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Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* king. seedlings

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* King. seedlings**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled "**Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* King. seedlings**" is a record of research work done independently by Ms. Lakshmy J Rajan (2014-17-103) under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of Ms. Lakshmy J Rajan (2014-17-103), a candidate for the degree of **Master of Science in Forestry**, agree that this thesis entitled **"Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* King. seedlings"** may be submitted by her, in partial fulfillment of the requirement for the degree.

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Lakshmy J Rajan

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Introduction

1. INTRODUCTION

Big leaf mahogany (*Swietenia macrophylla*) is an important commercial timber species in India, which is widely used for raising plantations and for afforestation programmes. However, this species is poorly studied in relation to its management including physiological responses to various environmental stresses. This tropical tree species is native to Central and South America and has a wide natural distribution, extending from Mexico to Bolivia and central Brazil (Lamb, 1966).

Most of the tropical forest species are associated with arbuscular mycorrhizal fungi (AMF). Depending on the successional stages and soil fertility, various forest species have shown a wide range of dependency on AMF (Janos, 1980; Le Tacon *et al.*, 1987). Arbuscular mycorrhizal fungi belonging to the genera Acaulospora and Glomus were dominant in the rhizopheres of the Meliaceae with 82% of the AM fungi identified in these two genera (Shi *et al.*, 2006). About twenty-three AMF species belonging to genera *Glomus, Acaulospora, Gigaspora* and *Rhizophagus* were found to be associated with the rhizosphere soil of mahogany trees growing in its natural habitat (Rodriguez-Morelos *et al.*, 2014). Among these, genera *Glomus* was the most predominant in the soils of Kerala, indicating its adaptability to a wide range of soil and environmental factors (Gopal *et al.*, 2005).

Nursery and plantation studies have demonstrated that, mycorrhizal fungi could be incorporated into nursery for raising healthy seedlings. Inoculation with AMF was found to be beneficial in many forest tree seedlings (Ajeesh *et al.*, 2015; Binu *et al.*, 2015; Dutt *et al.*, 2013). Root colonization with AMF was directly correlated with increment in biomass, height, collar diameter, relative growth rates and quality index. Arbuscular mycorrhizal fungi can also reduce the field mortality and improve growth of plantation trees through a simple inoculation technique. Arbuscular mycorrhizal fungi technology can also be introduced with the existing forestry systems to improve the soil and crop productivity. It allows farmers to reduce their inputs of chemical fertilizers and enhance plant survival, thus offsetting different ecological and environmental concerns.

Using global climate change models, it is predicted that droughts will become increasingly frequent and intense across the tropical regions (Cox *et al.* 2008; Williams *et al.* 2007). Plants respond to water deficient environments at morphological, anatomical and cellular levels by modifications that allow them to avoid the stress or increase their tolerance (Bray, 1997). When water supply is limited, crop management practices that improve water stress resistance can benefit plant growth and improve water use efficiency (Abdul-Baki *et al.*, 1992). Drought reduces tree growth and increase mortality rates, thereby shifting the competitive advantage toward species with greater drought stress tolerance (Brenes-Arguedas *et al.* 2011; Engelbrecht and Kursar 2003). It is widely reported that AMF can adapt to a wide range of soil water regimes and can survive extreme habitats (Mosse *et al.*, 1981). Hence, AMF is an unexploited potential bio-fertilizer that can be used in forest nurseries for the production of quality planting stock.

In the present scenario, the number of forest nurseries has increased with the increasing demand for tree seedlings for planting and afforestation programme. The irrigation alone costs around 50 percent of the total cost involved in the nursery. A better understanding about the effect of abiotic stress and plant responses will help nursery managers and foresters to avoid large scale failures on different planting programme (Rao, 2005). This study aims to understand the effect of various levels of water stress on the growth and development of *Swietenia macrophylla* seedlings in pot culture; and to analyze the efficiency of different strains of AMF in overcoming the various levels of water stress.

Review of literature

2. REVIEW OF LITERATURE

Variation in environmental factors control plant growth and development. The factors which limit productivity and cause significant losses can be termed as environmental stresses. These are significant barriers to the introduction of crop plants into areas that are not currently under cultivation (Gaspar *et al.*, 2002). Stresses associated with extremes of temperature, insufficient or excessive light or mineral nutrients, water shortage, outbreak of pathogenic bacteria, fungi and viruses; in single or in combination, are likely to augment the severity of complications to which plants are exposed (Duncan, 2000; Cherry *et al.*, 2000). An understanding of the mechanisms that regulate the form and function, and their significance in physiology, metabolism, ecology and agriculture must include knowledge of plant stress physiology. Key exertions to breed for traits that confer tolerance to drought, cold, heat, nutrient, and salinity stress are already made the way around the world.

The terminology "stress" has been defined precisely in mechanics but, in the case of biology it has been given extensively diverse meanings. Probably keeping up with the physical meaning, many of these definitions congregate in describing "stress" as any environmental factor unfavourable for the living organism under contemplation (Levitt, 1980). Stress can be either biotic or abiotic. Since plants are confined to the place where they grow, they have a limited capacity to escape unfavourable and unpredictable changes in their environment. Ingenious molecular strategies most often combined with modification of growth and developmental patterns are developed by plants to defend themselves against such biotic and abiotic stresses. The duration, severity, and rate at which a stress is imposed affect how a plant responds. Several adverse conditions in combination may elicit a response differing from that for a single type of stress. Features of the plant, including organ or tissue identity, development age, and genotype, also influence plant response to stress (Bray *et al.*, 2000).

Mechanisms that permit stress survival are termed as *resistance* mechanisms and can allow an organism to tolerate or avoid stress. In *tolerance*, plants have mechanisms that maintain high metabolic activity similar to that in the absence of stress under mild stress and reduced activity under severe stress. In contrast, mechanisms of *avoidance* involve a decline of metabolic activity, ensuing in a dormant state, upon exposure to extreme stress (Osmond *et al.*, 1987). A plant species may have several tolerance or avoidance mechanisms, or a combination of both.

2.1. IMPORTANCE OF ABIOTIC STRESS

Abiotic stress conditions can lead to widespread damages to agricultural production around the world (Boyer, 1982). Hence the question of how plant cells react to countless environmental stresses is one of the most imperative topics not only to plant biologists but also to agronomists. Drought, salinity and extreme temperatures disturb more than 10% of arable land, which results in more than 50% decline in the average yields of important crops worldwide (Bray *et al.*, 2000). Furthermore, by the year 2050, the world food production requirements are to be doubled to meet the ever-growing demands of the population (Tilman *et al.*, 2002). Stress conditions such as drought, salinity or heat stress have been the topic of interest for intense research (Cushman and Bohnert, 2000). Here, the crops are routinely subjected to a combination of different abiotic stresses (Moffat, 2002).

Plants have mechanisms to survive and adjust to different types of abiotic and biotic stress imposed by the frequently fluctuating environment. The system underlying the environmental stress response in plants is more innovative and conspicuous than in animals. Each abiotic stress condition entails a distinctive acclimation response, tailored to the specific needs of the plant. A combination of two or more different stresses might require a response that is also unique. Drought and heat stress characterize an exceptional example of two dissimilar abiotic stress conditions that occur in the field simultaneously (Jiang and Huang, 2001). Several studies have scrutinized the effects of a combination of drought and heat stress on the growth and productivity of maize, barley, sorghum and different grasses. It was found that a combination of drought and heat stress had a significantly greater detrimental effect on the growth and productivity of these crops when compared with each applied individually (Wang and Huang, 2004). Physiological characterization of plants subjected to drought, heat or a combination of both reveals several unique aspects, combining high respiration with low photosynthesis, closed stomata and high leaf temperature (Rizhsky *et al.*, 2002). When combined, different stress might involve antagonistic responses to that happen between the acclimation responses of plants to different abiotic stress conditions (Kreps *et al.*, 2002). For example, plants open their stomata for transpiration and thereby cool their leaves during heat stress. However, if the heat stress is accompanied by the drought stress, plants would not be able to open their stomata and their leaf temperature would rise (Rizhsky *et al.*, 2002). When combined with heat stress, salinity or heavy metal stress might present a similar problem to plants because of the improved transpiration which could result in enriched uptake of salt or heavy metals. Combined with high light conditions, cold stress or drought may cause enrichment in reactive oxygen species production by the photosynthetic apparatus since these conditions limit CO_2 availability which in turn leaves oxygen as one of the main reductive products of photosynthesis.

Tolerance or susceptibility to abiotic stresses is a very intricate event as it may upset numerous stages of plant development (Chinnusamy *et al.*, 2004). Plant stress tolerance comprises changes at whole-plant, tissue, cellular, physiological and molecular levels. A range of physiological and biochemical alterations in plants comprising leaf wilting, leaf area reduction, leaf abscission, root growth stimulation, production of reactive oxygen species, alterations in relative water content, electrolytic leakage and amassing of free radicals which disrupt cellular homeostasis succeeding lipid peroxidation, membrane damage, and inactivation of enzymes thus prompting cell viability takes place in plants (Bartels and Sunkar, 2005).

Molecular responses to abiotic stress consist of perception and transduction of the stress signal, gene expression and eventually metabolic changes in the plant thus imparting stress tolerance (Agarwal *et al.*, 2006). Many genes that are triggered in response to abiotic stresses at the transcriptional level deliver stress tolerance by the fabrication of vital metabolic proteins and also in the downstream gene regulation (Kavar *et al.*, 2007).

Plant hormones or phytohormones are produced in any one part of the organism which, when transferred to another part, influences a specific physiological process there (Went and Thimann, 1937). These can be broadly classified into two; those that play a principal role in response to biotic stress such as ethylene, jasmonic acid and salicylic acid and those that have essential roles in controlling the abiotic stress responses such as abscissic acid (Fraire-Velazquez *et al.*, 2011). Abscissic acid is the most investigated stress-responsive hormone, which is involved in the abiotic stress responses such as drought, osmotic and cold stress (Peleg and Blumwald, 2011; Vlot *et al.*, 2009). It encourages leaf stomata closure, thus decreasing transpirational water loss and photosynthetic rate which increases the water-use efficiency of the plant.

Calcium ion is one of the profuse intracellular secondary messenger molecules that are involved in many signal transduction pathways in plants. The concentration of cytosolic free calcium increases by abiotic stresses. Calcium signaling is significant in the regulation of cell cycle progression in response to abiotic stress as well as in the regulation of gene expression for plant defense against various stresses (Tuteja and Mahajen, 2007). Reactive Oxygen Species (ROS) are also fundamental secondary messengers involved in the response to diverse abiotic and biotic forms of stress. These are highly reactive and toxic. They cause damage to proteins, lipids, carbohydrates and DNA which eventually results in oxidative stress (Gill and Tuteja, 2010). They can develop in response to biotic stress like pathogens (Lamb and Dixon, 1997) or to abiotic stress like heat (Wahid *et al.*, 2007), cold (Kwon *et al.*, 2007), drought, salinity (Miller *et al.*, 2010) and others.

2.2. EFFECT OF DROUGHT STRESS ON SEEDLINGS

Water is the single most important constituent of a plant, encompassing more than 90% of its fresh weight. From a physiological perspective, water is the key component in sustaining cell turgor. Water loss from the aerial part of the plants will lead to water deficit inducing wilting, damage to cell membrane and ultimately cell death which in turn is compensated by increased uptake of water via root. Water stress is one of the dominant factors that limits seedling establishment and growth. Water stress can lead to reduction in leaf water potential which can induce stomatal closure and reduced gas exchange (Kramer and Boyer, 1995) and eventually decline in transpiration. Transpiration is inversely proportional to resistance to water vapor transport from boundary layer of the leaf to the air; and directly proportional to the gradient of water vapor concentration from the internal evaporation surface to the bulk air outside the leaf. Since stomata control only one part of the total resistance, their closure will differ with the extent of stomatal resistance relative to that of boundary layer resistance and cuticular resistance. Water stress also reduced CO_2 assimilation by plants possessing crassulacean acid metabolism in darkness or light. These reductions were correlated with decreases in transpiration.

Drought stress also portrayed a decline in growth rate, stomatal density and the proportion of starch and thylakoids in chloroplasts in *Betula pendula* Roth. clones (Paakkonen *et al.*, 1998). Effects of water stress include suppression in dark respiration, more or less proportionately but not very markedly by moderate to severe stress (Boyer, 1970). A notable exception is the much reproduced data of on loblolly pine, which showed that with growing water deficit, dark respiration reduced first at moderate stress, then amplified at severe stress to levels above the control, and finally dropped again at exceedingly severe stress (Brix, 1962).

Plant water-use efficiency can be interpreted as the amount of water used per carbon gain, unequivocally relates plant performance with water availability. The relationship between water-use efficiency and plant performance can demonstrate interspecific variations in drought tolerance strategies, ranging from stress tolerance to stress avoidance (Aranda *et al.*, 2012). Higher water use efficiency, lower photosynthetic rates, slower growth, and higher survival is associated with stress tolerance, while lower water-use efficiency, higher photosynthetic rates, faster growth, and lower survival is associated with stress avoidance (Chaves *et al.*, 2003).

Plant exposed to water stress may also produce methylated quaternary ammonium compounds, sugars, amino acids, proteins, and organic acids in their body tissues (Ingram and Bartels, 1996). Ben Ahmed *et al.* (2009) found that proline was amassed in olives under water deficit conditions. Furthermore, a close relationship between net photosynthetic rate and proline content was also recorded, pointing to the substantial role of this osmolyte in the upkeep of photosynthetic activity. Smirnoff (1993) found out that low water availability is often connected with the improved levels of reactive oxygen species, such as superoxide anion (O_2), hydrogen peroxide ($H_2 O_2$), hydroxyl radical (HO^-) and singlet oxygen ($^1O_2$). These are highly reactive species and interrupt normal metabolism of the plant and cause extensive peroxidation of membrane lipids, as well as lead to protein denaturation and mutation of nucleic acids (Bowler *et al.*, 1992). In order to cope with them, plants are equipped with a complex antioxidant system consisting of enzymatic and non-enzymatic scavengers of reactive oxygen species. The major enzymatic scavengers are superoxide dismutase, ascorbate peroxidase, catalase, whereas major non enzymatic scavengers include ascorbic acid, glutathione, flavanoids and carotenoids maintaining the reduced antioxidant pools.

Plasticity designates specialization with respect to a particular environment, through which the trees can acclimate to their local environment (Bradshaw, 1965). It can convene a competitive advantage to co-occurring individuals as they compete for limiting resources. For example; pioneer species in some cases have a developed plasticity in leaf traits related to photosynthesis, while shade-tolerant species have sophisticated plasticity in leaf traits related to light interception (Rozendaal *et al.*, 2006). Therefore in the framework of drought stress, species with high plasticity would be anticipated to exhibit a much greater performance where water is not limiting than the species with low plasticity which would be expected to accomplish equally well in environments with and without drought stress (Comita and Engelbrecht, 2009).

Al-harbi (2006) studied variation in height of six month old seedlings of two species *Conocarpus erectus* and *Eucalyptus microtheca* under sufficient irrigation, moderate water stress and severe water stress and found no significant variation. But they showed decrease in relative growth rate in response to water stress. Water-stressed citrus seedlings showed 25 per cent reduction in plant height (Wu *et al.*, 2013). Six month old seedlings of *Casuarina glauca*, under moderate and severe water stress, recorded a decrease in height by 23 and 32 per cent respectively than that of well irrigated control plants (Albouchi *et al.*, 2003).

Sneha *et al.* (2013) quantified water stress in mahogany (*Swietenia macrophylla*) seedlings using crop water stress index. Mahogany seedlings showed significant difference in collar diameter due to different irrigation treatments. Least irrigated seedlings showed reduction in collar diameter compared to the well-watered treatments. It was found that in well-watered mahogany seedlings, chlorophyll content was higher. Significant reduction in chlorophyll content was observed in treatment least irrigated seedlings. Severe drought caused rupture of chloroplast and disintegration of chlorophyll molecules.

Zokaee-Khosroshahi *et al.* (2014) identified morphological changes in young seedlings of five almond species (*Prunus dulcis*, *P. eburnea*, *P. eleagnifolia*, *P. haussknechti,* and *P. scoparia*) under drought stress. Drought stress caused a significant reduction in plant growth parameters such as fresh and dry weights of plant organs, leaf number, total leaf area, and leaf relative water content in all almond species. Specific leaf weight also increased significantly in drought-treated plants compared to control. No significant changes in shoot length, leaf area, or stomatal size and frequency were observed in response to drought treatments.

Effect of controlled irrigation on physiological and biometric characteristics in teak seedlings was monitored by Sneha *et al.* (2012). Six month old seedlings of teak (*Tectona grandis*) were irrigated with 100, 60 and 30 per cent of cumulative evapotranspiration at weekly intervals. Seedlings with least irrigation showed a significant reduction in relative chlorophyll content, seedling height, collar diameter, number of leaves, total dry weight and relative growth rate, whereas in well-irrigated seedlings these parameters were higher.

Rao *et al.* (2005) also reported reduced performance of teak seedlings under severe water stress in shoot-root biomass ratio. Similar result was reported in *Hopea odorata, Mimusops* *elengi* seedlings (Zainudin *et al.*, 2003) and *Dalbergia sissoo* (Singh and Singh, 2006). Singh and Singh (2006) reported that the collar diameter of two year old seedlings of *D. sisoo* was reduced by 38 per cent at low irrigation level when compared to the well watered ones. After 15 days of exposure to water stress, reduction in plant height up to 40 per cent when compared that of well irrigated seedlings was observed in eucalyptus and casuarina seedlings (Nautiyal *et al.*, 1994). A 50 per cent reduction in collar diameter was also observed in eucalyptus hybrid seedlings in response to moisture stress when compared to the well watered seedlings.

Shoot root biomass ratio appears to be governed by a functional balance between water uptake by root and photosynthesis by the shoot increases root growth. This functional balance is affected by water stress and more biomass is allocated towards roots to increase more water absorption. Increased shoot-root length ratio was observed in drought affected saplings of eucalyptus (Rose *et al.*, 1990 and Ngugi *et al.*, 2004), sandal (Hiremath, 2004) etc. Bongarton and Teskey (1987) reported that, when juvenile plants are under water stress above ground growth is affected more severely by water stress than below ground growth.

Reduction in the number of leaves due to water stress is an efficient mechanism of plants to reduce loss of water through transpiration through reduction of leaf area. Drought tolerant species are characterized by more number of leaves with smaller size to keep rate of photosynthesis intact while reducing transpiration. Reduced number of leaves under water stress was observed in seedlings of casuarina by Nautiyal *et al.* (1994). In one year old seedlings of four Mediterranean oak species, well irrigated seedlings showed more total leaf surface area and number of leaves compared to non-irrigated ones (Fotelli *et al.*, 2000). It is known that high soil water availability facilitate nutrient accumulation, leaf growth, leaf area and number of leaves which helps to produce more photosynthate, and thus greater growth and biomass production (Ceulemans *et al.*, 1993). Sufficient soil water availability through higher irrigation increased leaf size and overall biomass (Souch and Stephens, 1998). Myers and Landsberg (1989) observed significant reduction in leaf area and relative growth rate of seedlings of *Eucalyptus maculata* (mesic environment) and *E. brockwayi* (in arid environment).

Seedlings of *Leucaena leucocephala* showed 50 per cent reduction in relative growth rate under severe stressed condition and 30 per cent reduction under moderately stressed condition (El-Juhany and Aref, 2005). The decreased relative growth rate in the water-stressed seedlings was found to be associated with the decrease in leaf dry weight and specific leaf area. They also reported 23 and 35 per cent reduction in collar diameter under moderate and severe water stress respectively. The number of leaves was reduced by 47 and 65 per cent under moderate and severe water stress treatments. Under moderate and severe drought, reduction in stem weight of *Leucaena leucocephala* treatments was found to be 52 per cent and 65 per cent. A slight increase in root length due to water stress was also observed and a reduction in root dry weight by 21 per cent under moderate and 29 per cent under severe water stress was estimated in *Leucaena leucocephala.*

A 10–20 per cent decrease in average growth in response to water stress was observed in the seedlings of *Cinnamomum verum, Syzygium jambos* and *Memecylon eleagni* (Schumacher *et al.*, 2009). There are reports which correlate difference in relative growth rate to dry matter partitioning. They explain reduction in relative growth rate is attributed by reduced allocation of biomass to leaves, the site of photosynthesis (Poorter *et al.* 1990). But Norgren (1996) found no relationship between relative growth rates and dry matter partitioning between Scots pine and lodgepole pine seedlings. Depletion of water reserves leads to reduced growth rates, which are, among others, attributed to the lower photosynthetic rates due to stomatal closure and also to the reduced functionality of the root system, which is unable to support the unhindered supply of the canopy with nutrients and water (Bacelar *et al.*, 2007).

2.3. AMF AND ITS IMPORTANCE

Mycorrhiza is the symbiotic association between plant roots and fungi. The two common types of fungi involved in such association are arbuscular mycorrhizae fungi (AMF) and ectomycorrhizae. About 80% of all terrestrial plants, including most agricultural, horticultural, and hardwood crop species are able to establish this mutualistic association (Giovannetti *et al.*, 2006). The AMF hyphae proliferate into the soil helping plants to acquire mineral nutrients and water from the soil. (Javaid, 2009; Rillig and Mummey, 2006). It also penetrates into root cortical cells and forms a structure called arbuscule that serves as a mediator for the exchange of metabolites between fungus and host cytoplasm (Oueslati, 2003).

AMF fungi play a very important role in ecosystems through nutrient cycling (Wu *et al.*, 2011). It is well known that mycorrhizal association increases the nutrient acquisition area as the fungal hyphae extend beyond the root and into the nutrient undepleted zones (Marschner and

Dell, 1994). This symbiosis is alleged to improve plant resistance to drought and nutrient stress (Nasim, 2010). Mycorrhiza can overcome nutrient limitation to plant growth by enhancing nutrient acquisition, especially of slowly diffusing ions, such as phosphorus (P) to the plant (Marschner and Dell, 1994; Clark and Zeto, 2000; Sharda and Koide, 2010). About 80% of the P taken up by a mycorrhizal plant is supplied by the fungus. Inorganic P has low solubility, which results in very low mobility; consequently, a depletion zone develops when roots absorb inorganic phosphate. The fungal hyphae reach out to the P depletion zone to absorb P. Further, the fungal hyphae also secrete enzymes that are capable of solubilizing unavailable forms of phosphate (Joner and Johansen, 2000). In addition to their significant role in P acquisition, AM fungi can also provide other macro and micronutrients such as N, K, Mg, Cu and Zn, particularly in soils where they are present in less soluble forms (Meding and Zasoski, 2008; Smith and Read, 2008). A few authors have highlighted the importance of mycorrhizal association for nitrogen (N) nutrition (Gebauer and Meyer, 2003; Guescini *et al.*, 2007).

Soil aggregation is one of the main properties of soil structure. To a great extent, the effect of plants on soil aggregate formation is overseen by AMF activities (Rillig *et al.*, 2002). The AMF are known to endorse plant growth and development by improving nutrient acquisition as well as alleviating stress conditions of plants (Koide and Mosse, 2004). They also play a crucial role in the storage of soil carbon (Zhu and Miller, 2003; Rillig and Mummey, 2006).When the role played by mycorrhizal associations in enhancing nutrient uptake is mainly relevant in lower input agro-ecosystems, their role in maintaining soil structure is imperative to all of the ecosystems (Ryan and Graham, 2002). By influencing the root system, AMF enhance the entangling and meshing of soil particles by the plant roots and root hairs (Rillig and Mummey, 2006). Mycorrhizal fungi modify soil structure by (1) the growth of their external hyphae that extend into the soil to create a skeletal structure that holds soil particles together; (2) creation of conditions that are beneficial for the development of micro-aggregates with the help of the external hyphae; (3) the formation of macro aggregates by enmeshment of micro aggregates using external hyphae and roots; and (4) directly acquiring the carbon resources of the plant to the soils (Miller and Jastrow, 2000). This direct access influences the formation of soil aggregates since soil carbon is critical to form organic materials that are essential to cement soil particles.

The AMF and roots also affect the physical processes of soil through the production of extracellular compounds, principally long chain polysaccharides and proteins that improve soil structure (Czarnes *et al.*, 2000). This role of AM has been linked with the production of a unique fungal substance, named as glomalin (Zhu and Miller, 2003). Glomalin is a fungal protein class that is operationally quantified from soil as glomalin-related soil protein. Glomalin was believed to be emanated by the living fungus (Wright and Upadhyaya, 1996) until Driver *et al.* (2005) found that it is only released by AMF into the soil environment during hyphal turnover and after the death of the fungus. Glomalin has been found in agricultural, grassland, forest, desert, and non-cultivated soils (Rillig *et al.*, 2003; Bai *et al.*, 2009). Miller and Jastrow (2000) proposed that hyphae and glomalin together added up to 15% of soil organic carbon in grasslands. The stabilization of soil aggregates was correlated with concentration of glomalin after a three year's transition of a maize cropping system from conventional tillage to no-tillage (Wright *et al.*, 1999). There are indications that some crop rotations favour glomalin production and aggregate stabilization more than others (Wright and Anderson, 2000).

Inoculation experiments have revealed that diverse AMF species produce an extensive range of growth responses in the host plant that may range significantly from positive to negative. Even though nutrient uptake has been the emphasis of much research on the AMF association, there is confirmation that AMF also play a role in the overpowering crop pests and diseases, predominantly soil-borne fungal diseases (Linderman, 1994; Borowicz, 2001). Rather than total inhibition, a reduction in the severity of diseases is observed despite the fact that pathogen infection mostly reduces AMF colonization. But this still could result in a significant rise in the yield over those plants not inoculated with AMF. In some cases, the superficial resistance of a plant to a disease or pest may simply be due to the enhanced nutrition (Cordier *et al.*, 1996; Karagiannidis *et al.*, 2002), even though there is evidence for multiple mechanisms of resistance operating simultaneously (Whipps, 2004). Abdalla and Abdel-Fattah (2000) found that *Glomus mosseae* delivered some protection to peanut (*Arachis hypogaea* L.) against pod rot caused by *Rhizoctonia solani* and *Fusarium solani* . Besides improving peanut biomass, the inoculation reduced the richness of both pathogens signifying a direct interaction between mutualists and pathogens. Other types of pest and disease causing organism which are curbed by AMF include pathogenic nematodes (Talavera *et al.*, 2001), above ground fungal diseases (Feldmann and Boyle, 1998) and herbivores (Gange and West, 1994; Gange *et al.*, 2002).

Symbiosis with *Rhizophagus intraradices* reduced the nematode species composition as found in the rhizosphere of diverse legumes (Villenave *et al.*, 2003).

The AMF species do not appear to show specificity towards a plant species. In comparatively undisturbed agro-ecosystems involving perennial plants with minimal tillage, the mycorrhizal mycelium network remains intact. While in agro-ecosystems dominated by annual crops, the delayed establishment of AMF relative to plants could limit growth due to regular disturbance (Kuyper *et al.*, 2004). Even though AMF displays only a restricted degree of specificity, divergent plant species encourage the occurrence and quantity of diverse species of AMF, thus through the management it is quite possible to amend the mycorrhizal populations in the soil (Hart *et al.*, 2001). A mixture of plants, especially a mixture of trees and crops as in agroforestry systems, may root deeply, ensuing in a more equitable existence of AMF throughout the root zone (Cardoso *et al.*, 2003). This improves the volume of soil from which nutrients can be taken up competently.

2.4. MECHANISMS OF AMF TO MITIGATE STRESS

One of the unique characteristics of AMF, when in symbiotic relationship with plant roots, is the significant increase in root surface area due to production of extensive hypha helping seedlings grow under relatively harsh conditions, such as drought stress (Al Karaki *et al.*, 2004) and nutrient deficiency conditions (Marschener and Dell, 1994). The fungi do this by growing beyond the nutrient depletion zones that typically form around roots and by greatly increasing the absorptive surface of the root system (Smith and Read, 2008). The enhanced growth due to the presence of AMF in the root system of seedlings is already known to improve plant health and growth (Auge, 2001). A plant with a well-established symbiont is better off because of increased resistance to various stress factors. It has been observed that mycorrhizal seedlings absorb water more efficiently under water deficit environment (Khalvati *et al.*, 2005); which might be due to the modification in root architecture, that in turn contributes to a better root growth with numerous branching (Berta *et al.*, 2005).

Generally, AMF stimulates plant growth not only by providing necessary nutrients for growth, but also by helping the plant to tolerate environmental stress. The promotion in growth can be described by several mechanisms used by the mycorrhizal fungi under certain conditions. These include creation of metabolites like vitamins, amino acids, phytohormones and processes like mineralization and solubilization (Khan *et al.*, 2009; Smith and Read, 2008). They also impart other benefits including osmotic adjustment under osmotic stress, production and accumulation of secondary metabolites, enhanced photosynthesis rate, improved nitrogen fixation, and increased resistance against biotic and abiotic stresses (Wu and Xia, 2006; Khaosaad *et al.*, 2007; Schliemann *et al.*, 2008; Sheng *et al.*, 2009; Selvakumar and Thamizhiniyan, 2011; Shinde *et al.*, 2013). The AMF can also increase plant tolerance to heavy metals, salinity and drought and pathogens (Azcon-Aguilar *et al.*, 2002; Gosling, *et al.*, 2006; Marulanda *et al.*, 2009; Zhang *et al.*, 2010). They can also increase growth and yield by improving the negative influence caused by the allelochemicals (Javaid, 2008).

Proline act as an osmoregulator under stress conditions and AMF association modifies the physiological processes of plants by elevating its contents (Ashraf and Foolad, 2007). Similarly, the mechanisms used by AMF to relieve stress-induced adverse effects of salinity on plant growth includes improvement of plant nutrition, alteration in physiological and enzymatic activities, variation in sodium and potassium ion uptake and modification of the root architecture to facilitate water uptake (Evelin *et al.*, 2009; Gamalero *et al.*, 2010; Zhang *et al.*, 2011; Zolfaghari *et al.*, 2013). Physiological processes involved in osmoregulation like improved carbon dioxide exchange rate, stomatal conductance and water use efficiency are also influenced by AMF inoculation (Birhane *et al.*, 2012; Ruiz-Lozano and Aroca, 2010).

Al Karaki and Clark (1998) demonstrated that wheat plants colonized with *G. monosporum* have greater growth, acquisition of mineral nutrients, higher water use efficiency values and have greater ability to withstand drought than non arbuscular mycorrhizal plants when grown under water stress. However, AMF can only alleviate moderate drought stress, and in more severe drought conditions they become ineffective (RuizLozano and Azcon, 1995). It has been revealed that mycorrhizal plants tend to absorb water more efficiently than in non-mycorrhizal plants (Al-Karaki and Clark, 1999; Khalvati *et al.*, 2005) under a water deficit environment. This might be due to alteration in root architecture which leads to better root growth due to the presence of numerously branched roots (Berta *et al.*, 2005). The progressive effect of AMF on plant growth and development under drought stress might be due to its influence on abscissic acid concentration in plants (Jahromi *et al.*, 2008). Abscissic acid regulates the stomatal conductance by closing stomata under water-limited environment. They reported increased abscissic acid content in mycorrhizal lettuce plants compared to the non-mycorrhizal ones. It has also been perceived that AMF raise the tolerance of host plants towards salinity stress by improving water status of the inoculated plants by facilitating water transport in plants (Ouziad *et al.*, 2006). Mycorrhiza also enhances soluble sugars and electrolyte concentrations in host plants. Improved osmoregulation capacity in AMF inoculated maize was associated with higher soluble sugar and electrolyte concentrations (Feng *et al.*, 2002).

2.5. DROUGHT TOLERANCE THROUGH AMF SYMBIOSIS

Drought stress influences many physiological activities related to water relations in plants. They involve activities such as stomatal conductance, transpiration, photosynthesis, leaf and root hydration). Drought-reduced the leaf water potential, relative water content, stomatal conductance, whole plant transpiration, leaf transpirational surface area and plant biomass (Davies *et al*; 2002). Principally, stomatal conductance to water vapour and the photosynthetic rates are stimulated by AMF inoculation under drought conditions (Auge, 2001; Diaz and Roldan, 2000). There is substantial evidence to recommend that AMF is able to escalate the host plant's tolerance to water stress (Auge, 2004). Several mechanisms have been suggested to elucidate the effect, including improved stomatal regulation, improved root hydraulic conductivity, osmotic adjustment of the host and improved contact with soil particles through the binding effect of hyphae, enabling water to be extracted from smaller pores (Auge, 2001; 2004).

Improving crop production under drought conditions may also be effective when plant roots are inoculated with AMF. Wheat (*Triticum aestivum*) plants inoculated with *G. etunicatum* generally had higher colonization than plants colonized with *F. mosseae* under all soil moisture conditions. Biomass and grain yields were higher in mycorrhizal plants irrespective of soil moisture. *G. etunicatum* inoculated plants generally had higher biomass and grain yields than those colonized by *F. mosseae* (Al Karaki *et al.*, 2004)

In maize and other species, the most widely recognized contribution of AMF to host-plant nutrition involves their ability to extract P from outside the P depletion zone around plant roots (Liu *et al.*, 2003; Miller, 2000). AMF often alter rates of water influx and efflux in host plants, thus affecting tissue water content and leaf physiology. At times, AMF also postpone reductions in leaf water potential during periods of drought stress and hasten returns to control levels upon the alleviation of water-limiting conditions (Auge, 2001). Artificial inoculation with mycorrhizal fungi in the nursery is used to increase seedling performance in situations known by researchers and managers to have consistently positive results. Artificial inoculation with arbuscular mycorrhizal fungi, for example, *R. intraradices* for species such as incense cedar, redwood, giant sequoia, and western red-cedar significantly increase seedling density and growth in the nursery, and survival and early growth after out-planting on some sites (Kormanik *et al.*, 1980; Kormanik *et al.*, 1982).

The influence of AMF, viz; *Funneliformis mosseae* and *Rhizophagus intraradices,* on plant growth characteristics of black locust (*Robinia pseudoacacia* L.) seedlings was studied in pot culture under well-watered, moderate drought stress, and severe drought stress treatments (Yang *et al.*, 2014). The AMF colonization lead to an improvement of growth under all growth conditions, via improving leaf water status, chlorophyll concentration, photosynthesis, and nutrient uptake. Mycorrhizal seedlings had higher dry biomass, leaf relative water content, and water use efficiency compared with non mycorrhizal seedlings. Under all treatments, AMF colonization notably enhanced net photosynthetic rate, stomatal conductance, and transpiration rate, but decreased intercellular CO_2 concentration. Leaf chlorophyll concentrations were higher in AMF seedlings than those in non-AMF seedlings although there was no significant difference between AMF species.

Rajan *et al.* (2000) screened selected AMF for their symbiotic efficiency with *Tectona grandis*. Teak seedlings grown in AMF inoculated soil showed increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight than those grown in soils not inoculated with AMF. They found that *G. macro*carpum significantly enhanced the plant height as compared to all other treatments. However, seedlings treated with *G. leptotichum* and *G. fasciculatum* had a significantly higher stem girth than other treatments. The leaf area was significantly more in seedlings grown in the presence of *G.leptotichum*. They concluded that increased leaf area and enhanced nutrient content in seedlings colonized by *G. leptotichum* have probably resulted in significantly higher biomass compared to other treatments.

F. mosseae was found to be the most promising AMF symbiont for inoculating *Azadirachta indica* seedlings in the nursery (Sumana and Bagyaraj, 2003). Plant height, number of leaves and stem girth were significantly greater in seedlings inoculated with *F. mosseae,* when compared with non-inoculated seedlings; plant biomass was enhanced by about 70 per cent due to *F. mosseae* inoculation. Shoot and root biomass were also significantly higher in seedlings inoculated with *F. mosseae*. Such an increase in biomass was reported by Vasanthakrishna *et al.*

(1995) in *Casuarina equisetifolia* when inoculated with AMF species. Similar observations were reported in *Dalbergia sissoo* which showed higher biomass because of inoculation with *G. fasciculatum* (Sumana and Bagyaraj, 1996).

Increase in seedling height due to AMF inoculation has been reported in several studies (Wu *et al.*, 2011; Binu *et al.*, 2015). Symbiosis with *F. mosseae* significantly improved the plant growth parameters such as, plant height, stem diameter, shoot dry weight, root dry weight and total dry weight compared to the non-inoculated *Prunus persica* seedlings (Wu *et al.*, 2011). The plant height, stem diameter, shoot dry weight, root dry weight or total dry weight were increased significantly by 30.3 per cent, 17.2 per cent, 34.4 per cent, 64.5 per cent or 45.4 per cent respectively with the inoculation of *F. mosseae.* Inoculation with three different AMF (*G. occultum, F. mosseae* and *G. aggregatum*), resulted in significant increase in shoot height, diameter and leaf area of *Acacia mangium* seedlings when compared to that of the control seedlings (Ghosh and Verma, 2006). Seedlings inoculated with *G. occultum* had higher biomass than seedlings inoculated with other AMF species.

The *Dalbergia sissoo* seedlings when inoculated with AMF encouraged increased growth under glasshouse conditions, which could be of great importance with respect to its survival and growth in natural conditions (Bisht *et al.*, 2009). Enhancement in growth was observed for *Acacia holosericea* seedlings, when inoculated with *R. intraradices* (Duponnois and Plenchette, 2003) and *G. aggregatum*. There was increment in height, number of leaves, leaf area, leaf weigh, shoot weight and relative water content for *Santalum album* seedlings after AMF inoculation (Binu *et al.*, 2015). The study also suggested that better performance under partial shade was observed for seedlings inoculated with *F. mosseae*. *Anacardium occidentale* seedlings were inoculated with three species of AMF viz. *G. aggregatum, G. fasciculatum* and *F. mosseae* (Ananthakrishnan *et al.*, 2004). Among these, *G. fasciculatum* had significantly greater stem girth, number of leaves and intermodal length than the non-inoculated seedlings.

Symbiosis with AMF notably enhanced growth, gas exchange, chlorophyll concentration, chlorophyll fluorescence and water status of maize (*Zea mays* L.) plants in pot culture under well-watered and drought stress conditions (Zhu *et al.*, 2012). Drought stress significantly decreased AM colonization and total dry weight. The biovolume index and quality index were significantly higher in seedlings inoculated with *F. mosseae;* while, non-inoculated seedlings recorded the lowest biovolume and quality indices (Sumana and Bagyaraj, 2003). Teak seedlings inoculated *G. leptotichum* showed a greater biovolume index and quality index compared to all other treatments and this increase was upto an extent of 68 and 66.7 per cent, respectively, over non-inoculated seedlings (Rajan *et al.*, 2000). Such high values of biovolume index and quality index indicates a sturdier stem and a proportionate dry weight, which are desirable qualities among nursery seedlings (Hatchell, 1985). Inoculation with *R. intraradices, G. geosporum* and *A. brasilense* improved the seedling quality in *Azadirachta indica* seedlings by 104, 25 and 93 percent (Muthukumar *et al.*, 2001) over non-inoculated controls. Mycorrhizal Efficiency Index is a direct measurement of efficiency of AMF inoculation. Cruz *et al.* (1999) categorized the mycorrhizal efficiency index (MUE) in three groups: 40 per cent and above: high efficiency; 10-40 per cent: moderate efficiency; below 10 per cent; no efficiency. *Acacia mangium* seedlings, inoculated with G. *occultum* showed 57 per cent MUE; while, those inoculated with *F. mosseae* and *Glomus aggregatum* recorded 47 per cent and 46 per cent respectively (Ghosh and Verma, 2006). The high MUE value suggested that inoculation with AMF would be useful in the production of vigorous seedlings (that may establish better in the field and withstand drought or nutrient deficiency and pathogenic infections) in the nursery (Ghosh and Verma, 2006).

The high percentage of root colonization in AMF seedlings inoculated with AMF is directly correlated to a better nutrient uptake, increased chlorophyll content, an increase in the rate of photosynthesis and transpiration (Eissenstat *et al.*, 1993; Peng *et al.*, 1993: Mathur and Vyas, 2000; Rajasekaran and Nagarajan, 2005), and thereby improved root and shoot growth (Thaker and Fasrai, 2002; Farshian *et al.*, 2007). Comparatively, the seedlings inoculated with AMF have a low transpiration rates and higher water use efficiency, when compared with non mycorrhizal seedlings. This may be due to the decrease in stomatal conductance when colonized with AMF (Mathur and Vyas, 1995). Abbaspour *et al.* (2012) suggests controversies to above, by stating that mycorrhizal inoculation could increase the rate of transpiration, reduce leaf temperature and restrain the decomposition of chlorophyll, which was not true as per the present study. Inoculation with *F. mosseae* and *S. calospora* significantly reduced photosynthetic rate by 31 per cent in *Azadirachta excelsa* seedlings (Huat *et al.*, 2002). The difference in photosynthetic rate could probably be due to excessive starch accumulation in leaves of seedlings inoculated with AMF. Maximum photosynthetic rates in the *Dalbergia sissoo* were observed in AMF inoculated seedlings, an effect validated by increased root biomass (Bisht *et al.*, 2009). The transpiration rates for seedlings inoculated with AMF were higher, which could also explain higher nutrient content in the shoots of seedlings grown in these soils. Changes in transpiration could cause a change in the rate of photosynthesis changing the supply of carbohydrate to the fungus. Alternatively, higher nutrient uptake due to higher transpiration rates could be due to mass flow of nutrients towards the root (Sharma *et al.,* 1996; Bisht *et al.*, 2009). Relative water content was higher for seedlings inoculated with AMF, particularly those inoculated with *F. mosseae* grown under 50 and 25 per cent shade (Binu *et al.*, 2015).

Sumana and Bagyaraj (2003) reported that highest root colonization and spore numbers were observed in seedlings inoculated with *F. mosseae* and the lowest colonization and spore numbers were experienced by non-inoculated neem seedlings. The colonization percentage was found to be the highest in *Anacardium occidentale* seedlings inoculated with *F. mosseae;* when applied with three species of AMF viz. *G. aggregatum, G. fasciculatum* and *F. mosseae* (Ananthakrishnan *et al.*, 2004). Extra matrical chlamydospore counts from root zone soil of the inoculated seedlings also varied among the three AMF species. Inoculation with AMF showed an increase in percentage of colonized root for sandal seedling which increased with time (Binu *et al.*, 2015). The control seedlings recorded a lower spore count.

Materials and methods

3. MATERIALS AND METHODS

3.1. LOCATION

The study was conducted at the College of Forestry (CoF), Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala located at latitude 10^0 32'N and longitude 76^0 26'E at an elevation of about 22 m above mean sea level.

3.2. CLIMATE

The study site had a warm and humid tropical climate with a distinct summer and rainy season. The climatic parameters during the study period collected are given in Table 1.

Table 1.Climatic parameters of the study site from May 2015 to February 2016
(Source: Agrometereological observatory, Kerala Agricultural University campus)

Year	Month	Temperature (^{0}C) (Max.)	Temperature (^{0}C) (Min.)	Rainfall (mm)	Relative Humidity (%)	Evaporation (mm)
2015	May	32.9	24.7	259	80	3.1
	June	31	23.9	629.8	85	2.6
	July	30.3	23.5	510.1	85	2.8
	August	31	23.7	320.8	83	2.9
	September	31.9	24.1	242.2	81	3
	October	32.5	23.8	203.8	79	2.7
	November	31.6	23	151.2	75	2.8
	December	32.3	23.3	88.3	65	4
2016	January	33.2	23	23.8	56	5.1
	February	35.2	23.5	11.4	57	5.1

3.3. EXPERIMENTAL LAYOUT

The pot culture experiment was laid out in a completely randomized design with two factors in a polyhouse at College of Forestry tree nursery, Vellanikkara. Four different irrigation levels at 100, 80, 60 and 40 per cent of cumulative evapotranspiration and a control with normal daily irrigation were applied as first factor. As the second factor, an arrangement of three arbuscular mycorrhiza fungi (AMF) species namely *Funneliformis mosseae*, *Glomus etunicatum*, and *Rhizophagus intraradices* and a non-inoculum as a control were used. There were a total of 20 treatment combinations (Table 2) and the whole experiment was replicated four times.

Table 2. Different combinations of AMF and irrigation levels used in the study.

No.	Different treatment combinations used in the study
T1	*Funneliformis mosseae* with 100% evapotranspiration as irrigation
T2	*Funneliformis mosseae* with 80% evapotranspiration as irrigation
T3	*Funneliformis mosseae* with 60% evapotranspiration as irrigation
T4	*Funneliformis mosseae* with 40% evapotranspiration as irrigation
T5	*Funneliformis mosseae* with daily irrigation
T6	*Glomus etunicatum* with 100% evapotranspiration as irrigation
T7	*Glomus etunicatum* with 80% evapotranspiration as irrigation
T8	*Glomus etunicatum* with 60% evapotranspiration as irrigation
T9	*Glomus etunicatum* with 40% evapotranspiration as irrigation
T10	*Glomus etunicatum* with daily irrigation
T11	*Rhizophagus intraradices* with 100% evapotranspiration as irrigation
T12	*Rhizophagus intraradices* with 80% evapotranspiration as irrigation
T13	*Rhizophagus intraradices* with 60% evapotranspiration as irrigation
T14	*Rhizophagus intraradices* with 40% evapotranspiration as irrigation
T15	*Rhizophagus intraradices* with daily irrigation
T16	Non-inoculum with 100% evapotranspiration as irrigation
T17	Non-inoculum with 80% evapotranspiration as irrigation
T18	Non-inoculum with 60% evapotranspiration as irrigation
T19	Non-inoculum with 40% evapotranspiration as irrigation
T20	Non-inoculum with daily irrigation

3.4. METHODOLOGY

The research experiment was conducted with an objective to understand the effect of various levels of water stress on the growth and development of *Swietenia macrophylla* seedlings in pot culture and also to analyze the efficiency of different strains of mycorrhiza in overcoming the various levels of water stress induced artificially.

3.4.1. Procurement and mass multiplication of AMF

Vermipaste-based pure cultures of *Funneliformis mosseae, Glomus etunicatum* and *Rhizophagus intraradices* (Plate 1) were obtained from TERI (The Energy Research Institute, New Delhi). Each had a spore count of 1000 spores in 100g and was stored under refrigeration. Mass multiplication (Plate 3) was carried out in the acquired pure cultures. Grow-bags having a capacity of 5 kg were filled with autoclaved sterile vermiculite. 25 g of the pure culture was added to the vermiculite and *Zea mays* seeds (surface sterilized with 0.1% Sodium hypochlorite for 5 minutes and washed thoroughly with distilled water) were sown in it. The grow bags were irrigated with sterile water. At every 10 days interval, 50 ml of Hoagland's solution (Hoagland and Arnon, 1950) was applied to each of these grow bags. After 45 days, the maize roots were tested for root colonization percentage (Philips and Hayman, 1970). When the root colonization percentage was found to be 80 % or above, the shoots of the maize plants were removed. The root portion along with vermiculite, after mixing up thoroughly, was then stored in a cool place before inoculation (Plate 2).

3.4.2. Preparation of seedlings and inoculation of AMF

Mature pods were collected from 28 year old mature mahogany trees inside the CoF campus. The pods were kept under shade for after-ripening. The pods were then opened to get the seeds, which was dewinged and treated with 100 ppm benzyl adenine (BA) for 12 hours (Vidyasagaran *et al.*, 2014). After pretreatment, the seeds were then sown in the nursery beds (1.2 m x 12.2 m) fumigated with 5 % formaldehyde. The seedlings obtained were then transplanted into polybags of 30 cm x 15 cm filled with fumigated potting mixture (soil, sand and cow dung in 1:1:1 ratio). The seedlings were then arranged according to the experimental layout inside the polyhouse; and were subjected to irrigation regimes and inoculation.

3.4.3. Irrigation scheduling

The evaporation inside the polyhouse was estimated using a Piche evaporimeter (Plate 7) (Domuta *et al.*, 2011). Piche evaporimeter method is one of the indirect methods used for irrigation scheduling. Before scheduling the irrigation regimes, daily evapotranspiration data for 15 days were collected from the Piche evaporimeter and was calibrated against the evaporation data obtained from the local Agrometereological observatory situated 700 meters away. The crop

Plate 1. Vermipaste based pure cultures of arbuscular mycorrhizal fungi obtained from The Energy Research Institute, New Dehi.

Plate 2. Vermiculite based inoculum of arbuscular mycorrhizal fungi obtained after mass multiplication.

Plate 3. Mass multiplication of AMF in grow bags filled with sterile vermiculite and *Zea mays* as host.

evapotranspiration (ET_{crop}) was estimated as a product of reference evapotranspiration (ET_o) and crop coefficient (K_c); reference evapotranspiration being recorded from the Piche evaporimeter. The irrigation regimes at 100, 80, 60 and 40 per cent of cumulative evapotranspiration were then estimated using the available data and irrigation was executed accordingly. A treatment with daily irrigation was maintained as control. The mahogany seedlings (Plate 4) receiving different treatments were irrigated at weekly intervals.

Table 2. Different levels of irrigation applied as treatments.

Treatment	**Irrigation levels (in per cent)**
Control	Treatment with daily irrigation ad abundantium
IW/ET=1	Treatment with irrigation at 100 % ET once weekly
IW/ET=0.8	Treatment with irrigation at 80 % ET once weekly
IW/ET=0.6	Treatment with irrigation at 60 % ET once weekly
IW/ET=0.4	Treatment with irrigation at 40 % ET once weekly

IW= Irrigation water; ET= Crop evapotranspiration

3.5. OBSERVATIONS

3.5.1. Physiological observations

Growth analysis is used to account for growth in terms of functional or structural significance. The different types of growth analysis require different measurements of plant biomass and assimilatory area and methods of computing certain parameters that describe growth. Physiological responses of seedlings belonging to each treatment were taken at monthly intervals.

