.3	322	166	51.55	156	48.45	
Sf17	2	320	242	75.63	78	24.38	
Sf18	2.3	348	296	85.06	52	14.94	
Sf19	2.3	345	204	59.13	141	40.87	
Sf20	2.2	310	101	32.58	209	67.42	
Sf21	1.5	213	155	72.77	58	27.23	
Sf22	2.4	458	374	81.66	84	18.34	
Sf23	1.9	322	278	86.34	44	13.66	
Sf24	1.9	324	243	75.00	81	25.00	
Sf25	2.4	405	238	58.77	167	41.23	8 gall flowers
Sf26	2.4	406	312	76.85	84	20.69	
Sf27	1.7	277	197	71.12	80	28.88	
Sf28	2.4	336	315	93.75	21	6.25	14 gall flowers
Sf29	2.4	349	316	90.54	33	9.46	
Sf30	2.3	458	343	74.89	115	25.11	
Sf31	2.3	391	72	18.41	319	81.59	
Sf32	2	311	211	67.85	100	32.15	
Sf33	2.3	419	270	64.44	149	35.56	
Sf34	2.4	424	405	95.52	19	4.48	10 gall flowers
Sf35	2	291	243	83.51	48	16.49	
Sf36	2.1	356	340	95.51	16	4.49	
Sf37	2.1	366	355	96.99	11	3.01	
Sf38	1.6	209	31	14.83	178	85.17	
Sf39	1.9	301	267	88.70	34	11.30	
Sf40	2.3	332	211	63.55	121	36.45	
Sf41	2.1	290	283	97.59	7	2.41	
Sf42	1.9	283	253	89.40	30	10.60	
Sf43	1.8	309	292	94.50	17	5.50	

Appendix 1. Status of *F. sycomorus* seeds from each sample figs (where **Sf** = Seeds from respective fig).

Fig code	Diameter	Total number of seeds	Damaged seeds		Normal seeds		Remark
			Number	Percent	Number	Percent	
Sf44	1.9	342	286	83.63	56	16.37	
Sf45	1.7	356	257	72.19	99	27.81	
Sf46	1.6	362	155	42.82	207	57.18	
Sf47	1.7	369	302	81.84	67	18.16	8 gall flowers
Sf48	1.9	326	216	66.26	108	33.13	
Sf49	2.4	465	320	68.82	145	31.18	
Sf50	1.5	205	128	62.44	77	37.56	
Sf51	1.5	230	140	60.87	90	39.13	9 gall flowers
Sf52	1.5	232	179	77.16	53	22.84	
Sf53	1.6	215	162	75.35	53	24.65	
Sf54	1.6	231	124	53.68	107	46.32	
Sf55	1.7	288	244	84.72	44	15.28	
Sf56	2.1	341	241	70.67	101	29.62	
Sf57	2.1	293	194	66.21	99	33.79	
Sf58	2.3	354	342	96.61	12	3.39	
Sf59	2.1	305	147	48.20	158	51.80	
Sf60	2	257	240	93.39	17	6.61	
Sf61	2.2	347	198	57.06	149	42.94	
Sf62	2.2	279	198	70.97	81	29.03	
Sf63	2.3	339	330	97.35	9	2.65	
Sf64	2	250	151	60.40	99	39.60	
Sf65	2	230	107	46.52	123	53.48	
Sf66	2.1	384	312	81.25	72	18.75	9 gall flowers
Sf67	2.2	352	324	92.05	28	7.95	
Sf68	1.7	224	76	33.93	138	61.61	
Sf69	1.7	215	199	92.56	16	7.44	
Sf70	1.9	298	265	88.93	33	11.07	
Sf71	2.2	363	280	77.13	83	22.87	
Sf72	1.6	232	213	91.81	19	8.19	
Sf73	1.9	296	252	85.14	44	14.86	
Sf74	1.8	275	254	92.36	21	7.64	
Sf75	2	284	120	42.25	155	54.58	
Sf76	2.1	231	149	64.50	82	35.50	
Sf77	2.1	278	203	73.02	75	26.98	
Sf78	1.5	168	155	92.26	13	7.74	8 gall flowers
Sf79	1.8	235	116	49.36	119	50.64	
Sf80	1.8	292	190	65.07	102	34.93	
Sf81	2	289	232	80.28	57	19.72	
Sf82	1.9	321	218	67.91	103	32.09	
Sf83	1.9	317	305	96.21	12	3.79	
Sf84	1.7	246	214	86.99	32	13.01	

Fig code	Diameter	Total number of seeds	Damaged seeds		Normal seeds		Remark
			Number	Percent	Number	Percent	
Sf85	2	301	263	87.38	38	12.62	
Sf86	1.9	268	240	89.55	28	10.45	
Sf87	1.9	237	132	55.70	105	44.30	
Sf88	2.2	314	182	57.96	132	42.04	
Sf89	2.2	312	223	71.47	89	28.53	
Sf90	1.9	281	242	86.12	39	13.88	
Sf91	1.9	284	211	74.30	73	25.70	
Sf92	1.8	279	251	89.96	28	10.04	
Sf93	2.4	427	258	60.42	169	39.58	
Sf94	1.5	216	197	91.20	19	8.80	
Sf95	2.3	363	249	68.60	114	31.40	
Sf96	2.4	424	217	51.18	207	48.82	
Sf97	1.6	215	172	80.00	43	20.00	8 gall flowers
Sf98	2.2	357	276	77.31	81	22.69	
Sf99	1.8	244	190	77.87	54	22.13	
Sf100	2.2	349	276	79.08	73	20.92	
Sf101	2.2	337	131	38.87	206	61.13	
Sf102	2	291	217	74.57	74	25.43	
Sf103	2.1	285	164	57.54	121	42.46	12 gall flowers
Sf104	1.8	194	108	55.67	86	44.33	
Sf105	1.7	203	160	78.82	43	21.18	
Sf106	1.8	220	193	87.73	27	12.27	
Sf107	2.1	247	171	69.23	76	30.77	
Sf108	1.9	285	223	78.25	62	21.75	
Sf109	1.8	296	189	63.85	107	36.15	
Sf110	1.9	317	223	70.35	94	29.65	
Sf111	1.9	338	195	57.69	143	42.31	
Sf112	1.7	274	233	85.04	39	14.23	
Sf113	1.9	351	262	74.64	89	25.36	
Sf114	2	376	217	57.71	159	42.29	
Sf115	2	364	160	43.96	204	56.04	
Sf116	1.9	322	281	87.27	41	12.73	9 gall flowers
Sf117	1.9	359	275	76.60	184	51.25	
Sf118	1.6	178	162	91.01	16	8.99	
Sf119	2	301	218	72.43	83	27.57	
Sf120	1.8	279	258	92.47	21	7.53	
Sf121	1.9	311	277	89.07	34	10.93	
Sf122	1.7	290	217	74.83	73	25.17	
Sf123	1.7	267	236	88.39	31	11.61	
Sf124	1.8	283	237	83.75	46	16.25	
Sf125	1.6	269	208	77.32	61	22.68	
TOTAL		**37720**	**27739**	**73.54**	**10056**	**26.66**	

Appendix 1 continued

DECLARATION

I Wondye Kebede hereby declare that, this thesis is my original work and has not already been presented nor is being currently submitted for a degree in any university or for publication. It is free for use as far as proper citation and acknowledgment is made.

Wondye Kebede Signature _____ Date_____

Advisor

Professor Legesse Negash Signature _____ Date_____