3.5.1.1. Rate of photosynthesis

The photosynthetic rates of different treatments were recorded using infra-red gas analyzer (LI 6400 Portable photosynthesis System, LI-COR) (Plate 8) and the amount of CO_2 expressed in $\mu mol CO_2\ m^{-2}\ s^{-1}$ (McDermitt *et al.*, 1989).

Plate 4. Visual symptoms of water stress on mahogany seedlings under different levels of irrigation. (A) Mahogany seedlings under daily irrigation (B) Mahogany seedlings under irrigation at IW/ET=1 (C) Mahogany seedlings under irrigation at IW/ET=0.8 (D) Mahogany seedlings under irrigation at IW/ET=0.6 (E) Mahogany seedlings under irrigation at IW/ET=0.4

3.5.1.2. Stomatal conductance

The stomatal conductance of the seedlings belonging to different treatments was recorded using infra-red gas analyzer (LI 6400 Portable photosynthesis System, LI-COR) and expressed as s cm^{-1} (McDermitt *et al.,* 1989).

3.5.1.3. Rate of transpiration

The transpiration rates of seedlings belonging to different treatments were recorded using infra-red gas analyzer (LI 6400 Portable photosynthesis System, LI-COR) model and the amount of H_2O expressed in $\mu molCO_2$ m^{-2} s^{-1}(McDermitt *et al.,* 1989).

3.5.1.4. Leaf temperature

The leaf temperature of the seedlings belonging to different treatments was recorded using a thermocouple attached to the infra-red gas analyzer (LI 6400 Portable photosynthesis System, LI-COR) and expressed in °C (McDermitt *et al.,* 1989).

3.5.1.5. Chlorophyll content

In order to find the effect of AMF inoculation in chlorophyll content at monthly intervals, the chlorophyll content of the seedlings was measured using chlorophyll meter (SPAD-502, Minolta) (Plate 6) from selected three mature leaves from the second whorl (Takebe and Yoneyama, 1989).

3.2.1.6. Relative water content

In order to estimate the relative water content a small portion of leaf was cut and put kept in water for 3 hours. Leaf samples were dried using a blotting paper and turgid weight was measured. These samples were then dried in hot sir oven set a temperature of 120 °C for two days and dry weight was taken (Weatherley, 1950). The RWC was calculated based on the formula

$$\text{Relative Water Content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.5.1.7. Plant water potential

The water potential of the seedlings belonging to different treatments was measured with the aid of plant water status console (Plate 5) (Scholander *et al.*, 1965). The pre-drawn water potential was recorded by cutting leaf from the plant with a sharp blade and taking immediate reading in the instrument. The readings were taken as soon as the leaves were collected in order to avoid errors due to water loss through the cut ends. Water potential was expressed in MPa.

3.5.1.8. Leaf area ratio

The term Leaf Area Ratio (LAR) suggested by Radford (1967), expressed the ratio between the leaf area lamina to the plant biomass. LAR can also be described as the leafiness of a plant or amount of leaf area formed per unit biomass and expressed in cm^2g^{-1} of plant dry weight.

$$\text{Leaf Area Ratio} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

3.5.1.9. Leaf weight ratio

Leaf weight ratio is expressed as the dry weight of leaves to whole plant dry weight (Kvet *et al.,* 1971).

$$\text{Leaf Weight Ratio} = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$$

3.5.1.10. Specific leaf area

Specific leaf area is a measure of the leaf area of the plant to leaf dry weight and expressed in cm^2gm^{-1} (Kvet *et al.,* 1971).

$$\text{Specific leaf weight} = \frac{\text{leaf area}}{\text{leaf weight}}$$

Plate 5. Measurement of plant water status using pressure bomb apparatus.

Plate 6. Measurement of chlorophyll content using SPAD meter.

Plate 7. Pische's evaporimeter used for measuring evapotranspiration.

Plate 8. Infrared gas analyzer used for measuring physiological attributes.

3.5.1.11. Specific leaf weight

It is a measure of leaf weight per unit leaf area. Therefore, it is a ratio expressed as gcm^{-2} (Pearce *et al.,* 1969).

$$\text{Specific leaf weight} = \frac{\text{leaf weight}}{\text{leaf area}}$$

3.5.1.12. Absolute growth rate

Absolute Growth Rate is the total gain in height by a plant within a specific time interval (Hunt, 1990). It is generally expressed as cm/day.

$$\text{Absolute Growth Rate} = \frac{h_2 - h_1}{t_2 - t_1}$$

Where,

h_1 = plant height at time (t_1)

h_2 = plant height at time (t_2)

3.5.1.13. Relative growth rate

Relative growth rate (RGR) expresses the increase in total plant dry weight in a time interval in relation to the initial weight. It is the dry matter increment per unit biomass per unit and expressed is as dry weight/unit dry weight/ unit time ($g\ g^{-1}\ day^{-1}$) (Williams, 1946).

$$\text{Relative Growth Rate} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where,

W_1 = whole plant dry weight at time (t_1)

W_2 = whole plant dry weight at time (t_2)

3.5.1.14. Net assimilation rate

Net Assimilation Rate (NAR) is defined as dry matter increment per unit leaf area per unit time (Williams, 1946). The NAR is a measure of the average photosynthesis efficiency of leaves in a crop community. It is expressed as the grams of dry weight per unit weight or area per unit time ($g\ g^{-1} day^{-1}$).

$$\text{Net Assimilatory Rate} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{(\log_e L_2 - \log_e L_1)}{(L_2 - L_1)}$$

Where,

W_1 and W_2 is dry weight of whole plant at time t_1 and t_2 respectively

L_1 and L_2 are leaf weights or leaf area at t_1 and t_2 respectively

t_1 - t_2 are time interval days

3.5.2. Biometric observations

From each replication, three seedlings were randomly selected. These were then subjected to destructive analysis at 30, 60, 90, 120, 150 and 180 days after treatments. The observations recorded are given below.

3.5.2.1. Shoot height

The height of the seedlings was measured from collar to the terminal bud with a meter scale and expressed in centimetres.

3.5.2.2. Tap root length

The length of the tap root was recorded in centimetres from collar to the tip.

3.5.2.3. Collar diameter

Digital Vernier calliper was used to record the collar diameter of the seedlings. The collar diameters were measured in millimetres along two diametrically opposite directions of the seedlings.

3.5.2.4. Leaf area

Leaf area was measured using a leaf area meter (LI 3100, LI-COR) and was expressed in cm^2.

3.5.2.5. Number of leaves

Number of leaves retained and functional leaves (fully opened) were counted and recorded.

3.5.2.6. Number of lateral roots

Number of lateral roots produced by individual seedlings was recorded.

3.5.2.7. Fresh weight of leaves

The fresh weight of leaves was recorded using an electronic balance and expressed in gram.

3.5.1.8. Fresh weight of roots

The fresh weight of roots was recorded using electronic balance and expressed in gram.

3.5.2.9. Fresh weight of shoot

The fresh weights of shoots were recorded using an electronic balance and expressed in gram.

3.5.2.10. Dry weight of leaves

After measuring fresh weight, the leaves portion of the seedlings was dried in hot air oven at a temperature of 80°C for 48 hours. The dry weight was also recorded using an electronic weighing balance and expressed in gram.

3.5.2.11. Dry weight of roots

The root portion of the seedlings was dried in hot air oven at a temperature of 80°C for about 48 hours. The dry weight was recorded using an electronic weighing balance and expressed in gram.

3.5.2.12. Dry weight of shoots

After measuring fresh weight, the shoot portion of the seedlings was dried in hot air oven at a temperature of 80°C for 48 hours. The dry weight was also recorded using an electronic weighing balance and expressed in gram.

3.5.2.13. Total fresh weight

The total fresh weight of the seedlings was worked out by adding the fresh weight of shoots, leaves and roots, and is expressed in grams.

3.5.2.14. Total dry weight

Total dry weight was worked out by adding the dry weight of shoot, leaves and roots, and is expressed in grams.

3.5.2.15. Shoot-root length ratio

Shoot-root length ratio was worked out at monthly intervals using the formula

$$\text{Shoot-root length ratio} = \frac{\text{Shoot length (cm)}}{\text{Root length (cm)}}$$

3.5.2.16. Shoot-root biomass ratio

Shoot-root biomass ratio was worked out at monthly intervals using the formula

$$\text{Shoot- root biomass ration} = \frac{\text{Shoot weight (g)}}{\text{Root weight (g)}}$$

3.5.2.17. Vigour index I

The vigour index I of the seedlings was calculated using the formula (Kharb *et al.*, 1994).

$$\text{Vigour index I} = \frac{\text{Germination percentage} \times (\text{Shoot length} + \text{Total seedling length})}{100}$$

3.5.2.18. Vigour index II

The vigour index II of the seedlings was calculated using the formula (Kharb *et al.*, 1994).

$$\text{Vigour index I} = \frac{\text{Germination percentage} \times \text{Seedling dry weight}}{100}$$

3.5.3. Per cent of AMF association

3.5.3.1. Root colonisation per cent

The per cent AMF colonization in the roots of different treatments was determined at 150 and 180 days (Plate 9) (Phillips and Hayman, 1970). The root samples were washed with distilled water and cut into bits of one centimetre length. The root bits were then fixed with FAA (Formaldehyde: Acetic acid: Alcohol) solution for 24 hours. The roots were then treated with 10 per cent KOH solution and cleared by boiling at 90^0 C for about 60 minutes. The KOH solution is decanted and excessive KOH is neutralized with two per cent hydrochloric acid for 10 minutes. The root segments were then stained with 0.05 per cent trypan blue in lacto phenol. This mixture is gently heated at 80^0 C for 10 minutes. The stained roots are then arranged on a clean slide covered with cover slips. The root bits are then examined under a compound microscope for the presence of mycelium, vesicles and arbuscules. The AMF colonisation per cent was calculated from the formula.

$$\text{AMF colonization per cent} = \frac{\text{Number of root bits of positive AMF colonization}}{\text{Total number of root bits observed}} \times 100$$

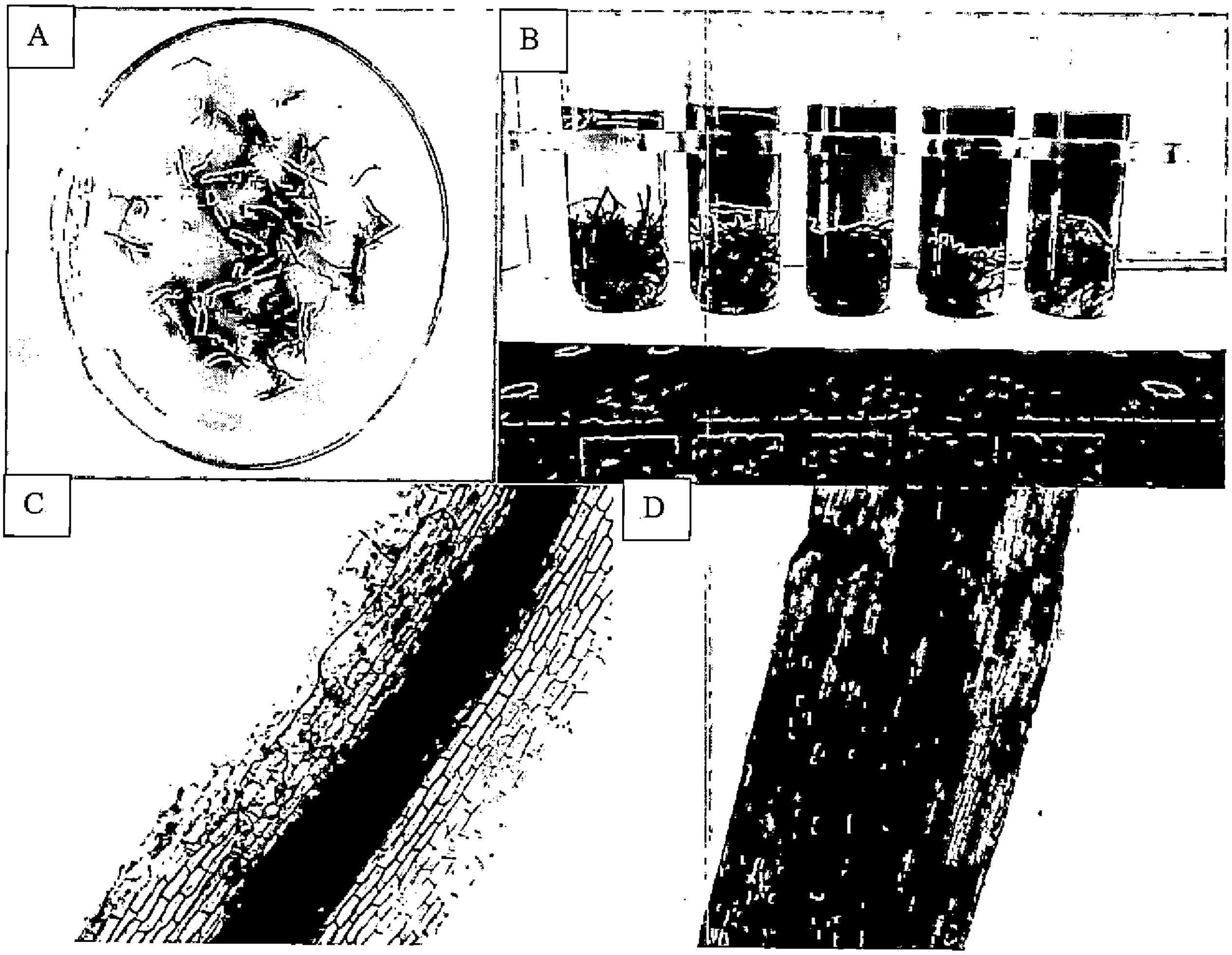


Plate 9. Determination of root colonization percentage (A) Root samples cut into segments of one centimeter length (B) Root segments stained with 0.05 per cent trypan blue in lacto phenol (C) Root segments examined under a compound microscope showing mycelium (D) Root segments examined under a compound microscope showing vesicles

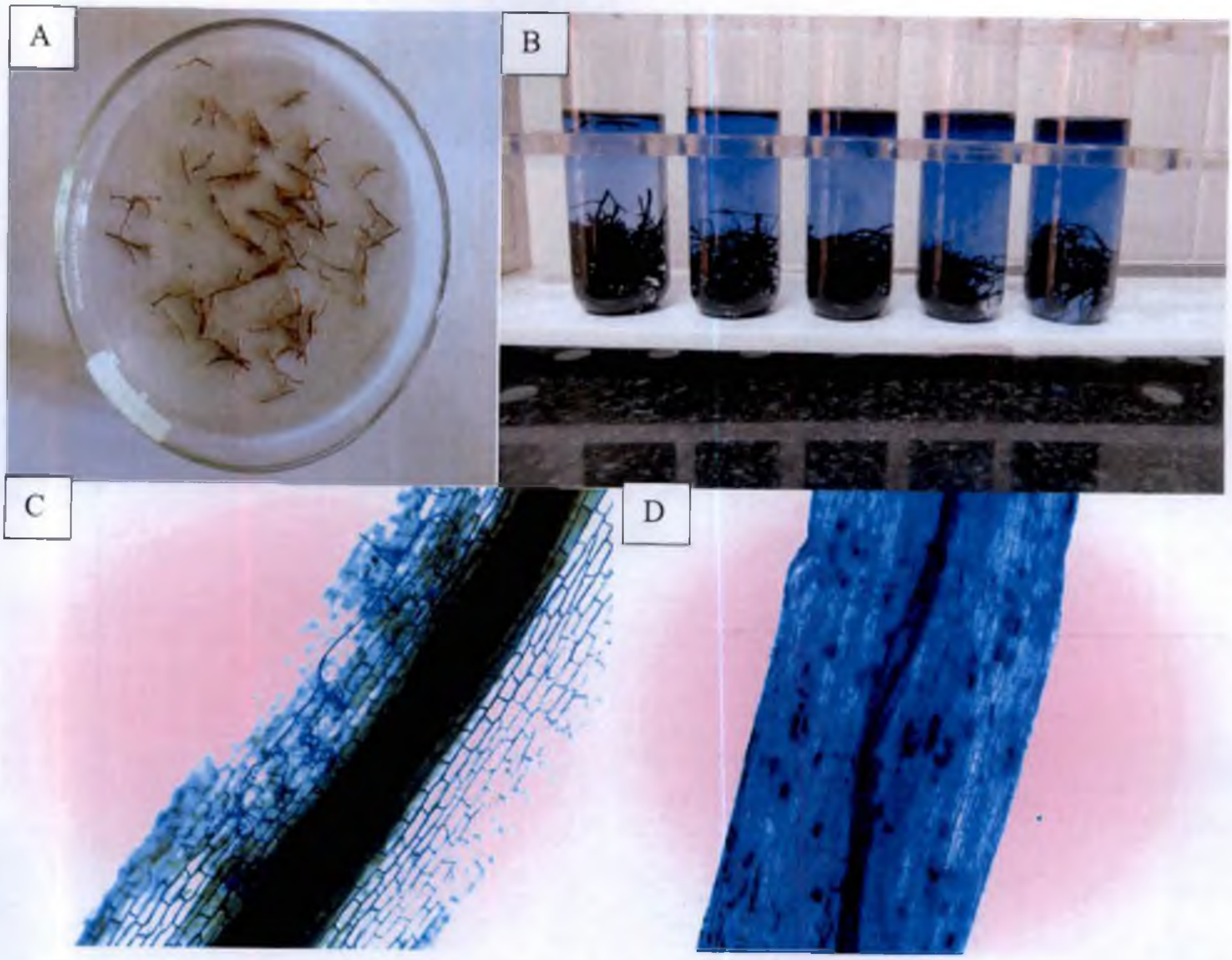


Plate 9. Determination of root colonization percentage (A) Root samples cut into segments of one centimeter length (B) Root segments stained with 0.05 per cent trypan blue in lacto phenol (C) Root segments examined under a compound microscope showing mycelium (D) Root segments examined under a compound microscope showing vesicles

3.5.3.2. Total spore count

The extramatrical chlamydospores produced by the AMF were estimated using the wet sieving and decanting technique (Plate 10) (Gerdemann and Nicolson, 1963). Twenty five grams of the freshly collected soil samples from each poly bag is put into 1 litres of plastic beaker. It is then suspended with about 250 ml of tap water. Soil macro-aggregates are crushed with hands and thoroughly stirred. The suspension after settling down was then passed through a series of sieves ranging from 600, 300, 212, 150, 105 and 45 μm kept one below the other in the order. Remove each sieve, each time washing down the contents to lower sieves using a jet of water. The contents of the 105 and 45 μm sieves are transferred to a 100 ml beaker. It is then transferred to a nylon mesh (45μm) or Whatman No.1 filter paper placed in Petri dish separately. The Petri dish containing the nylon mesh or Whatman No.1 filter paper with the spores was observed under stereo microscope (Plate 11, 12) and the total AMF spore count was estimated and expressed per gram of inoculum.

3.5.5. Quality assessment of seedlings

The biometric observations obtained from the seedlings were used to calculate the seedling quality indices.

3.5.5.1. Quality index

Dickson's quality index (Dickson *et al.,* 1960) is used to assess the quality of seedling based on the height, stem diameter and dry biomass. It is calculated using the following formula (Hatchell, 1985).

$$\text{Quality index} = \frac{\text{Seedling dry biomass (g)}}{\frac{\text{Height (cm)}}{\text{Diameter (mm)}} + \text{Top dry biomass(g)}}$$

3.5.5.2. Biovolume index

Biovolume index is a non-destructive method to estimate the quality of the seedlings. It is calculated using the formula suggested by Hatchell (1985).

$$\text{Biovolume index} = \text{Plant height (cm)} \times \text{Stem diameter (mm)}$$

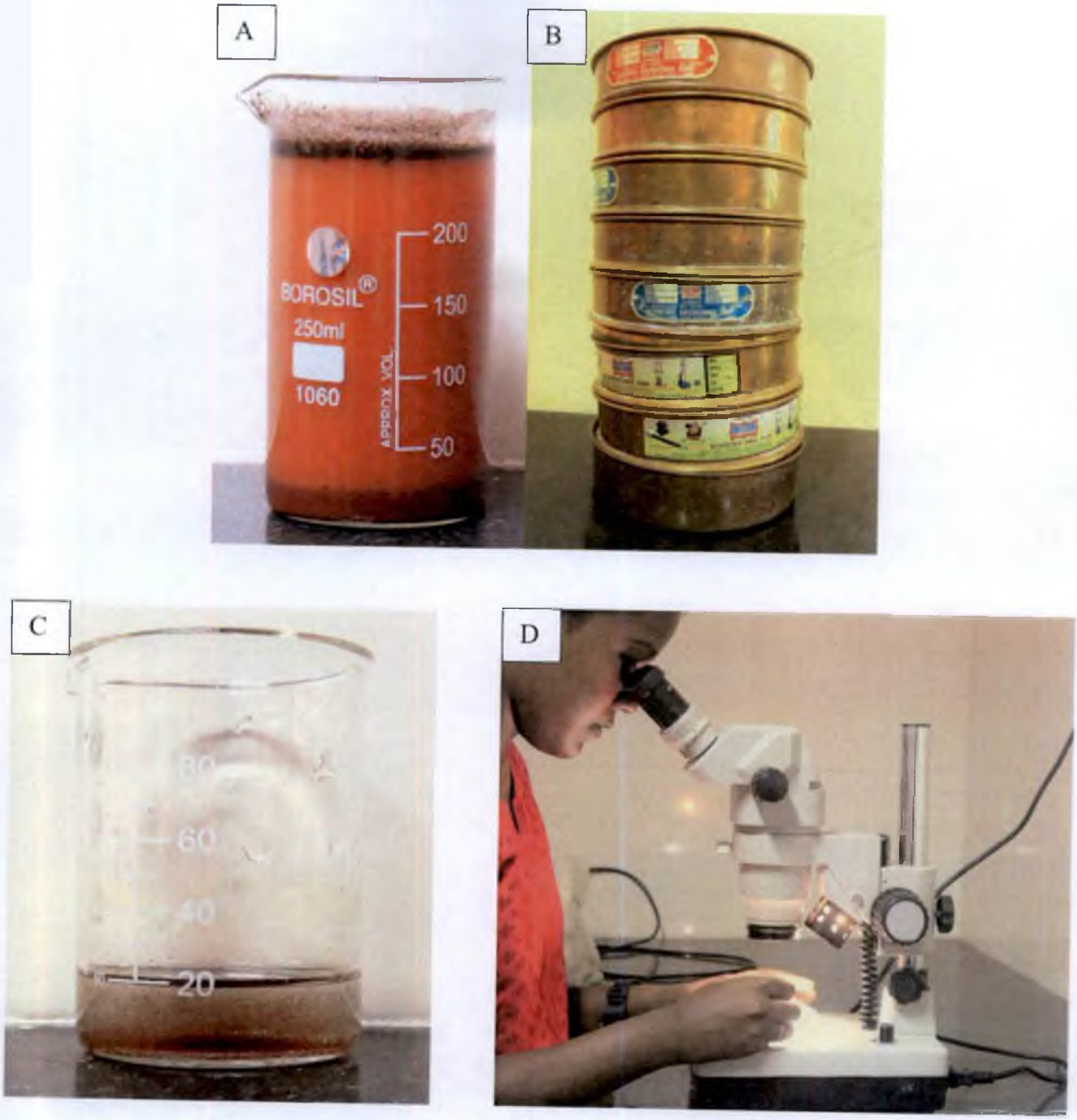


Plate 10. Wet sieving method (A) Soil samples suspended with tap water (B) Sieves for isolation of AMF (C) AMF spores collected in a beaker after wet sieving (C) AMF spores counted and picked with tooth-pick under stereomicroscope

Plate 11. Identification of AMF spores using compound microscope after wet sieving method.

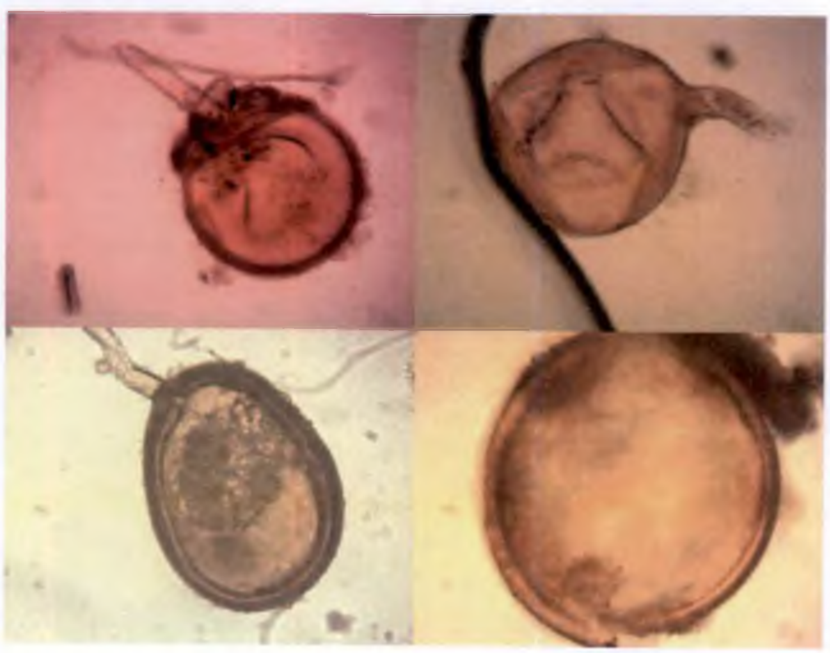


Plate 12. AMF spores obtained after wet sieving method

3.5.5.3. Mycorrhizal Efficiency Index

Mycorrhizal efficiency index (MEI) or Mycorrhizal Inoculation Efficiency or Mycorrhizal Dependency allows assessment of the growth improvement by mycorrhizal fungus (Secilia and Bagyaraj, 1994).

Mycorrhizal Use Efficiency index (MUE) =

$$\frac{\text{Dry matter of inoculated plant} - \text{Dry matter of non inoculated plant}}{\text{Dry matter of inoculated plant}} \times 100$$

Results

4. RESULTS

The results pertaining to the research experiment titled "Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* King. seedlings" are described in this chapter. A total of 20 treatment combinations, with four different irrigation levels and three arbuscular mycorrhizal fungi (AMF) species were used. Treatment with normal daily irrigation and non-inoculated seedlings were used as controls. One month after the application of treatments, various physiological and biometric parameters were studied at monthly interval, for six months.

4.1. PHYSIOLOGICAL OBSERVATIONS

4.1.1. Rate of photosynthesis

Different AMF species and irrigation regimes had significant effect on the photosynthetic rate of the seedlings (Table 4). A significant reduction in the rate of photosynthesis was observed for the non- inoculated seedlings throughout the experiment. Between the three AMF species, no significant difference was observed at 30 days after inoculation while significant difference was observed at 60, 90,120 and 150 days. At 60 days, seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher values of photosynthesis (3.16 and 2.98 μmolCO_2 m-^{2} s^{-1}respectively) while *F. mosseae* had lower value (2.55 μmolCO_2 m-^{2} s^{-1}). At 90 and 120 days, the seedlings treated with *R. intraradices* and *G. etunicatum* did not differ; while, lowest values were recorded again for *F. mosseae* (1.16 and 2.21 μmolCO_2 m-^{2} s^{-1}). At 150 days, the seedlings inoculated with *G. etunicatum* had the highest value (3.13 μmolCO_2 m-^{2} s^{-1}) while, lower values were recorded for *F. mosseae* (1.63 μmolCO_2 m-^{2} s^{-1}). No significant differences were observed between treatments at 180 days.

While considering the different irrigation regimes, it was found that, there was no significant difference between the control and the treatment IW/ET=1 after 30 days. The highest value (4.31 μmolCO_2 m-^{2} s^{-1}) was noted for the treatment IW/ET=1 and the lowest value (2.09 μmolCO_2 m-^{2} s^{-1}) was observed for IW/ET=0.4. At 60 days, the highest value (4.29 μmolCO_2 m-^{2} s^{-11}) was observed for IW/ET=0.8 and the lowest value (1.75 μmolCO_2 m-^{2} s^{-11}) for IW/ET= 0.4. The treatment IW/ET=1 and IW/ET=0.8 had higher values (1.59 and 1.58 μmolCO_2 m-^{2} s^{-1}) while, IW/ET=0.4 had lowest values (0.78 μmolCO_2 m-^{2} s^{-11}) at 90 days. At 120 and 150 days, the control treatment had higher values (3.4 and 3.32 µmolCO_2 m-^{2} s^{-1}respectively) while, lower values (1.75 and 1.05 µmolCO_2 m-^{2} s^{-11}) were recorded for IW/ET=0.4. At 180 days, highest value (2.98 µmolCO_2 m-^{2} s^{-1}) was obtained for treatment IW/ET=0.8 and the lowest (1.12 µmolCO_2 m-^{2} s^{-1}) for IW/ET=0.4.

Table 4. Rate of photosynthesis (µmolCO_2 m-^{2} s^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Rate of photosynthesis (µmolCO_2 m-^{2} s^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	3.97	2.05^c	1.04^c	1.52^c	1.62^c	1.60
	R. intraradices	3.66	3.16^a	1.44^a	3.75^a	2.49^b	1.68
	G. etunicatum	3.69	2.98^a	1.29^{ab}	3.68^a	3.13^a	2.00
	F. mosseae	3.54	2.55^b	1.16^{bc}	2.21^b	1.63^c	1.84
	F value	**0.49^{ns}**	**10.38***	**5.34***	**38.02***	**13.73***	**2.41^{ns}**
Irrigation	Control	4.71^a	3.07^b	1.12^b	3.40^a	3.32^a	1.50^c
	IW/ET=1	4.91^a	2.31^c	1.59^a	2.29^a	2.35^b	1.92^b
	IW/ET=0.8	4.31^b	4.29^a	1.58^a	2.52^b	3.12^a	2.98^a
	IW/ET=0.6	3.44^c	2.00^{cd}	1.09^b	2.98^{ab}	1.25^c	1.40^{cd}
	IW/ET=0.4	2.09^d	1.75^d	0.78^c	1.75^c	1.05^c	1.12^d
	F value	**73.76***	**35.80***	**17.19***	**11.23***	**21.92***	**32.21***
AMF x Irrigation	**F value**	**7.32***	**13.44***	**8.22***	**6.20***	**6.86***	**7.28***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant throughout the period of study (Figure 1). At 30 days, higher rate of photosynthesis was recorded for seedlings not inoculated with AMF under the treatment IW/ET=1.0 (5.45 µmolCO_2 m-^{2} s^{-1}). At 60 days, however, higher rate of photosynthesis was recorded for seedlings inoculated with *R. intraradices* under the treatment IW/ET=0.8 (5.78 µmolCO_2 m-^{2} s^{-1}). Higher rates of photosynthesis, at 90 days were recorded for non-inoculated seedlings (1.96 µmolCO_2 m-^{2} s^{-1}) as well as seedlings inoculated with *R. intraradices* and *F. mosseae* (1.89 µmolCO_2 m-^{2} s^{-1}and 1.86 µmolCO_2 m-^{2} s^{-1}) under the

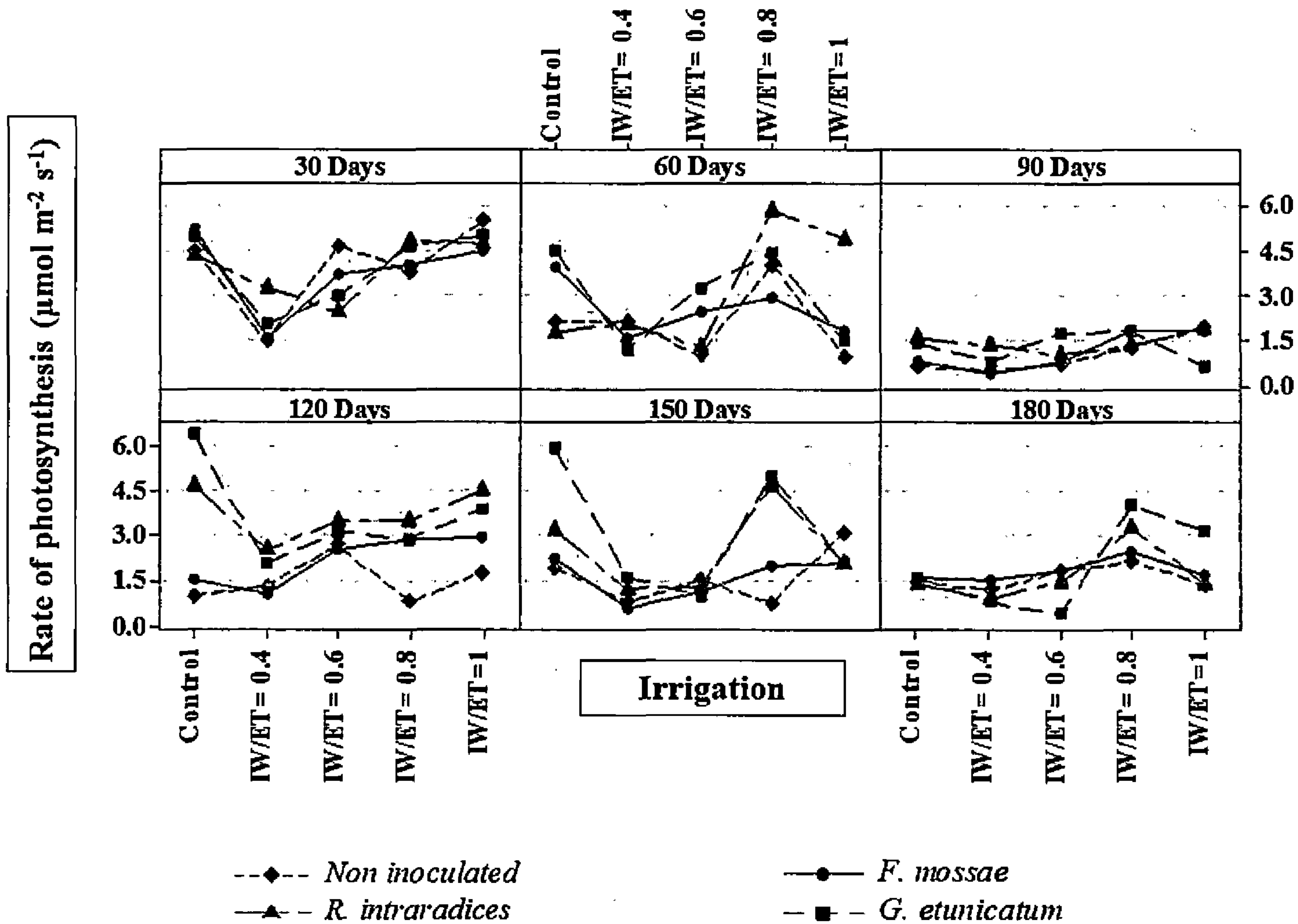


Figure 1. Rate of photosynthesis (µmol m^{-2} s^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

treatment IW/ET=1.0. At 120 and 150 days, higher rates of photosynthesis were observed for seedlings inoculated with *G. etunicatum* under control irrigation treatment (6.40 µmolCO_2 m^{-2} $s^{-1}$and 5.93 µmolCO_2 m^{-2} s^{-1}).At 180 days, seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.8 recorded higher values (4.04 µmolCO_2 m^{-2} s^{-1}).

4.1.2. Stomatal conductance

The variation in stomatal conductance due to the application of different AMF species and irrigation regimes are shown in Table 5. There was a significant variation in the stomatal conductance of seedlings when treated with different AMF species. The non-inoculated seedlings had lower stomatal conductance throughout the period of experiment. Among different AMF species, *G. etunicatum* (0.087 s cm^{-1}) and *F. mosseae* (0.108 s cm^{-1}) had higher values at 30 and 60 days respectively. Even though, there was no significant difference among AMF treatments with respect to stomatal conductance after 90 days, they differed at 120 and 150 days. At 120 and 150 days, seedlings inoculated with *R. intraradices* (0.076 s cm^{-1} and 0.027 s cm^{-1} respectively) and *G. etunicatum* (0.080 s cm^{-1} and 0.033 s cm^{-1} respectively) recorded higher stomatal conductance, when compared to the other treatments. However, after 180 days, seedlings treated with *G. etunicatum* had the highest (0.033 s cm^{-1}) value.

Among the different irrigation regimes, IW/ET=0.6 recorded the highest value (0.082 s cm^{-1}) while, IW/ET=0.4 and control recorded the lower (0.058 s cm^{-1}) stomatal conductance for seedlings after 30 days. However, at 60 days, IW/ET=0.8 had the highest values (0.118 s cm^{-1}) while, there was no significant differences among other treatments. The treatments IW/ET=1 (0.108 s cm^{-1}) and IW/ET=0.8 (0.128 s cm^{-1}) had higher conductance after 90 days; whereas, IW/ET=0.4 (0.036 s cm^{-1}) had the lowest conductance. At 120 days, the treatment IW/ET=0.8 (0.085 s cm^{-1}) and control (0.088 s cm^{-1}) had higher stomatal conductance and IW/ET=0.4 had the least (0.030 s cm^{-1}). IW/ET=1 exhibited highest stomatal conductance (0.035 s cm^{-1}) after 150 days; while, IW/ET=0.04 had the lowest (0.022 s cm^{-1}). At 180 days, IW/ET=1 recorded the highest (0.040 s cm^{-1}) value.

The effect of interaction was found to be significant throughout the period of study (Figure 2). At 30 days, higher stomatal conductance (0.150 s cm^{-1}) was recorded for seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.6. Seedlings inoculated with *F.*

mosseae (0.166 s cm^{-1}) under the treatment IW/ET=0.8 recorded higher stomatal conductance at 60 days. At 90 days, higher stomatal conductance was recorded for seedlings not inoculated with AMF under the treatment IW/ET=0.8 (0.171 s cm^{-1}). At 150 days, higher stomatal conductance was recorded for seedlings inoculated with *R. intraradices* under the treatment IW/ET=0.6 (0.040 s cm^{-1}). At 120 and 180 days, seedlings inoculated with *G. etunicatum* under control treatment and treatment IW/ET=1.0 had higher values (0.126 s $cm^{-1}$and 0.108 s cm^{-1}).

Table 5. Stomatal conductance (s cm^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Stomatal conductance (s cm^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.056^{b}	0.060^{c}	0.074	0.064^{b}	0.033^{b}	0.018^{b}
	R. intraradices	0.068^{b}	0.087^{ab}	0.079	0.076^{a}	0.027^{a}	0.016^{b}
	G. etunicatum	0.087^{a}	0.079^{bc}	0.080	0.080^{a}	0.033^{a}	0.033^{a}
	F. mosseae	0.068^{b}	0.108^{a}	0.087	0.065^{b}	0.027^{b}	0.003^{b}
	F value	**4.25***	**5.93***	**0.66^{ns}**	**19.71***	**23.36***	**9.16***
Irrigation	Control	0.058^{b}	0.079^{b}	0.064^{b}	0.088^{a}	0.024^{c}	0.019^{b}
	IW/ET=1	0.075^{ab}	0.067^{b}	0.108^{a}	0.075^{b}	0.035^{a}	0.040^{a}
	IW/ET=0.8	0.076^{ab}	0.118^{a}	0.128^{a}	0.085^{a}	0.035^{a}	0.013^{b}
	IW/ET=0.6	0.082^{a}	0.074^{b}	0.064^{b}	0.079^{b}	0.032^{a}	0.014^{b}
	IW/ET=0.4	0.058b	0.078^{b}	0.036^{c}	0.030^{c}	0.022^{d}	0.018^{b}
	F value	**2.58***	**4.66***	**23.58***	**126.34***	**90.91***	**13.04***
AMF x Irrigation	**F value**	**4.71***	**3.97***	**7.75***	**47.88***	**12.83***	**13.73***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.1.3. Rate of transpiration

The seedlings inoculated with AMF had higher transpiration rates at 30 and 60 days; and they differed significantly from non-inoculated seedlings. At 90 days, *F. mosseae* and non-inoculated seedlings had higher transpiration values (3.02 and 3.16 μmolCO_2 m^{-2} s^{-1}), while *G.*

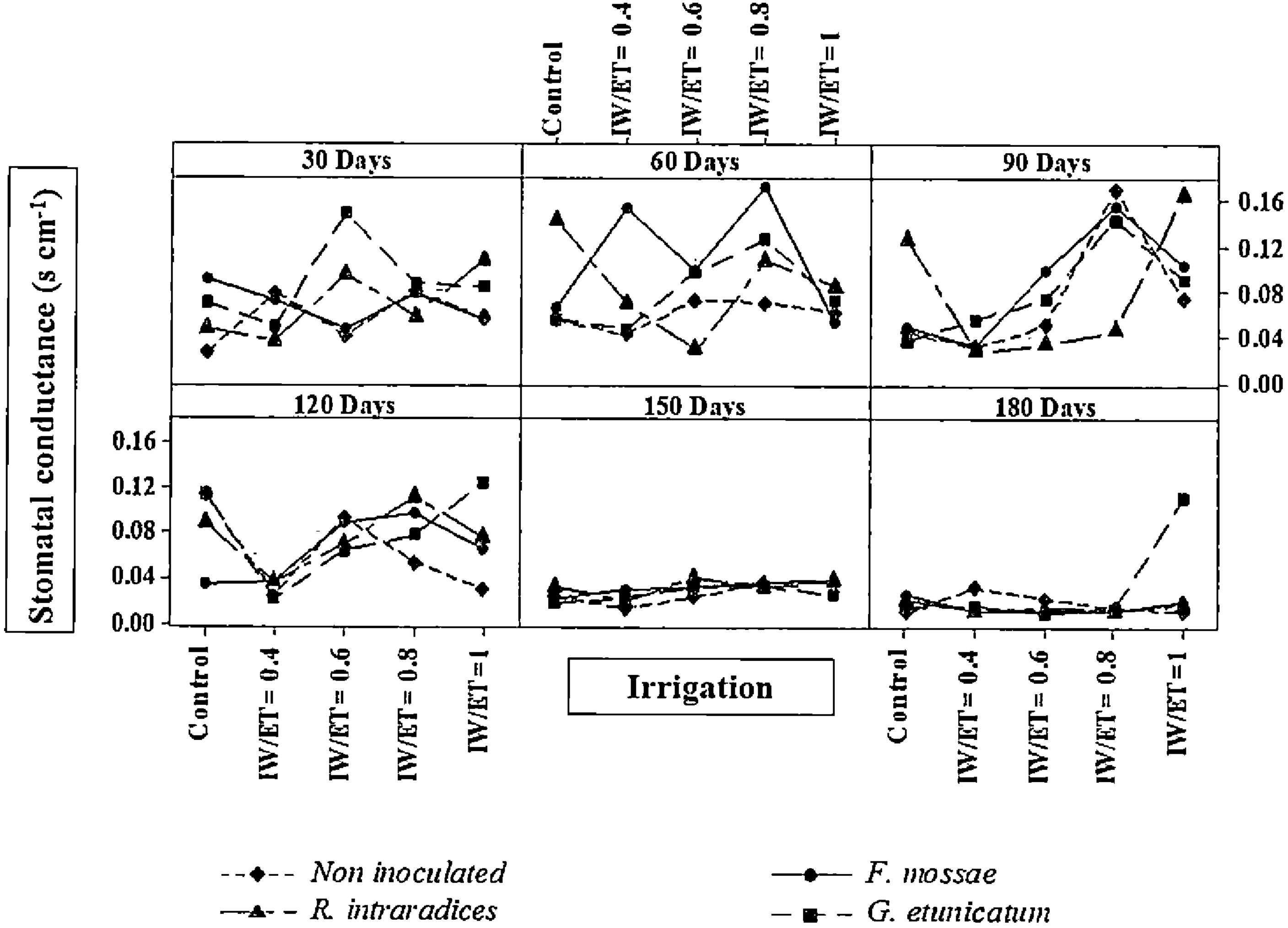


Figure 2. Stomatal conductance (s cm^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

etunicatum (2.61 µmolCO_2 m-^{2} s^{-1}) had the lowest. No significant difference was found between the transpiration rates for seedlings inoculated with different AMF species while; the non-inoculated seedlings recorded the least value (0.97 µmolCO_2 m-^{2} s^{-1}) after 120 days. At 150 and 180 days, *G. etunicatum* recorded the higher values (2.01 µmolCO_2 m-^{2} s^{-1} and 1.06 µmolCO_2 m-^{2} s^{-1} respectively) while; the control seedlings had the lower values (1.64 µmolCO_2 m-^{2} s^{-1} and 0.87 µmolCO_2 m-^{2} s^{-1} respectively) (Table 6).

Table 6. Rate of transpiration (µmolCO_2 m-^{2} s^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Rate of transpiration (µmolCO_2 m-^{2} s^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	2.36^b	4.02^b	3.16^a	0.97^b	1.64^b	0.87^d
	R. intraradices	2.83^{ab}	4.48^{ab}	2.88^b	1.19^a	1.99^a	0.94^c
	G. etunicatum	3.39^a	4.27^{ab}	2.61^c	1.19^a	2.01^a	1.06^a
	F. mosseae	2.85^{ab}	4.91^a	3.02^{ab}	1.14^a	1.69^b	0.99^b
	F value	**4.39***	**2.68***	**9.08***	**11.90***	**24.80***	**19.93***
Irrigation	Control	2.73^a	4.01^{bc}	3.22^a	0.72^d	1.61^c	1.03^b
	IW/ET=1	3.26^a	3.46^c	3.10^a	1.75^a	2.20^a	0.94^c
	IW/ET=0.8	3.29^a	5.77^a	3.21^a	1.04^c	2.20^a	1.11^a
	IW/ET=0.6	3.11^b	4.47^b	2.64^b	0.80^d	1.80^b	0.90^{cd}
	IW/ET=0.4	1.91^b	4.39^b	2.43^b	1.31^b	1.35^d	0.86^d
	F value	**6.53***	**10.97***	**17.19***	**150.49***	**70.66***	**24.79***
AMF x Irrigation	**F value**	**4.57***	**6.99***	**17.34***	**46.57***	**9.26***	**21.14***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

At 30 and 90 days, IW/ET=1 (3.26 and 3.10 µmolCO_2 m-^{2} s^{-1}), IW/ET=0.8 (3.29 and 3.21 µmolCO_2 m-^{2} s^{-1}) and control treatments (2.73 and 3.22 µmolCO_2 m-^{2} s^{-1}) had similar higher values while, IW/ET=0.6 (3.11 and 2.64 µmolCO_2 m-^{2} s^{-1}) and IW/ET=0.4 (1.91 and 2.43 µmolCO_2 m-^{2} s^{-1}) recorded lower values. At 60 days, however, IW/ET=0.8 had the highest value (5.77 µmolCO_2 m-^{2} s^{-1}) while, IW/ET=1 had the lowest value (3.46 µmolCO_2 m-^{2} s^{-1}). The

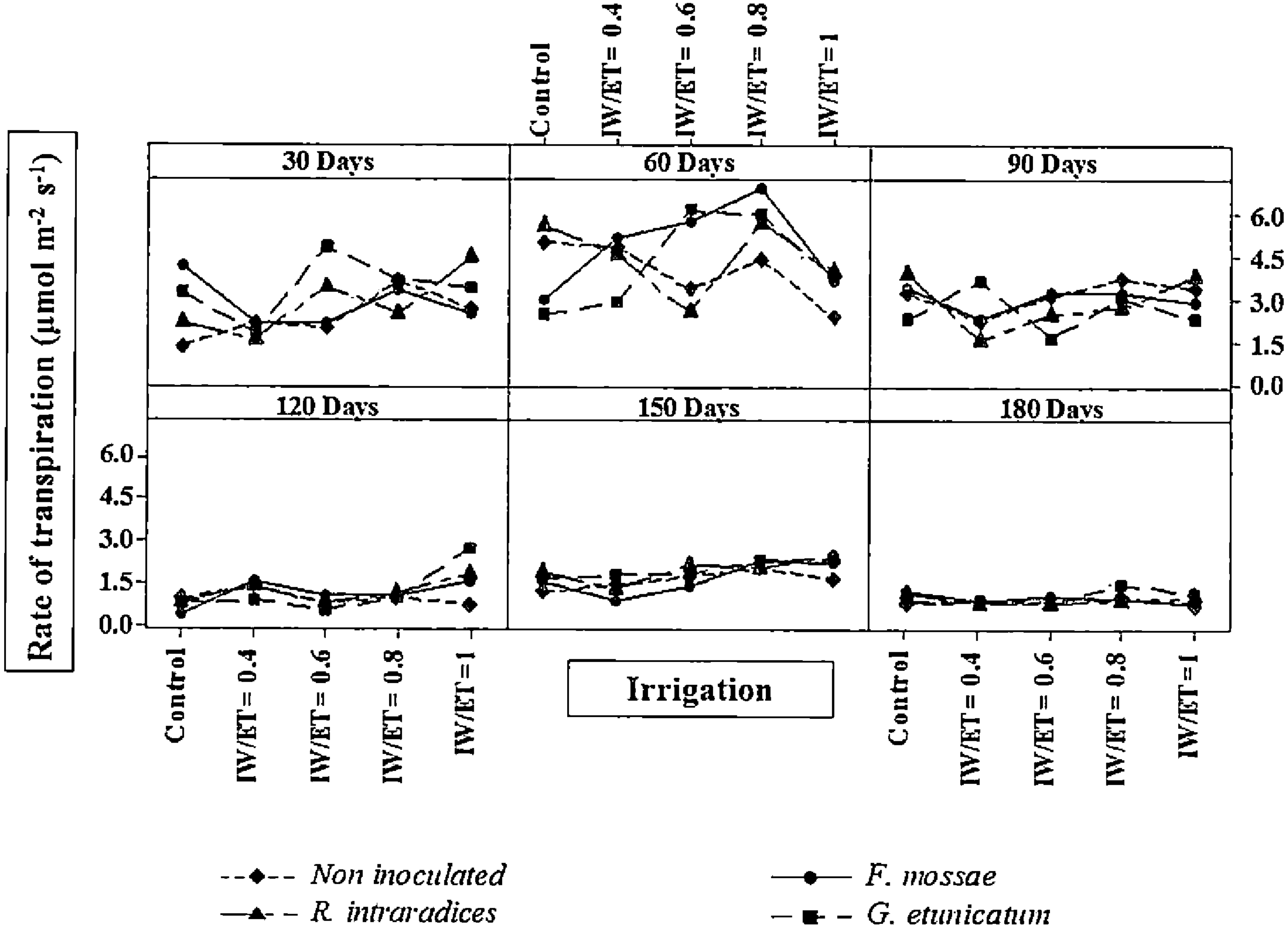


Figure 3. Rate of transpiration (µmol m^{-2} s^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

treatment IW/ET=1 (1.75 μmolCO_2 m^{-2} s^{-1}) recorded highest value at 120 days while, IW/ET=0.6 (0.80 μmolCO_2 m^{-2} s^{-1}) and control treatment (0.72 μmol m^{-2} s^{-1} μmolCO_2 m^{-2} s^{-1}) had higher values and IW/ET=0.4 (1.35 μmolCO_2 m^{-2} s^{-1}) had the least. The treatment IW/ET=0.8 displayed higher values (1.11 μmolCO_2 m^{-2} s^{-1}) after 180 days while, IW/ET=0.4 recorded the least once again (0.86 μmolCO_2 m^{-2} s^{-1}).

The effect of interaction was found to be significant throughout the period of study (Figure 3). At 30, 120 and 180 days, seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.6, control irrigation and treatment IW/ET=1.0 recorded higher transpiration rates (4.87 μmolCO_2 m^{-2} s^{-1}, 2.81 μmolCO_2 m^{-2} s^{-1} and 1.51 μmolCO_2 m^{-2} s^{-1}). At 60 days, however, higher rate of transpiration was observed for seedlings inoculated with *F. mosseae* under the treatment IW/ET=0.8 (6.93 μmolCO_2 m^{-2} s^{-1}). At 90 days, higher transpiration rates (3.89 μmolCO_2 m^{-2} s^{-1}) was recorded for seedlings inoculated with *R. intraradices* under the control treatment. Seedlings inoculated with *R. intraradices* and *G. etunicatum* under the irrigation treatment IW/ET=1.0 had higher values at 150 days (2.44 and 2.43 μmolCO_2 m^{-2} s^{-1}).

4.1.4. Leaf temperature

The leaf temperature of mahogany seedlings, when inoculated with different AMF species under various irrigation regimes over a period of 180 days is given in the Table 7. At 30 days, there were no significant differences between the AMF inoculated seedlings and non-inoculated seedlings. The highest leaf temperature was recorded for the non-inoculated seedlings (34.24 ^{0}C) and the least for *R. intraradices* (33.7^0 C), *G. etunicatum* (34.05 ^{0}C) and *F. mosseae* (33.79 ^{0}C) inoculated seedlings. At 60 days, however, the control seedlings (39.37 ^{0}C) and those inoculated with *F. mosseae* (39.19 ^{0}C) had higher temperature; while, *G. etunicatum* (37.77 ^{0}C) had the lowest temperature. At 90 and 120 days of treatment, the non-inoculated seedlings had higher temperature (39.05 ^{0}C and 33.7 ^{0}C respectively) whereas seedlings inoculated with *G. etunicatum* displayed lowest leaf temperature (35.19 ^{0}C and 32.43 ^{0}C respectively). No significant differences in leaf temperatures were noticed after 150 days. At 180 days, seedlings inoculated with *G. etunicatum* (41.07 ^{0}C) exhibited lowest leaf temperature while, the others had higher leaf temperature.

While considering the various irrigation regimes, the control seedlings maintained a lower leaf temperature while the treatment IW/ET=0.4 exhibited higher temperature consistently. At 60, 90 and 180 days, however, the treatment IW/ET=1 recorded the lowest values (36.13 ^{0}C, 34.82 ^{0}C and 39.39 ^{0}C).

Table 7. Leaf temperature (^{0}C) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Leaf temperature (^{0}C)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	34.24^a	39..37^a	39.05^a	33.70^a	41.96	42.67^a
	R. intraradices	33.70^b	37.41^{ab}	37.62^{ab}	32.67^c	42.12	42.89^a
	G. etunicatum	34.05^{ab}	37.77^b	35.19^c	32.43^c	42.11	41.07^b
	F. mosseae	33.79^{ab}	39.19^a	36.56^{bc}	33.27^b	41.85	43.11^a
	F value	**2.09***	**2.83***	**5.46***	**37.86***	**0.82^{ns}**	**9.04***
Irrigation	Control	30.26^d	36.67^b	32.61^c	28.77^e	40.13c	41.79^b
	IW/ET=1	33.61^c	36.13^b	34.82^b	35.24^b	41.95^b	39.39^c
	IW/ET=0.8	34.97^b	37.18^b	40.30^a	29.53^d	41.99^b	43.21^a
	IW/ET=0.6	34.99^b	40.46^a	36.66^b	30.88^c	41.69^b	43.96^a
	IW/ET=0.4	35.90^a	41.73^a	41.17^a	40.67^a	44.29^a	43.82^a
	F value	**133.62***	**14.42***	**21.24***	**22.36**	**87.99***	**30.64***
AMF x Irrigation	**F value**	**16.49***	**14.54***	**8.86***	**27.62***	**4.57***	**23.98***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant throughout the period of study (Figure 4). At 30 days, the non-inoculated seedlings (36.32 ^{0}C) and those seedlings inoculated with different AMF species belonging to the treatment IW/ET=0.4 had higher leaf temperatures (35.94 ^{0}C, 35.86 ^{0}C and 35.50 ^{0}C for seedlings inoculated with *R. intraradices*, *G. etunicatum* and *F. mosseae* respectively). At 60 days, higher leaf temperature was recorded for non-inoculated seedlings belonging to the treatment IW/ET=0.4 (49.45 ^{0}C). At 90 days, higher leaf temperature was observed in seedlings inoculated with *R. intraradices* (42.85) and G. *etunicatum* (42.39 ^{0}C) of treatment IW/ET=0.4. Higher values were also recorded for non-inoculated

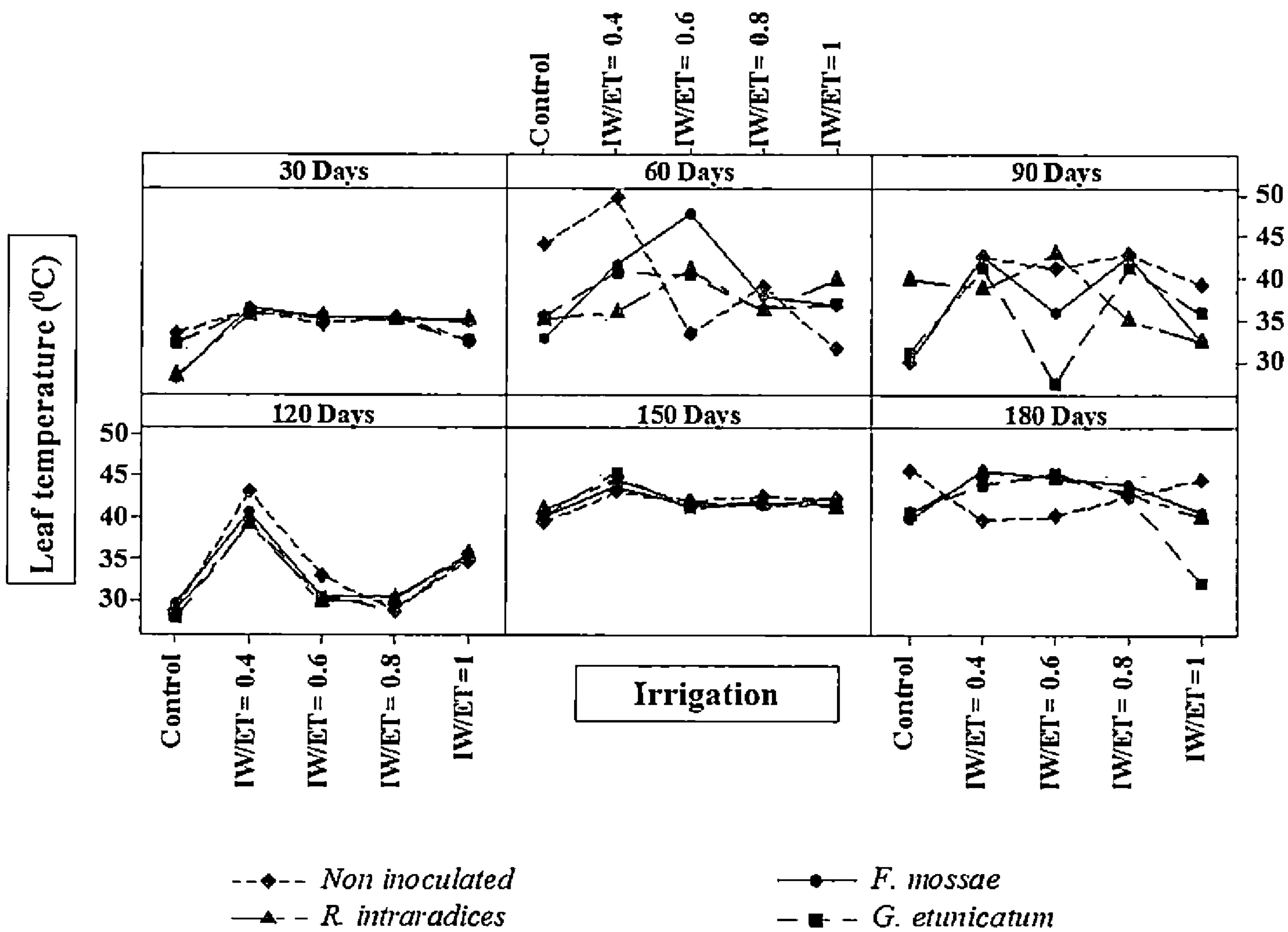


Figure 4. Leaf temperature (^{0}C) of mahogany seedlings as influenced by AMF and irrigation interaction

seedlings belonging to the treatment IW/ET=0.8, IW/ET=0.6 and IW/ET=0.4 (42.88 ^{0}C, 42.45 ^{0}C and 42.58 ^{0}C respectively). At 120 days, the non-inoculated seedlings of the treatment IW/ET=0.4 recorded higher values (43.24 ^{0}C) while, seedlings inoculated with G. *etunicatum* of treatment IW/ET=0.4 had higher values at 150 days (45.44 ^{0}C). At 180 days, seedlings inoculated with *R. intraradices* (45.67 ^{0}C), *G. etunicatum* (45.52 ^{0}C) and *F. mosseae* (45.82 ^{0}C) belonging to the treatment IW/ET=0.4 recorded higher values. Higher values were also recorded for seedlings inoculated with *R. intraradices* (45.10 ^{0}C) and *F. mosseae* (44.95 ^{0}C) of treatment IW/ET=0.6 and for the non-inoculated seedlings of the treatment IW/ET=1 (44.72 ^{0}C).

4.1.5. Chlorophyll content

Table 8. Chlorophyll content of mahogany seedlings as influenced by AMF and irrigation.

Factors	**Treatments**	**Chlorophyll content (SPAD values)**					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	28.35^{c}	29.85^{c}	31.36^{c}	31.36^{c}	33.54^{c}	35.44^{b}
	R. intraradices	33.17^{a}	34.92^{a}	35.38^{b}	35.38^{b}	36.55^{ab}	38.45^{ab}
	G. etunicatum	31.47^{ab}	32.59^{b}	38.57^{a}	38.57^{a}	38.31^{a}	40.21^{a}
	F. mosseae	30.08^{bc}	31.58^{bc}	33.82^{b}	33.82^{b}	34.02^{bc}	36.46^{b}
	F value	**6.79***	**7.08***	**14.27***	**14.25***	**5.23***	**4.13***
Irrigation	Control	39.98^{a}	41.48^{a}	45.06^{a}	45.06^{a}	46.36^{a}	48.6^{a}
	IW/ET=1	36.40^{b}	37.42^{b}	41.04^{b}	41.06^{b}	43.43^{a}	45.16^{b}
	IW/ET=0.8	33.69^{c}	35.19^{b}	37.31^{c}	37.31^{c}	37.55^{b}	39.38^{c}
	IW/ET=0.6	24.46^{d}	25.96^{c}	27.31^{d}	27.31^{d}	27.83^{c}	30.07^{d}
	IW/ET=0.4	19.32^{e}	21.12^{d}	23.19^{e}	23.19^{e}	23.08^{d}	24.98^{e}
	F value	**95.78***	**89.79***	**106.8***	**106.86***	**86.17***	**72.65***
AMF x Irrigation	**F value**	**6.30***	**5.66***	**5.37***	**5.36***	**4.90***	**4.15***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

In order to find out the influence of AMF inoculation and irrigation regimes on the seedling physiology, the chlorophyll content of the seedlings was also measured (Table 8) at monthly

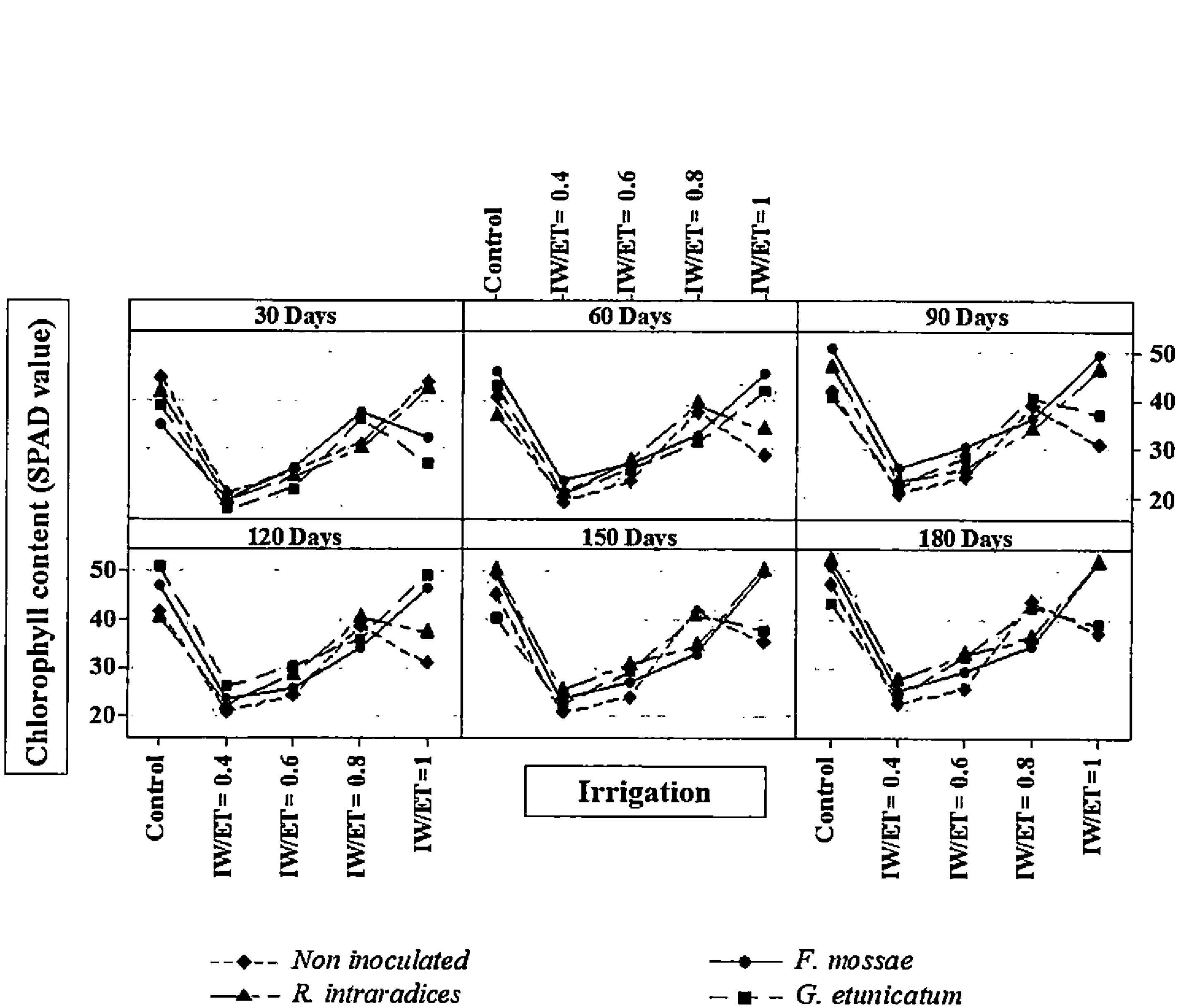


Figure 5. Chlorophyll content (SPAD value) of mahogany seedlings as influenced by AMF and irrigation interaction

intervals. For seedlings inoculated with *R. intraradices*, higher SPAD values (33.17 and 34.92) were noted at 30 and 60 days after inoculation. For the remaining period of experiment, however, higher chlorophyll content were recorded from seedlings inoculated with *G. etunicatum*. Non inoculated seedlings recorded the lowest chlorophyll content (28.35, 29.85, 31.36, 31.36 and 33.54) at 30, 60, 90, 120 and 150 days after inoculation; while, at 180 days, both *F. mosseae* and non-inoculated seedlings recorded the lowest value. With respect to the various irrigation regimes, the control seedlings always tended to have higher chlorophyll content than the rest; while, the treatment IW/ET=0.4 maintained regular lower values throughout the experiment.

The effect of interaction was found to be significant throughout the period of study (Figure 5). At 30 days, higher values were recorded for non-inoculated seedlings (44.53 and 43.78) and seedlings inoculated with *R. intraradices* (41.46 and 42.29) belonging to the control treatment and treatment IW/ET=1.0. At 60 days, seedlings inoculated with *F. mosseae* under control treatment (46.03) and treatment IW/ET=1.0 (45.28) had higher chlorophyll content. At 90 days, however, seedlings inoculated with *F. mosseae* under control treatment (50.92) only showed higher content of chlorophyll. At 120 days, higher chlorophyll content was recorded for seedlings inoculated with *G. etunicatum* of control treatment (50.86) and treatment IW/ET=1.0 (49.92). At 150 days, seedlings inoculated with *R. intraradices* under control treatment (50.39) and treatment IW/ET=1.0 (50.22) had higher chlorophyll content while, seedlings inoculated with *F. mosseae* under treatment IW/ET=1.0 alone had higher values (49.93). At 180 days, seedlings inoculated with *R. intraradices* (52.29 and 52.13) and *F. mosseae* (51.15 and 51.83) belonging to the control treatment and treatment IW/ET=1.0 had higher content of chlorophyll.

4.1.6. Relative Water Content (RWC)

The analysis of the RWC of the mahogany seedlings under different treatments over a period of time showed significant variations (Table 9). At 30 and 60 days, seedlings inoculated with *R. intraradices* had higher of relative water content (72.72 and 69.12). *R. intraradices* and *G. etunicatum* did not differ significantly in relative water content at 60 and 120 days. However, the values for seedlings inoculated with *G. etunicatum* were significant for the rest of the period. The non-inoculated seedlings had a lower percentage of relative water content regularly. During the course of experiment, the control seedlings demonstrated the highest RWC; whereas, the treatment IW/ET=0.4 maintained the lowest values.

The effect of interaction was not significant at 30 and 120 days (Figure 6). At 60 days, seedlings inoculated with *G. etunicatum* under control treatment had higher RWC (90.89). At 90 days, seedlings inoculated with *G. etunicatum* (92.26) and *F. mosseae* (90.94) under control treatment recorded higher values. At 150 and 180 days, higher values were recorded by seedlings inoculated with *R. intraradices* (80.96 and 76.32), *G. etunicatum* (81.71 and 76.38) and *F. mosseae* (80.94 and 75.13) under control treatment.

Table 9. Relative water content (%) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Relative water content (%)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	59.55^{d}	60.85^{b}	54.45^{d}	53.99^{c}	48.99^{d}	46.88^{d}
	R. intraradices	72.72^{a}	69.12^{a}	61.35^{c}	68.68^{a}	67.72^{b}	56.51^{b}
	G. etunicatum	69.54^{b}	69.06^{a}	74.74^{a}	67.12^{a}	68.68^{a}	59.23^{a}
	F. mosseae	66.66^{c}	59.55^{b}	68.74^{b}	59.71^{b}	57.60^{c}	53.08^{c}
	F value	**38.02***	**27.92***	**70.83***	**54.51***	**54.51***	**36.37***
Irrigation	Control	88.79^{a}	87.48^{a}	86.79^{a}	80.85^{a}	80.85^{a}	75.03^{a}
	IW/ET=1	70.89^{b}	70.66^{b}	74.74^{b}	69.79^{b}	69.79^{b}	62.40^{b}
	IW/ET=0.8	65.53^{c}	63.19^{c}	66.28^{c}	60.91^{c}	60.91^{c}	52.44^{c}
	IW/ET=0.6	58.92^{d}	58.74^{d}	57.57^{d}	55.85^{d}	55.85^{d}	42.61^{d}
	IW/ET=0.4	51.47^{e}	43.15^{e}	49.17^{e}	44.49^{e}	44.49^{e}	37.15^{e}
	F value	**192.37***	**221.56***	**156.5***	**178.12***	**178.12***	**238.09***
AMF x Irrigation	**F value**	**0.98^{ns}**	**2.18***	**2.19***	**1.57^{ns}**	**2.89***	**2.15***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.1.7. Plant water status

The plant water status was measured for different treatment of AMF species and different irrigation levels at 120, 150 and 180 days of experiment (Table 10). At 120 days, the non-inoculated seedlings had lower values (-1.87 MPa) of water potential; while, those inoculated with *G. etunicatum* had highest value (-1.49 MPa). At 150 and 180 days, the lowest values were

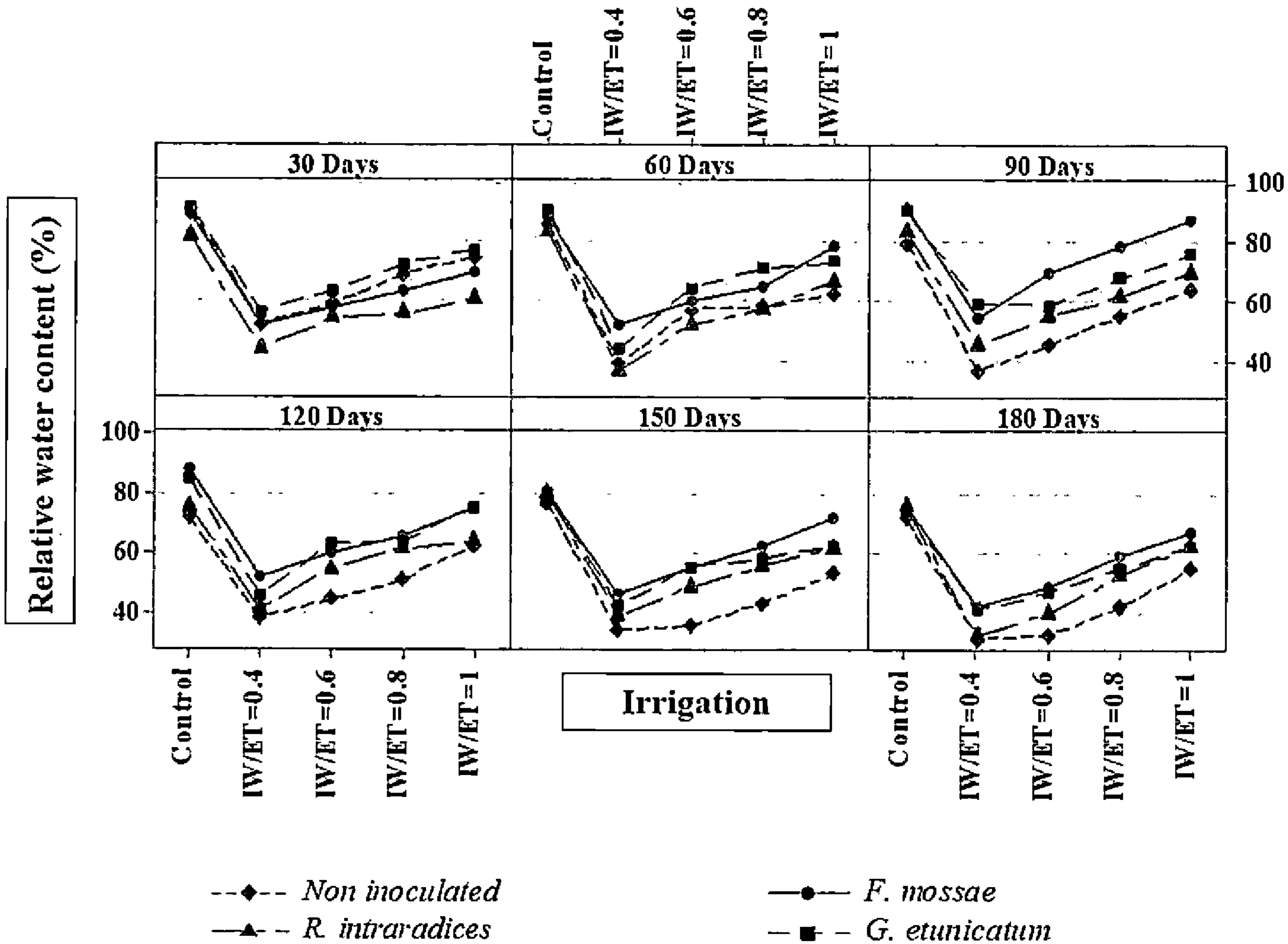


Figure 6. Relative water content (%) of mahogany seedlings as influenced by AMF and irrigation interaction

recorded for non-inoculated seedlings (-2.02 MPa and -2.15 MPa) while, those with *G. etunicatum* had the highest value (-1.67 MPa and -1.75 MPa).

The irrigation regimes however maintained a steady trend. Over the period of time, the lower values were observed for treatment IW/ET=0.4 (-2.62, -2.75 and -2.83 MPa respectively); and higher for control seedlings (-0.91, -1.15 and -1.16 MPa respectively). The effect of interaction was significant at 120, 150 and 180 days (Figure 7). Lower values for plant water potential was recorded for seedlings not inoculated with AMF belonging to the treatment IW/ET=0.4 consistently (-2.69, -2.87 and -2.90 MPa).

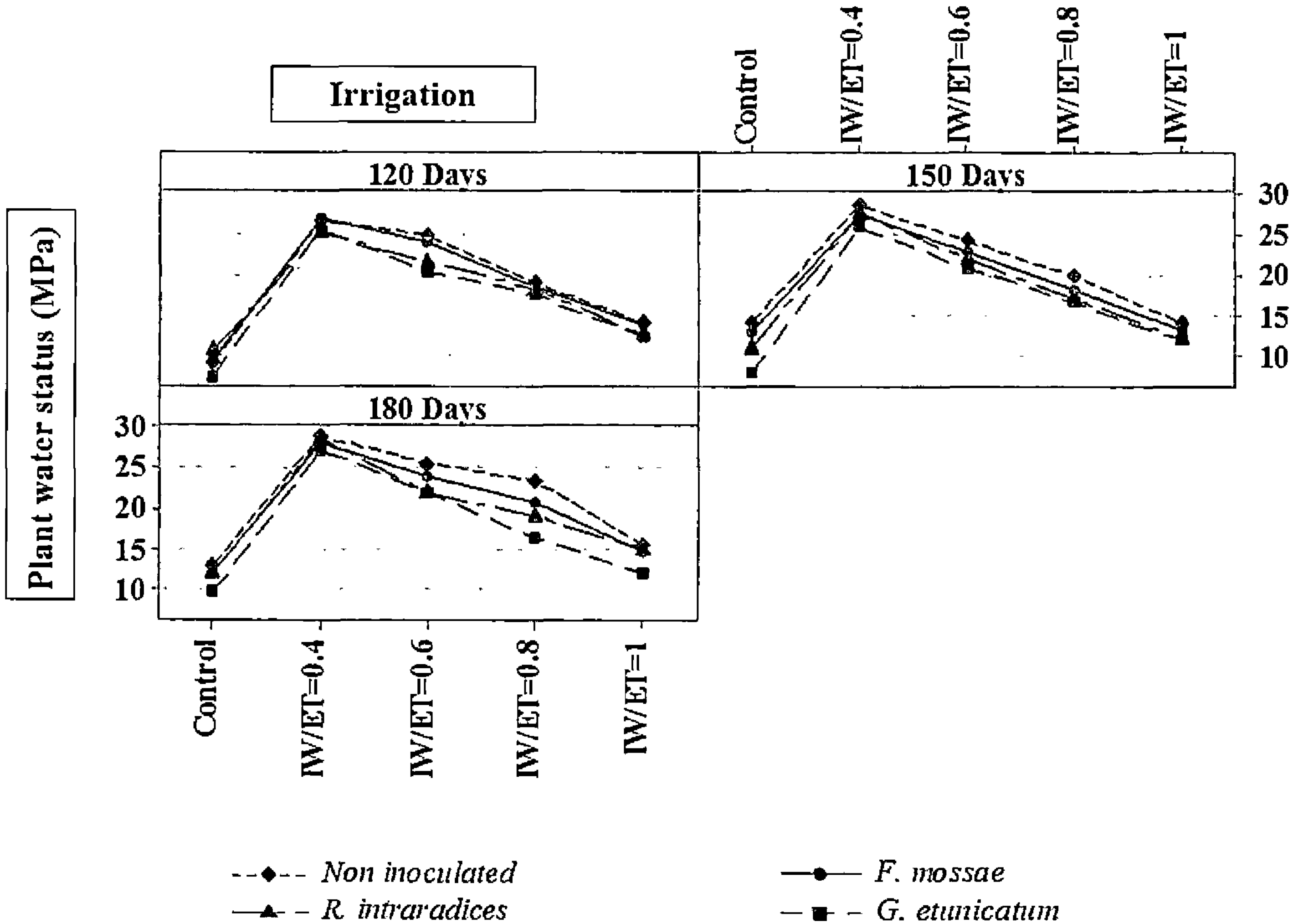
Table 10. Plant water status (MPa) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Plant water status (MPa)		
		120 days	150 days	180 days
AMF	Non inoculated	-1.87^{d}	-2.02^{d}	-2.15^{c}
	R. intraradices	-1.77^{c}	-1.79^{b}	-1.94^{b}
	G. etunicatum	-1.49^{a}	-1.67^{a}	-1.75^{a}
	F. mosseae	-1.66^{b}	-1.89^{c}	-1.99^{b}
	F value	**22.01***	**80.07***	**43.61***
Irrigation	Control	-0.91^{a}	-1.15^{a}	-1.16^{a}
	IW/ET=1	-1.31^{b}	-1.28^{b}	-1.45^{b}
	IW/ET=0.8	-1.83^{c}	-1.80^{c}	-2.00^{c}
	IW/ET=0.6	-2.27^{d}	-2.26^{d}	-2.35d
	IW/ET=0.4	-2.62^{e}	-2.75^{e}	-2.81e
	F value	**9.44***	**287.23***	**614.59***
AMF x Irrigation	**F value**	**4.11***	**4.89***	**3.61***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.1.8. Leaf Area Ratio

The leaf area ratio of mahogany seedlings inoculated with different AMF species had significant variations throughout the study (Table 11). At 30 days, seedlings inoculated with *R.*


Irrigation
120 Days
150 Days
180 Days
Plant water status (MPa)
30
25
20
15
10
Control
IW/ET=0.4
IW/ET=0.6
IW/ET=0.8
IW/ET=1
Non inoculated
F. mossae
R. intraradices
G. etunicatum

intraradices and *G. etunicatum* had higher leaf area ratios (53.35 and 66.59); whereas, non-inoculated seedlings and those inoculated with *F. mosseae* had lower ratios (45.90 and 50.94). At 60 and 90 days, no significant variations were observed among the treatments. At 150 and 180 days, higher leaf area ratios were recorded for both *R. intraradices* (89.60 and 198.36) and *G. etunicatum* (103.51 and 186.64); while, the non-inoculated seedlings and those inoculated with *F. mosseae* had lower ratios. At 120 days, seedlings inoculated with *R. intraradices* recorded highest values while, non-inoculated seedlings and those inoculated with *F. mosseae* maintained the lowest.

Table 11. Leaf Area Ratio ($cm^2\ g^{-1}$) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Leaf Area Ratio ($cm^2\ g^{-1}$)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	45.90^{b}	34.95	32.47	31.92^{c}	50.14^{b}	86.34^{b}
	R. intraradices	53.35^{ab}	25.44	37.31	95.68^{a}	89.60^{a}	198.36^{a}
	G. etunicatum	66.59^{a}	23.95	31.39	68.82^{b}	103.51^{a}	186.64^{a}
	F. mosseae	50.94^{b}	23.25	29.98	33.66^{c}	47.71^{b}	111.44^{b}
	F value	**2.79***	**1.18^{ns}**	**0.99^{ns}**	**34.84***	**18.75***	**19.01***
Irrigation	Control	84.36^{a}	35.43^{a}	75.84^{a}	93.15^{a}	135.54^{a}	291.47^{a}
	IW/ET=1	76.13^{a}	29.08^{ab}	32.01^{b}	96.38^{a}	79.90^{b}	188.79^{b}
	IW/ET=0.8	48.99^{b}	17.19^{b}	30.77^{b}	41.55^{b}	89.06^{b}	123.19^{c}
	IW/ET=0.6	34.56^{bc}	13.65^{b}	14.74^{c}	45.68^{b}	52.14^{c}	90.76^{c}
	IW/ET=0.4	26.93^{c}	39.14^{a}	10.57^{c}	10.84^{c}	7.07^{d}	34.27^{d}
	F value	**18.27***	**3.95***	**52.30***	**39.85***	**43.77***	**48.68***
AMF x Irrigation	**F value**	**0.87***	**1.69***	**3.90***	**3.27***	**2.77***	**4.12***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

Among the different irrigation regimes, there was no significant difference between the control and the treatment IW/ET=1 after 30 and 120 days. Higher values were recorded for these treatments. The highest ratios at 60, 90,150 and 180 days (35.43, 75.84, 135.54 and 291.47) were observed for the control. The treatment IW/ET=0.4 had lower leaf area ratios (26.93, 10.84, 7.07

Figure 7. Plant water status (MPa) of mahogany seedlings as influenced by AMF and irrigation interaction

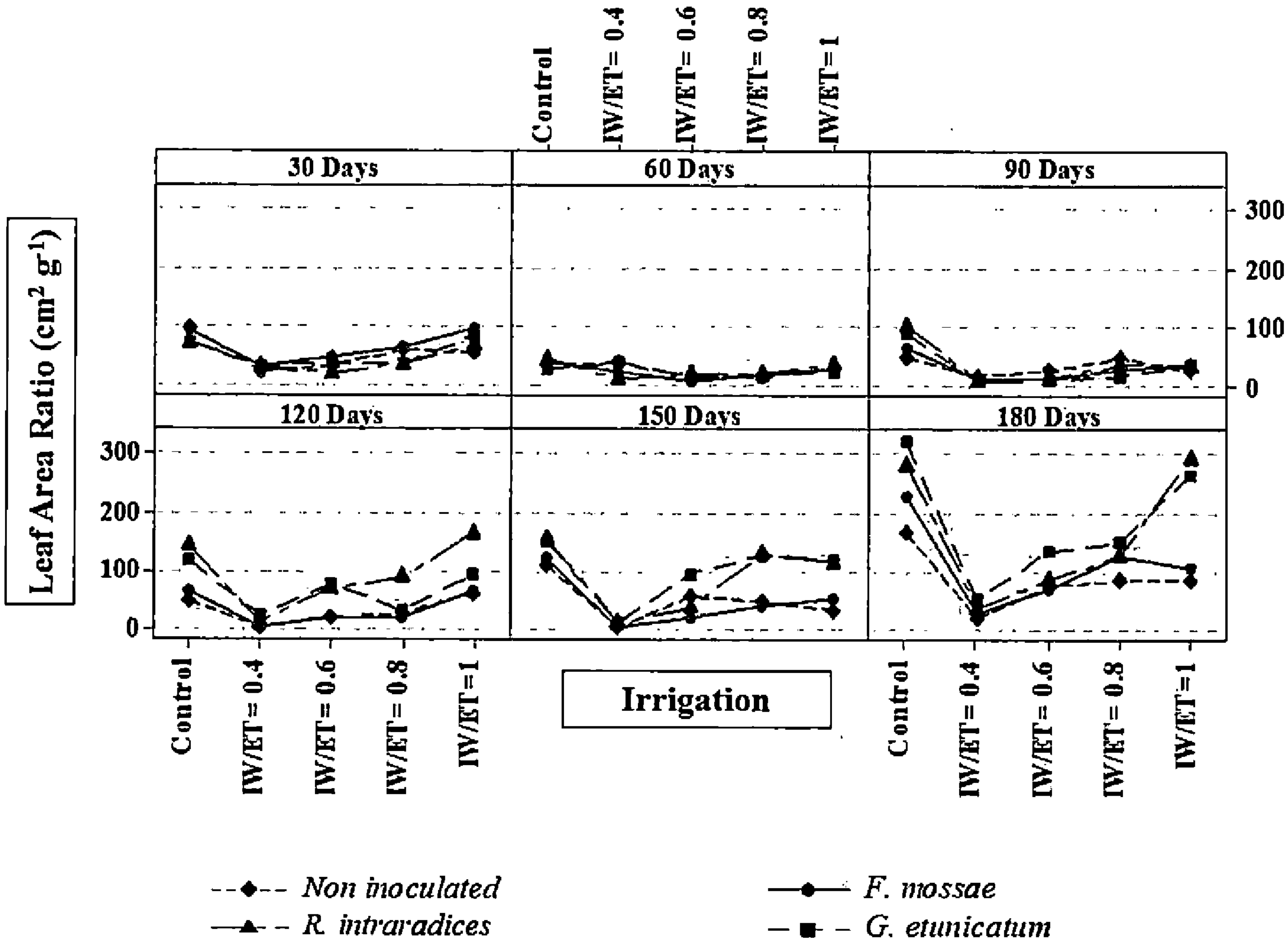


Figure 8. Leaf Area Ratio (cm^2 g^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

and 34.27) at 30, 120, 150 and 180 days; whereas, treatment IW/ET=0.4 and IW/ET=0.6 (10.57 and14.74) both had lower ratios at 60 days.

The effect of interaction was significant throughout the period of study (Figure 8). At 30 days, seedlings inoculated with *F. mosseae* showed higher value (99.82) under treatment IW/ET=1. Seedlings not inoculated with AMF and those inoculated with *F. mosseae* under the control treatment also had higher values at 30 days (99.12 and 98.26). At 60, 90 and 150 days, seedlings inoculated with *R. intraradices* under control treatment showed higher values (44.65, 101.4 and 156.5) respectively. Seedlings inoculated with *R. intraradices* had higher values under treatment IW/ET=1 (165.7) at 120 days. At 150 and 180 days, seedlings inoculated with *G. etunicatum* showed higher values (150.6 and 445.6) under control treatment.

4.1.9. Leaf Weight Ratio

The leaf weight ratio of mahogany seedlings inoculated with different AMF species had significant variations throughout the study (Table 12). The seedlings inoculated with *R. intraradices* and *G. etunicatum* (0.45 and 0.46) had higher value at 30 days while, non-inoculated seedlings showed the lowest (0.42). Seedlings inoculated with *G. etunicatum* and *F. mosseae* had higher values (0.45) at 60 days while, lower values were recorded for non-inoculated seedlings (0.41). However, at 90 days, seedlings inoculated with both *R. intraradices* and *F. mosseae* had higher values (0.44) while, lower values were recorded for non-inoculated seedlings (0.41) and those inoculated with *G. etunicatum* (0.43). Seedlings inoculated with *R. intraradices* had higher leaf weight ratio at 120 and 150 days after the inoculation (0.68 and 0.63) while, non- inoculated seedling showed minimum values (0.38 and 0.37). No significant variations were observed at 180 days.

After 30 days of application of treatments, no significant variations were observed for seedlings under different irrigation regimes. At 60 days, the highest leaf weight ratio was recorded for IW/ET=0.8 (0.49); and lowest for IW/ET=0.6 (0.34). Lowest leaf weight ratio (0.41) was recorded for IW/ET=0.4 at 90 days; while the others had no variations among them. The treatments IW/ET=1 (0.49) and IW/ET=0.8 (0.49) had higher leaf weight ratios at 120 days; while lowest values as shown by control (0.42). At 150 and at 180 days, IW/ET=0.8 (0.48 and

0.46) and IW/ET=0.6 (0.50 and 0.45) had higher ratios; while IW/ET=0.4 had lower leaf weight ratios (0.44 and 0.42).

Table 12. Leaf Weight Ratio of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Leaf Weight Ratio					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.42^{b}	0.41^{b}	0.41^{b}	0.38^{c}	0.37^{c}	0.45
	R. intraradices	0.45^{a}	0.44^{ab}	0.44^{a}	0.68^{a}	0.63^{a}	0.44
	G. etunicatum	0.46^{a}	0.45^{a}	0.43^{b}	0.45^{b}	0.45^{b}	0.44
	F. mosseae	0.44^{ab}	0.45^{a}	0.44^{a}	0.37^{c}	0.42^{b}	0.45
	F value	**2.97***	**3.14***	**6.21***	**74.7***	**75.87***	**0.86^{ns}**
Irrigation	Control	0.44	0.46^{b}	0.45^{a}	0.42^{c}	0.47^{ab}	0.44^{ab}
	IW/ET=1	0.46	0.42^{c}	0.43^{a}	0.49^{a}	0.46^{ab}	0.44^{ab}
	IW/ET=0.8	0.42	0.49^{a}	0.43^{a}	0.49^{a}	0.48^{a}	0.46^{a}
	IW/ET=0.6	0.45	0.34^{d}	0.44^{a}	0.51^{ab}	0.50^{a}	0.45^{a}
	IW/ET=0.4	0.45	0.47^{ab}	0.41^{b}	0.44^{bc}	0.44^{b}	0.42^{c}
	F value	**1.97^{ns}**	**25.47***	**5.10***	**4.18***	**2.72***	**3.14***
AMF x Irrigation	**F value**	**0.86***	**2.57***	**0.89***	**6.95***	**7.16***	**1.93***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant throughout the period of study (Figure 9). Seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET=1 had higher values at 30 days (0.47). At 60 days, seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET=0.8 had higher values (0.57). Higher values were recorded for seedlings inoculated with *R. intraradices* under control irrigation treatment at 90 days (0.47). At 120 and 150 days, significantly higher values were observed in seedling inoculated with *R. intraradices* under irrigation treatment IW/ET=0.8 (0.97 and 0.75). Higher values were also recorded for seedlings inoculated with *R. intraradices* under irrigation treatment IW/ET=0.6 (0.76) at 150 days. At 180 days, non- inoculated seedlings under the treatment IW/ET=0.8 showed higher values (0.48).

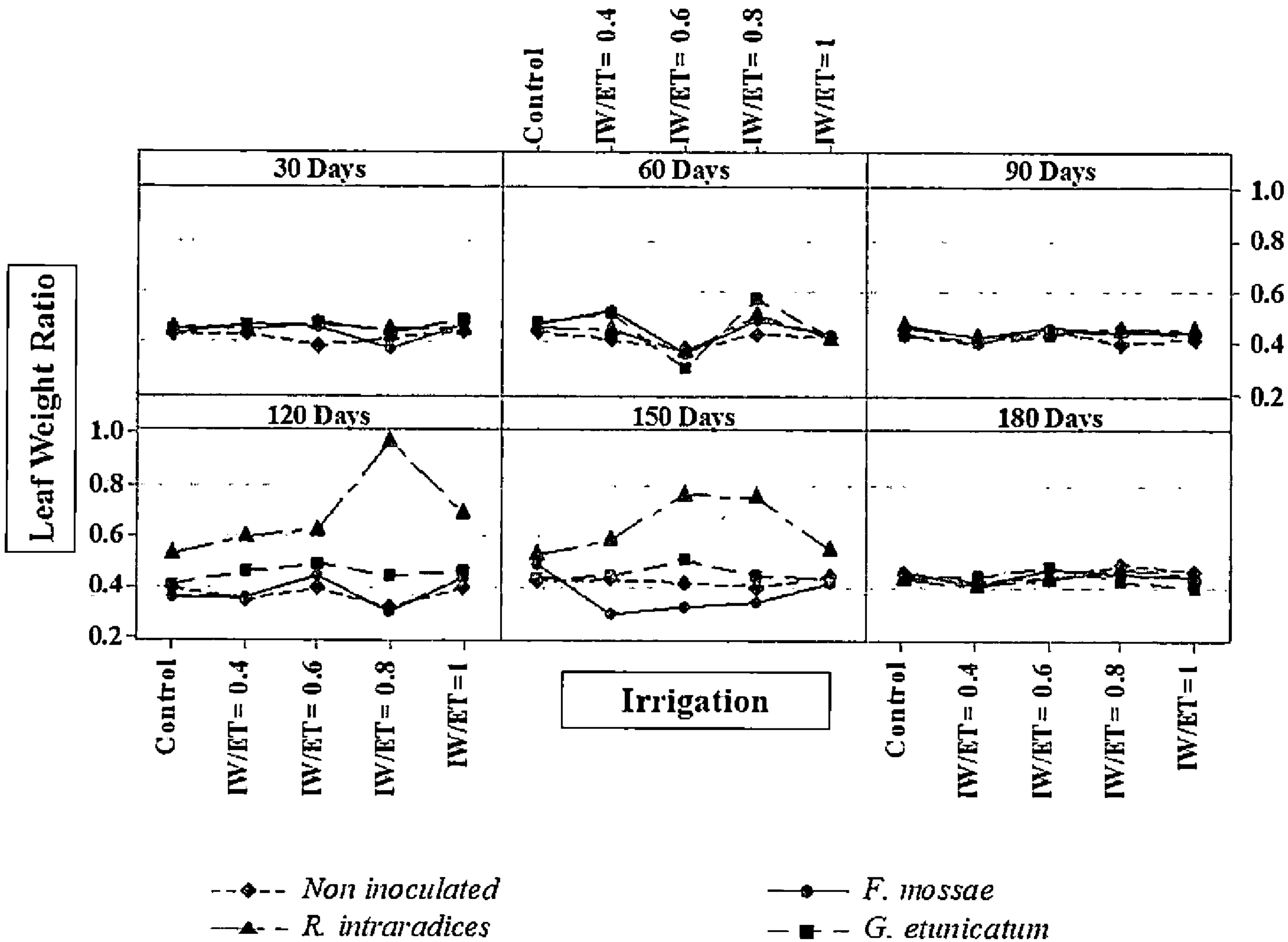


Figure 9. Leaf Weight Ratio of mahogany seedlings as influenced by AMF and irrigation interaction

4.1.10. Specific Leaf Area

Use of different AMF strains resulted in significant variations in specific leaf area of the seedlings (Table 13). The non- inoculated seedlings had the highest values throughout the study. At 30, 90 and 180 days, the seedlings inoculated with *R. intraradices* and *G. etunicatum* recorded lower specific leaf area values. All seedlings inoculated with AMF were observed to have lower specific leaf area values at 60, 120 and 150 days.

Table 13. Specific Leaf Area ($cm^2\ g^{-1}$) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Specific Leaf Area ($cm^2\ g^{-1}$)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	110.98^{a}	80.49^{a}	60.55^{a}	48.25^{a}	60.34^{a}	47.49^{a}
	R. intraradices	68.11^{c}	55.92^{b}	45.82^{c}	46.33^{a}	40.29^{b}	38.02^{b}
	G. etunicatum	70.5^{c}	48.73^{b}	49.12^{bc}	38.53^{b}	46.43^{b}	39.45^{b}
	F. mosseae	90.95^{b}	42.27^{b}	56.51^{ab}	42.25^{ab}	39.64^{b}	46.81^{a}
	F value	**19.68***	**6.83***	**5.69***	**3.44***	**9.66***	**15.51***
Irrigation	Control	76.59	85.33^{a}	94.16^{a}	56.75^{a}	62.39^{a}	55.33^{a}
	IW/ET=1	86.99	79.81^{a}	47.89^{b}	53.95^{a}	56.81^{ab}	47.65^{b}
	IW/ET=0.8	90.68	46.48^{b}	46.65^{b}	44.79^{b}	50.74^{b}	45.15^{b}
	IW/ET=0.6	86.16	39.62^{b}	41.11^{bc}	34.19^{c}	41.5^{c}	39.63^{c}
	IW/ET=0.4	85.25	33.04^{b}	35.16^{c}	29.53^{c}	22.28^{d}	26.95^{c}
	F value	**1.06^{ns}**	**11.29***	**55.76***	**20.79***	**21.62***	**57.73***
AMF x Irrigation	**F value**	**1.18***	**2.17***	**7.84***	**2.37***	**4.87***	**5.32***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

While considering the irrigation regimes, control seedlings had dominance over the rest at 90, 150 and 180 days. Control seedlings along with IW/ET=1 had higher specific leaf area at 60 and 120 days. The treatment IW/ET=0.4 had lower the specific leaf area throughout the study.

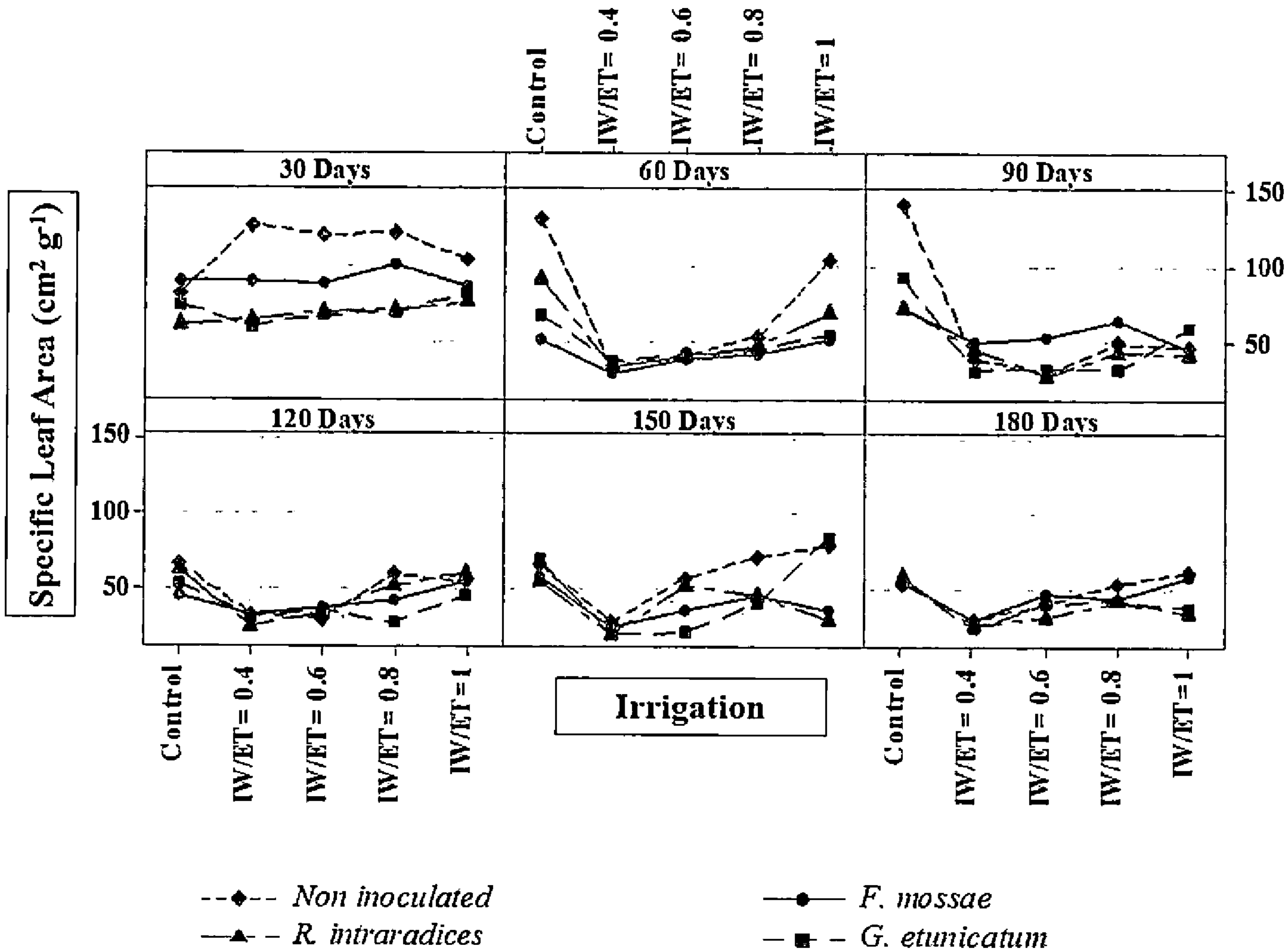


Figure 10. Specific Leaf Area (cm^2 g^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

The treatment IW/ET=0.4 and IW/ET=0.6 recorded lower specific leaf area at 60, 120 and 180 days. No significant variations were noticed at 30 days.

The effect of interaction was found to be significant throughout the period of study (Figure 10). Higher value was observed for non-inoculated seedlings under treatment IW/ET=0.4 at 30 days (128.23). At 60, 90 and 120 days, non- inoculated seedlings under the control irrigation treatment showed higher values (131.1, 140.2 and 66.34). Seedlings inoculated with *G. etunicatum* under the treatment IW/ET=1 recorded higher values at 150 days (83.82). Higher value was observed for non-inoculated seedlings under treatment IW/ET=1 at 180 days (61.84).

4.1.11. Specific Leaf Weight

Table 14. Specific Leaf Weight (g cm-^{2}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Specific Leaf Weight (g cm-^{2})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.012^b	0.021^b	0.022^c	0.030	0.020^c	0.023^b
	R. intraradices	0.017^a	0.025^a	0.025^{bc}	0.034	0.030^b	0.029^a
	G. etunicatum	0.015^a	0.026^a	0.030^a	0.030	0.038^a	0.030^a
	F. mosseae	0.011^b	0.027^a	0.026^{ab}	0.028	0.035^{ab}	0.024^b
	F value	**7.24***	**3.36***	**4.89***	**0.55^{ns}**	**9.64***	**17.05***
Irrigation	Control	0.014	0.019^c	0.012^c	0.182^b	0.025^b	0.019^d
	IW/ET=1	0.012	0.020^b	0.025^b	0.020^b	0.031^b	0.023^c
	IW/ET=0.8	0.013	0.023^c	0.273^b	0.039^a	0.023^b	0.024^c
	IW/ET=0.6	0.016	0.035^a	0.293^b	0.038^a	0.025^b	0.028^b
	IW/ET=0.4	0.014	0.027^a	0.374^a	0.037^a	0.050^a	0.039^a
	F value	**2.06^{ns}**	**15.32***	**30.93***	**9.56***	**16.49***	**64.14***
AMF x Irrigation	**F value**	**0.56***	**1.22***	**4.05***	**1.62***	**3.93***	**2.64***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

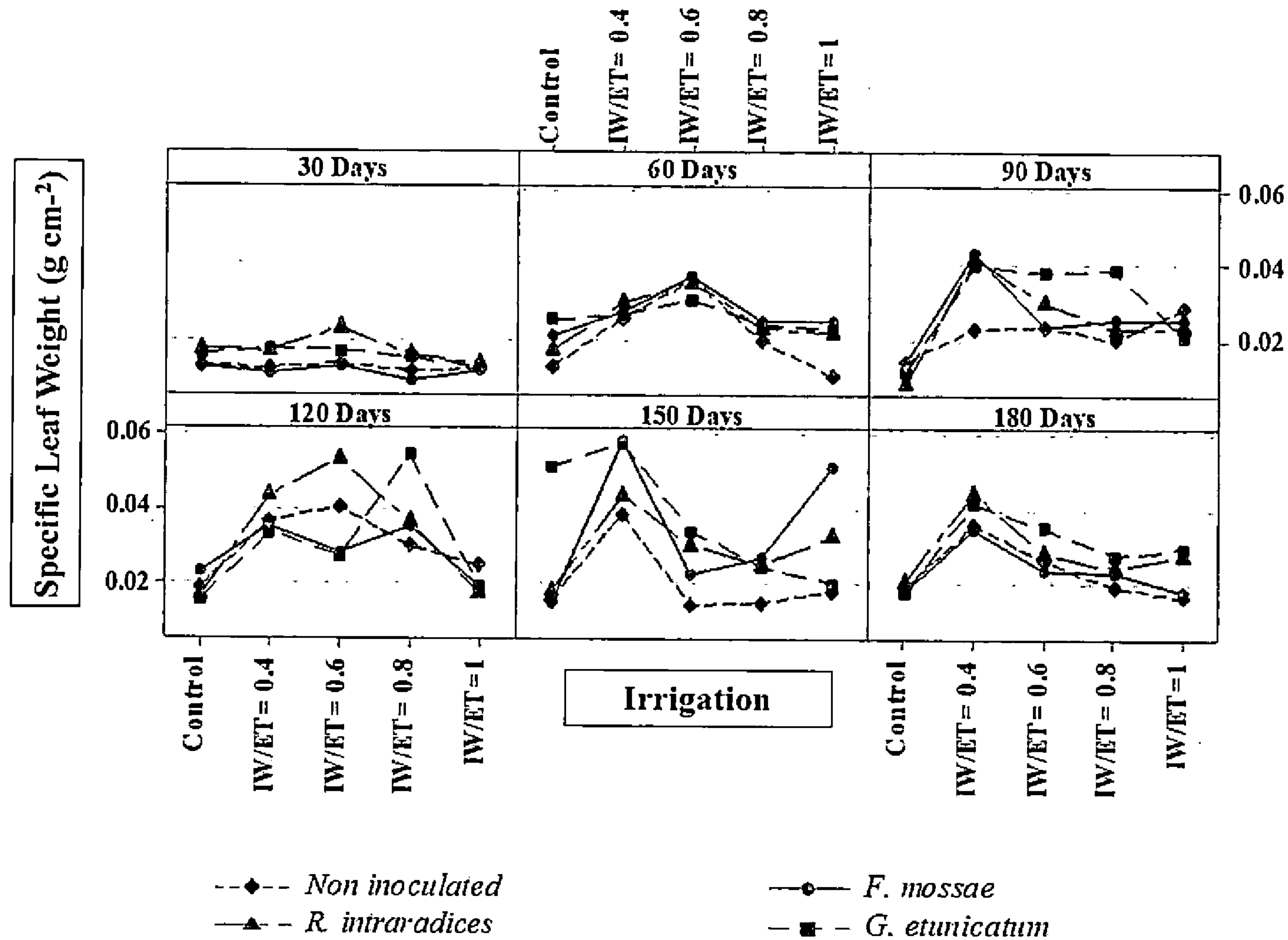


Figure 11. Specific Leaf Weight (g cm-^{2}) of mahogany seedlings as influenced by AMF and irrigation interaction

The average performance of mahogany seedlings when treated with different AMF species and irrigation regimes in terms of specific leaf weight is seen in the Table 14. Seedlings inoculated with *R. intraradices* and *G. etunicatum* had highest of specific leaf weight values at 30, 150 and 180 days. At 60 days, all seedlings inoculated with AMF were observed to have higher specific leaf weight values. No significant variations due to irrigation regimes were seen at 30 days. Among the various irrigation regimes, the treatment IW/ET=0.4 had higher the specific leaf weight at 90, 150 and 180 days. At 60 days, both IW/ET=0.6 and IW/ET=0.4 and 120 days recorded higher the specific leaf weight. IW/ET=0.8, IW/ET=0.6 and IW/ET=0.4 had higher the specific leaf weight at 120 days. The control seedlings recorded lower values at 60, 90 and 180 days throughout the studies. Control and IW/ET=1 both had lower values at 120 and 150 days.

The effect of interaction was found to be significant throughout the period of study (Figure 11). At 30 and 60 days, higher values were recorded for seedlings inoculated with *R. intraradices* under treatment IW/ET=0.6 (0.022 and 0.037). At 60 days, higher values were also observed for seedlings inoculated with *G. etunicatum* (0.037) and *F. mosseae* (0.036) under treatment IW/ET=0.6. Seedlings inoculated with *F. mosseae* (0.043) had higher values under treatment IW/ET=0.4. Seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET= 0.8 recorded higher values at 120 days (0.059). At 150 and 180 days, seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET= 0.4 recorded higher values (0.057 and 0.042). Seedlings inoculated with *F. mosseae* (0.058) and *R. intraradices* (0.045) of irrigation treatment IW/ET=0.4 also had higher values at 150 and 180 days respectively.

4.1.12. Absolute Growth Rate (AGR)

The mean performance of mahogany seedlings when treated with different AMF species and irrigation regimes in terms of AGR is given in the Table 15. The seedlings inoculated with *R. intraradices* had highest AGR at 60 days (0.66) while, at 90, 120 and 180 days, seedlings inoculated with *G. etunicatum* recorded higher AGR (0.71, 0.74 and 0.44). At 150 days, seedlings inoculated with AMF species had higher AGR values. Non inoculated seedlings consistently had lower growth rates with an exemption at 120 days when growth rates were shared as par with R. *intraradices* treated seedlings.

Significant variation with respect to AGR was also observed for various irrigation regimes. At 60 days, IW/ET=0.8 had highest values while, IW/ET=0.4 had the lowest. At 90 days, both control and IW/ET=1 had higher values; whereas, lower values were recorded by treatment IW/ET=0.4. The treatment IW/ET=0.8 had highest value at 120 days while, lower values were observed in both IW/ET=0.6 and IW/ET=0.4. At 150 days, the highest value was recorded by IW/ET=0.6 and the lowest value by IW/ET=0.4.

Table 15. Absolute Growth Rate (cm day^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Absolute Growth Rate (cm day^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	-	0.13^{d}	0.20^{d}	0.18^{c}	0.19^{b}	0.21^{b}
	R. intraradices	-	0.66^{a}	0.56^{b}	0.15^{c}	0.33^{a}	0.37^{ab}
	G. etunicatum	-	0.51^{b}	0.71^{a}	0.74^{a}	0.36^{a}	0.44^{a}
	F. mosseae	-	0.42^{c}	0.29^{c}	0.31^{b}	0.30^{a}	0.33^{ab}
	F value	-	**81.70***	**117.9***	**205.19***	**8.62***	**3.02***
Irrigation	Control	-	0.44^{ab}	0.57^{a}	0.39^{b}	0.32^{b}	0.34
	IW/ET=1	-	0.39^{bc}	0.56^{a}	0.26^{c}	0.36^{b}	0.37
	IW/ET=0.8	-	0.51^{a}	0.35^{b}	0.56^{a}	0.19^{c}	0.33
	IW/ET=0.6	-	0.48^{ab}	0.27^{c}	0.26^{c}	0.46^{a}	0.25
	IW/ET=0.4	-	0.34^{c}	0.47^{d}	0.26^{c}	0.15^{c}	0.39
	F value	-	**6.53***	**29.25***	**40.13***	**19.72***	**0.78^{ns}**
AMF x Irrigation	**F value**	-	**2.99***	**5.57***	**4.66***	**1.86***	**1.45***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant over the period of experiment (Figure 12). At 60 days, seedlings inoculated with *R. intraradices* with control irrigation showed higher AGR (0.83). Seedlings inoculated with *G. etunicatum* under the control irrigation treatment recorded higher values at 90 days (0.93). At 120 days, seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.8 recorded higher values (1.06). Seedlings inoculated with

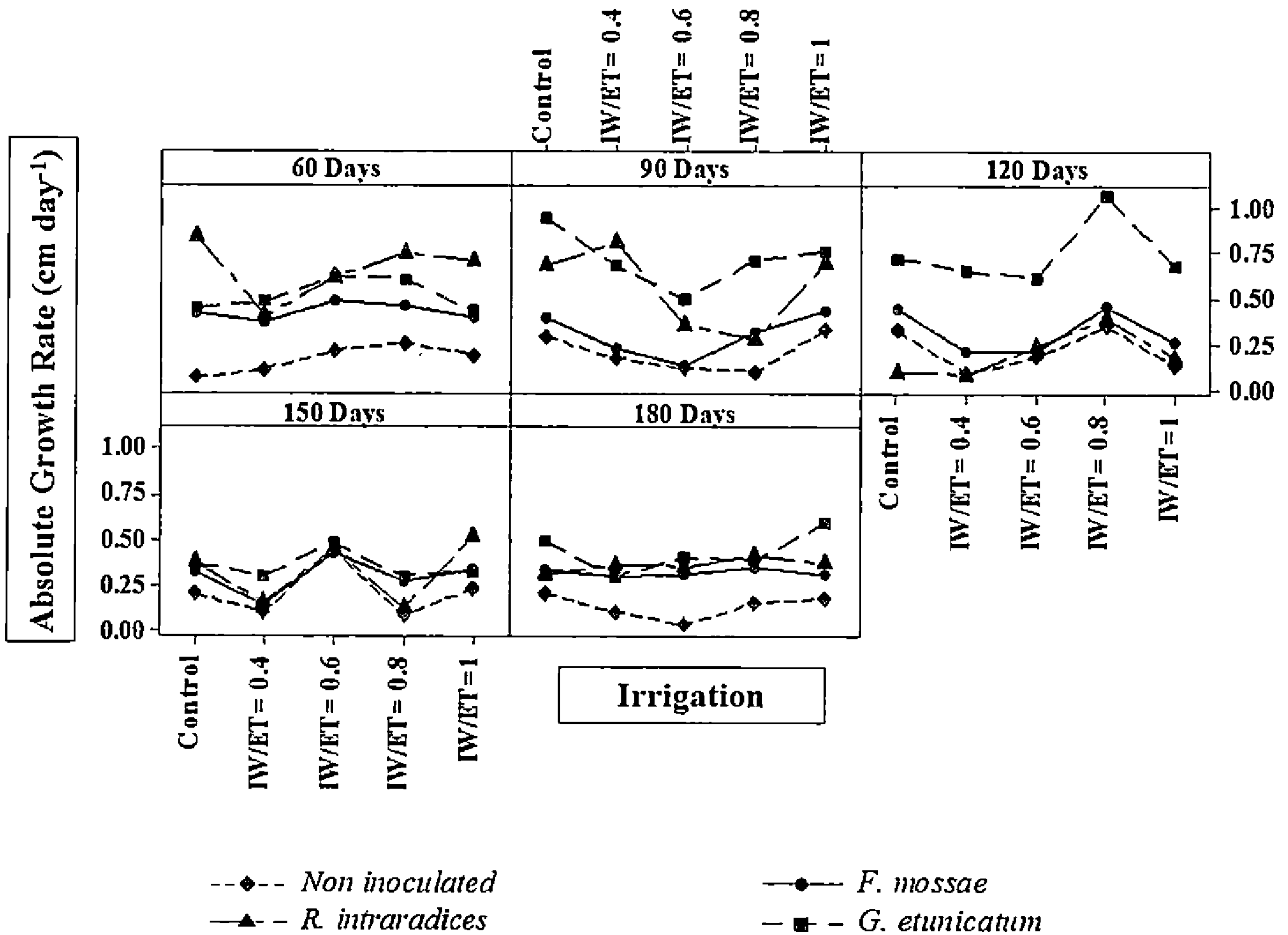


Figure 12. Absolute Growth Rate (cm day^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

R. intraradices with irrigation IW/ET=1 showed higher AGR (0.52) at 150 days. At 180 days, seedlings inoculated with *G. etunicatum* under treatment IW/ET=1.0 recorded higher values (0.06).

4.1.13. Relative Growth Rate (RGR)

Relative growth rate of mahogany seedlings treated with different AMF species and irrigation regimes are demonstrated in the Table 16. Seedlings inoculated with *R. intraradices* had higher absolute growth rate at 60 days (0.007). At 90, 120 and 180 days, seedlings inoculated with *G. etunicatum* had higher RGR (0.006, 0.008 and 0.004). Non inoculated seedlings maintained lower RGR consistently except at 90 days. At 90 days, seedlings inoculated

Table 16. Relative Growth Rate (g g^{-1} day^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Relative Growth Rate (g g^{-1} day^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	-	0.005^{b}	0.006^{a}	0.002^{c}	0.003	0.001^{c}
	R. intraradices	-	0.007^{a}	0.003^{b}	0.004^{b}	0.004	0.006^{a}
	G. etunicatum	-	0.006^{b}	0.006^{a}	0.008^{a}	0.003	0.004^{b}
	F. mosseae	-	0.010^{b}	0.004^{ab}	0.008^{a}	0.004	0.001^{c}
	F value	-	**14.31***	**4.94***	**16.32***	**0.79^{ns}**	**41.31***
Irrigation	Control	-	0.007^{a}	0.005^{b}	0.006^{c}	0.006^{a}	0.003^{b}
	IW/ET=1	-	0.008^{a}	0.002^{c}	0.008^{a}	0.003^{b}	0.003^{b}
	IW/ET=0.8	-	0.007^{a}	0.005^{b}	0.003^{d}	0.003^{b}	0.004^{ab}
	IW/ET=0.6	-	0.008^{a}	0.003^{bc}	0.007^{ab}	0.001^{c}	0.005^{a}
	IW/ET=0.4	-	0.004^{b}	0.008^{a}	0.003^{d}	0.006^{a}	0.001^{c}
	F value	-	**7.15***	**9.74***	**10.15***	**11.43***	**11.63***
AMF x Irrigation	**F value**	-	**3.93***	**4.82***	**5.21***	**1.66***	**3.11***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

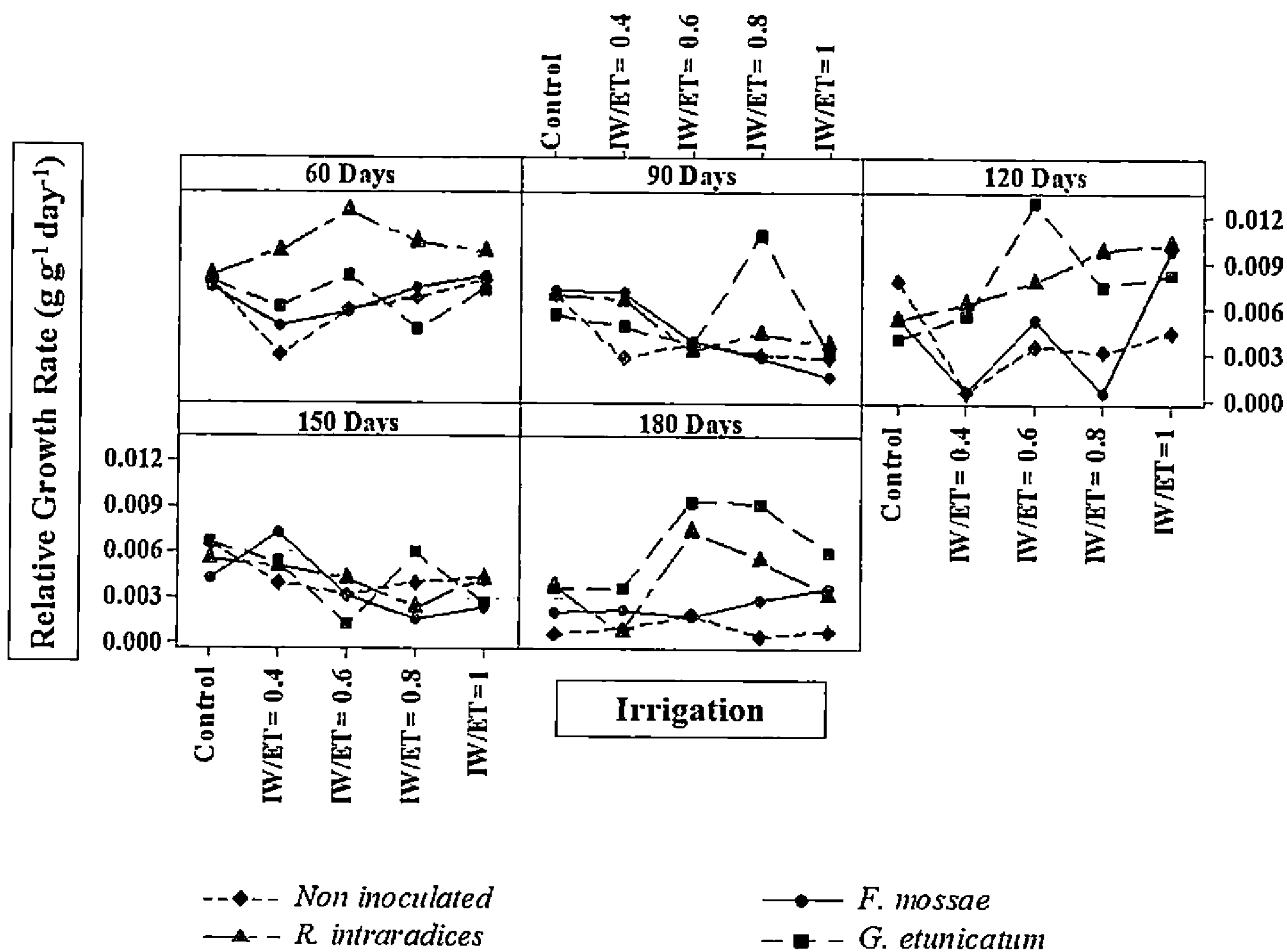


Figure 13. Relative Growth Rate (g g^{-1} day^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

with *F. mosseae* had lower RGR, which was on par with *G. etunicatum* treated seedlings. At 150 days, different treatments did not differ in RGR.

Significant variations with respect to RGR were observed for various irrigation regimes. At 60 days, IW/ET=0.4 had lowest values (0.004) while, the others had the significant higher values. At 90 days, however, IW/ET=0.4 had highest value (0.008); whereas, lowest values were recorded by the treatment IW/ET=1 (0.002). The treatment IW/ET=1 had higher value at 120 days (0.008) while, lowest value was observed in IW/ET=0.4 (0.002). At 150 days, the highest value was recorded by control (0.006) and IW/ET=0.4 (0.006); and the lowest value by IW/ET=0.6 (0.001). The treatment IW/ET=0.6 and IW/ET=0.8 had higher value at 180 days (0.004 and 0.005) whereas IW/ET=0.4 recorded the lowest (0.001).

The effect of interaction was found to be significant throughout the period of study (Figure 13). At 60 days, the seedlings inoculated with *F. mosseae* with irrigation treatment IW/ET=0.6 had higher RGR (0.013). Seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET=0.8 and treatment IW/ET=0.4 recorded higher values at 90 and 120 days respectively (0.011 and 0.013). At 150 days, the seedlings inoculated with *F. mosseae* with irrigation treatment IW/ET=0.4 had higher RGR (0.005). At 180 days, seedlings inoculated with *R. intraradices* with irrigation treatment IW/ET=0.6 and IW/ET=0.4 showed higher values (0.009 and 0.009) respectively.

4.1.14. Net Assimilation Rate (NAR)

The performance of mahogany seedlings when provided with treated AMF species and irrigation regimes in terms of NAR is given in the Table 17. At 60 days, the seedlings inoculated with *R. intraradices* displayed highest values (0.018) of NAR while, the non-inoculated seedlings had the lowest (0.012). No significant differences in NAR were observed at 90, 120 and 150 days. After 180 days, the highest values were recorded for both *R. intraradices* (0.013) and *G. etunicatum* (0.011); and the lowest NAR was recorded for non-inoculated seedlings (0.001).

Among various irrigation regimes, no significant variation was observed 90 days after the application of treatment. Highest NAR were recorded at 60, 150 and 180 days for the treatment IW/ET=0.6. At 120 and 150 days, IW/ET=1 recorded the highest values. The treatment

IW/ET=0.4 had the lowest assimilation rates after 60 and 180 days. Also at 120 days, IW/ET=0.8 and IW/ET=0.4 depicted the lowest values for assimilation. At 150 days, both control and IW/ET=0.4 recorded lower values.

The effect of interaction was found to be significant throughout the period of study (Figure 14). At 60, and 90 days, seedlings inoculated with *R. intraradices* with irrigation treatment IW/ET=0.6 and IW/ET=0.8 had higher NAR values (0.036 and 0.043). At 150 days, higher value was observed for non-inoculated seedlings with irrigation treatment IW/ET=1.0 (0.024). At 120 and 180 days, seedlings inoculated with *R. intraradices* under treatment IW/ET=1 recorded higher values (0.038 and 0.023).

Table 17.Net Assimilation Rate (g g^{-1} day^{-1}) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Net Assimilation Rate (g g^{-1} day^{-1})					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	-	0.012^{c}	0.013	0.019	0.008	0.001^{b}
	R. intraradices	-	0.018^{b}	0.014	0.006	0.003	0.013^{a}
	G. etunicatum	-	0.014^{bc}	0.013	0.011	0.008	0.011^{a}
	F. mosseae	-	0.025^{a}	0.011	0.021	0.011	0.001^{b}
	F value	**-**	**10.65***	**0.16^{ns}**	**2.20^{ns}**	**1.79^{ns}**	**18.78***
Irrigation	Control	-	0.016^{b}	0.010	0.013^{ab}	0.014^{b}	0.006^{b}
	IW/ET=1	-	0.020^{ab}	0.005	0.026^{a}	0.003^{a}	0.007^{ab}
	IW/ET=0.8	-	0.017^{b}	0.002	0.004^{b}	0.006^{ab}	0.007^{ab}
	IW/ET=0.6	-	0.023^{a}	0.009	0.017^{ab}	0.001^{a}	0.011^{a}
	IW/ET=0.4	-	0.011^{c}	0.009	0.009^{b}	0.013^{b}	0.001^{c}
	F value	**-**	**5.84***	**1.79^{ns}**	**3.98***	**3.98***	**1.38***
AMF x Irrigation	**F value**	**-**	**2.73***	**1.26***	**1.64***	**1.38***	**1.38***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

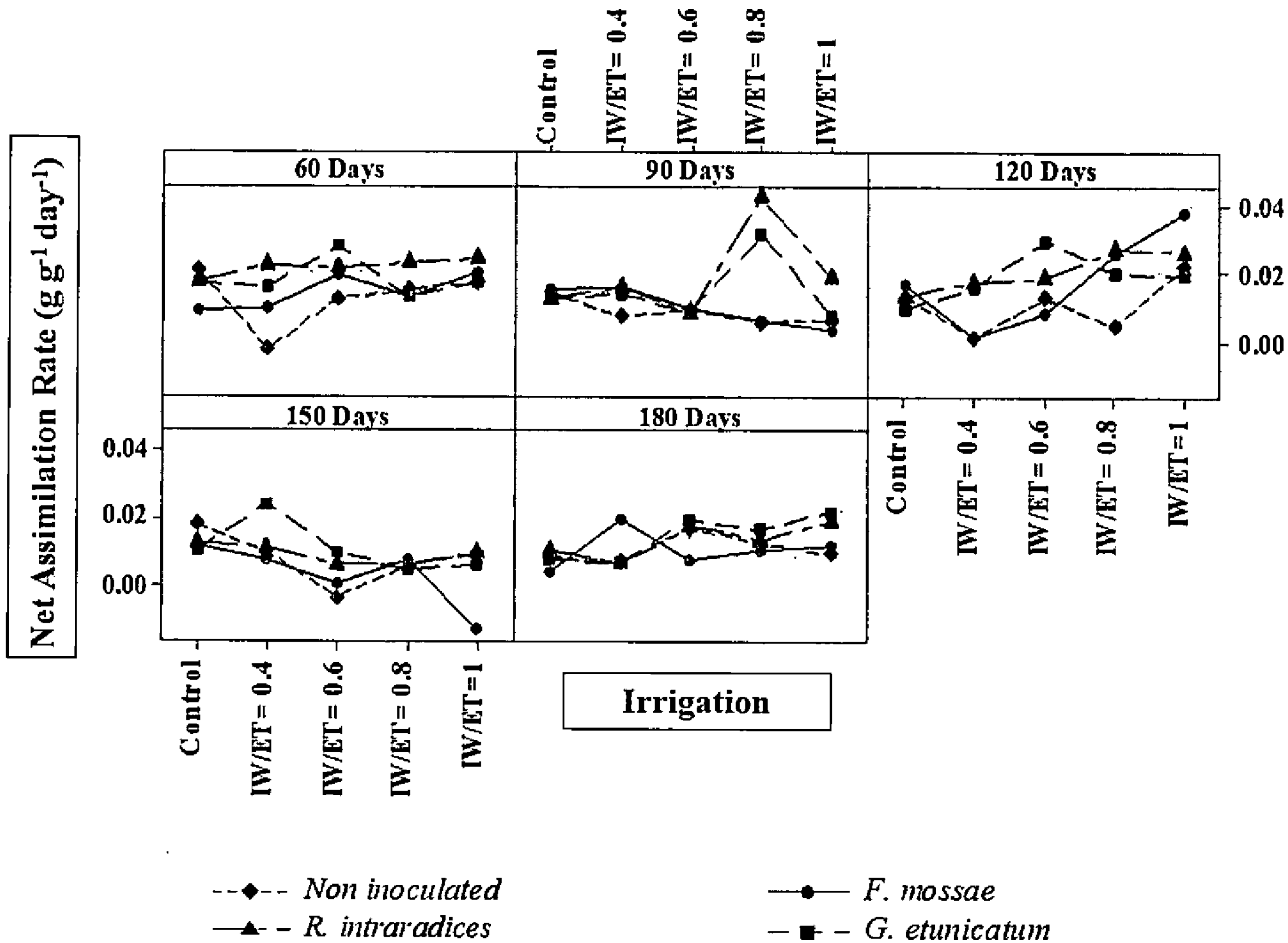


Figure 14.Net Assimilation Rate (g g^{-1} day^{-1}) of mahogany seedlings as influenced by AMF and irrigation interaction

4.2. BIOMETRIC OBSERVATIONS

4.2.1. Shoot height

Seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher shoot length (20.10 cm and 19.63 cm) at 30 days after inoculation; while, those inoculated with *F. mosseae* (16.81 cm) and non-inoculated ones (16.65 cm) had lower shoot lengths (Table 18). At 60 days, seedlings inoculated with *R. intraradices* (31.17 cm) dominated the group; and those inoculated with *F. mosseae* (24.78 cm) had the lowest shoot height. The seedlings inoculated with *G. etunicatum* predominantly had an increased shoot growth during the later period of studies; while, the non-inoculated seedlings maintained the slightest growth (Plate 13). The irrigation regimes however, maintained a persistent trend where the control seedlings recorded highest growth and the treatment IW/ET=0.4 had the lowest growth throughout the study (Plate 14).

Table 18. Shoot height (cm) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Shoot height (cm)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	16.65^{b}	20.68^{d}	24.70^{d}	27.98^{d}	28.16^{d}	33.87^{d}
	R. intraradices	20.10^{a}	31.17^{a}	38.78^{b}	44.24^{b}	43.25^{b}	56.97^{b}
	G. etunicatum	19.63^{a}	29.70^{b}	41.77^{a}	51.94^{a}	50.08^{a}	66.44^{a}
	F. mosseae	16.81^{b}	24.78^{c}	31.96^{c}	37.62^{c}	32.26^{c}	48.94^{c}
	F value	**45.57***	**140.78***	**212.56***	**612.87***	**327.90***	**5663.87***
Irrigation	Control	22.29^{a}	32.42^{a}	41.42^{a}	50.15^{a}	56.63^{a}	63.17^{a}
	IW/ET=1	21.99^{a}	29.96^{b}	40.69^{b}	44.52^{b}	51.86^{b}	59.07^{b}
	IW/ET=0.8	16.93^{b}	27.14^{c}	33.02^{c}	44.41^{b}	46.76^{c}	52.98^{c}
	IW/ET=0.6	17.41^{b}	25.11^{d}	29.55^{d}	31.47^{c}	41.63^{d}	45.10^{d}
	IW/ET=0.4	12.86^{c}	18.29^{e}	26.82^{e}	31.68^{c}	32.80^{c}	37.46^{e}
	F value	**169.57***	**143.12***	**125.96***	**336.69***	**185.95***	**2584.09***
AMF x Irrigation	**F value**	**4.47***	**3.06***	**2.00***	**0.98^{ns}**	**2.93^{ns}**	**7.31^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

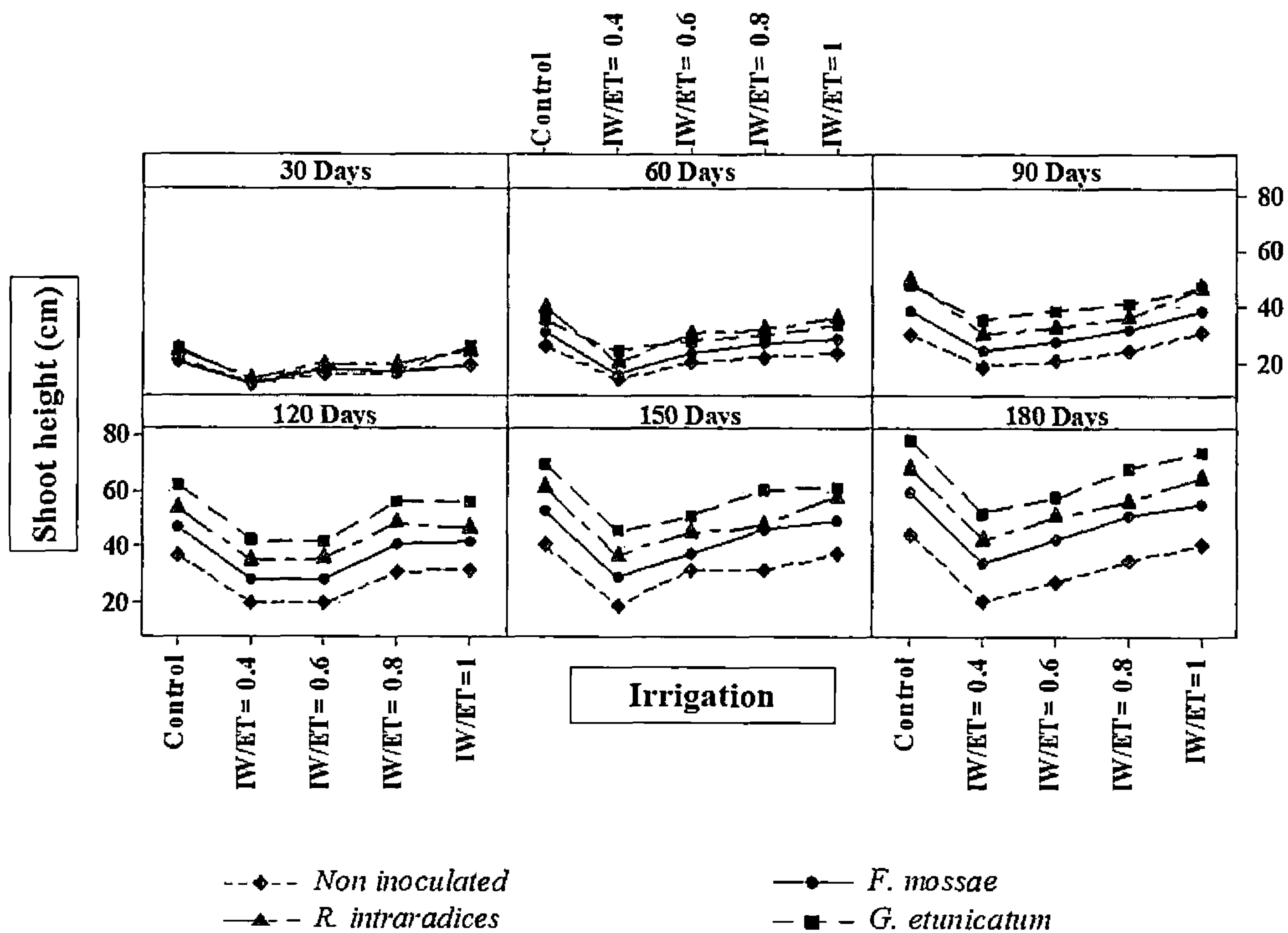


Figure 15. Shoot height (cm) of mahogany seedlings as influenced by AMF and irrigation interaction

Control; IW/ET=1; IW/ET=0.8; IW/ET=0.6; IW/ET=0.4

Control; IW/ET=1; IW/ET=0.8; IW/ET=0.6; IW/ET=0.4

Control; IW/ET=1; IW/ET=0.8; IW/ET=0.6; IW/ET=0.4

Control; IW/ET=1; IW/ET=0.8; IW/ET=0.6; IW/ET=0.4

Plate 13. Height of mahogany seedlings grown under different AMF species A) Seedlings inoculated with *Rhizophagus intraradices* (B) Seedlings inoculated with *Glomus etunicatum* (C) Seedlings inoculated with *Funneliformis mosseae* (D) Seedlings not inoculated with AMF.

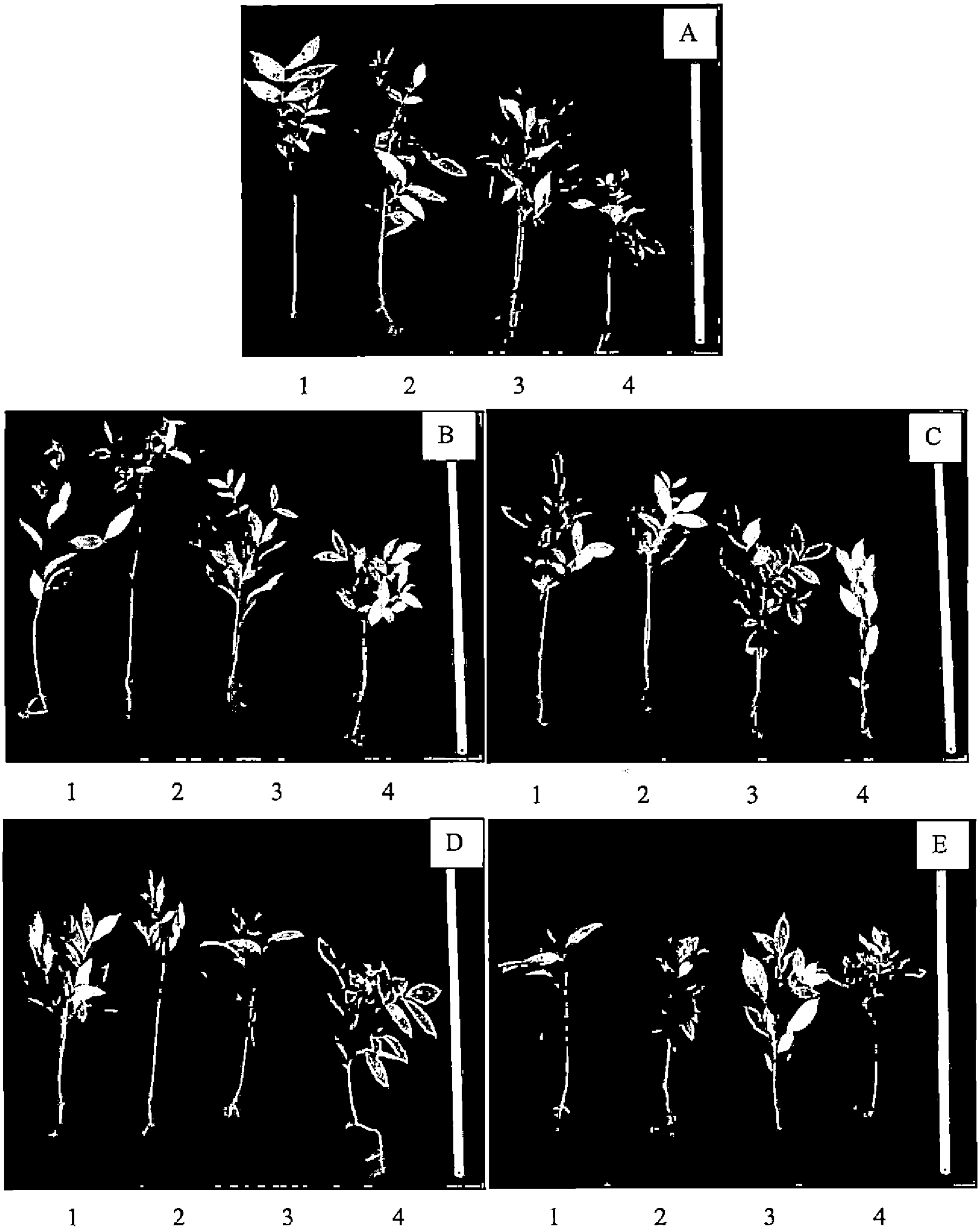


Plate 14. Height of mahogany seedlings grown under different levels of irrigation and under different treatment of AMF *viz.* 1. *R. intraradices* 2. *G. etunicatum* 3. *F. mossae* 4. Non inoculated. (A) Mahogany seedlings under daily irrigation (B) Mahogany seedlings under irrigation at IW/ET=1 (C) Mahogany seedlings under irrigation at IW/ET=0.8 (D) Mahogany seedlings under irrigation at IW/ET=0.6 (E) Mahogany seedlings under irrigation at IW/ET=0.4

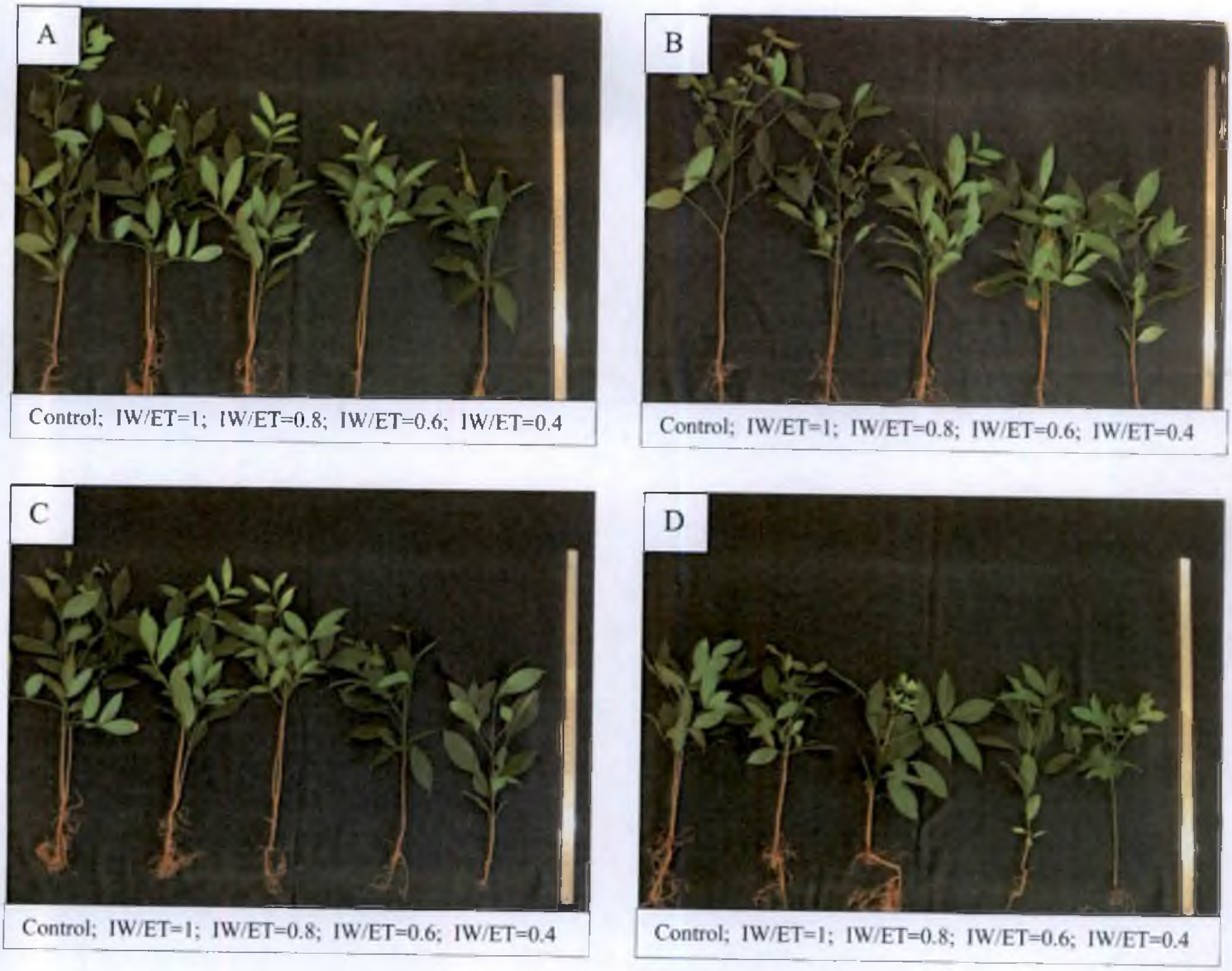


Plate 13. Height of mahogany seedlings grown under different AMF species A) Seedlings inoculated with *Rhizophagus intraradices* (B) Seedlings inoculated with *Glomus etunicatum* (C) Seedlings inoculated with *Funneliformis mosseae* (D) Seedlings not inoculated with AMF.

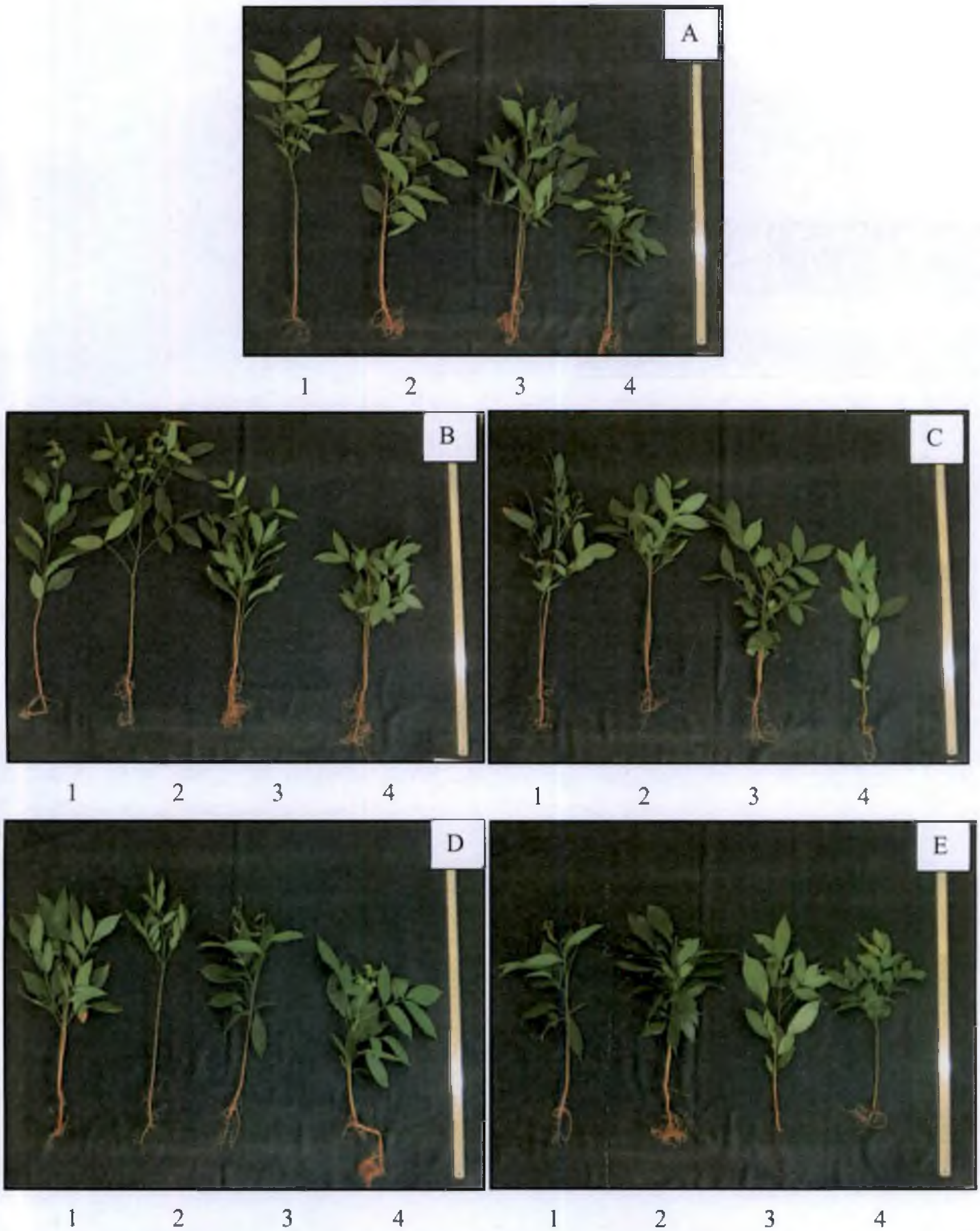


Plate 14. Height of mahogany seedlings grown under different levels of irrigation and under different treatment of AMF *viz.* 1. *R. intraradices* 2. *G. etunicatum* 3. *F. mossae* 4. Non inoculated. (A) Mahogany seedlings under daily irrigation (B) Mahogany seedlings under irrigation at IW/ET=1 (C) Mahogany seedlings under irrigation at IW/ET=0.8 (D) Mahogany seedlings under irrigation at IW/ET=0.6 (E) Mahogany seedlings under irrigation at IW/ET=0.4

The effect of interaction between AMF and irrigation regimes was not significant at 120, 150 and 180 days (Figure 15). Higher shoot height was observed for seedlings inoculated with *R. intraradices* and *G. etunicatum* under control treatment and treatment IW/ET=1.0 at 30 days. At 60 days, higher shoot height was recorded for seedlings inoculated with *R. intraradices* under control treatment alone. At 90 days, however, seedlings inoculated with *R. intraradices* and *G. etunicatum* under control treatment recorded higher values for shoot height.

4.2.2. Taproot length

The results on taproot length as influenced by the various treatments are given in Table 19. The seedlings inoculated with *R. intraradices* had a longer taproot at 30, 60 and 90 days after the inoculation (21.79 cm, 30.42 cm and 36.58 cm); while, those inoculated with *G. etunicatum*

Table 19. Taproot length (cm) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Taproot length (cm)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	16.41^{c}	16.32^{c}	18.41^{d}	20.40^{d}	21.91^{d}	26.66^{d}
	R. intraradices	21.79^{a}	30.42^{a}	36.58^{a}	38.77^{b}	42.81^{b}	46.94^{b}
	G. etunicatum	20.58^{b}	25.93^{b}	35.24^{b}	47.38^{a}	51.95^{a}	56.92^{a}
	F. mosseae	20.34^{b}	24.94^{b}	26.70^{c}	30.41^{c}	33.94^{c}	38.02^{c}
	F value	**65.54***	**167.97***	**833.4***	**286.3***	**170.6***	**67.32***
Irrigation	Control	21.58^{a}	24.58^{c}	32.75^{a}	35.87^{b}	28.97^{b}	42.68
	IW/ET=1	23.39^{b}	27.07^{a}	33.01^{a}	36.91^{a}	40.34^{a}	44.22
	IW/ET=0.8	20.12^{c}	25.29^{bc}	29.83^{b}	35.37^{b}	38.99^{b}	42.74
	IW/ET=0.6	17.08^{d}	23.69^{c}	27.44^{c}	33.28^{c}	36.79^{c}	40.77
	IW/ET=0.4	16.73^{d}	21.38^{d}	26.87^{c}	29.76^{d}	33.17^{d}	40.25
	F value	**79.13***	**17.03***	**62.45***	**137.95***	**83.57***	**0.85^{ns}**
AMF x Irrigation	**F value**	**11.89***	**5.91***	**4.05^{ns}**	**17.66^{ns}**	**16.25^{ns}**	**1.06^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

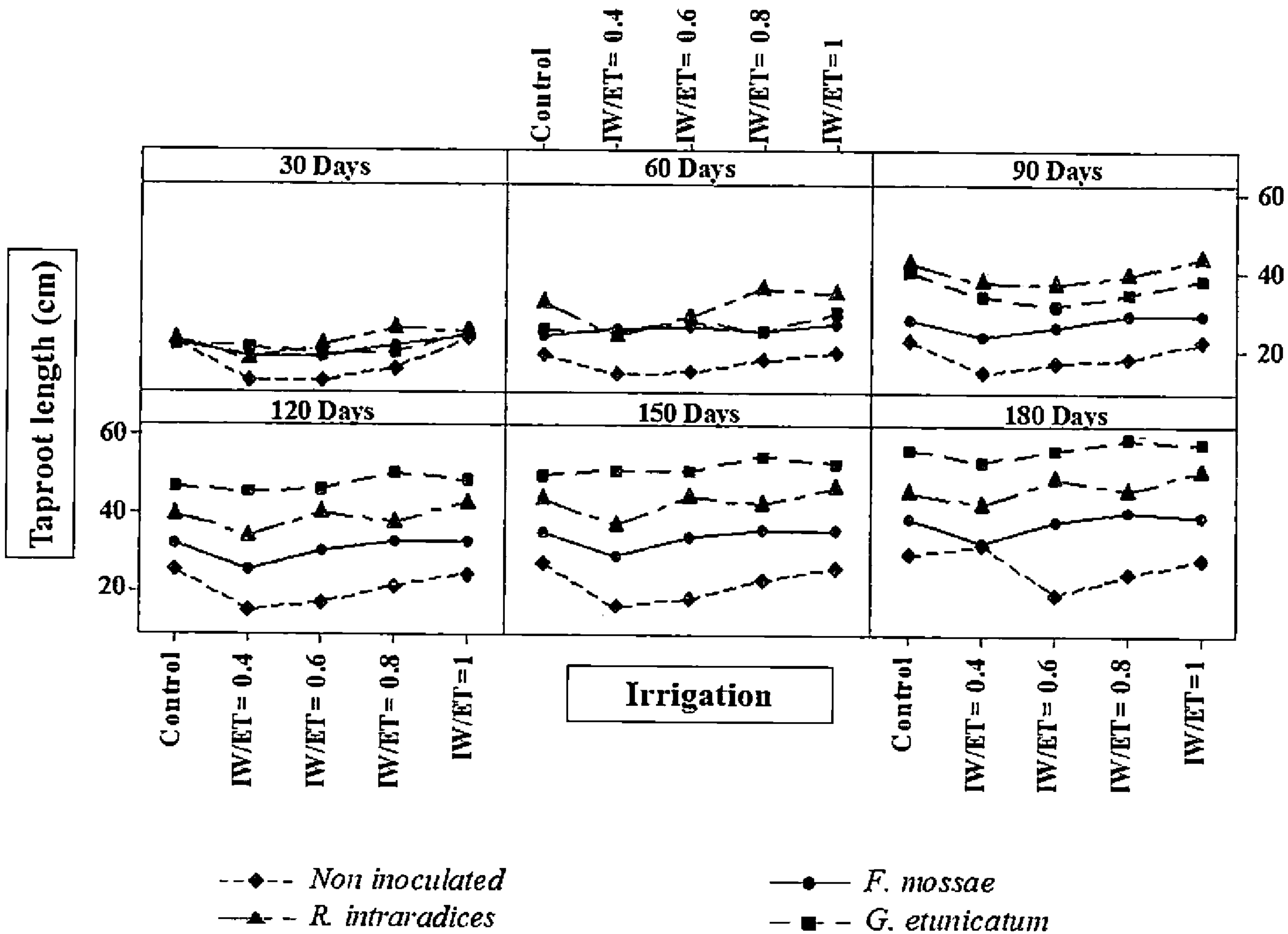


Figure 16. Taproot length (cm) of mahogany seedlings as influenced by AMF and irrigation interaction

dominated during the later period of studies (47.38 cm, 51.95 cm and 56.92 cm). The non-inoculated seedlings maintained the least taproot growth for the whole duration of experiment (Plate 15).

The irrigation regimes also had significant effect on the growth of taproot. At 30 days after the application of treatments, longer roots were observed for the control seedlings (21.58 cm). The treatment IW/ET=1 had longest roots at 60, 90, 120 and 150 days (27.07 cm, 33.01 cm, 36.91 cm and 40.34 cm). Shortest roots were observed for treatment IW/ET=0.4 alone after 60, 120 and 150 days of treatment (21.38 cm, 29.76 cm and 33.17 cm). The treatment IW/ET=0.6 had shorter roots (17.08 cm and 27.44 cm) along with the treatment IW/ET=0.4, at 30 and 90 days after the treatment. No significant variations were observed for taproot length at 180 days.

The effect of interaction was significant at 30 and 60 days (Figure 16). At 30 and 60 days, higher taproot length was observed for seedlings inoculated with *R. intraradices* at IW/ET=0.8 (25.19 and 35.22 cm).

4.2.3. Collar girth

The collar girth of mahogany seedlings was significantly influenced by various treatments (Table 20). Use of different AMF strains did not produce any significant variation in the collar girth of the seedlings at 30 days. However, seedlings inoculated with *R. intraradices* maintained higher collar girth throughout the rest of the period (2.83 mm, 3.80 mm,4.93 mm, 5.27mm and 6.60 mm); along with *G. etunicatum* on 150 and 180 days after treatment (5.98 mm and 7.38 mm).

While considering the various irrigation regimes, the control seedlings exhibited dominance over the rest throughout the studies along with IW/ET=1 and IW/ET=0.8 at 30 days; and with IW/ET=1 at 90 days. The treatment IW/ET=0.4 had the least collar girth during the course of the study along with IW/ET=0.6 at 30 and 120 days.

The effect of interaction was found to be significant for 30, 60 and 120 days (Figure17). At 30 days, higher collar girth was observed for seedlings inoculated with *G. etunicatum* under treatment IW/ET=1. At 60 days, seedlings inoculated with *R. intraradices* of control treatment

Plate 15. Development of root system and fine roots under different AMF treatments (without and with rhizosphere soil) A) Seedlings inoculated with *Rhizophagus intraradices* (B) Seedlings inoculated with *Glomus etunicatum* (C) Seedlings inoculated with *Funneliformis mosseae* (D) Seedlings not inoculated with AMF.

had higher values. Higher collar girth was observed for seedlings inoculated with *R. intraradices* of treatment IW/ET=1 and control treatment at 120 days.

Table 20. Collar girth (mm) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Collar girth (mm)					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	1.73	1.86^{c}	1.82^{d}	2.64^{d}	3.47^{c}	4.24^{c}
	R. intraradices	1.84	2.83^{a}	3.80^{a}	4.93^{a}	5.27^{a}	6.60^{a}
	G. etunicatum	1.78	2.49^{b}	3.39^{b}	4.20^{b}	5.98^{a}	7.38^{a}
	F. mosseae	1.65	1.97^{c}	2.84^{c}	3.19^{c}	4.31^{b}	5.28^{b}
	F value	**0.76^{ns}**	**40.91***	**45.06***	**40.35***	**17.65***	**24.35***
Irrigation	Control	2.17^{a}	2.98^{a}	3.53^{a}	4.97^{a}	6.08^{a}	7.11^{a}
	IW/ET=1	2.12^{a}	2.45^{b}	3.59^{a}	4.30^{b}	5.17^{b}	6.43^{ab}
	IW/ET=0.8	1.97^{a}	2.22^{c}	2.84^{b}	3.82^{b}	4.77^{bc}	5.72^{bc}
	IW/ET=0.6	1.32^{b}	2.10^{c}	2.63^{bc}	2.66^{c}	4.26^{cd}	5.41^{cd}
	IW/ET=0.4	1.18^{b}	1.70^{d}	2.23^{c}	2.94^{c}	3.50^{d}	4.71^{d}
	F value	**21.24***	**35.19***	**16.87***	**28.09***	**10.99***	**8.66***
AMF x Irrigation	**F value**	**2.42***	**2.55***	**0.79^{ns}**	**1.85***	**0.13^{ns}**	**0.13^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.2.4. Leaf area

The analysis of leaf area of the mahogany seedlings under different treatments over a period of time recorded significant variations (Table 21). However, no significant variation was noted for leaf area for seedlings inoculated with different AMF species after 30 days of treatment. Seedlings inoculated with *G. etunicatum* had larger leaf area throughout the duration of the studies (86.48 cm^2, 159.22 cm^2, 209.54 cm^2, 350.69 cm^2 and 358.49 cm^2); along with *R. intraradices* on 60 and 120 days after treatment (91.83 cm^2 and 204.93 cm^2). Non- inoculated seedlings maintained smaller leaf area along with *F. mosseae* at 60 days, with *F. mosseae* and *R. intraradices* at 90 and 150 days respectively.

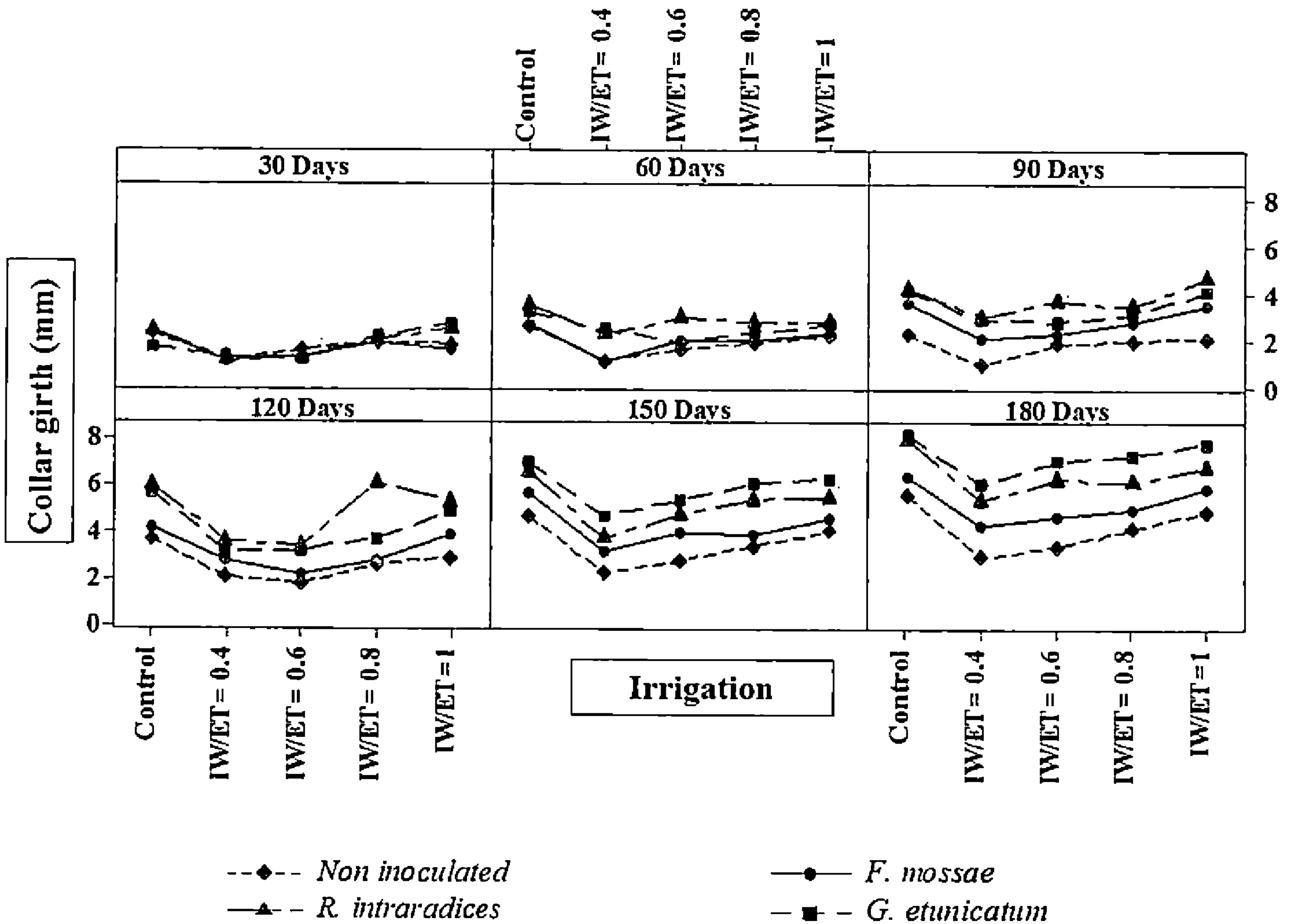


Figure 17.Collar girth (mm) of mahogany seedlings as influenced by AMF and irrigation interaction

Among the various irrigation regimes, the control had higher leaf area over the rest throughout the study. The treatment IW/ET=0.4 had smaller leaf area during the course of the study (55.97 cm^2, 63.11 cm^2, 57.05 cm^2, 54.31 cm^2, 68.11 cm^2 and 73.72 cm^2); along with IW/ET=0.6 at 30, 60 and 90 days (59.65 cm^2, 65.33 cm^2 and 59.31 cm^2).

Table 21. Leaf area (cm^2) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Leaf area (cm^2)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	85.84	76.97^b	130.61^b	124.92^c	212.84^b	208.60^d
	R. intraradices	63.86	91.83^a	140.57^b	204.93^a	239.48^b	316.67^b
	G. etunicatum	88.04	86.48^a	159.22^a	209.54^a	350.69^a	358.49^a
	F. mosseae	87.63	72.55^b	124.17^b	154.50^b	202.78^b	241.44^c
	F value	**1.33^{ns}**	**8.97***	**6.47***	**23.36***	**28.27***	**87.08***
Irrigation	Control	118.51^a	110.13^a	334.3^a	288.13^a	525.15^a	545.91^a
	IW/ET=1	117.32^a	102.89^a	124.39^b	279.99^a	272.38^b	379.59^b
	IW/ET=0.8	92.77^b	68.32^b	118.15^b	114.78^b	231.33^c	245.89^c
	IW/ET=0.6	59.65^c	65.33^b	59.31^c	130.14^b	160.27^d	170.40^d
	IW/ET=0.4	55.97^c	63.11^b	57.05^c	54.31^c	68.11^e	73.72^e
	F value	**80.24***	**47.69***	**287.1***	**123.20***	**150.90***	**499.46***
AMF x Irrigation	**F value**	**0.34***	**0.37***	**1.52***	**2.62***	**7.14***	**11.92***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant throughout the period of study (Figure18). At 30 days, seedlings inoculated with *R. intraradices* of the control treatment had higher leaf area. At 60 days, seedlings inoculated with *R. intraradices* of the control treatment and treatment IW/ET=1.0 recorded higher leaf area. At 90 days, seedlings inoculated with G. *etunicatum* under control treatment and seedlings inoculated with *R. intraradices* of the control treatment and treatment IW/ET=1.0 recorded higher leaf area. At 90, 150 and 180 days, higher leaf area was observed for seedlings inoculated with G. *etunicatum* under daily irrigation control treatment.

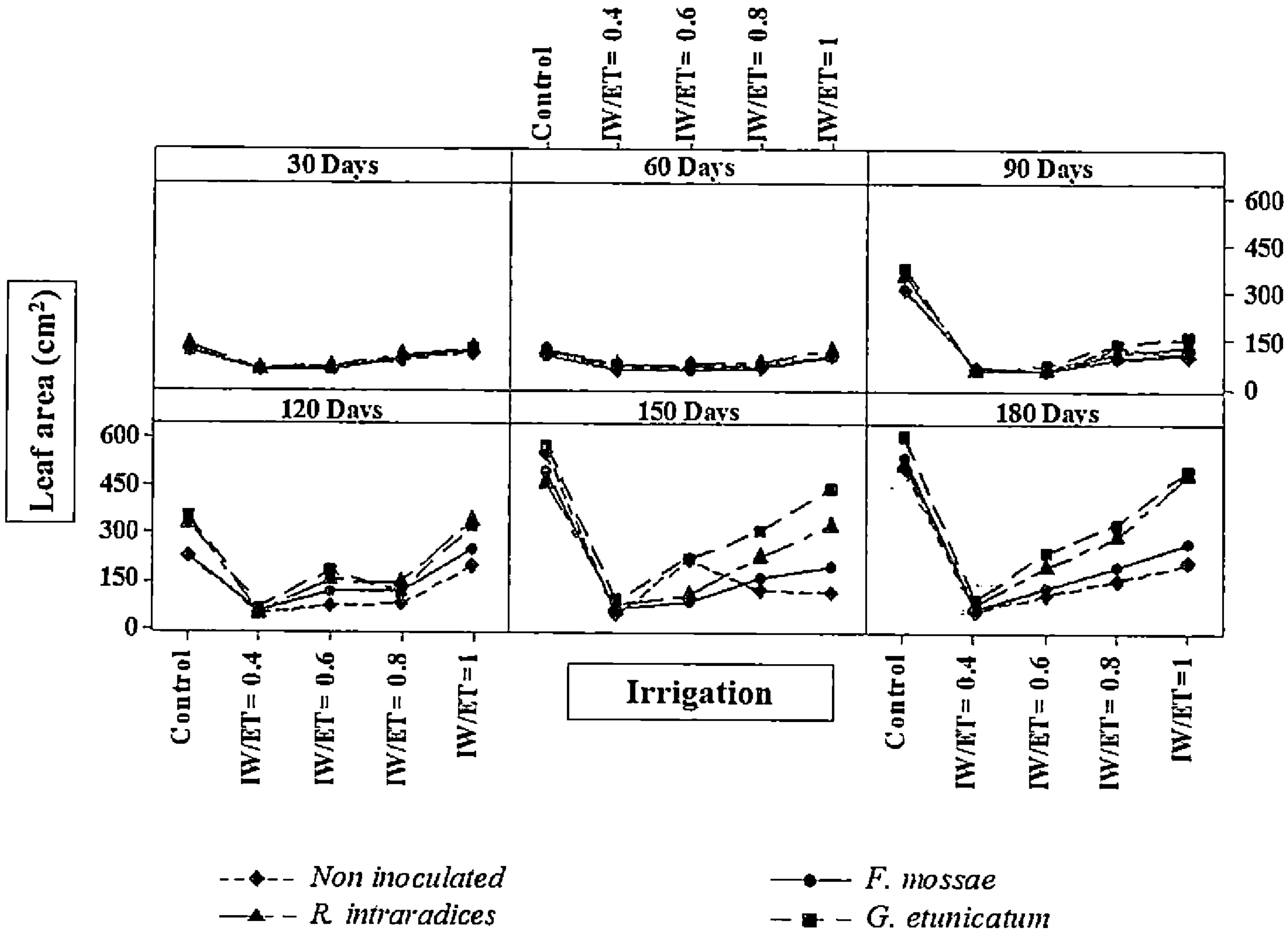


Figure 18. Leaf area (cm^2) of mahogany seedlings as influenced by AMF and irrigation interaction

4.2.5. Number of leaves

Treatment of seedlings with different AMF species and irrigation regimes had generally a significant effect on the production of leaves (Table 22). All the three AMF species positively influenced the production of leaves at 30 days. No significant variation was however observed in 60 and 90 days. For the rest of the period, seedlings inoculated with *R. intraradices* (5.18, 5.28 and 8.51) and *G. etunicatum* (5.38, 5.65 and 8.96) had a higher production of leaves significantly than the rest. At 120 and 150 days, seedlings inoculated with *F. mosseae* (3.9 and 4.55) also had significantly lower number of leaves on par with the control seedlings (3.78 and 4.38).

Table 22. Number of leaves of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Number of leaves					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	3.03^{b}	2.95	3.20	3.78^{b}	4.38^{b}	6.27^{c}
	R. intraradices	3.60^{a}	3.48	3.27	5.18^{a}	5.28^{a}	8.51^{a}
	G. etunicatum	3.65^{a}	3.20	3.35	5.38^{a}	5.65^{a}	8.96^{a}
	F. mosseae	3.70^{a}	3.33	3.47	3.90^{b}	4.55^{b}	7.32^{b}
	F value	**2.78***	**1.90^{ns}**	**0.59^{ns}**	**18.86***	**9.72***	**19.44***
Irrigation	Control	4.90^{a}	4.31^{a}	4.25^{a}	5.96^{a}	6.73^{a}	10.29^{a}
	IW/ET=1	4.16^{b}	3.71^{b}	3.94^{a}	5.65^{a}	6.15^{ab}	9.04^{b}
	IW/ET=0.8	3.37^{c}	3.08^{c}	3.44^{b}	4.77^{b}	5.77^{b}	7.72^{c}
	IW/ET=0.6	2.87^{c}	2.37^{d}	2.75^{c}	4.10^{c}	4.27^{c}	6.79^{d}
	IW/ET=0.4	2.17^{d}	2.73^{cd}	2.23^{d}	2.33^{d}	1.92^{d}	4.98^{e}
	F value	**26.29***	**17.83***	**24.77***	**44.84***	**80.55***	**4.98***
AMF x Irrigation	**F value**	**0.77***	**1.83***	**0.68***	**0.86***	**0.41***	**2.05***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

A significant increase in production of leaves was observed in the control treatment (4.25, 5.96 and 6.73) as well as the treatment IW/ET=1 (3.94, 5.65 and 6.15) at 90, 120 and 150

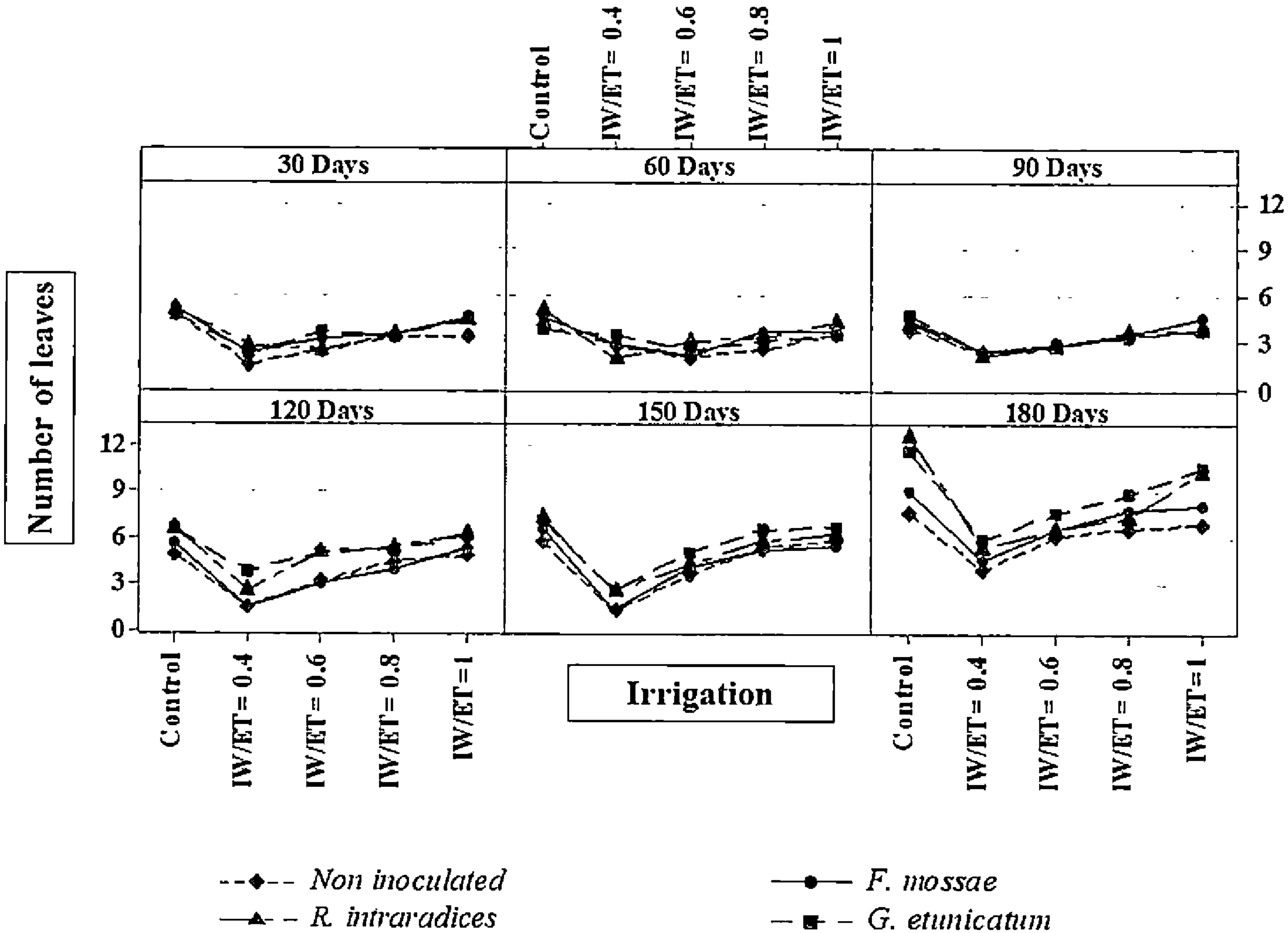


Figure 19. Number of leaves of mahogany seedlings as influenced by AMF and irrigation interaction

days. It was also found that the treatment IW/ET=0.4 had the least production of leaves in it throughout the experiment; along with the treatment IW/ET=0.6 at 60 days (2.37).

The effect of interaction was found to be significant throughout the period of study (Figure 19). At 30 days, all seedlings under the control irrigation treatment recorded higher values (5.00, 5.00, 4.80 and 4.80 for seedlings inoculated with *F. mosseae, R. intraradices, G. etunicatum* and non-inoculated seedlings respectively). At 90 days, seedlings inoculated with *G. etunicatum* under control irrigation treatment had high values (4.70). At 120 and 150 days, seedlings inoculated with *R. intraradices* (6.70 and 7.40) and *G. etunicatum* (6.80 and 7.30) under control irrigation treatment had higher production of leaves. Seedlings inoculated with *R. intraradices* under the daily irrigation treatment had higher number of leaves at 60 and 180 days (5.00 and 12.67).

4.2.6. Number of lateral roots

Different AMF species and irrigation regimes had a significant influence on the production of lateral roots also (Table 23). However, no significant variation was observed at 30 days after treatment. Seedlings inoculated with *R. intraradices* (18.5 and 19.58) and *G. etunicatum* (17.1 and 19.67) had a higher production of lateral roots at 60 and 90 days. At 120 days, a higher production of lateral roots was noted for seedlings inoculated with *R. intraradices* (23.68) alone. At 150 and 180 days, seedlings inoculated with *G. etunicatum* resulted in higher lateral root production (25.83 and 28.38). Non inoculated seedlings were found to have lower lateral root production (10.52, 13.83, 16.28, 18.63 and 20.97) during the period of study; along with *F. mosseae* at 60 and 90 days (12.15 and 14.33).

A significant increase in the production of lateral roots was observed in the control treatment throughout the study. Higher production of lateral roots was recorded for the treatment IW/ET=1 at 30 days, along with the control treatment. The treatment IW/ET=0.4 had lower production of lateral root throughout the experiment along with the treatment IW/ET=0.6 at 150 days.

The effect of interaction was significant at 30 and 90 days (Figure 24). At 30 days, seedlings inoculated with *R. intraradices* under the treatment IW/ET=1.0 and seedlings not inoculated with AMF under the control treatment recorded higher values (18.25 and 18.00). At

90 days, seedlings inoculated with *G. etunicatum* under the control treatment had higher production of lateral roots (23.75).

Table 23. Number of lateral roots of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Number of lateral roots					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	15.42	10.52^{b}	13.83^{b}	16.28^{c}	18.63^{d}	20.97^{d}
	R. intraradices	14.95	18.50^{a}	19.58^{a}	23.68^{a}	23.63^{b}	26.43^{b}
	G. etunicatum	15.02	17.10^{a}	19.67^{a}	20.88^{b}	25.83^{a}	28.38^{a}
	F. mosseae	15.07	12.15^{b}	14.33^{b}	19.73^{b}	21.13^{c}	23.93^{c}
	F value	**0.15^{ns}**	**21.55***	**11.67***	**53.10***	**22.56***	**14.98***
Irrigation	Control	16.75^{ab}	16.37^{a}	19.87^{a}	22.27^{a}	25.58^{a}	28.02^{a}
	IW/ET=1	17.10^{a}	16.31^{a}	17.54^{b}	22.58^{a}	22.40^{b}	25.77^{b}
	IW/ET=0.8	15.29^{bc}	15.44^{bc}	17.16^{b}	20.27^{b}	22.27^{c}	25.02^{b}
	IW/ET=0.6	14.37^{c}	13.54^{c}	15.98^{c}	17.90^{c}	20.90^{d}	23.46^{c}
	IW/ET=0.4	12.04^{d}	11.7^{d}	13.71^{d}	17.71^{c}	19.40^{e}	22.37^{d}
	F value	**11.57***	**57.69***	**46.24***	**24.31***	**10.27***	**42.35***
AMF x Irrigation	**F value**	**0.38***	**4.34^{ns}**	**2.53***	**0.46^{ns}**	**3.48^{ns}**	**1.34^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.2.7. Fresh weight of leaves

Effects of different AMF species and irrigation regimes on the fresh weight of leaves are given in the Table 24. The observations show a significant reduction in the fresh weight of leaves for the seedlings not inoculated with AMF throughout the experiment. Between the three AMF species, no significant difference was observed after the first 30 days of inoculation; while, significant differences was observed after 60, 90, 120 and 150 days. At 60 and 90 days, seedlings inoculated with *R. intraradices* (6.68g and 8.45g respectively) and *G. etunicatum* (6.28g and 7.97 g respectively) had higher values for fresh weight of leaves while *F. mosseae* had lower values (5.45 and 7.11 respectively). At 120 days, highest values were recorded for seedlings

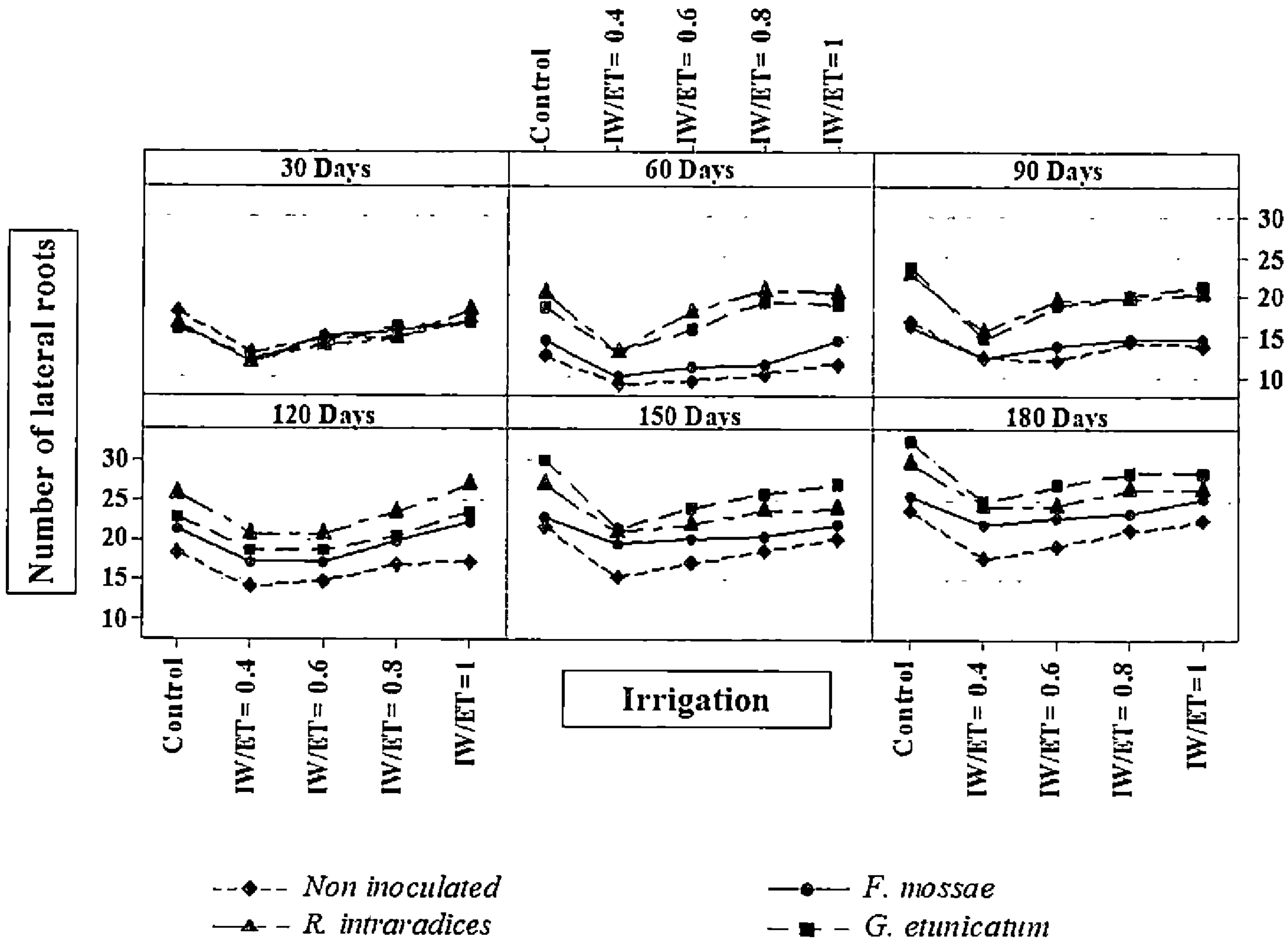


Figure 20. Number of lateral roots of mahogany seedlings as influenced by AMF and irrigation interaction

inoculated with *R. intraradices* (15.39) and lowest values were recorded again for *F. mosseae* (11.75g). At 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (9.43g and 21.79g respectively) while lowest values were recorded again for *F. mosseae* (6.94g and 16.31g respectively).

Table 24. Fresh weight of leaves (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Fresh weight of leaves (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	2.60	5.27^{b}	5.40^{c}	8.75^{d}	6.64^{c}	13.99^{d}
	R. intraradices	2.49	6.68^{a}	8.45^{a}	15.39^{a}	7.90^{b}	19.15^{b}
	G. etunicatum	2.71	6.28^{a}	7.97^{a}	13.87^{b}	9.43^{a}	21.79^{a}
	F. mosseae	2.60	5.45^{b}	7.11^{b}	11.75^{c}	6.94^{c}	16.31^{c}
	F value	**0.87^{ns}**	**15.05***	**21.81***	**35.65***	**23.55***	**34.56***
Irrigation	Control	3.77^{a}	7.99^{a}	11.03^{a}	14.23^{a}	11.39^{a}	23.78^{a}
	IW/ET=1	3.41^{b}	7.91^{a}	6.97^{b}	13.73^{a}	8.84^{b}	21.26^{b}
	IW/ET=0.8	3.28^{b}	7.10^{b}	6.91^{b}	14.08^{a}	7.26^{c}	18.54^{c}
	IW/ET=0.6	1.26^{c}	3.11^{c}	5.88^{c}	10.12^{b}	6.15^{d}	14.35^{d}
	IW/ET=0.4	1.29^{c}	3.50^{c}	5.36^{c}	10.04^{b}	4.99^{e}	11.12^{e}
	F value	**126.61***	**156.74***	**48.41***	**16.04***	**73.97***	**63.04***
AMF x Irrigation	**F value**	**1.61***	**1.29***	**5.32***	**0.61^{ns}**	**0.84***	**1.10***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

While considering the different irrigation regimes, the control seedlings had higher values for fresh weight of leaves throughout the experiment but, was no significant difference was observed between the control (7.99g) and the treatment IW/ET=1 (7.91g) at 60 days. The lowest values were noted for the treatment IW/ET=0.6 (1.26 g, 3.11g, 5.88g and10.12g) and IW/ET=0.4 (1.29g, 3.50g, 5.36g and 10.04g) at 30, 60, 90 and 120 days. At 150 and 180 days, the lowest values (4.99 g and 11.12 g) were recorded for IW/ET=0.4 alone.

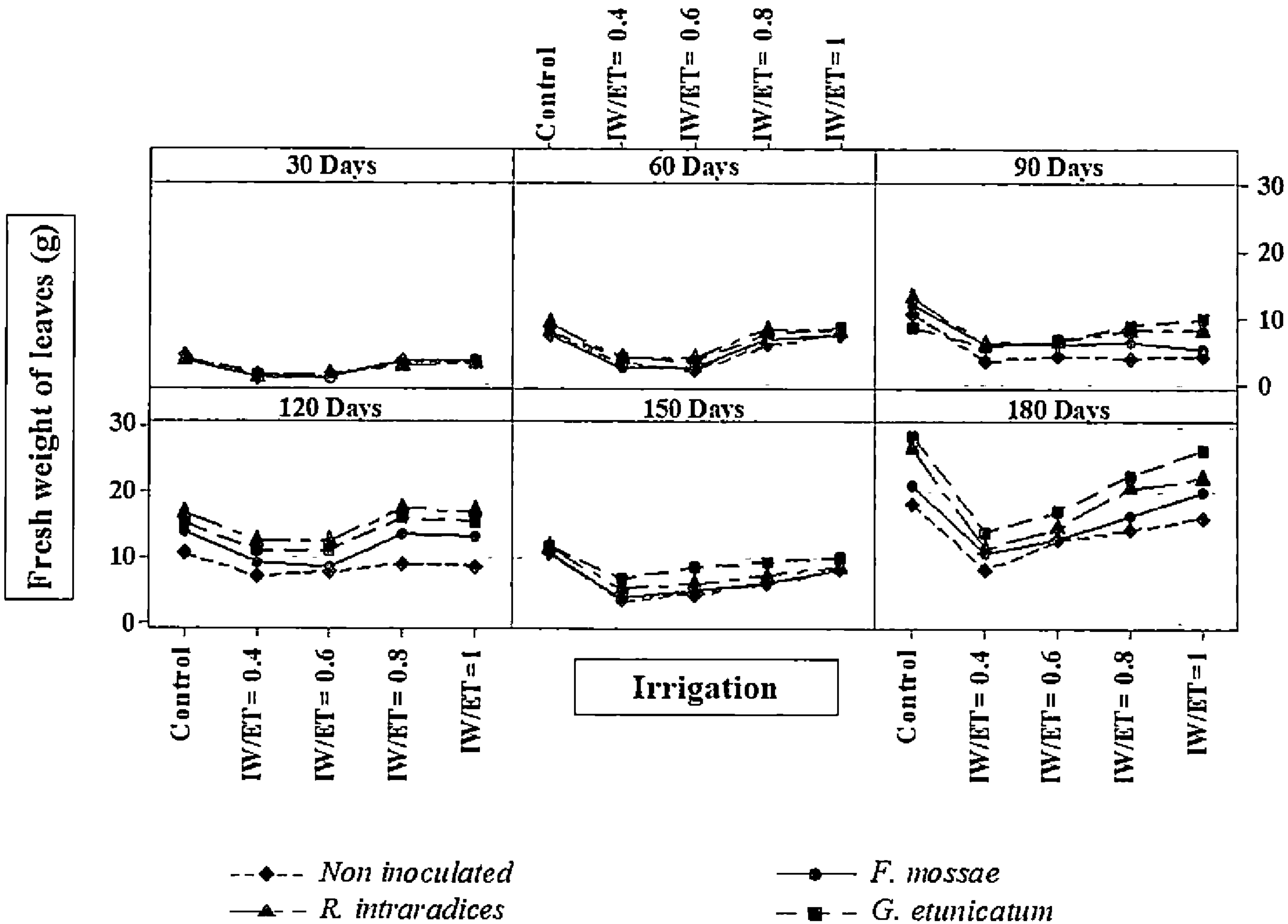


Figure 21. Fresh weight of leaves (g) of mahogany seedlings as influenced by AMF and irrigation interaction

The effect of interaction was significant throughout the period of study except for 120 days (Figure 21). At 30 days, higher fresh weight of leaves was recorded for seedlings not inoculated with AMF under the control treatment (4.2 g). At 60 and 90 days, higher values were recorded for seedlings inoculated with *R. intraradices* under the control treatment (9.12 g and 12.9 g). Seedlings inoculated with *G. etunicatum* under control irrigation treatment had higher values at 150 and 180 days (12.00 g and 28.65 g). At 150 days, higher value was recorded for seedlings inoculated with *R. intraradices* under the control treatment too (11.9 g).

4.2.8. Fresh weight of root

Influence of different AMF species and irrigation regimes on the fresh weight of roots are given in the Table 25. The observations show a significant reduction in the fresh weight of roots for the seedlings not inoculated with AMF throughout the experiment except at 30 days; where, the lowest values were recorded for *R. intraradices* (1.80 g). Among the three AMF species, after the first 30 days of inoculation, the highest values were observed for seedlings inoculated with *G. etunicatum* (2.49 g). At 60 days, seedlings inoculated with *R. intraradices* had higher values for fresh weight of roots (5.39 g). At 90 days, highest values were recorded for seedlings inoculated with both *R. intraradices* and *G. etunicatum* (6.57 g and 6.45 g respectively). At 120, 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (7.53 g, 15.94 g and 11.25 g respectively).

There was no significant difference between the control and the treatment IW/ET=1 after 30, 60, 90 and 180 days. The highest value at 120 days (9.48 g) was noted for the control treatment. At 150 days, highest values (14.91 g) was observed for control seedlings along with IW/ET=1 (14.59g), IW/ET=0.8 (13.47 g) and IW/ET= 0.6 (13.42 g). The treatment IW/ET=0.4 had lowest values (1.39 g, 3.82 g, 8.03 g and 6.09 g) at 30, 90, 150 and 180 days. Also, IW/ET=0.4 had lower values along with IW/ET=0.6 (2.75 g and 3.65 g) at 60 and 120 days.

The effect of interaction was found to be throughout the period of study (Figure 22). Seedlings not inoculated with AMF under the control treatment had higher fresh weight of roots (4.75g) at 30 days while, seedlings inoculated with *R. intraradices* under the treatment IW/ET=1 recorded higher value at 60 days (7.01 g). At 90 days, seedlings inoculated with *R. intraradices* (9.05 g) and *F. mosseae* (7.83 g) under control irrigation treatment had higher values along with seedlings inoculated with *R. intraradices* (8.03 g) and *G. etunicatum* (8.93 g) under treatment IW/ET=1. At 150 days, higher value was observed for seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.6 (19.93 g). At 120 and 180 days, seedlings inoculated with *G. etunicatum* under control irrigation treatment had higher fresh weight of roots (10.10 g and 13.34 g).

Table 25. Fresh weight of root (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Fresh weight of root (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	2.28^{ab}	3.99^{c}	4.88^{c}	4.85^{c}	9.13^{c}	7.86^{c}
	R. intraradices	1.80^{c}	5.39^{a}	6.57^{a}	6.00^{b}	13.37^{b}	9.49^{b}
	G. etunicatum	2.49^{a}	4.64^{b}	6.45^{a}	7.53^{a}	15.94^{a}	11.25^{a}
	F. mosseae	1.94^{bc}	3.68^{c}	5.46^{b}	5.09^{c}	13.10^{b}	8.73^{b}
	F value	**4.82***	**22.47***	**17.44***	**20.68***	**28.77***	**17.68***
Irrigation	Control	2.75^{a}	6.05^{a}	7.71^{a}	9.48^{a}	14.91^{a}	11.88^{a}
	IW/ET=1	2.76^{a}	5.69^{a}	7.92^{a}	6.59^{b}	14.59^{a}	12.11^{a}
	IW/ET=0.8	1.98^{b}	5.11^{b}	5.82^{b}	5.71^{c}	13.47^{a}	8.38^{b}
	IW/ET=0.6	1.77^{bc}	2.75^{c}	3.94^{c}	3.65^{d}	13.42^{a}	8.20^{b}
	IW/ET=0.4	1.39^{c}	2.55^{c}	3.82^{c}	3.89^{d}	8.03^{b}	6.09^{c}
	F value	**14.32***	**86.49***	**82.79***	**63.01***	**22.7***	**45.78***
AMF x Irrigation	**F value**	**7.40***	**0.84***	**1.45***	**0.61***	**3.07***	**0.61***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.2.9. Fresh weight of shoot

Effects of application of different AMF species and irrigation regimes on the fresh weight of roots are described in the Table 26. The observations had a significant reduction in the fresh weight of roots for the seedlings not inoculated with AMF throughout the experiment except at 60 and 90 days where the lowest values were recorded for the non-inoculated seedlings and for seedling treated with *F. mosseae*. No significant variation in fresh weight of shoot was observed

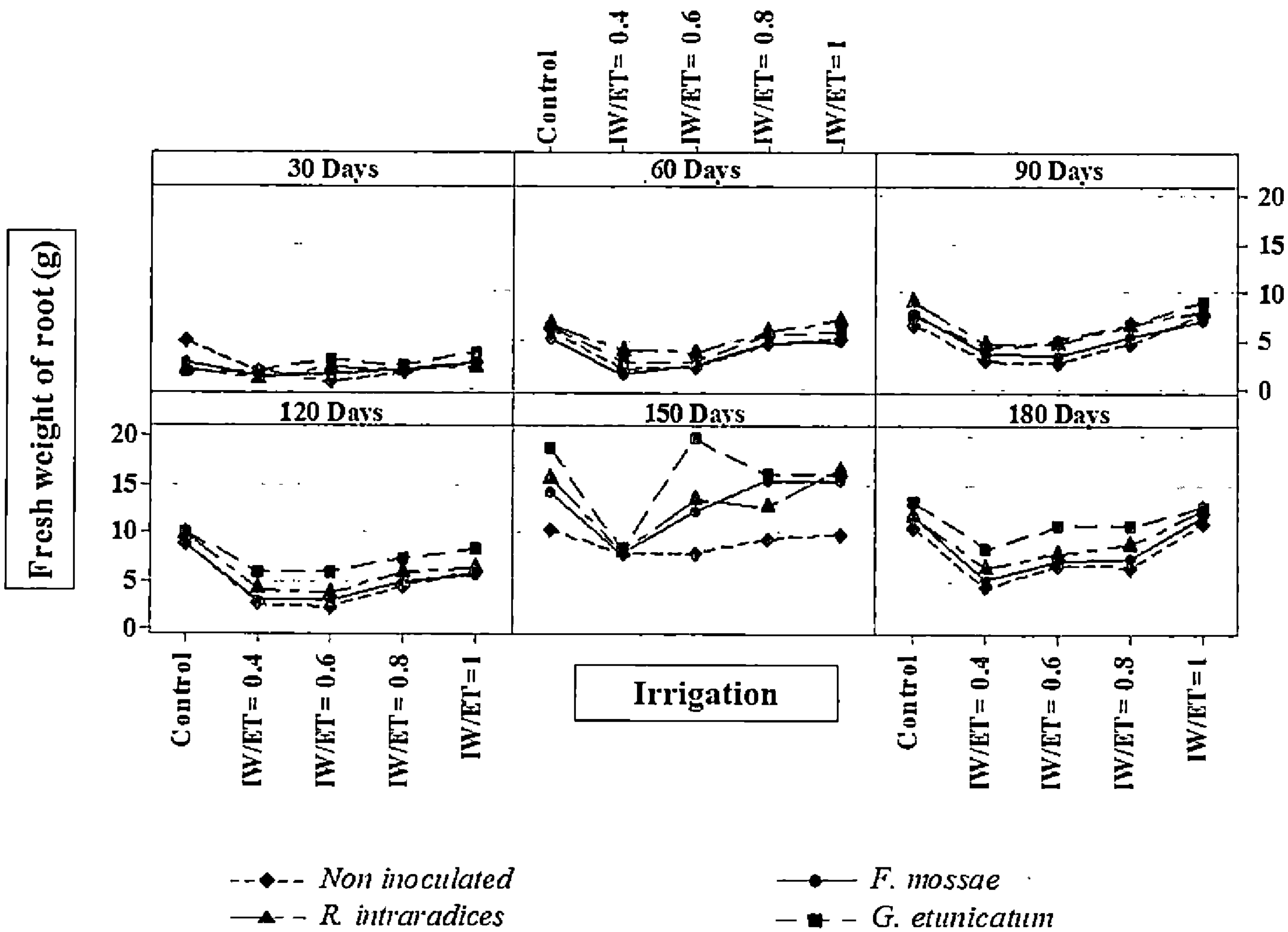


Figure 22. Fresh weight of root (g) of mahogany seedlings as influenced by AMF and irrigation interaction

with respect to AMF species at 30 days. At 60 days, seedlings inoculated with *G. etunicatum* had higher fresh weight of shoots (5.80g). At 90 days, highest values were recorded for seedlings inoculated with *R. intraradices* (6.39g). At 120, 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (7.56g, 8.86g and 9.23g respectively).

Table 26. Fresh weight of shoot (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Fresh weight of shoot (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	3.11	3.65^{c}	3.96^{c}	4.77^{c}	6.07^{d}	6.35^{d}
	R. intraradices	2.96	4.48^{d}	6.39^{a}	5.88^{b}	7.18^{b}	7.86^{b}
	G. etunicatum	3.02	5.80^{a}	5.68^{b}	7.56^{a}	8.86^{a}	9.23^{a}
	F. mosseae	2.66	3.78^{c}	3.91^{c}	5.30^{bc}	6.60^{c}	7.24^{c}
	F value	**1.76^{ns}**	**27.84***	**47.91***	**31.16***	**52.52***	**29.82***
Irrigation	Control	4.18^{a}	6.59^{a}	7.17^{a}	9.31^{a}	10.61^{a}	12.30^{a}
	IW/ET=1	3.95^{a}	6.01^{a}	7.26^{a}	6.60^{b}	8.75^{b}	9.25^{b}
	IW/ET=0.8	2.87^{b}	4.14^{b}	4.82^{b}	5.73^{c}	6.74^{c}	7.55^{c}
	IW/ET=0.6	1.99^{c}	2.62^{c}	2.61^{c}	4.02^{b}	5.44^{d}	4.47^{d}
	IW/ET=0.4	1.69^{c}	2.76^{c}	3.07^{c}	3.72^{d}	4.33^{e}	4.78^{d}
	F value	**47.25***	**76.66***	**119.2***	**86.81***	**183.23***	**173.62***
AMF x Irrigation	**F value**	**2.32***	**0.49***	**2.39***	**1.06***	**2.05***	**1.23***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

Among the different irrigation regimes, there were no significant differences between control and treatment IW/ET=1 at 30, 60 and 90 days. The highest values were recorded were these observations. The highest values at 120,150 and 180 days (9.31g, 10.61g and12.30g) were recorded for the control treatment. At 30, 60, 90 and 180 days, the lowest values was observed for treatments IW/ET=0.6 (1.99g, 2.62g, 2.61g and 4.47g) and IW/ET= 0.4 (1.69g, 2.76g, 3.07g and 4.78g). The treatment IW/ET=0.4 alone had lowest values (3.72g) at 120 days.

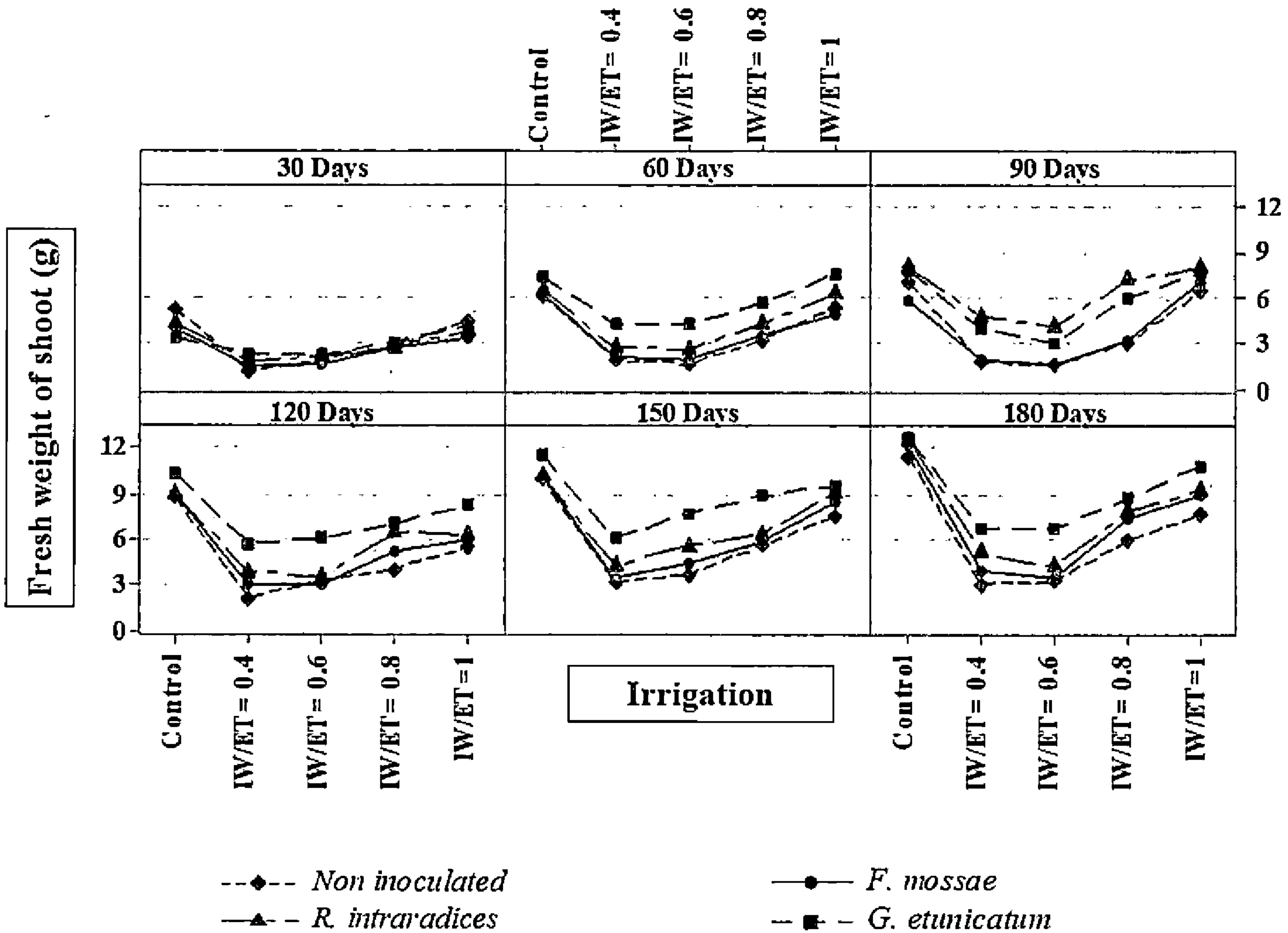


Figure 23. Fresh weight of shoot (g) of mahogany seedlings as influenced by AMF and irrigation interaction

The effect of interaction was significant throughout the study (Figure 23). Seedlings not inoculated with AMF under the control treatment had higher fresh weight of shoots (5.18g) at 30 days. Seedlings inoculated with *G. etunicatum* under the control irrigation treatment and treatment IW/ET=1 recorded higher values at 60 days (7.51 g and 7.42 g). At 90 days, seedlings inoculated with *R. intraradices* (7.99 g), *G. etunicatum* (7.81 g) and *F. mosseae* (7.04 g) belonging to irrigation treatment IW/ET=1had higher values along with seedlings inoculated with *R. intraradices* (7.96 g), *G. etunicatum* (7.71 g) and non-inoculated seedlings (7.01 g) under control treatment. At 120, 150 and 180 days, higher value was observed for seedlings inoculated with *G. etunicatum* control irrigation treatment (10.37 g, 11.67 g and12.77g). At 180 days, seedlings inoculated with *R. intraradices* (7.01 g) also showed higher values.

4.2.10. Dry weight of leaves

The performance of mahogany seedlings based on the application of different AMF species and irrigation regimes on the dry weight of leaves are given in the Table 27. Between the three AMF species, after the first 30 and 60 days of inoculation, the highest values (1.48g and 2.10g) were observed for seedlings inoculated with *R. intraradices*. At 90 days, seedlings inoculated with *G. etunicatum* also had higher values for dry weight of leaves (3.12 g). At 120 and 150 days, the highest values were recorded for seedlings inoculated with both *R. intraradices* (4.27g and 5.59g respectively) and *G. etunicatum* (4.39g and 5.69g respectively). Again at 180 days, seedlings inoculated with *G. etunicatum* indicated highest values for dry weight of leaves (7.25g). The observations had a significant reduction with respect to the dry weight of the leaves for the mahogany seedlings not inoculated with AMF throughout the experiment, except for 30, 90 and 150 days. In these days, lowest values were also recorded for seedlings inoculated with *F. mosseae* and *R. intraradices*.

While considering the different irrigation regimes, the highest dry weights for leaves were recorded for the control seedlings for all months. However, no significant difference between the control and the treatment IW/ET=1 was evident at 120 days. At 30, 60 and 150 days, no significant difference between the treatments IW/ET= 0.6 and IW/ET=0.4 was observed for which the lowest values were documented. The treatment IW/ET=0.4 had lowest values at 90, 120 and 180 days (1.46g, 1.93g and 2.77g).

The effect of interaction was found to be significant except at 120 and 180 days (Figure 24). Seedlings inoculated with *R. intraradices* under the control irrigation recorded higher values at 30 and 60 days (2.11 g and 3.01 g). Seedlings inoculated with *G. etunicatum* under the treatment IW/ET=0.8 recorded higher values at 90 days (4.44 g). At 90 and 150 days, higher value were also observed for seedlings inoculated with *R. intraradices* (4.34 g and 8.77 g), *G. etunicatum* (4.29 g and 8.77 g) and *F. mosseae* (4.13 g and 8.59 g) belonging to irrigation control treatment.

Table 27. Dry weight of leaves (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Dry weight of leaves (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.98^{c}	1.56^{c}	2.23^{c}	2.98^{c}	4.38^{b}	4.91^{c}
	R. intraradices	1.48^{a}	2.10^{a}	2.25^{c}	4.27^{a}	5.59^{a}	6.26^{b}
	G. etunicatum	1.31^{b}	2.00^{ab}	3.12^{a}	4.39^{a}	5.69^{a}	7.25^{a}
	F. mosseae	0.99^{c}	1.89^{b}	2.51^{b}	3.53^{b}	4.80^{b}	5.96^{b}
	F value	**18.50***	**19.23***	**31.63***	**22.63***	**16.38***	**38.72***
Irrigation	Control	1.66^{a}	2.81^{a}	3.85^{a}	5.13^{a}	8.53^{a}	9.98^{a}
	IW/ET=1	1.46^{b}	2.27^{b}	2.74^{b}	5.23^{a}	6.44^{b}	7.67^{b}
	IW/ET=0.8	1.18^{c}	2.16^{b}	2.75^{b}	3.57^{b}	4.41^{c}	5.59^{c}
	IW/ET=0.6	0.90^{d}	1.14^{c}	1.84^{c}	3.06^{c}	4.03^{d}	4.45^{d}
	IW/ET=0.4	0.76^{d}	1.06^{c}	1.46^{d}	1.93^{d}	3.16^{d}	2.77^{e}
	F value	**34.57***	**158.58***	**126.93 ***	**85.65***	**181.94***	**264.29***
AMF x Irrigation	**F value**	**0.84***	**2.39***	**12.89***	**1.86^{ns}**	**1.97***	**3.59^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.2.11. Dry weight of root

The dry weight of roots of the mahogany seedlings under different treatments had significant variations over the period of time (Table 28). Seedlings inoculated with *R.*

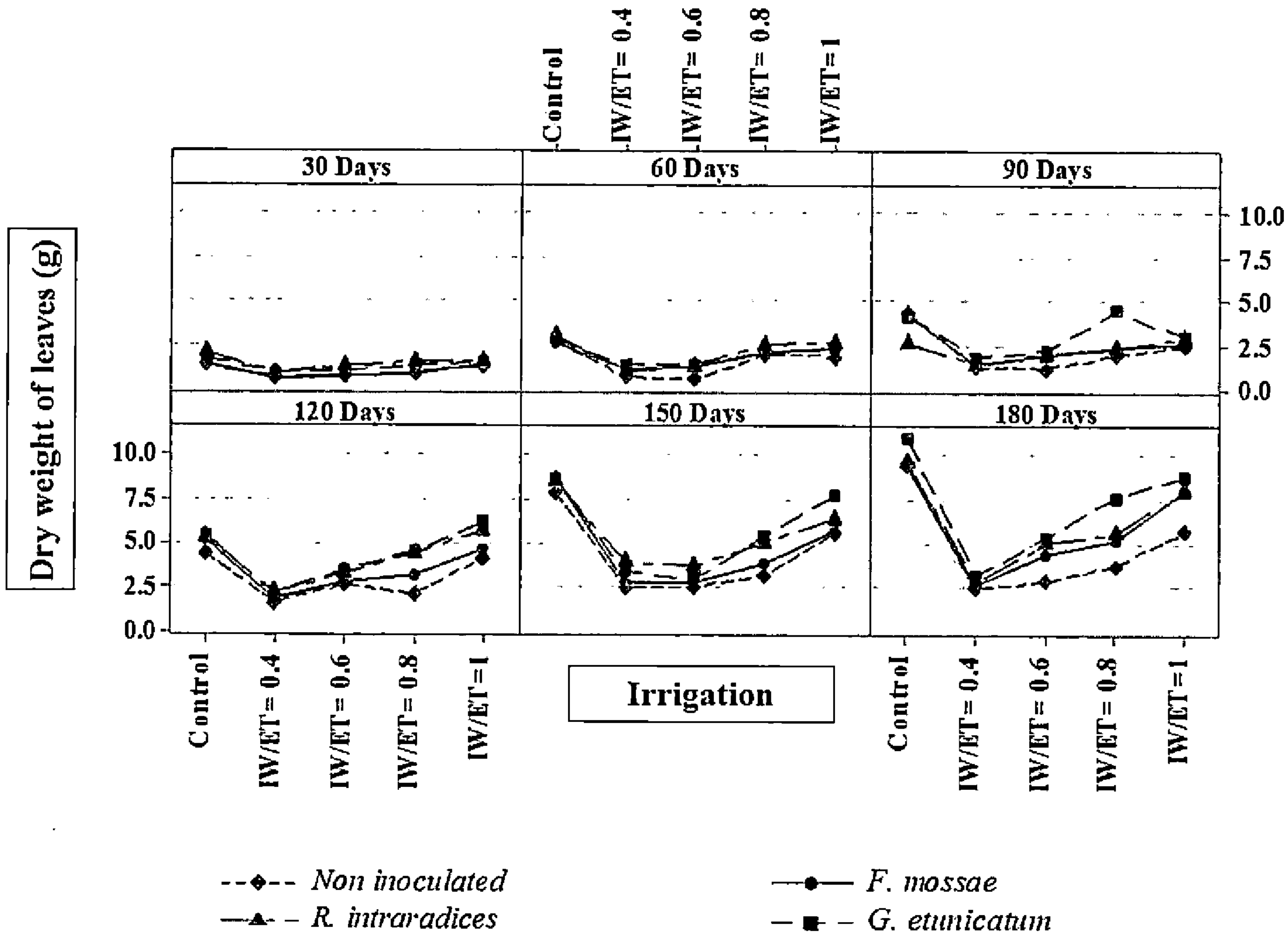


Figure 24. Dry weight of leaves (g) of mahogany seedlings as influenced by AMF and irrigation interaction

intraradices (1.26g and 1.99 g) and *G. etunicatum* (1.30g and 2.16g) depicted higher dry weight of roots after 30 and 60 days after treatment. At 90 and 180 days, however, *G. etunicatum* had higher dry weight of roots (6.12g and 7.75g). No significant variation was noted for dry weight of roots for seedlings inoculated with different AMF species at 120 and 150 days of treatment.

Among the various irrigation regimes, the control seedlings had higher dry weight over the study period, and it was on par with IW/ET=1 at 60 and 180 days. The treatments IW/ET=0.6 and IW/ET=0.4 had lower values of root dry weight during the course of the study except at 60 days when lowest values (0.94g) was demonstrated by IW/ET=0.4 only. No significant variation in dry weights was observed at 120 and 150 days.

Table 28. Dry weight of root (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	**Treatments**	**Dry weight of root (g)**					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	0.79^b	1.31^c	1.97^c	5.96	10.08	4.13^c
	R. intraradices	1.26^a	1.99^a	2.36^b	4.12	5.02	5.98^b
	G. etunicatum	1.30^a	2.16^a	6.12^a	4.19	5.37	7.75^a
	F. mosseae	0.88^b	1.68^b	2.29^b	3.22	4.13	5.40^b
	F value	**33.28***	**25.2***	**28.40***	$\mathbf{0.45^{ns}}$	$\mathbf{0.67^{ns}}$	**17.26***
Irrigation	Control	1.49^a	2.40^a	3.50^a	5.45	7.10	8.76^a
	IW/ET=1	1.17^b	2.38^a	2.73^b	4.12	5.81	7.92^a
	IW/ET=0.8	1.23^b	1.56^b	2.57^b	3.35	4.00	5.35^b
	IW/ET=0.6	0.69^c	1.63^b	1.72^c	6.92	3.03	4.02^c
	IW/ET=0.4	0.72^c	0.94^c	1.66^c	2.03	2.80	3.03^c
	F value	**47.43***	**54.75***	**55.44***	$\mathbf{0.98^{ns}}$	$\mathbf{0.70^{ns}}$	**37.00***
AMF x Irrigation	**F value**	**1.66***	**1.16***	**4.55***	**1.17***	**1.04***	**2.31***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The effect of interaction was found to be significant throughout the period of study (Figure 25). At 30 days, higher dry weight of roots was recorded for seedlings inoculated *R.*

intraradices under the control irrigation treatment (1.95 g). At 60 days, higher dry weight of roots were recorded for seedlings inoculated with *G. R. intraradices* under IW/ET=1 (2.79 g). Seedlings inoculated with *G. etunicatum* under the control irrigation treatment and treatment IW/ET=0.8 recorded higher values at 90 days (4.12 g and 4.02 g). At 120 and 150 days, higher dry weight of roots was recorded for seedlings inoculated with *G. etunicatum* under the control irrigation treatment (6.33 g and 8.50 g). At 180 days, higher dry weight of roots were recorded for seedlings inoculated with *G. etunicatum* under IW/ET=1 (11.96 g).

4.2.12. Dry weight of shoot

Table 29. Dry weight of shoot (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Dry weight of shoot (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.32	0.52^{c}	0.74	2.45	1.46^{b}	1.63^{c}
	R. intraradices	0.61	0.70^{a}	1.80	1.40	1.86^{a}	2.08^{b}
	G. etunicatum	0.44	0.67^{ab}	1.04	1.46	1.92^{a}	2.41^{a}
	F. mosseae	0.33	0.62^{b}	0.83	1.16	1.60^{b}	1.98^{b}
	F value	**1.04^{ns}**	**27.99***	**0.84^{ns}**	**0.61^{ns}**	**18.39***	**38.49***
Irrigation	Control	0.60	0.93^{a}	1.28	1.98	2.85^{a}	3.32^{a}
	IW/ET=1	0.48	0.99^{b}	0.91	3.27	2.15^{b}	2.56^{b}
	IW/ET=0.8	0.38	0.67^{c}	2.24	1.19	1.47^{c}	1.86^{c}
	IW/ET=0.6	0.43	0.47^{d}	0.61	1.01	1.17^{d}	1.48^{d}
	IW/ET=0.4	0.17	0.26^{e}	0.49	0.64	0.89^{e}	0.92^{e}
	F value	**0.98^{ns}**	**259.94***	**1.42^{ns}**	**1.66^{ns}**	**195.05***	**262.08***
AMF x Irrigation	**F value**	**1.00***	**3.15***	**1.00***	**0.94^{ns}**	**2.04***	**3.58***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

There was no significant variation with respect to the dry weight of shoot at 30, 90 and 120 days after inoculation (Table 29). Seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher dry weight of shoot at 60 days after inoculation (0.70g and 0.67g) while the non-inoculated ones had lower dry weight of shoot (0.52g) at this stage. At 150 days seedlings inoculated with *R. intraradices* (1.86g) and *G. etunicatum* (1.92g) amassed greater dry weights compared to the non-inoculated ones and those inoculated with *F. mosseae*. The seedlings inoculated with *G. etunicatum* had an increased dry weight of shoot while the non-inoculated seedlings maintained the slightest growth. The irrigation regimes, maintained a consistent trend where, the control seedlings had the maximum accumulation of dry weight of shoot; while, IW/ET=0.4 had, the minimum. However, at 30, 90 and 120 days, no significant variations were observed for different treatments.

The effect of interaction was found to be significant except at 120 days (Figure 26). At 30 days, higher values were observed for seedlings inoculated with *R. intraradices, G. etunicatum* and *F. mosseae* under control irrigation (0.64 g, 0.62 g and 0.62 g). At 60 days, seedlings inoculated with *R. intraradices* and *G. etunicatum* under control irrigation (0.99 g and 0.94 g) had higher values. At 150 days, higher values were observed for seedlings inoculated with *G. etunicatum, R. intraradices* and *F. mosseae* under control irrigation (2.96 g, 2.92 g and 2.86 g). At 180 days, seedlings inoculated with *G. etunicatum* under control irrigation had higher dry weight of shoot (3.68 g).

4.2.13. Total fresh weight

Influence of different AMF species and irrigation regimes on the total fresh weight of mahogany seedlings are described Table 30. No significant variation was observed in total fresh weight due to AMF inoculation at 30 days. A significant reduction in the total fresh weight was observed for non-inoculated seedlings throughout the experiment except at 60 days. At 60 days, seedlings inoculated with *G. etunicatum* had higher values (12.08 g) for fresh weight of shoots. The lowest values were observed for seedlings inoculated with *F. mosseae* together with the non-inoculated ones. At 90 and 120 days, highest values were recorded for seedlings inoculated with *R. intraradices* (21.41 g and 27.27 g) and *G. etunicatum* (20.11 g and 28.96 g). At 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (34.23 g and 42.27 g respectively).

While considering the different irrigation regimes, there was no significant difference between the control and the treatment IW/ET=1 at 30 and 60 days for which the highest values were recorded. The highest values at 90, 120, 150 and 180 days (25.92g, 33.02g, 36.91g and 47.96g) were recorded for the control treatment. At 30, 60, 90 and 120 days, the lowest values were both observed for treatments IW/ET=0.6 (3.25g, 5.73g, 12.43g and17.79g) and IW/ET= 0.4 (2.98g, 6.26g, 12.25g and 17.66g). The treatment IW/ET=0.4 alone had lowest values (17.36g and 21.99g) at 150 and 180 days.

Table 30. Total fresh weight (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Total fresh weight (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	5.44	8.92^{c}	14.25^{c}	18.36^{c}	21.84^{c}	28.20^{d}
	R. intraradices	5.26	11.16^{b}	21.41^{a}	27.27^{a}	28.45^{b}	36.51^{b}
	G. etunicatum	5.73	12.08^{a}	20.11^{a}	28.96^{a}	34.23^{a}	42.27^{a}
	F. mosseae	5.71	9.23^{c}	16.49^{b}	22.14^{b}	26.64^{b}	32.29^{c}
	F value	**1.25^{ns}**	**28.41***	**40.85***	**35.40***	**34.93***	**32.75***
Irrigation	Control	7.95^{a}	14.59^{a}	25.92^{a}	33.02^{a}	36.91^{a}	47.96^{a}
	IW/ET=1	7.35^{a}	13.92^{a}	22.16^{b}	26.92^{b}	32.19^{b}	42.62^{b}
	IW/ET=0.8	6.15^{b}	11.24^{b}	17.55^{c}	25.52^{b}	27.48^{c}	34.47^{c}
	IW/ET=0.6	3.25^{c}	5.73^{c}	12.43^{d}	17.79^{c}	25.01^{c}	27.02^{d}
	IW/ET=0.4	2.98^{c}	6.26^{c}	12.25^{d}	17.66^{c}	17.36^{d}	21.99^{e}
	F value	**106.05***	**171.02***	**109***	**51.49***	**58.42***	**83.11***
AMF x Irrigation	**F value**	**2.15***	**0.79***	**2.87***	**0.47^{ns}**	**1.56***	**0.28^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with similar superscript along the column do not differ significantly

The interaction effect was significant throughout the period of study except for at 120 and 180 days (Figure 27). Seedlings inoculated with *F. mosseae* under the control irrigation treatment recorded higher values at 30 days (9.31 g). Higher values for total fresh weight was observed for seedlings inoculated with *R. intraradices* (15.60 g and 14.25 g) and *G. etunicatum* (15.25 g and 16.13 g) under the control irrigation treatment and treatment IW/ET=1. Seedlings inoculated with *F. mosseae* under the control irrigation treatment also recorded higher total fresh weight at 90 days (13.90 g). At 90 days, seedlings inoculated with *R. intraradices* (29.89 g) had

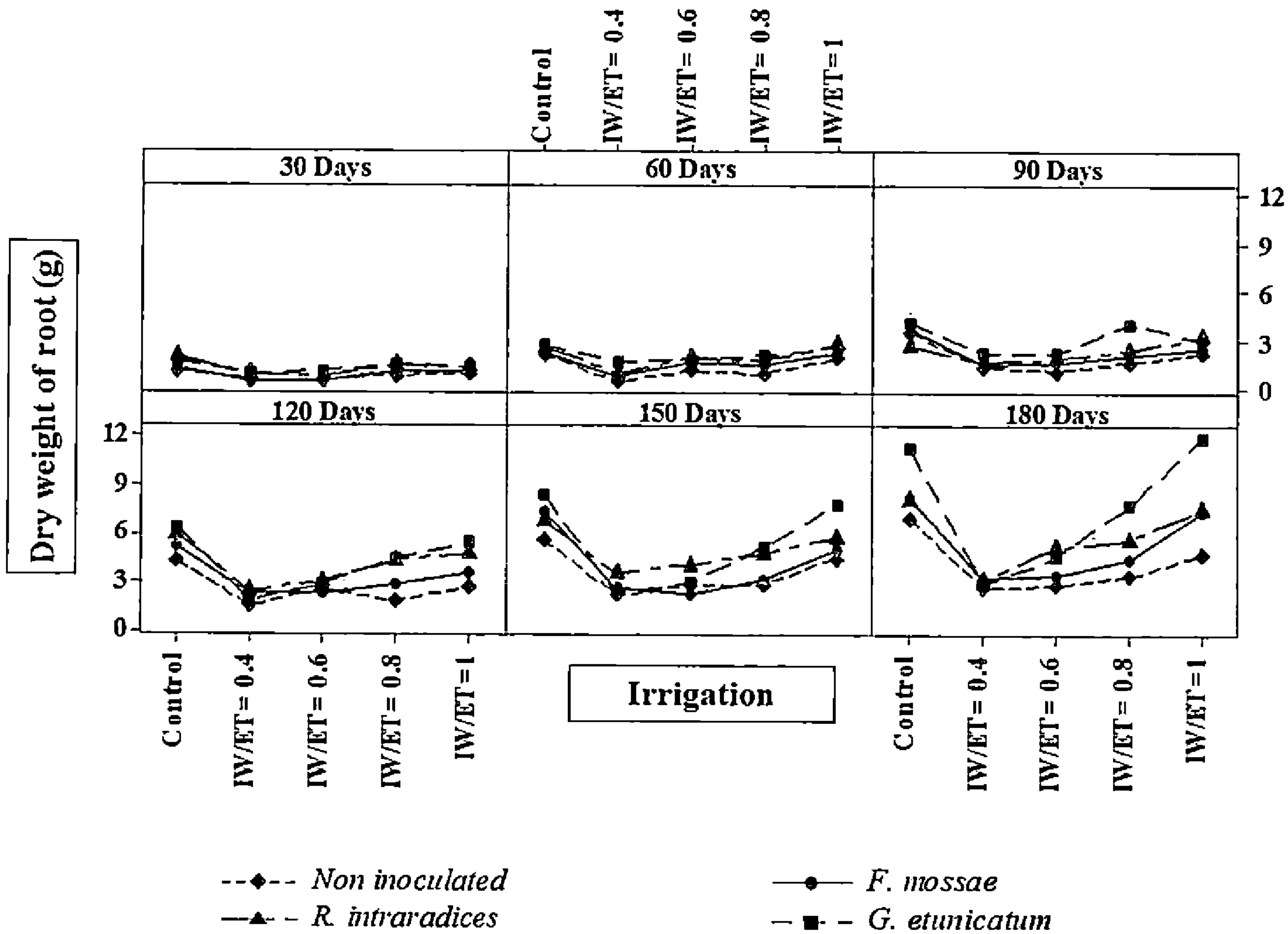


Figure 25. Dry weight of root (g) of mahogany seedlings as influenced by AMF and irrigation interaction

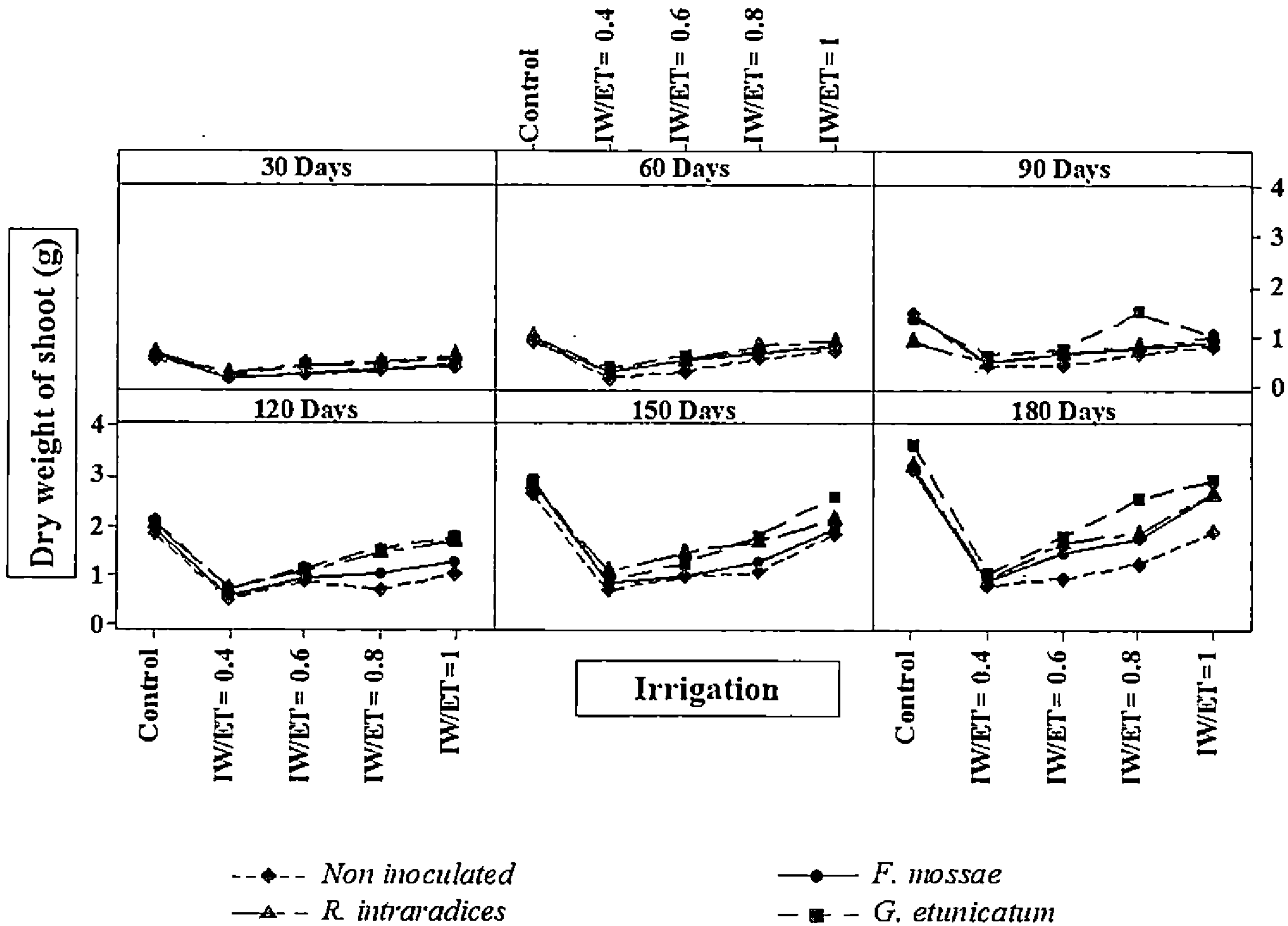


Figure 26. Dry weight of shoot (g) of mahogany seedlings as influenced by AMF and irrigation interaction

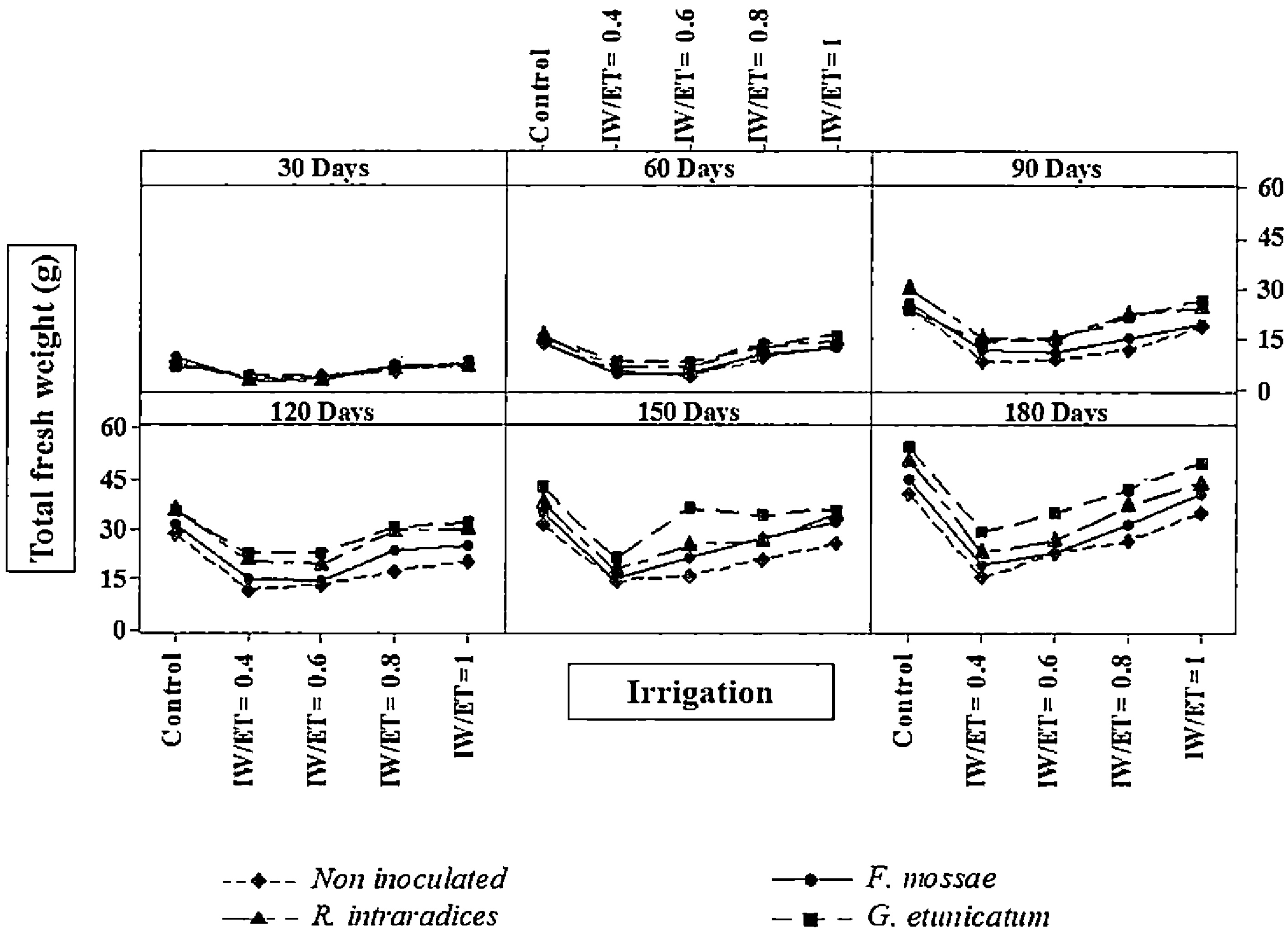


Figure 27. Total fresh weight (g) of mahogany seedlings as influenced by AMF and irrigation interaction

the non-inoculated ones had lower dry weight of shoot (0.52g) at this stage. At 150 days seedlings inoculated with *R. intraradices* (1.86g) and *G. etunicatum* (1.92g) amassed greater dry weights compared to the non-inoculated ones and those inoculated with *F. mosseae*. The seedlings inoculated with *G. etunicatum* had an increased dry weight of shoot while the non-inoculated seedlings maintained the slightest growth. The irrigation regimes, maintained a consistent trend where, the control seedlings had the maximum accumulation of dry weight of shoot; while, IW/ET=0.4 had, the minimum. However, at 30, 90 and 120 days, no significant variations were observed for different treatments.

The effect of interaction was found to be significant except at 120 days (Figure 26). At 30 days, higher values were observed for seedlings inoculated with *R. intraradices, G. etunicatum* and *F. mosseae* under control irrigation (0.64 g, 0.62 g and 0.62 g). At 60 days, seedlings inoculated with *R. intraradices* and *G. etunicatum* under control irrigation (0.99 g and 0.94 g) had higher values. At 150 days, higher values were observed for seedlings inoculated with *G. etunicatum, R. intraradices* and *F. mosseae* under control irrigation (2.96 g, 2.92 g and 2.86 g). At 180 days, seedlings inoculated with *G. etunicatum* under control irrigation had higher dry weight of shoot (3.68 g).

4.2.13. Total fresh weight

Influence of different AMF species and irrigation regimes on the total fresh weight of mahogany seedlings are described Table 30. No significant variation was observed in total fresh weight due to AMF inoculation at 30 days. A significant reduction in the total fresh weight was observed for non-inoculated seedlings throughout the experiment except at 60 days. At 60 days, seedlings inoculated with *G. etunicatum* had higher values (12.08 g) for fresh weight of shoots. The lowest values were observed for seedlings inoculated with *F. mosseae* together with the non-inoculated ones. At 90 and 120 days, highest values were recorded for seedlings inoculated with *R. intraradices* (21.41 g and 27.27 g) and *G. etunicatum* (20.11 g and 28.96 g). At 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (34.23 g and 42.27 g respectively).

While considering the different irrigation regimes, there was no significant difference between the control and the treatment IW/ET=1 at 30 and 60 days for which the highest values were recorded. The highest values at 90, 120, 150 and 180 days (25.92g, 33.02g, 36.91g and 47.96g) were recorded for the control treatment. At 30, 60, 90 and 120 days, the lowest values were both observed for treatments IW/ET=0.6 (3.25g, 5.73g, 12.43g and17.79g) and IW/ET= 0.4 (2.98g, 6.26g, 12.25g and 17.66g). The treatment IW/ET=0.4 alone had lowest values (17.36g and 21.99g) at 150 and 180 days.

Table 30. Total fresh weight (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Total fresh weight (g)					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	5.44	8.92^{c}	14.25^{c}	18.36^{c}	21.84^{c}	28.20^{d}
	R. intraradices	5.26	11.16^{b}	21.41^{a}	27.27^{a}	28.45^{b}	36.51^{b}
	G. etunicatum	5.73	12.08^{a}	20.11^{a}	28.96^{a}	34.23^{a}	42.27^{a}
	F. mosseae	5.71	9.23^{c}	16.49^{b}	22.14^{b}	26.64^{b}	32.29^{c}
	F value	**1.25^{ns}**	**28.41***	**40.85***	**35.40***	**34.93***	**32.75***
Irrigation	Control	7.95^{a}	14.59^{a}	25.92^{a}	33.02^{a}	36.91^{a}	47.96^{a}
	IW/ET=1	7.35^{a}	13.92^{a}	22.16^{b}	26.92^{b}	32.19^{b}	42.62^{b}
	IW/ET=0.8	6.15^{b}	11.24^{b}	17.55^{c}	25.52^{b}	27.48^{c}	34.47^{c}
	IW/ET=0.6	3.25^{c}	5.73^{c}	12.43^{d}	17.79^{c}	25.01^{c}	27.02^{d}
	IW/ET=0.4	2.98^{c}	6.26^{c}	12.25^{d}	17.66^{c}	17.36^{d}	21.99^{e}
	F value	**106.05***	**171.02***	**109***	**51.49***	**58.42***	**83.11***
AMF x Irrigation	**F value**	**2.15***	**0.79***	**2.87***	**0.47^{ns}**	**1.56***	**0.28^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with similar superscript along the column do not differ significantly

The interaction effect was significant throughout the period of study except for at 120 and 180 days (Figure 27). Seedlings inoculated with *F. mosseae* under the control irrigation treatment recorded higher values at 30 days (9.31 g). Higher values for total fresh weight was observed for seedlings inoculated with *R. intraradices* (15.60 g and 14.25 g) and *G. etunicatum* (15.25 g and 16.13 g) under the control irrigation treatment and treatment IW/ET=1. Seedlings inoculated with *F. mosseae* under the control irrigation treatment also recorded higher total fresh weight at 90 days (13.90 g). At 90 days, seedlings inoculated with *R. intraradices* (29.89 g) had

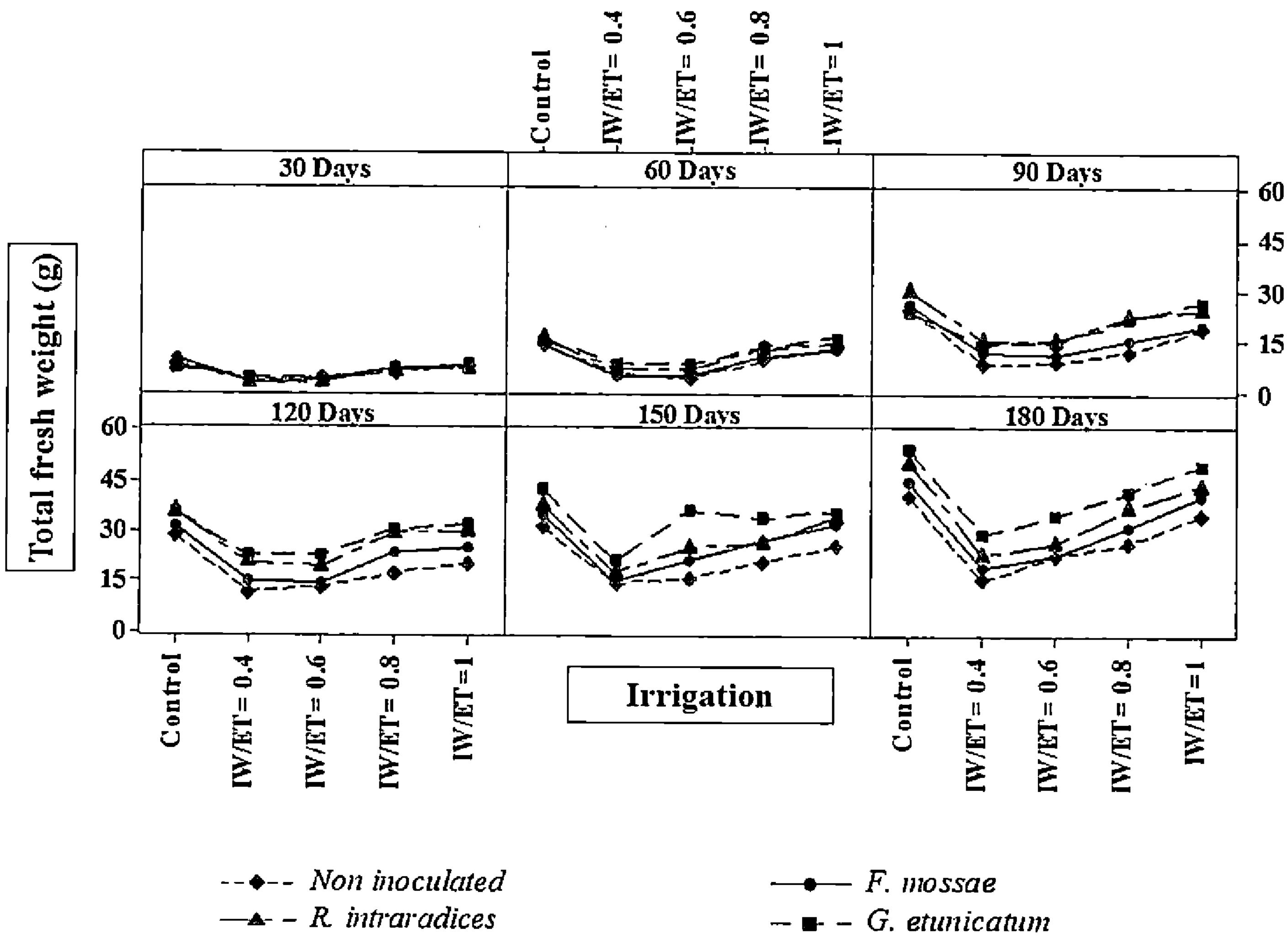


Figure 27. Total fresh weight (g) of mahogany seedlings as influenced by AMF and irrigation interaction

higher values under control treatment. Seedlings inoculated with *G. etunicatum* under the control irrigation treatment recorded higher values at 150 days (42.67 g).

4.2.14. Total dry weight

The response of mahogany seedlings to different AMF species and irrigation regimes with respect to total dry weight are given in the Table 31. There was a significant reduction in the total dry weight for non-inoculated seedlings throughout the experiment. At 30 and 90 days, however, lower values were also recorded for the seedlings inoculated with *F. mosseae* along with the non-inoculated ones. At 30 and 60 days, seedlings inoculated with *R. intraradices* (3.21g and 4.79g) and *G. etunicatum* (3.05g and 4.83g) had higher values for total dry weight. At 90 days, higher values were recorded for the seedlings inoculated with *G. etunicatum* (7.28g).

Table 31. Total dry weight (g) of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Total dry weight (g)					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	2.09^{b}	3.39^{c}	4.94^{c}	7.91	9.42^{c}	10.68^{c}
	R. intraradices	3.21^{a}	4.79^{a}	6.42^{ab}	7.94	10.52^{b}	14.32^{b}
	G. etunicatum	3.05^{a}	4.83^{a}	7.28^{a}	10.04	12.98^{a}	17.41^{a}
	F. mosseae	2.21^{b}	4.19^{b}	5.64^{c}	9.76	12.48^{a}	13.34^{b}
	F value	**36.54***	**33.47***	**3.32***	**2.32^{ns}**	**21.62***	**34.05***
Irrigation	Control	3.75^{a}	6.14^{a}	8.63^{a}	12.56^{a}	18.49^{a}	22.05^{a}
	IW/ET=1	3.11^{b}	5.45^{b}	6.38^{c}	12.62^{a}	14.40^{b}	18.15^{b}
	IW/ET=0.8	2.78^{c}	4.39^{c}	7.56^{ab}	8.11^{b}	9.88^{c}	12.85^{c}
	IW/ET=0.6	1.91^{d}	3.24^{d}	4.17^{d}	6.68^{bc}	7.23^{d}	9.95^{d}
	IW/ET=0.4	1.65d	2.27^{e}	3.61^{d}	4.59^{c}	6.73^{d}	6.72^{e}
	F value	**67.03***	**146.53***	**12.07***	**18.23***	**156.85***	**134.49***
AMF x Irrigation	**F value**	**1.09***	**1.77***	**1.73***	**0.94***	**2.82***	**3.01***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with similar superscript along the column do not differ significantly

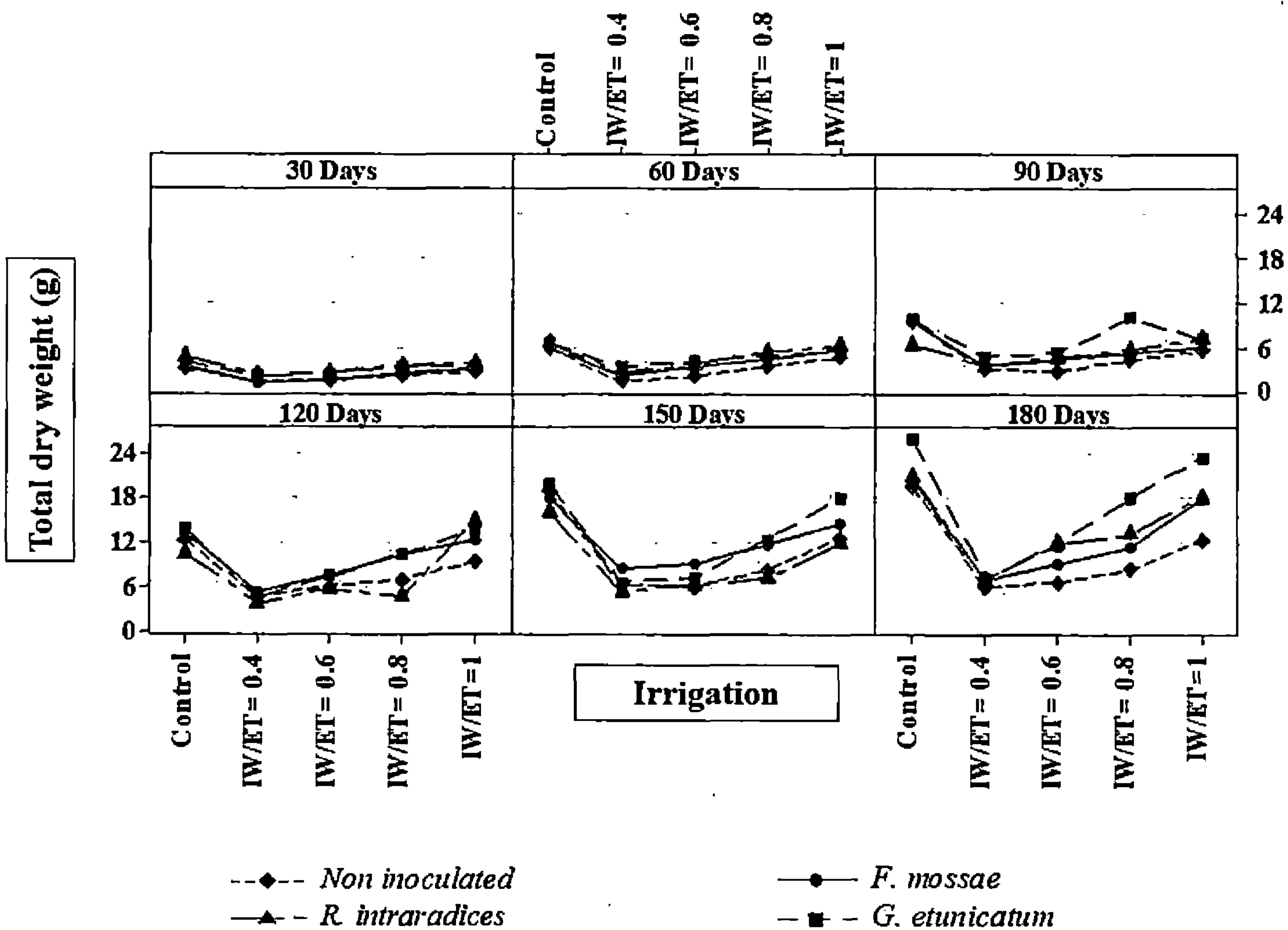


Figure 28. Total dry weight (g) of mahogany seedlings as influenced by AMF and irrigation interaction

No significant variations were observed with respect to AMF species at 120 days. At 150 and 180 days, seedlings inoculated with *G. etunicatum* had the highest values (12.98g and 17.41g respectively) along with *F. mosseae* at 150 days (12.48g).

While considering the different irrigation regimes, the highest values at 30, 60, 90, 120, 150 and 180 days was documented for the control treatment. There was no significant difference between the control and the treatment IW/ET=1 at 120 days for both of which the highest values were recorded. At 30, 90 and 150 days, the lowest values were both observed for treatments IW/ET=0.6 (1.91g, 4.17g and7.23g) and IW/ET= 0.4 (1.65g, 3.61g and6.73g). The treatment IW/ET=0.4 had lowest values for total dry weight at 60, 120 and 180 days (2.27g, 4.59g and 6.72g).

The interaction effect was significant throughout the period of study (Figure 28). At 30 days, seedlings inoculated with *R. intraradices* belonging to control irrigation treatment recorded higher values (4.71 g). Seedlings inoculated with *R. intraradices* and *G. etunicatum* under the control irrigation treatment recorded higher values at 60 days (6.60 g and 6.39 g). At 90 and 120 days, seedlings inoculated with *R. intraradices* under irrigation treatment IW/ET=0.8 and IW/ET=1 recorded higher values (10.82 g and 15.10 g). Seedlings inoculated with *G. etunicatum* under the control irrigation treatment recorded higher values at 150 and 180 days (20.23 g and 26.16 g).

4.2.15. Shoot root length ratio

The performance of mahogany seedlings when treated with different AMF species and irrigation regimes in terms of shoot root length ratio is given in the Table 32. Highest values for shoot-root length ratio were observed for non-inoculated seedlings throughout the course of study. *R. intraradices* had highest values for shoot-root length ratio at 30 days; whereas, at 60 and 150 days highest values were recorded for both *R. intraradices* (1.02 and 1.17) and *G. etunicatum* (1.03 and 1.12). All the three AMF species had similar values at 90 days. At 120 days, highest shoot-root length ratio was recorded for seedlings inoculated with *F. mosseae* (1.23) among different AMF species; while, the non-inoculated ones documented the highest ratio (1.3). At 150 and 180 days, *R. intraradices* (1.17 and 1.23) and *G. etunicatum* (1.12 and 1.17) had the lowest values.

Table 32. Shoot root length ratio of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Shoot root length ratio					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	1.08^{a}	1.26^{a}	1.53^{a}	1.37^{a}	1.47^{a}	1.40^{a}
	R. intraradices	0.84^{c}	1.02^{c}	0.97^{b}	1.14^{d}	1.17^{c}	1.23^{c}
	G. etunicatum	0.95^{b}	1.03^{c}	1.19^{b}	1.09^{c}	1.12^{c}	1.17^{d}
	F. mosseae	0.92^{b}	1.17^{b}	1.19^{b}	1.23^{b}	1.26^{b}	1.28^{bc}
	F value	**22.46***	**25.05***	**4.52***	**50.34***	**86.50***	**6.45***
Irrigation	Control	1.04^{a}	1.35^{a}	1.29	1.41^{a}	1.47^{a}	1.52^{a}
	IW/ET=1	0.95^{b}	1.12^{b}	1.27	1.23^{c}	1.31^{b}	1.36^{b}
	IW/ET=0.8	0.88^{c}	1.11^{b}	1.14	1.29^{b}	1.26^{c}	1.27^{c}
	IW/ET=0.6	1.06^{a}	1.11^{b}	1.09	0.98^{e}	1.23^{c}	1.16^{d}
	IW/ET=0.4	0.81^{d}	0.91^{c}	1.32	1.13^{d}	1.03^{d}	1.05^{e}
	F value	**22.31***	**33.88***	**0.67^{ns}**	**74.84***	**71.37***	**46.63***
AMF x Irrigation	**F value**	**8.92***	**4.30***	**1.18***	**3.32***	**13.43***	**2.53***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

With respect to the irrigation regimes, the control treatments had significantly higher values for shoot-root length ratio throughout the study. The treatment IW/ET=0.4 had the least shoot-root length ratio throughout the course of study.

The effect of interaction was found to be significant throughout the period of study (Figure 29). At 30, 60 and 150 days, higher shoot-root length ratio was recorded for seedlings not inoculated with AMF under the treatment IW/ET=0.6 (1.36, 1.39 and 1.79). Seedlings not inoculated with AMF and seedlings inoculated *F. mosseae* under the control treatment also recorded higher values at 60 days (1.39 and 1.39 respectively). Seedlings not inoculated with AMF under treatment IW/ET=0.4 had higher values at 90 days (2.32). Higher shoot-root length ratio was recorded for seedlings inoculated with *F. mosseae* under the control irrigation treatment (1.48) at 120 days. At 180 days, higher shoot-root length ratio was recorded for seedlings inoculated with *R. intraradices* under the control irrigation treatment (1.61).

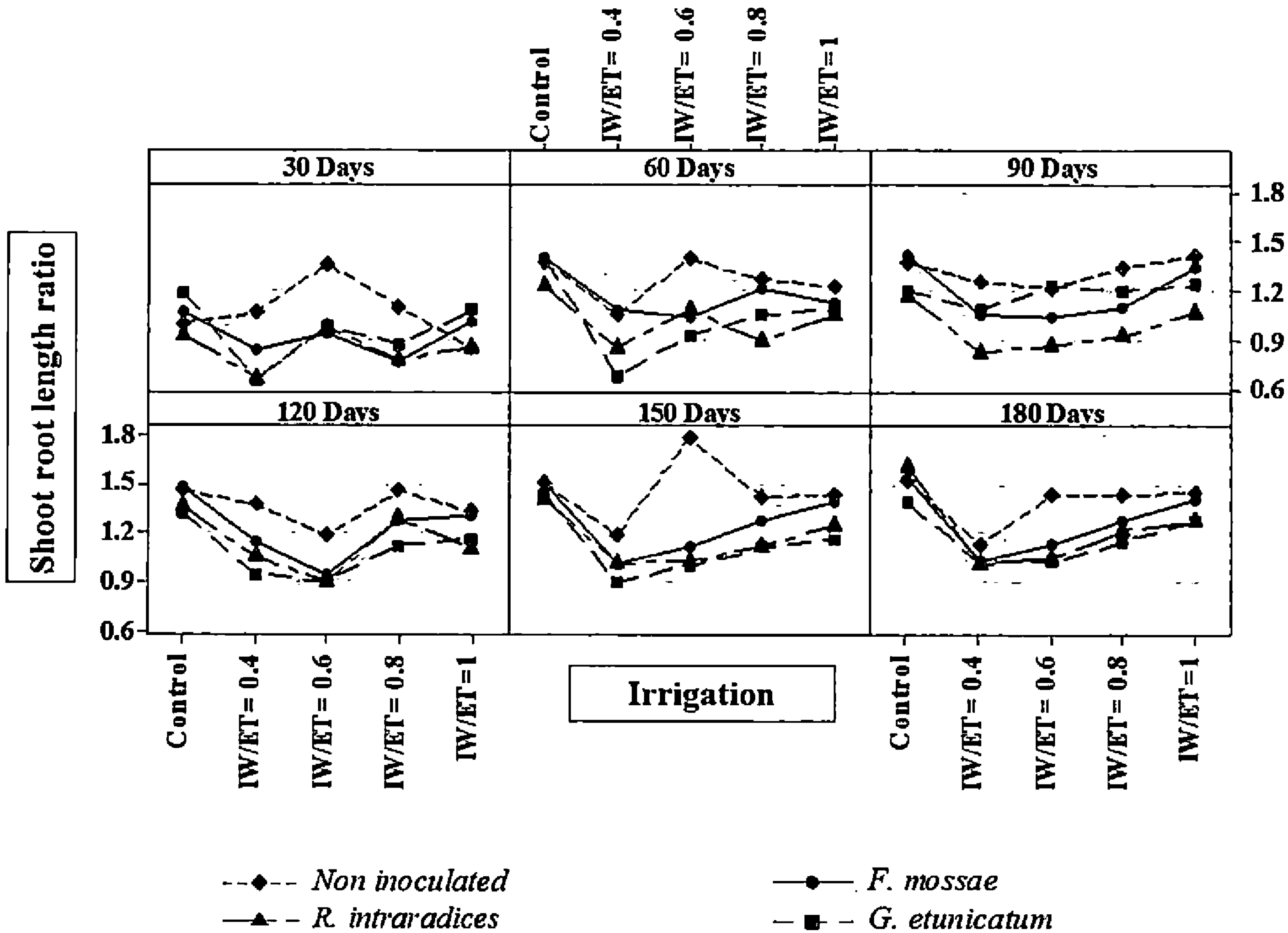


Figure 29. Shoot root length ratio of mahogany seedlings as influenced by AMF and irrigation interaction

4.2.16. Shoot root biomass ratio

The mean shoot root biomass ratio of mahogany seedlings treated with different AMF species had no significant variations; except at 30 and 60 days (Table 33). During this period of time, the highest values were recorded for non-inoculated seedlings (1.89 and 1.96). Highest values were also recorded *F. mosseae* (1.76) at 60 days. The lowest ratios were observed for the

Table 33. Shoot root biomass ratio of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Shoot root biomass ratio					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	1.89[a]	1.96[a]	1.49	2.18	1.62	1.57
	R. intraradices	1.38[b]	1.63[ab]	1.68	1.44	1.72	1.63
	G. etunicatum	1.64[ab]	1.29[b]	1.34	1.78	1.79	1.66
	F. mosseae	1.64[ab]	1.76[a]	1.51	1.61	1.65	1.60
	F value	**2.47[ns]**	**3.41***	**0.60[ns]**	**0.85[ns]**	**0.35[ns]**	**0.77[ns]**
Irrigation	Control	2.21[a]	1.59	1.49	1.37	1.89	1.83
	IW/ET=1	1.69[b]	1.36	1.38	2.52	1.55	1.47
	IW/ET=0.8	1.35[b]	2.38	1.89	1.55	1.56	1.51
	IW/ET=0.6	1.57[b]	1.08	1.53	1.88	1.76	1.88
	IW/ET=0.4	1.36[b]	1.90	1.24	1.44	1.69	1.40
	F value	**5.54***	**8.54***	**1.54***	**1.78***	**0.95***	**2.34***
AMF x Irrigation	**F value**	**1.84***	**1.95***	**0.97***	**1.49***	**2.21***	**2.21***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

seedlings inoculated with AMF at 30 days. However, seedlings treated with both *R. intraradices* (1.63) and *G. etunicatum* (1.29) had lower values at 60 days. With respect to irrigation regimes, the highest values were noted for control seedlings while the rest recorded no significant variations.

The interaction effect was significant throughout the period of study (Figure 30).Seedlings not inoculated with AMF under the control treatment had higher shoot root

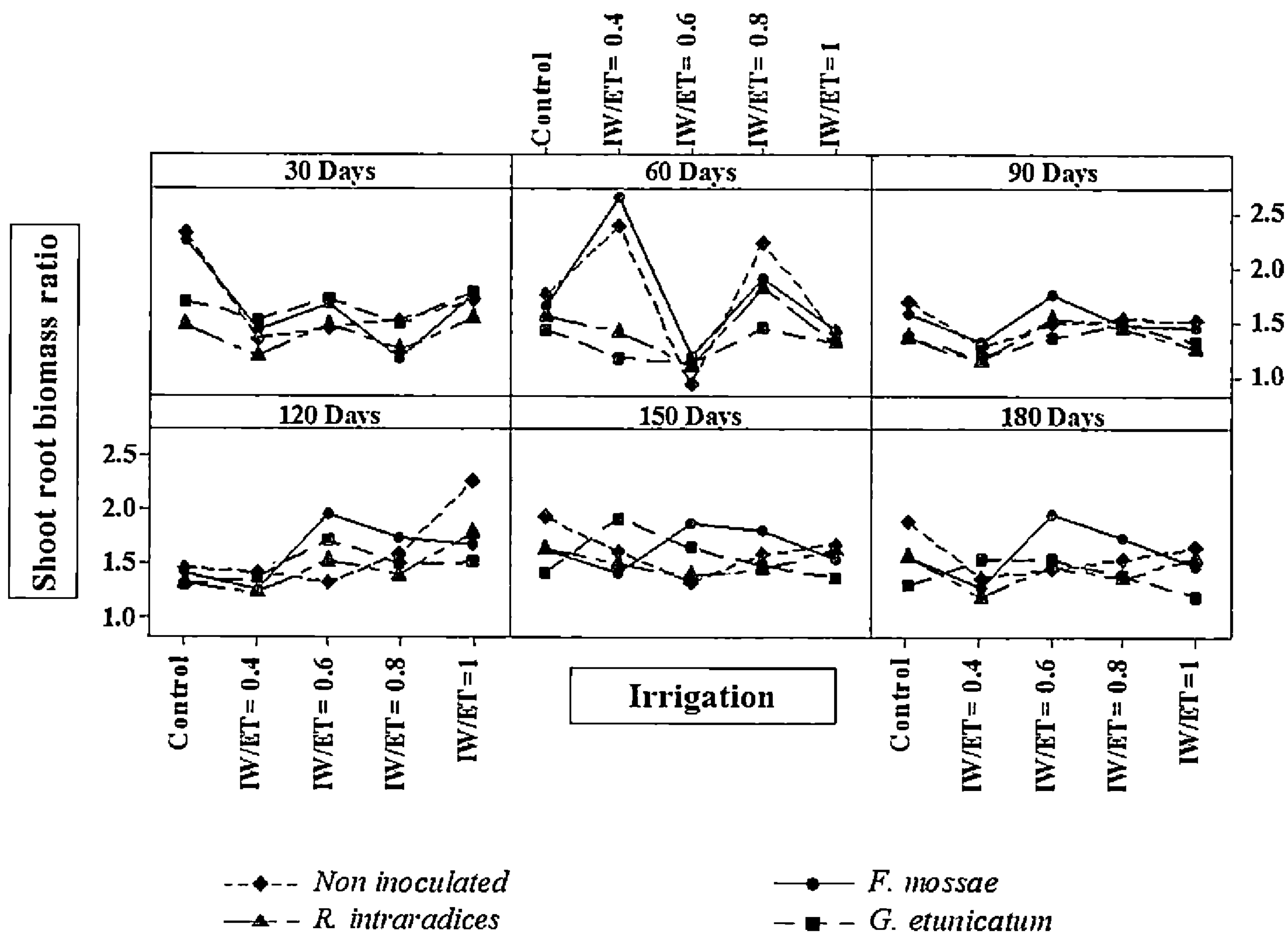


Figure 30. Shoot root biomass ratio of mahogany seedlings as influenced by AMF and irrigation interaction

biomass ratio (2.24 g) at 30 days. At 60 days, seedlings not inoculated with AMF under the irrigation treatment IW/ET=0.8 had higher shoot root biomass ratios (3.39 g). Seedlings inoculated *F. mosseae* belonging to irrigation treatment IW/ET=0.6 had higher values at 90 days (1.68). At 120 and 180 days, seedlings inoculated with *G. etunicatum* had higher shoot root biomass ratio under the irrigation treatment IW/ET=0.6 (2.76 and 2.62). At 150 and 180 days, higher values were observed for seedlings inoculated with seedlings inoculated with *R. intraradices* under control irrigation treatment (2.62 and 2.57).

4.2.17. Vigour index I

The vigour index I of mahogany seedlings inoculated with different AMF species had significant variations throughout the study (Table 34). At 30 and 60 days, seedlings inoculated with *R. intraradices* had highest index values (50.84 and 76.07); whereas, non-inoculated seedlings had lowest index values (40.76 and 47.29). At 90 days, higher index values were recorded for both *R. intraradices* (96.06) and *G. etunicatum* (97.39); while, the non-inoculated seedlings recorded lowest value (55.59). At 120, 150 and 180 days, seedlings inoculated with *G. etunicatum* displayed highest values while non-inoculated seedlings maintained lower index values.

Among the irrigation regimes, there was no significant difference between the control and the treatment IW/ET=1 after 30, 60 and 90 days. Also, these treatments recorded the highest values. The highest values at 120,150 and 180 days (111.65, 124.84 and 138.61) were observed for control. The treatment IW/ET=0.4 maintained lowest values throughout the experiment.

The effect of interaction was not significant at 120, 150 and 180 days (Figure 31). At 30 days, higher index values were observed for seedlings inoculated with *G. etunicatum* under the control treatment (58.17) and treatment IW/ET=1 (61.42) whereas, seedlings inoculated with *R.intraradices* had higher values under the treatment IW/ET=1 (59.67). At 60 days, seedlings inoculated with *R. intraradices* had higher values under control treatment (90.02). At 90 days, seedlings inoculated with *R. intraradices* had higher values under control treatment (115.12) and the treatment IW/ET=1 (112.23). Seedlings inoculated with *G. etunicatum* under the control irrigation treatment and treatment IW/ET=1 also recorded higher values at 90 days (110.23 and 109.86).

Table 34. Vigour index I of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Vigour index I					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	40.76[d]	47.29[d]	55.59[c]	62.61[d]	70.87[d]	77.42[d]
	R. intraradices	50.84[a]	76.07[a]	96.06[a]	104.35[b]	117.24[b]	131.93[b]
	G. etunicatum	49.08[b]	69.98[b]	97.39[a]	124.04[a]	137.99[a]	155.64[a]
	F. mosseae	44.24[c]	61.09[c]	74.31[b]	86.63[c]	98.75[c]	111.44[c]
	F value	**83.61***	**225***	**419.86***	**134.91***	**735.22***	**600.97***
Irrigation	Control	54.26[a]	73.34[a]	94.78[a]	111.65[a]	124.84[a]	138.61[a]
	IW/ET=1	55.29[a]	71.33[a]	93.78[a]	103.28[b]	118.13[b]	133.15[b]
	IW/ET=0.8	44.27[b]	6.24[b]	78.65[b]	101.84[b]	108.66[c]	121.94[c]
	IW/ET=0.6	42.55[c]	60.61[c]	70.97[c]	78.89[c]	98.45[d]	107.41[d]
	IW/ET=0.4	34.81[d]	47.52[d]	66.03[d]	76.36[b]	80.99[e]	94.44[e]
	F value	**233.30***	**122.8***	**145.32***	**394.43***	**215.69***	**145.57***
AMF x Irrigation	**F value**	**5.25***	**3.95***	**1.73***	**1.09[ns]**	**3.01[ns]**	**1.69[ns]**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.2.18. Vigour index II

Non-significant variations with respect to vigour index II were observed for mahogany seedlings when treated with different AMF species at 30, 120 and 150 days (Table 35). *R. intraradices* (3.93) and *G. etunicatum* (3.95), both recorded higher values at 60 days while, non-inoculated seedlings recorded the lowest value (2.78). *G. etunicatum* (5.97 and 14.28) had highest values at 90 and 180 days; while the non-inoculated seedlings had the lower values.

Non-significant variations were seen for seedlings at 30, 120 and 150 days after applying the irrigation treatments. At 60, 90 and 180 days, the control seedling had higher index values while, the treatment IW/ET=0.4 had lower index values along with the treatment IW/ET=0.6 at 90 days.

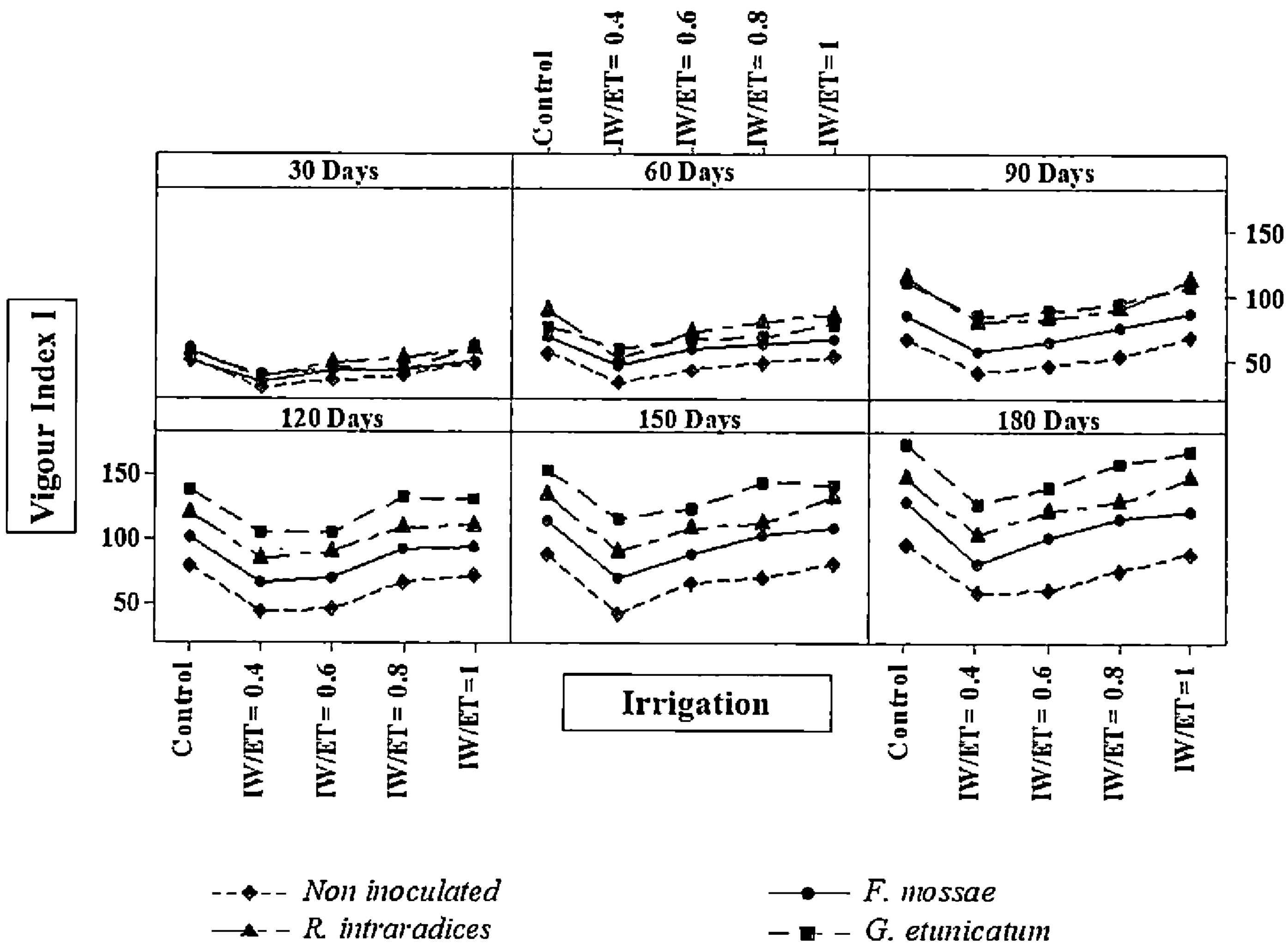


Figure 31. Vigour index I of mahogany seedlings as influenced by AMF and irrigation interaction

The effect of interaction was not significant at 60, 120 and 180 days (Figure 32). At 30 days, seedlings inoculated with *R. intraradices* had higher values under control treatment (3.42) and the treatment IW/ET=1 (3.56). Seedlings inoculated with *G. etunicatum* and *F. mosseae* under the control irrigation treatment also recorded higher values at 30 days (3.46 and 3.32 respectively). At 90 days, seedlings inoculated with *R. intraradices* belonging to irrigation treatment IW/ET=0.8 had higher value (9.62). Seedlings inoculated with *G. etunicatum* under the control irrigation treatment recorded higher value at 150 days (16.47).

Table 35. Vigour index II of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Vigour index II					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	1.71	2.78^{c}	4.05^{b}	6.14	13.05	8.75^{c}
	R. intraradices	7.30	3.93^{a}	5.26^{ab}	8.00	10.23	11.75^{b}
	G. etunicatum	2.49	3.95^{a}	5.97^{a}	8.23	10.64	14.28^{a}
	F. mosseae	1.81	3.43^{b}	4.62^{b}	6.49	8.63	10.94^{b}
	F value	**8.04^{ns}**	**35.15***	**3.32***	**1.22^{ns}**	**0.47^{ns}**	**34.05***
Irrigation	Control	3.21	5.04^{a}	7.08^{a}	10.98	15.16	18.08^{a}
	IW/ET=1	2.68	4.58^{b}	5.23^{b}	9.66	11.81	14.88^{b}
	IW/ET=0.8	2.10	3.73^{c}	6.19^{ab}	6.61	8.10	10.50^{c}
	IW/ET=0.6	7.61	2.65^{d}	3.42^{c}	9.02	6.32	8.16^{d}
	IW/ET=0.4	1.05	1.64^{e}	2.96^{c}	3.77	11.80	5.51^{e}
	F value	**1.29***	**1.78^{ns}**	**12.07***	**0.89^{ns}**	**1.35***	**134.49^{ns}**
AMF x Irrigation	**F value**	**1.00***	**3.11^{ns}**	**1.73***	**1.09^{ns}**	**3.01***	**1.69^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

4.3. Quality assessment

4.3.1. Seedling quality index

The average performance of mahogany seedlings when treated with different AMF species and irrigation regimes in terms of seedling quality index is given in the Table 36.

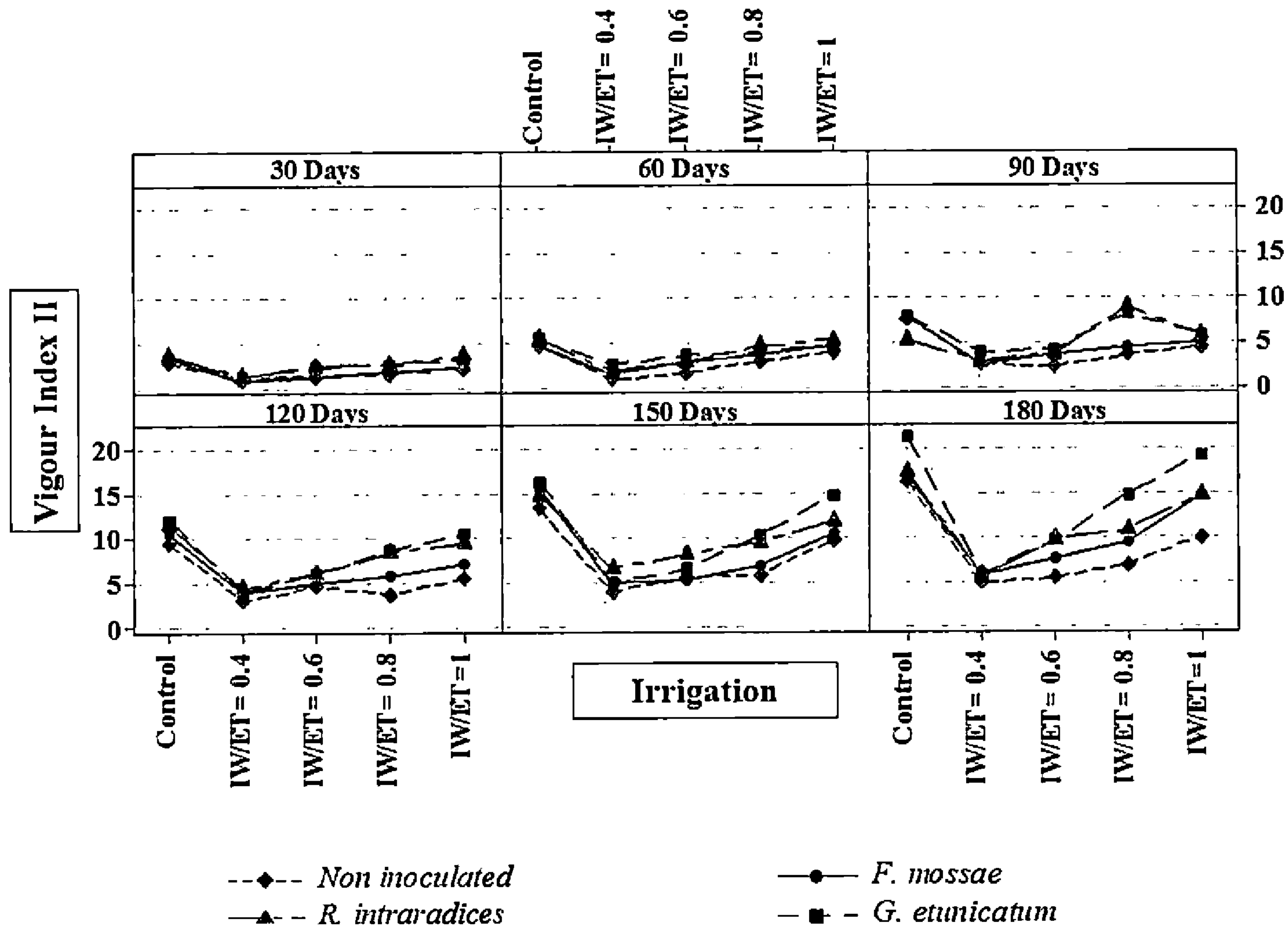


Figure 32. Vigour index II of mahogany seedlings as influenced by AMF and irrigation interaction

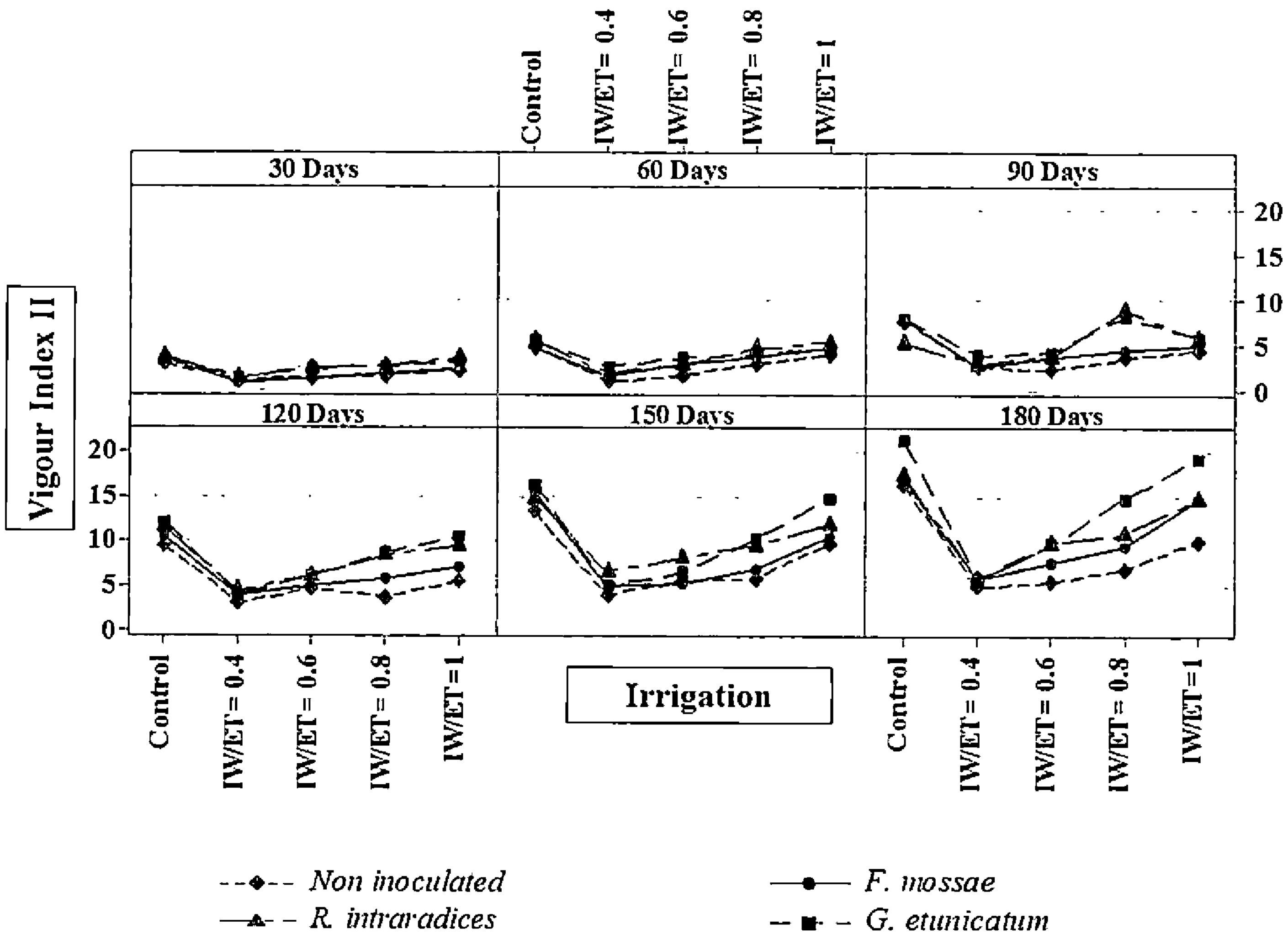


Figure 32. Vigour index II of mahogany seedlings as influenced by AMF and irrigation interaction

Seedling quality index of mahogany seedlings when subjected to different AMF species had no significant variations among them at 30, 120 and 150 days after inoculation. At 60, 90 and 180 days, the highest values for seedling quality index were recorded for seedlings inoculated with *G. etunicatum* (0.21, 0.29 and 0.69). Non- inoculated seedlings had lower values (0.14, 0.18 and 0.49) at 60, 90 and 180 days. At 180 days, non-inoculated seedlings recorded no significant difference in seedling quality when compared to that of *R. intraradices* and *F. mosseae.* No significant variations were observed with respect to irrigation regimes at 30, 120 and 150 days.

Table 36. Seedling quality index of mahogany seedlings as influenced by AMF and irrigation.

Factors	**Treatments**	**Seedling Quality Index**					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	0.08	0.14^c	0.18^c	1.45	0.68	0.49^b
	R. intraradices	0.40	0.17^b	0.23^b	0.38	0.48	0.56^b
	G. etunicatum	0.15	0.21^a	0.29^a	0.38	0.48	0.69^a
	F. mosseae	0.10	0.18^b	0.23^b	0.29	0.41	0.51^b
	F value	**1.15^{ns}**	**19.56***	**10.94***	**1.18^{ns}**	**0.78^{ns}**	**7.75***
Irrigation	Control	0.19	0.27^a	0.35^a	0.52	0.67	0.77^a
	IW/ET=1	0.15	0.21^b	0.25^b	0.39	0.54	0.67^b
	IW/ET=0.8	0.12	0.17^c	024^b	1.57	0.41	0.51^c
	IW/ET=0.6	0.42	0.14^d	0.17^c	0.46	0.33	015^c
	IW/ET=0.4	0.05	0.08^e	0.15^c	0.19	0.62	0.35^d
	F value	**0.84^{ns}**	**82.85***	**29.02***	**0.92^{ns}**	**0.93^{ns}**	**23.32***
AMF x Irrigation	**F value**	**0.99***	**1.69***	**1.60***	**0.89***	**1.04***	**1.16***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

At 60, 90 and 180 days, highest values were obtained for control seedlings (0.27, 0.35 and 0.77). The treatment IW/ET=0.4 had lowest values at 60 and 180 days (0.08 and 0.35). At 90 days, the lowest values were noted for both IW/ET=0.6 (0.17) and IW/ET=0.4 (0.15).

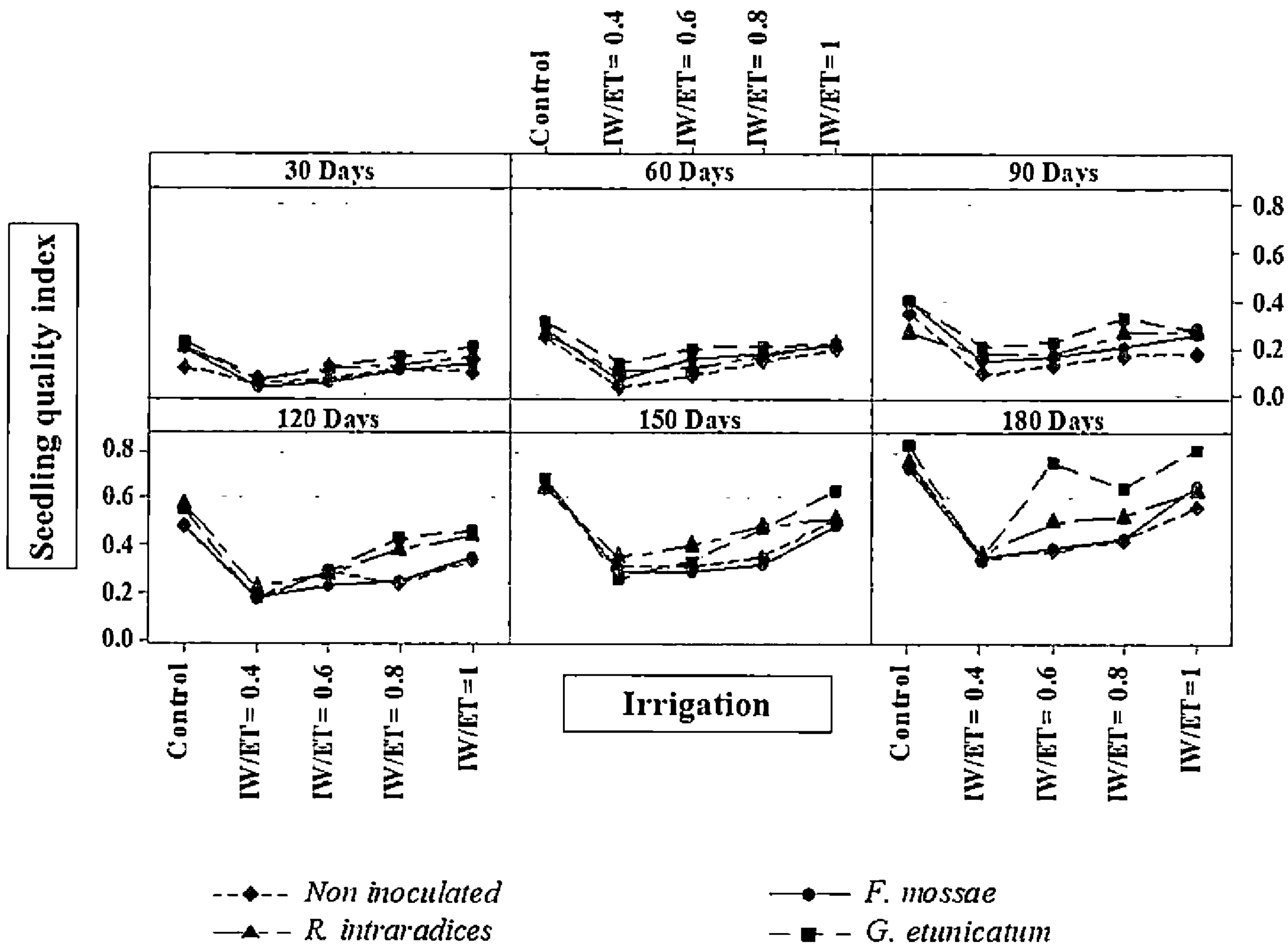


Figure 33. Seedling quality index of mahogany seedlings as influenced by AMF and irrigation interaction

The effect of treatments on interaction was significant throughout the experiment (Figure 33). Higher values were observed for seedlings inoculated with *G. etunicatum* (0.41) and *F. mosseae* (0.40) under control treatment at 90 days. At 120 days, seedlings inoculated with *R. intraradices* (0.57) and *G. etunicatum* (0.56) under control treatment had higher values. At 30, 60, 150 and 180 days, higher seedling quality indices were recorded for seedlings inoculated with G. *etunicatum* under control treatment (0.22, 0.31, 0.69 and 0.82).

4.3.2. Biovolume index

Table 37. Biovolume index of mahogany seedlings as influenced by AMF and irrigation.

Factors	**Treatments**	**Biovolume index**					
		30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
AMF	Non inoculated	60.35^{c}	72.39^{d}	100.76^{d}	134.82^{c}	198.59^{d}	271.21^{d}
	R. intraradices	80.13^{a}	178.25^{a}	303.72^{a}	418.74^{a}	501.78^{b}	696.37^{b}
	G. etunicatum	73.59^{ab}	140.73^{b}	266.11^{b}	425.23^{a}	667.40^{a}	920.37^{a}
	F. mosseae	63.26^{ac}	99.47^{c}	172.52^{c}	224.23^{b}	341.93^{c}	468.41^{c}
	F value	**5.76***	**118.48***	**100.52***	**106.76***	**60.58***	**82.37***
Irrigation	Control	94.41^{a}	172.99^{a}	273.09^{a}	444.52^{a}	599.47^{a}	771.66^{a}
	IW/ET=1	98.09^{a}	142.59^{b}	278.06^{a}	366.12^{b}	497.47^{b}	691.80^{a}
	IW/ET=0.8	73.56^{b}	120.51^{c}	186.95^{b}	317.49^{c}	431.85^{bc}	576.65^{b}
	IW/ET=0.6	45.21^{c}	105.35^{d}	159.06^{bc}	186.34^{d}	355.28^{c}	502.00^{b}
	IW/ET=0.4	35.39^{c}	72.11^{e}	132.99^{c}	189.39^{d}	253.08^{d}	397.37^{c}
	F value	**43.91***	**63.49***	**35.69***	**51.71***	**20.76***	**18.91***
AMF x Irrigation	**F value**	**3.03***	**3.05***	**1.69^{ns}**	**2.82***	**0.39^{ns}**	**0.49^{ns}**

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with similar superscript along the column do not differ significantly

The biovolume index of mahogany seedlings inoculated with different AMF species had significant variations throughout the study (Table 37). At 30, 60 and 90 days, seedlings inoculated with *R. intraradices* had highest values of biovolume index (80.13, 178.25 and 303.72); whereas, non-inoculated seedlings had lower index values (60.35, 72.39 and 1.76). At

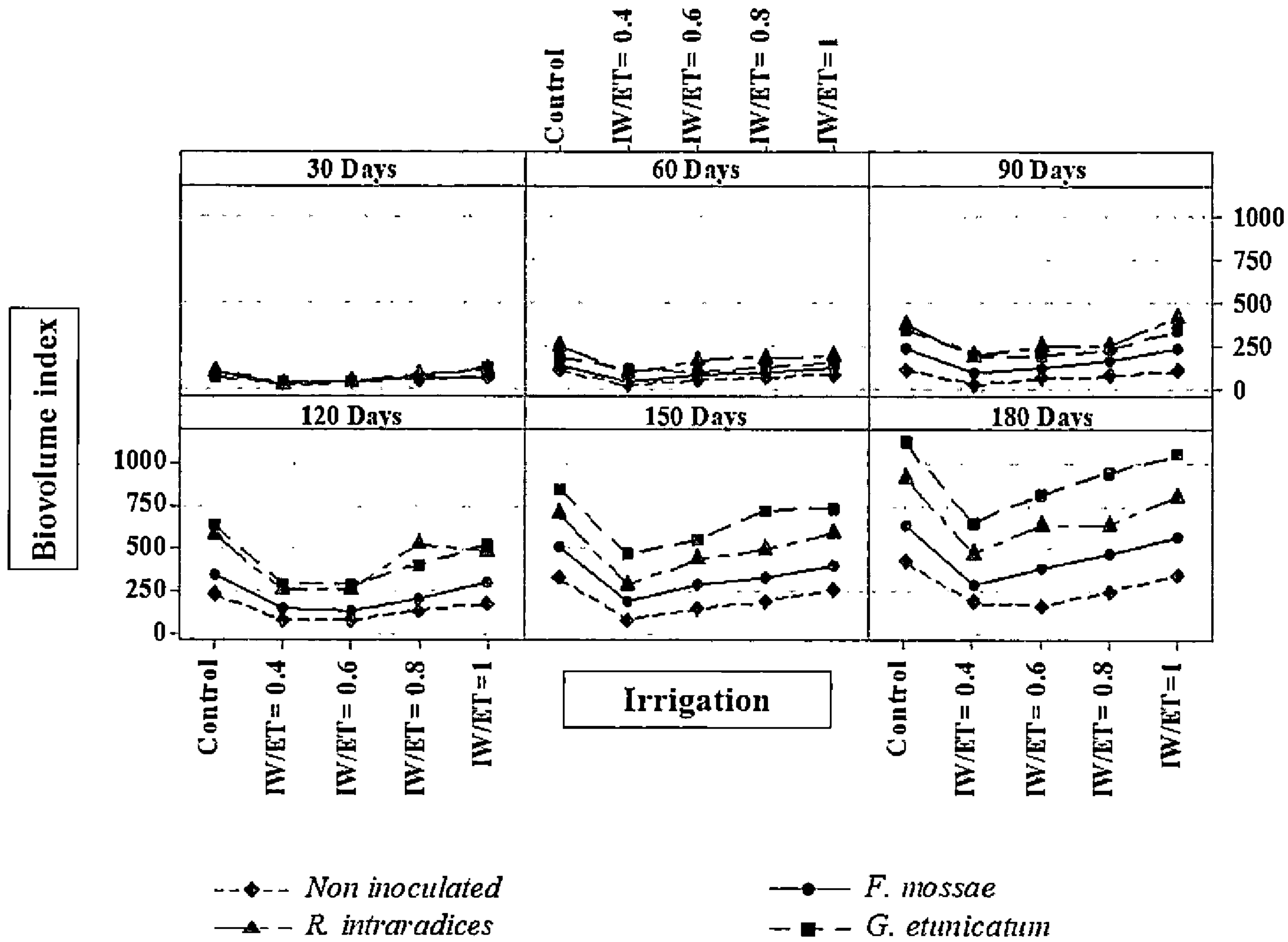


Figure 34. Biovolume index of mahogany seedlings as influenced by AMF and irrigation interaction

120 days, maximum values were recorded for both *R. intraradices* (418.74) and *G. etunicatum* (425.23) while, the non-inoculated seedlings displayed minimum (134.82). At 150 and 180 days, seedlings inoculated with *G. etunicatum* had highest values (667.40 and 920.37) while, non-inoculated seedlings maintained their trend.

There was no significant difference between the control and the treatment IW/ET=1 after 30, 90 and 180 days. The highest values were recorded for these treatments. However, the highest values at 60,120 and 150 days (172.99, 444.52 and 599.47) were recorded for control. The treatment IW/ET=0.4 had lower values (72.11, 132.99, 253.08 and 397.37) at 60, 90, 150 and 180 days. Treatment IW/ET=0.6 also had lower values (45.21 and186.34) at 30 and 120 days.

The effect of treatments on interaction was not significant at 90, 150 and 180 days (Figure 34). At 30 days, higher biovolume index was observed for seedlings inoculated with *G. etunicatum* of treatment IW/ET=1.0 (110.6). Higher biovolume index value at 60 days was observed for control seedlings inoculated with *R. intraradices* (250.3). At 120 days, higher biovolume index was observed for seedlings inoculated with *G. etunicatum* under irrigation control (650.9).

4.3.3. Mycorrhiza Efficiency Index

The mycorrhiza efficiency index of mahogany seedlings under different AMF treatments are given in the Table 38. The non-inoculated seedlings had the lowest mycorrhiza efficiency index throughout the study. Seedlings inoculated with *G. etunicatum* and *R. intraradices* recorded higher values at 30, 60, 120 and 150 days. At 90 and 180 days, seedlings inoculated with *G. etunicatum* had higher values.

Considering various irrigation regimes, all treatments were on par, except IW/ET=0.4 (-28.31) for mycorrhiza efficiency index at 30 days. At 60 days, the highest efficiency was recorded for IW/ET=0.6 (37.29) and IW/ET=0.4 (38.97); while the lowest was recorded for control (5.10). The treatments IW/ET=0.8 (25.63) and IW/ET=0.6 (31.14) had highest mycorrhiza efficiency index at 90 days while, control had the lowest. At 120 days, IW/ET=1 and IW/ET=0.8 recorded highest mycorrhiza efficiency index values (24.19 and 31.45) while, IW/ET=0.6 recorded lowest (7.18). The treatment IW/ET=0.8 had highest value at 150 days

(21.83) while, IW/ET=0.6 had lowest (5.24). Highest values for mycorrhiza efficiency index were recorded for all except control and IW/ET=0.4 (5.89) at 180 days.

Table 38. Mycorrhiza Efficiency Index of mahogany seedlings as influenced by AMF and irrigation.

Factors	Treatments	Mycorrhiza Efficiency Index					
		30 days	60 days	90 days	120 days	150 days	180 days
AMF	Non inoculated	0.00^{b}	0.00^{c}	0.00^{c}	0.00^{c}	0.00^{c}	0.00^{c}
	R. intraradices	27.61^{a}	33.28^{a}	18.03^{b}	29.26^{a}	24.89^{a}	23.54^{b}
	G. etunicatum	26.02^{a}	33.31^{a}	30.40^{a}	27.61^{a}	23.30^{a}	34.01^{a}
	F. mosseae	-22.15^{c}	24.34^{b}	14.25^{b}	14.68^{b}	6.11^{b}	18.75^{b}
	F value	**21.17***	**116.23***	**30.69***	**28.69***	**35.55***	**25.18***
Irrigation	Control	13.28^{a}	5.10^{d}	-13.29^{c}	10.45^{bc}	10.03^{cd}	7.37^{b}
	IW/ET=1	14.66^{a}	12.41^{c}	13.57^{b}	24.19^{a}	13.09^{bc}	26.70^{a}
	IW/ET=0.8	16.29^{a}	19.90^{b}	25.63^{a}	31.45^{a}	21.83^{a}	27.52^{a}
	IW/ET=0.6	23.42^{a}	37.29^{a}	31.14^{a}	7.18^{c}	5.24^{d}	27.89^{a}
	IW/ET=0.4	-28.31^{b}	38.97^{a}	8.81^{b}	16.17^{b}	17.70^{ab}	5.89^{b}
	F value	**12.81***	**84.63***	**44.30***	**12.32***	**7.06***	**12.89***
AMF x Irrigation	**F value**	**4.98***	**11.78***	**11.21***	**2.12***	**5.49***	**2.14***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with similar superscript along the column do not differ significantly

The effect of interaction of treatments was significant throughout the experiment (Figure 35). At 30 days, higher mycorrhiza efficiency index was observed for seedlings inoculated with *G. etunicatum* (48.20) and *R. intraradices* (44.83) under the treatment IW/ET=0.6. At 60 days, higher efficiency was observed for seedlings inoculated with *G. etunicatum* (61.74) under the treatment IW/ET=0.4. However, at 90 days, seedlings inoculated with *G. etunicatum* (57.64) under the treatment IW/ET=0.8 had higher efficiency. At 120 days, higher mycorrhiza efficiency index was observed for seedlings inoculated with *R. intraradices* (49.78) and *G. etunicatum* (49.57) under the treatment IW/ET=0.8. At 150 and 180 days, seedlings inoculated with *G. etunicatum* under the treatment IW/ET=0.8 (41.23 and 52.68).

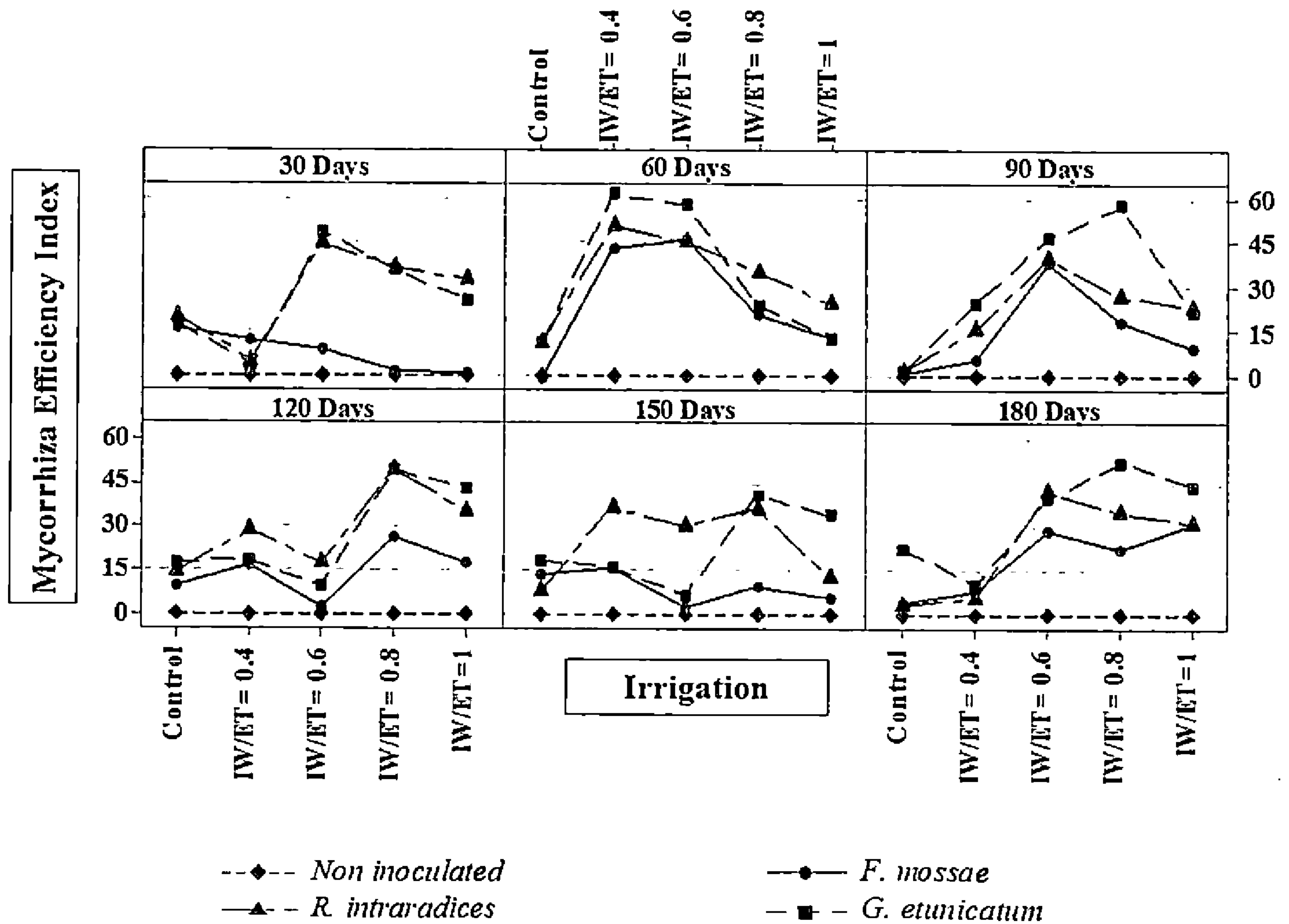


Figure 35. Mycorrhiza Efficiency Index of mahogany seedlings as influenced by AMF and irrigation interaction

4.4. Percentage of AMF association

4.4.1. Root Colonization Percentage

Table 39. Root Colonization Percentage (%) of mahogany seedlings under different treatments

Factors	Treatments	Root Colonization Percentage	
		150 days	180 days
AMF	Non inoculated	0.00^{d}	0.00^{c}
	R. intraradices	35.07^{b}	32.68^{b}
	G. etunicatum	45.48^{a}	44.89^{a}
	F. mosseae	27.13^{c}	27.38^{b}
	F value	**147.24***	**91.64***
Irrigation	Control	29.65^{b}	26.04^{c}
	IW/ET=1	40.59^{a}	42.11^{a}
	IW/ET=0.8	33.80^{b}	32.59^{b}
	IW/ET=0.6	17.22^{c}	17.49^{d}
	IW/ET=0.4	13.34^{c}	12.95^{d}
	F value	**40.47***	**27.78***
AMF x Irrigation	**F value**	$\mathbf{5.86^{ns}}$	$\mathbf{1.13^{ns}}$

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

The root colonization percentage was calculated at 150 and 180 days of the experiment. At 150 and 180 days, the highest colonization percentage was observed for *G. etunicatum* (45.48 and 44.89) and the lowest was observed for non-inoculated seedlings (Table 39). With respect to various irrigation regimes, the IW/ET=1 had highest colonization percentage (40.59) while, the lower values were recorded by IW/ET=0.6 (17.22 and 17.49) and IW/ET=0.4 (13.34 and 12.95) respectively, at 150 and 180 days. The effect of treatments on interaction was not significant at 150 and 180 days (Figure 36).

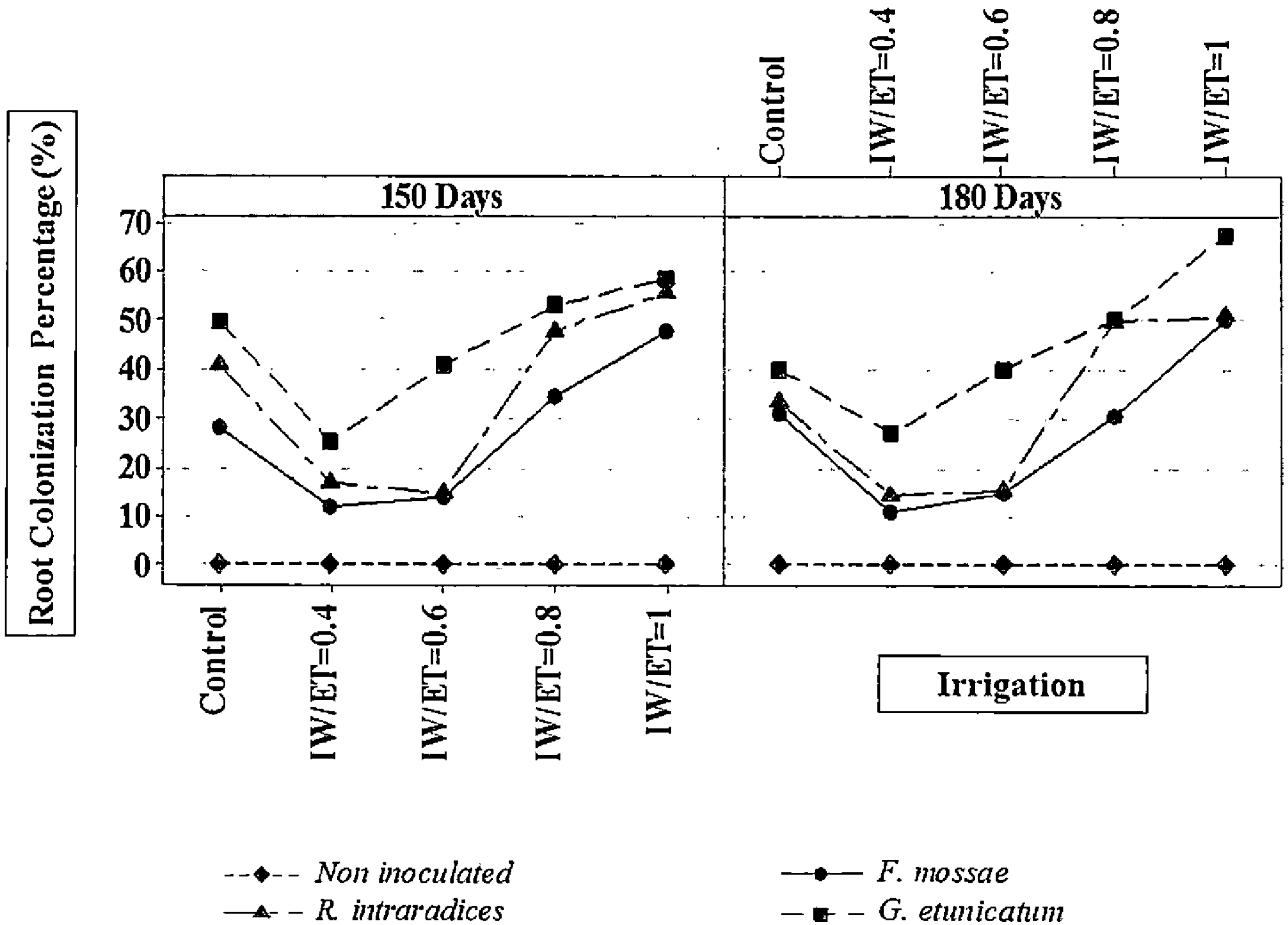


Figure 36. Root Colonization Percentage (%) of mahogany seedlings as influenced by AMF and irrigation interaction

4.4.2. Total Spore Count

Table 40.Total Spore Count of mahogany seedlings under different treatments

Factors	Treatments	Total Spore Count	
		150 days	180 days
AMF	Non inoculated	0.00[c]	0.00[c]
	R. intraradices	114.8[a]	64.00[b]
	G. etunicatum	82.05[a]	85.55[a]
	F. mosseae	50.60[ab]	54.30[b]
	F value	**3.70***	**95.20***
Irrigation	Control	52.81	49.81[c]
	IW/ET=1	138.12	79.87[a]
	IW/ET=0.8	60.75	64.81[b]
	IW/ET=0.6	31.44	33.50[d]
	IW/ET=0.4	26.19	26.81[d]
	F value	**2.51[ns]**	**26.55***
AMF x Irrigation	**F value**	**1.27***	**4.54***

* Significant at 0.05 levels; ns- non significant at 0.05 levels. Values with same superscript along the column do not differ significantly

Total spore count under different treatments had significant variations at 150 and 180 days (Table 40). At 150 days, high total spore count was observed for both *R. intraradices* (114.8) and *G. etunicatum* (82.05). *G. etunicatum* recorded the highest total spore count at 180 days (85.55). Among the irrigation regimes, no significant variations were observed for spore count at 150 days. At 180 days, however, IW/ET=1 recorded highest spore count (79.87) while, control had lowest spore count (49.81). The effect of treatments on interaction was significant at 150 and 180 days (Figure 37). At 150 days, highest spore count was observed for seedlings inoculated with *R. intraradices* (367.4) under IW/ET=1 irrigation treatment. At 180 days, however, highest spore count was observed for seedlings inoculated with *G. etunicatum* under treatment IW/ET=1 (128.3).

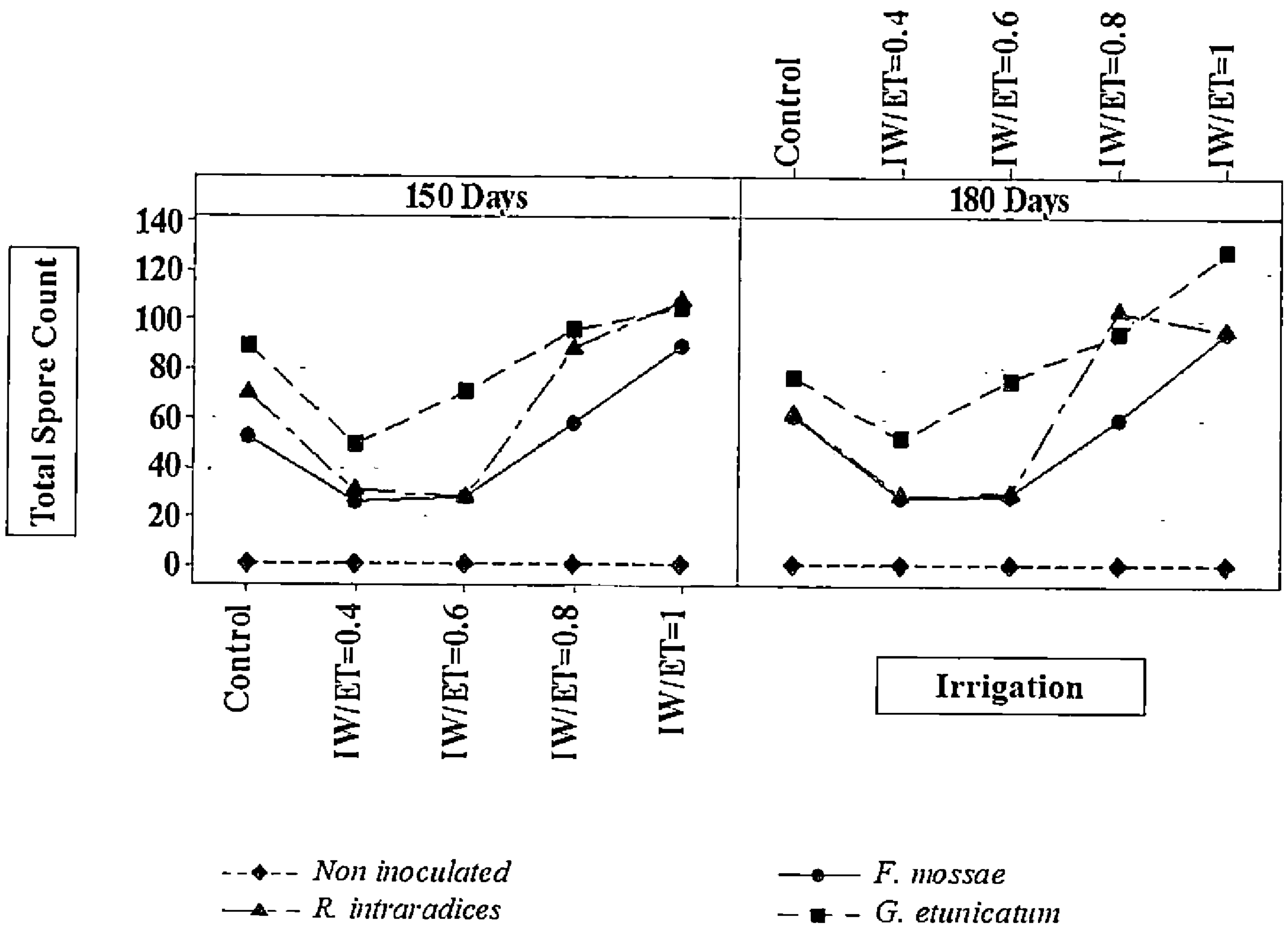


Figure 37. Total Spore Count of mahogany seedlings as influenced by AMF and irrigation interaction

Discussion

5. DISCUSSION

The results of the experiment on influence of different treatments of arbuscular mycorrhizal fungi (AMF) and irrigation regimes on the physiological and biometric aspects of mahogany seedlings is discussed here under.

5.1. Physiological observations

From the observations, it was apparent that increasing levels of drought stress decreased the rate of photosynthesis in mahogany seedlings. The control treatment (daily irrigation) and IW/ET=1 showed higher rates of photosynthesis, while IW/ET=0.4 showed lowest rates throughout the experiment. At the end of six months, the highest rate of photosynthesis was observed for IW/ET=0.8 and the lowest rate was recorded for IW/ET=0.4. The seedlings inoculated with *Rhizophagus intraradices* and *Glomus etunicatum* showed higher values of photosynthesis till 120 days. However, seedlings inoculated with *G. etunicatum* showed highest rate of photosynthesis for the rest of the period. The effect of interaction was found to be significant throughout the period of study. Higher rates of photosynthesis, were recorded for non-inoculated seedlings as well as seedlings inoculated with *R. intraradices* and *F. mosseae* under the control irrigation and treatment IW/ET=1.0. Among the various physiological, biochemical and molecular processes that controls plant growth (Rapparini and Penuelas, 2014); photosynthesis is the fundamental process that provides the organic blocks that contributes substantially to the plant growth and development. According to Taiz and Zeiger (2010), the chemical energy consumed in various metabolic processes is derived from the conversion of light energy into chemical energy. However, stressful environments such as drought can hinder this process in most seedlings by changing the ultrastructure of the organelles. Abiotic stresses can reduce the photosynthetic rate by stress-induced stomatal or non stomatal limitations (Rahnama *et al.* 2010). Drought stress, at its mild intensity can inhibit leaf photosynthesis and stomatal conductance in most seedlings (Medrano *et al.*, 2002). In the current study, it was found that the rate of photosynthesis was significantly lower for the non- inoculated seedlings, compared to the inoculated ones. This indicates that AMF colonization helps to maintain a high gas exchange capacity by reducing the stomatal resistance and by improving transpiration fluxes (Zhu *et al.*, 2011). Several studies have reported that inoculation with arbuscular mycorrhizal fungi can increase the photosynthetic rate in tree seedlings. Rate of photosynthetic was higher for mahogany seedlings inoculated with *F. mosseae* and *R. intraradices* (Ajeesh, 2015). Maximum rates of photosynthesis were observed in AMF inoculated seedlings of *Dalbergia sissoo* due to increment in root biomass (Bisht *et al.,* 2000), which may be helpful in increased nutrient uptake from the rhizosphere. Auge (2001) confirmed that mycorrhizal seedlings frequently show higher photosynthetic rates than non-mycorrhizal seedlings, which is related to the symbiosis effect of AMF on stomatal resistance. He also suggested that AMF colonization can increase the rate of photosynthetic assimilation and export. Zhu *et al.* (2012) demonstrated higher photosynthetic rates in mycorrhizal maize seedlings than non-mycorrhizal seedlings under well-watered and drought stress conditions. Yang *et al.* (2014) found that drought stress inhibited the leaf net photosynthetic rate and the leaf stomatal conductance of black locust (*Robinia pseudoacacia*) seedlings. It was also noticed that mycorrhizal seedlings had higher net photosynthetic rate and improved stomatal conductance under both well watered and mild drought stress treatments, but not for severe drought stress treatment. The findings of this study are similar with these reports. More carbon assimilation per unit water transpired, i.e., greater photosynthetic capacity, can increase water use efficiency and enhance tolerance of mycorrhizal seedlings to osmotic stress (Nandy *et al.*, 2007).

The investigation on the influence of AMF on the leaf stomatal conductance of mahogany seedlings indicated that stomatal conductance was higher on the AMF inoculated seedlings. Generally, seedlings inoculated with *R. intraradices* and *G. etunicatum* showed higher values of stomatal conductance. After six months of treatment, however, the highest stomatal conductance was observed for seedlings inoculated with *G. etunicatum.* This indicates the superiority of the AMF species, *G. etunicatum* over the others. Significantly lower values of stomatal conductance were observed for non-inoculated seedlings throughout the experiment. High values for stomatal conductance was observed for the treatment IW/ET=0.8. After six months, a significant increase in the stomatal conductance was observed for IW/ET=1. Generally, the treatment IW/ET=0.4 recorded the lowest stomatal conductance. The effect of interaction was found to be significant throughout the period of study. Higher stomatal conductance was recorded for seedlings inoculated with *R. intraradices* under the treatment IW/ET=0.6. Seedlings inoculated with *G. etunicatum* under control treatment and treatment IW/ET=1.0 also had higher values. Stomatal conductance is a key phenomenon in seedlings as it is vital for both prevention of desiccation and CO_2 acquisition (Medici *et al.* 2007). Stomatal control of water loss has been identified as an early plant response to water deficit, which leads to a limitation in carbon uptake by the leaves (Chaves, 1991). Stomata closure in response to drought stress generally happens either due to a decline in leaf turgor or water potential (Ludlow, 1980), which was also found true in this study. The positive effects of AMF have been attributed to the uptake of water and nutrients from soil by external hyphae (Subramanian and Charest 1997), regulation of stomatal conductance by hormonal signals (Aroca *et al.*,2008), optimization of osmotic adjustment (Wu and Xia, 2006) and improvement in root hydraulic conductivity (Auge, 2004). Colonization of squash plants with *R. intraradices* resulted in increased stomatal conductance relative to non-AM controls, by an average of 27% under amply watered unstressed conditions (Auge *et al.*, 2008). Zhu *et al.* (2011), in his study observed that stomatal conductance in AMF inoculated seedlings was significantly higher than in non-inoculated seedlings under both well watered and mild drought stress treatments. Compared to non-inoculated seedlings, stomatal conductance was found to be 24 per cent higher in inoculated seedlings. The lower values of stomatal resistance in mycorrhizal seedlings indicate that these seedlings were able to keep the stomata open longer than non-mycorrhizal seedlings (Subramanian *et al.* 1995), since they are better hydrated. Reductions of leaf gas exchange in water-limiting conditions have been widely documented in genera such as Acer and Tilia (Lemoine *et al.*, 2001; Turnbull *et al.*, 2002; Aasamaa *et al.*, 2004; Fini *et al.*, 2009) and in oaks (Abrams, 1990; Drunasky and Struve, 2005). If inoculation is effective in reducing the impact of water stress, acclimated plants through mycorrhizal inoculation should be able to sustain higher leaf gas exchange under drought. The higher stomatal conductance of AMF plants has been associated with higher leaf water potential or higher leaf water content as well as with greater osmotic adjustment and higher turgor at similar water potential (Auge *et al.*, 2015). Hyphae penetrate pores that are inaccessible to roots, and they spread beyond the root zone, effectively increasing the available volume of soil solution (Smith and Read, 2008). Dakessian *et al.* (1986) and Franson *et al.* (1991) provided evidence that AMF root systems can better exploit bound water in drying soils, in some cases providing access to soil water below the permanent wilting water potential of than non- mycorrhizal plants. This explains the ability of AMF plants to maintain stomatal opening longer than non- mycorrhizal plants as soils dry.

In the present study, the treatments IW/ET=1 and IW/ET=0.8 recorded higher values of transpiration rate, while IW/ET=0.4 had lower values. After 30 and 90 days of treatments, higher rates of transpiration was observed for the irrigation control, IW/ET=1 and IW/ET=0.8 treatments. After six months, highest value was observed for treatment IW/ET=0.8 only. Mahogany seedlings inoculated with AMF recorded increased rates of transpiration, than the non- inoculated seedlings. Seedlings inoculated with both *R. intraradices* and *G. etunicatum* had the highest transpiration rates at 150 days. After six months, however, G. *etunicatum* recorded the highest values, while non - inoculated seedlings recorded the lowest. The effect of interaction was found to be significant throughout the period of study. Seedlings inoculated with *R. intraradices* and *G. etunicatum* under control irrigation and treatment IW/ET=1.0. Stomatal closure is known to have a more inhibitory effect on transpiration of water than that on CO_2 diffusion into the leaf tissues (Chaves *et al.*, 2009). The findings of this study are on par with the findings of Yang *et al.* (2014), who reported that transpiration rate of black locust seedlings were inhibited by drought stress. Colonization with AMF greatly improved leaf transpiration rate of the black locust seedlings in well watered and mild drought stress treatment but not for severe drought stress treatment. Water shortage reduced assimilation and transpiration in linden and oak (Fini *et al.*, 2011). Plants must make a compromise between the photosynthetic CO_2 uptake and transpirational water loss, especially when water availability is low. Therefore, in addition to the effects of inoculation on carbon assimilation, changes in water flow through plants as induced by different mycorrhizal fungi deserve attention. Increases in transpiration following inoculation with AMF have been frequently reported and reviewed by others (Dixon *et al.*, 1980; Auge, 2001; Navarro *et al.*, 2009). When mycorrhizal plants show higher transpiration, it may be related to the increased water uptake by the mycorrhizal root system, delayed stomatal closure in response to decreasing soil water potential, and to increased soil-to-plant hydraulic conductance (Auge *et al.*, 1986).

The current study showed that control seedlings and treatment IW/ET=1 maintained lower leaf temperatures, while the treatment IW/ET=0.4 exhibited higher temperature consistently. The leaf temperature of mahogany seedlings, when inoculated with different AMF species had significantly lower values than the non-inoculated seedlings. Among the various AMF species used, leaf temperature was significantly lower for those seedlings inoculated with *G. etunicatum.* At six months, seedlings inoculated with *F. mosseae, R. intraradices* and those not inoculated with AMF recorded the higher leaf temperatures, while the lowest leaf temperature was noted for *G. etunicatum*. This may be because of the high rate of transpiration

(Table 5) and stomatal conductance (Table 4) for the seedlings inoculated with *G. etunicatum,* a fact which is substantiated in this study. Because leaves lose temperature through evaporative cooling and thus is an indirect measure of transpiration. The effect of interaction was found to be significant throughout the period of study. The non-inoculated seedlings and those seedlings inoculated with different AMF species belonging to the treatment IW/ET=0.4 had higher leaf temperatures. Higher values were also recorded for seedlings inoculated with *R. intraradices* and *F. mosseae* of treatment IW/ET=0.6 and for the non-inoculated seedlings of the treatment IW/ET=1. Leaf temperature increases with increasing levels of drought stress which accounts for lower transpiration rates due to the reduced water availability. Havaux (1992) observed that in various members of *Solanaceae*, photosynthesis was significantly less inhibited by temperatures above 38±40 °C in dehydrated seedlings compared with well-watered seedlings. The effects of water deficit on photosynthetic capacity in lupins were shown to be dependent on leaf temperature (Chaves *et al.*, 1992). In *Lupinus albus*, stomata were more open at higher temperatures (25 °C) than at lower temperatures (15 °C), in either well-watered or water-stressed conditions (Correia *et al.*, 1999). The data indicated that at optimal or sub-optimal temperatures for photosynthesis (25 and 15 °C, respectively), photosynthetic capacity only decreased at leaf relative water contents of 60 per cent. However, when the temperature rose above the optimum (35 °C), photosynthetic capacity was affected at a higher leaf water status (80 per cent). It is well known that leaf temperature affects the stomatal aperture of leaves (Jones, 1992). According to Mathur and Vyas (1995), seedlings inoculated with AMF have a low transpiration rates and higher water use efficiency, when compared with non mycorrhizal seedlings. He suggested that this might be due to the decrease in stomatal conductance when colonized with AMF. Contrary to the above discussion, Abbaspour *et al.* (2012) suggests an opposite view, by stating that mycorrhizal inoculation could increase the rate of transpiration, leaf temperature and restrain the decomposition of chlorophyll.

In the present study, the irrigation control seedlings which is daily irrigated always had higher chlorophyll content, while the treatment IW/ET=0.4 had lower values. Higher chlorophyll content was recorded mostly from seedlings inoculated with *G. etunicatum*, along with those seedlings inoculated with *R. intraradices*. For the period of six months, the lowest chlorophyll content was observed for non-inoculated seedlings. The effect of interaction was found to be significant throughout the period of study. Higher chlorophyll content was recorded for seedlings inoculated with *G. etunicatum* and *R. intraradices* of control treatment and treatment IW/ET=1.0. Chlorophyll concentration is an important index for evaluating plant photosynthetic efficiency and environmental stress (Zhu *et al.,* 2012). However, this organelle is highly sensitive to stressful environments such as drought and plays a premier role in the modulation of stress responses (Saravanavel *et al.,* 2011). The decrease in chlorophyll content is a commonly observed phenomenon under drought stress (Din *et al.,* 2011). Drought stress not only causes a substantial damage to photosynthetic pigments, but also leads to the deterioration of thylakoid membrane (Anjum *et al.* 2011). Thus, a reduction in photosynthetic capacity in seedlings exposed to drought stress is expected. The outcomes of the present study are also in agreement to these finding (Table 3). Moreover, chlorophyll content in seedlings of *Albizia lebbeck* and *Cassia siamea* was found to be less under water stress (Saraswathi and Paliwal, 2011). The results are also in agreement with those found by Sanchez-Blanco *et al.* (2004) and Morte *et al.* (2001) who detected higher chlorophyll concentrations in mycorrhizal seedlings subjected to drought stress. Beltrano and Ronco (2008) reported the loss of leaf chlorophyll concentration in wheat seedlings under water deficit, while it was not modified by AMF inoculation in seedlings under well-watered conditions. Chlorophyll content in mycorrhizal seedlings was significantly higher than those of non-mycorrhizal ones under moderate and severe water stress. This is possibly due to the fact that at low soil water potential, mycorrhizal seedlings can absorb more water than non-mycorrhizal ones, as mentioned by Porcel and Ruiz-Lozano (2004). In addition, Mathur and Vyas (2000) concluded that arbuscular mycorrhizal root colonization increased chlorophyll synthesis, which could be associated with higher photosynthesis rates and plant growth. Inoculation with three AMF species (*G. occultum, F. mosseae* and *G. aggregatum*) caused significant increase in chlorophyll content of *Acacia mangium* seedlings, when compared to the control ones (Ghosh and Verma, 2006). Chlorophyll content was higher for mahogany seedlings inoculated with *F. mosseae* and *R. intraradices* (Ajeesh, 2015).

Water status largely influences plant growth and physiological processes. The AMF symbiosis can improve tissue water content and leaf physiology and affect the plant water relations under drought stress. The regulation of plant water status by the symbiosis may relate to host phenology, phosphorous and carbon nutrition (Auge, 2001).During the course of experiment, the irrigation control seedlings demonstrated the highest relative water content (RWC) consistently, whereas, the treatment IW/ET=0.4 maintained the lowest RWC. The non-inoculated seedlings showed a reduced RWC throughout the period of the experiment. Seedlings inoculated with *R. intraradices* and *G. etunicatum* displayed higher RWC throughout the studies. After 150 days, the RWC was higher in seedlings inoculated with *G. etunicatum*. The effect of interaction was not significant at 30 and 120 days. Seedlings inoculated with *R. intraradices*, *G. etunicatum* and *F. mosseae* under control treatment had higher RWC. A similar trend was observed with plant water potential also. The plant water potential was measured at 120, 150 and 180 days for different treatments of AMF and irrigation. The effect of different irrigation regimes over plant water potential maintained a steady trend throughout the study. Over the period of time, the lowest water potential values were observed for treatment IW/ET=0.4 and highest for the control seedlings. Six months after the application of treatments, the lowest water potential was recorded for non-inoculated seedlings; whereas, the seedlings inoculated with *G. etunicatum* had highest values. The effect of interaction was significant at 120, 150 and 180 days. Higher values for plant water potential was recorded for seedlings inoculated with AMF belonging to the control treatment consistently. Plant water potential and RWC are two major traits used to understand the effects of drought stress. Higher RWC is beneficial for moving water through the seedlings to the evaporating surfaces and for maintaining the stomata open (Nelsen and Safir, 1982). Plant conductance is mainly determined by plant water status. Any change in plant water relations induced by inoculation may be crucial in determining the response of leaf gas exchange during water stress. Leaf water potential was not affected by inoculation in well-watered conditions (Davies *et al*., 1993; Bryla and Duniway, 1997). At lower soil moistures, leaf water potential declined less in plants inoculated with AMF. Increased leaf water potential of mycorrhizal plant as a consequence of fungus-mediated tolerance and avoidance mechanisms results in increased plant tolerance to drought (Porcel and Ruiz-Lozano, 2004). Koide (1993) highlighted the importance of comparing mycorrhizal and non-mycorrhizal plants with a similar size to assess accurately the effect on water transport. Leaf and/or xylem water potential is often higher for mycorrhizal plants compared to non-inoculated ones (Subramanian and Charest, 1995; Morte *et al*., 2001; Porcel and Ruiz-Lozano, 2004; Sánchez-Blanco *et al*., 2004), resulting in a higher capacity to transport water. Xylem water potential was lower compared to non-inoculated *Agrostis stolonifera L.* plants, but with similar results, i.e., a higher capacity to transport water for the same difference between soil and xylem water potential (Gonzalez-Dugo, 2010). Beltrano and Ronco (2008) found that the leaf RWC of well-watered inoculated seedlings did not differ from that of the well-watered non-inoculated ones. The inoculation affected RWC when seedlings were subjected to severe water stress and it was significantly higher in mycorrhizal compared to non mycorrhizal seedlings. Similarly, in the present study, a significant decrease in the RWC was observed with increasing levels of drought stress. It was reported that, although water stress treatments reduced leaf RWC, inoculation by *G. claroideum* allowed wheat seedlings to maintain higher RWC compared with non-mycorrhizal seedlings. These results are similar to findings by Amerian *et al.* (2001) in maize seedlings, inoculated with *F. mosseae* and *R. intraradices.* Panwar (1993) also reported that mycorrhizal symbiosis postpones the RWC decrease in stressed wheat seedlings. However, some authors have shown that under drought situations mycorrhizal inoculation did not change leaf RWC (Diallo *et al.*, 2001; Davies *et al.*, 2002; Goicoechea *et al.*, 2005). Leaf water status is important to understand AMF effects on drought stress alleviation because it provides information for the evaluation of plant physiological and biochemical changes (Jordans *et al.*, 2000). Auge (2001) pointed out that stomatal conductance and leaf water potential are linked functionally. Changes in one usually drive changes in the other. Similarly, higher stomatal conductance and transpiration rates in mycorrhizal compared to non-mycorrhizal seedlings may indicate lower resistance to water vapor transfer from inside the leaves to the atmosphere, which allows leaves to maintain more normal water balance (Auge, 2004; Wu and Xia, 2006). It is well documented that AMF symbiosis can improve the water status of host plant. Mycorrhizal seedlings have better water status due to the presence of external hyphae helping in the extraction of soil water (Ruiz-Lozano and Azcon, 1995), stomatal regulation through hormonal signals (Aroca *et al.*, 2008), indirect effect of improved phosphate and other nutrient uptake (Subramanian and Charest, 1997), greater osmotic adjustment (Wu and Xia, 2006) and higher root hydraulic conductivity (Auge, 2004) than non-mycorrhizal seedlings. Sanchez-Blanco *et al.* (2004) found that under drought conditions leaf water potential decreased in both non-mycorrhizal and mycorrhizal seedlings, although this decrease was lower in water-stressed mycorrhizal seedlings. Consequently, the leaf water potential did tend to be higher in AMF leaves. A trend toward slightly higher leaf water potential has been observed recently in more highly evolved plant taxa having higher productivity (Auge *et al.*, 2008). Porcel and Ruiz-Lozano (2004) reported that mycorrhizal seedlings had higher leaf water potential compared with non-mycorrhizal seedlings under drought stress. Most importantly, while AMF did not significantly influence the physiology of the seedlings in well watered conditions, it helped the plants to maintain high activity under stress. In other words, with AMF colonization, seedlings do not face stress at lower irrigation levels. Higher leaf water potential of mycorrhizal plants would therefore be consistent with the higher rates of gas exchange that often accompany mycorrhizal symbiosis and that are presumed to be necessary to supply the carbon needs of the fungal symbiont (Auge *et al.*, 2008).

In the current study, the seedlings inoculated with *R. intraradices* and *G. etunicatum* showed highest leaf area ratio (LAR), whereas, the non-inoculated seedlings and those inoculated with *F. mosseae* showed lowest leaf area ratios. At 60 and 90 days, however, no significant variations were observed among the treatments. At 120 days, seedlings inoculated with *R. intraradices* displayed highest values. The highest LAR values were mostly recorded for the control treatment. There was no significant difference between the control and IW/ET=1 treatment at 30 and 120 days, for which the highest LAR were recorded. The treatment IW/ET=0.4 generally showed lowest LAR values. The effect of interaction was significant throughout the period of study. Seedlings not inoculated with AMF and those inoculated with *F. mosseae* under the control treatment had higher values. Seedlings inoculated with *R. intraradices* and *G. etunicatum* under control treatment also had higher values. In the present study, seedlings inoculated with AMF showed higher leaf weight ratios (LWR) than non-inoculated ones. Those seedlings inoculated with *R. intraradices* had higher values, while, non-inoculated seedlings had the lowest LWR values. *G. etunicatum* and *F. mosseae* together recorded higher LWR values at 30 and 60 days of treatment. No significant variations were observed among the recorded data at six months. At 30 days, no significant variations were observed among various irrigation regimes. At 60 days, the highest LWR values were recorded for IW/ET=0.8 and lowest for IW/ET=0.6. After six months, higher LWR were observed for all treatments except IW/ET=0.4. The effect of interaction was found to be significant throughout the period of study. Seedlings inoculated with *G. etunicatum* under the irrigation treatment IW/ET=1 and seedlings inoculated with *R. intraradices* under control irrigation treatment. The LAR is the ratio between leaf area of plant and its dry weight. The loss of leaf area is an important stress avoidance strategy and is considered as a plant's first defensive mechanism against drought stress (Levitt, 1980). During water stress, depending on the intensity and duration of the drought, seedlings tend to minimize transpirational water loss by reducing their number of leaves and leaf area (Jones and Cortlett, 1992). Zhu *et al.* (2012) demonstrated that total dry weight was significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. The decrease in dry matter may be due to the considerable reduction of photosynthesis and plant growth (Shao *et al.*, 2008). Rajan *et al.* (2000), who screened selected AMF for their symbiotic efficiency with *Tectona grandis* found a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils not inoculated with AMF.

In this study, the non- inoculated seedlings maintained the highest specific leaf area (SLA) values while, those inoculated with *R. intraradices* and *G. etunicatum* recorded the lowest SLA values. Seedlings inoculated with *F. mosseae* recorded the lowest SLA values at 60, 120 and 150 days. While considering the various irrigation regimes, the control seedlings had higher SLA values over the rest throughout the studies, along with the treatment IW/ET=1 at 60 and 120 days. The treatment IW/ET=0.4 and IW/ET=0.6 had the lower SLA during the course of the study. The effect of interaction was found to be significant throughout the period of study. Higher value was observed for non-inoculated seedlings under the control irrigation treatment showed higher values. Specific leaf area and leaf dry matter content are important traits in plant ecology because they are associated with many critical aspects of plant growth and survival (Shipley and Vu, 2002). In *leucaena leucocephala*, decreased RGR in the water-stressed seedlings was found to be associated with the decrease in leaf dry weight and SLA (El-Juhany and Aref, 1999).

The treatment IW/ET=0.4 showed higher the specific leaf weight (SLW) throughout the period. The control seedlings mostly had lower SLW values throughout the studies and along with IW/ET=1 at 120 and 150 days. In the present study, seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher values while the lowest values were observed for non-inoculated seedlings. The effect of interaction was found to be significant throughout the period of study. Higher values were recorded for seedlings inoculated with *R. intraradices, G. etunicatum* and *F. mosseae* under treatment IW/ET=0.6. Seedlings inoculated with *G. etunicatum, F. mosseae* and *R. intraradices* of irrigation treatment IW/ET=0.4 also had higher values at 150 and 180 days respectively. Specific leaf weight indicates leaf dry mass per area. It has been widely exploited as a reliable morpho-physiological marker contributing to drought tolerance for various crop seedlings (Ali *et al.*, 2011). Xu and Zhou (2005) suggested that variations in SLW under drought conditions may be caused by variations in the concentration of carbohydrates such as starch. Kramer (1983) found that mild drought increased SLW by increasing leaf and cuticle thickness and the amount of surface waxes. It has been also reported that drought stress causes an increase in sclerenchyma cells and cell wall thickness and thereby increases SLW (Krause *et al.*, 1993). No significant variations were noticed at 30 days. Zokaee-Khosroshahi *et al.* (2014) found that, there was significant increase in SLW among various *Prunus* species due to drought stress. The control seedlings of all samples had the lowest SLW values, and the highest values were observed in seedlings treated with the highest level of drought stress. The results of this study are also in agreement with these findings.

Higher absolute growth rates (AGR) were observed for irrigation control, IW/ET=0.8 and IW/ET=0.6 at 60 days, while IW/ET=0.4 showed the lowest. At 90 days, both control and IW/ET=1showed higher values, whereas lower values were observed in the treatment IW/ET=0.4. The treatment IW/ET=0.8 showed higher values at 120 days while lower values were recorded for the rest of treatment. This can be attributed AGR to the increased growth rate of seedling height in accordance with increasing levels of drought. Generally, the seedlings inoculated with *G. etunicatum* had higher AGR, whereas non-inoculated seedlings had lower growth rates. This is due to the reduced height growth of non-inoculated seedlings than inoculated seedlings. Seedlings inoculated with *R. intraradices* demonstrated higher AGR at 60 days. At six months, seedlings inoculated with AMF recorded higher rates than non-inoculated seedlings. This can be attributed to the decreased growth in height in accordance with increasing levels of drought. The effect of interaction was found to be significant over the period of experiment. Seedlings inoculated with *R. intraradices* and *G. etunicatum* under the control irrigation treatment and treatment IW/ET=1.0 recorded higher values. Water stressed citrus seedlings showed 25 per cent reduction in plant height (Wu *et al.*, 2013). Seedling height increased due to AMF inoculation in several studies (Rajan *et al.*, 2000; Binu *et al.*, 2015). Plant height, number of leaves and stem girth were significantly higher in seedlings inoculated with *F. mosseae* when compared to non-inoculated seedlings for *Azadirachta indica* seedlings in the nursery (Sumana and Bagyaraj, 2003).

In the present study, seedlings inoculated with *R. intraradices* demonstrated higher relative growth rate (RGR) at 60 days. Generally, seedlings inoculated with *G. etunicatum* had higher RGR, while, non-inoculated seedlings had lower RGR. At 60 days, IW/ET=0.4 showed minimum values, while the others showed the higher values. The treatment IW/ET=1 showed higher values at 120 days, while, lower similar values were demonstrated by IW/ET=0.4. The treatment IW/ET=0.8 and IW/ET=0.6 had highest values at 180 days, whereas IW/ET=0.4 recorded the lowest. This can be attributed to the reduced growth rate of seedlings in accordance with increasing levels of drought. The effect of interaction was found to be significant throughout the period of study. At 180 days, seedlings inoculated with *R. intraradices* with irrigation treatment IW/ET=0.6 and IW/ET=0.4 showed higher values. There are reports which correlate difference in relative growth rate to dry matter partitioning. They explain reduction in RGR is attributed by reduced allocation of biomass to leaves, the site of photosynthesis (Poorter *et al.,* 1990). But Norgren (1996) found no relationship between RGR and dry matter partitioning between Scots pine and lodgepole pine seedlings. Significant reduction in RGR was observed in the mahogany (Sneha *et al.*, 2013) as well as teak seedlings (Sneha *et al.*, 2012) maintained under water stress. For seedlings with lower irrigation levels, relative growth rate was lower than well watered treatments. Seedlings of *Leucaena leucocephala* showed 50 per cent reduction in RGR under severe stressed condition and 30 per cent reduction under moderately stressed condition (El-Juhany and Aref, 1999). A 10–20 per cent decrease in average growth in response to water stress was observed in the seedlings of *Cinnamomum verum, Syzygium jambo* and *Memecylon eleagni* (Schumacher *et al.*, 2009).

In the present study, however, no significant differences for net assimilation rates (NAR) were observed at 90, 120 and 150 days. At 60 days, the seedlings inoculated with *R. intraradices* displayed highest values of NAR while the non-inoculated seedlings showed the lowest. At 180 days, the highest values were recorded for seedlings inoculated with *R. intraradices* and *G. etunicatum* while, the lowest ones for non-inoculated seedlings. Among the various irrigation regimes, no significant variations were observed at 90 days after the application of treatment. Highest NAR were recorded at 60, 150 and 180 days for the treatment IW/ET=0.6. At 120 and 150 days, highest values was observed for IW/ET=1. The treatment IW/ET=0.4 documented the lowest assimilation rates after 60 and 180 days. The effect of interaction was found to be significant throughout the period of study. Seedlings inoculated with *R. intraradices* with irrigation treatment IW/ET=0.6 and IW/ET=0.8 had higher NAR values. As drought progresses, stomatal closure occurs for increasingly longer periods of the day in field-grown seedlings

(Tenhunen *et al.*, 1987). This depression in gas exchange simultaneously reduces daily carbon assimilation. This eventually leads to water loss at the time of highest evaporative demand in the atmosphere and leads to a near optimization of carbon assimilation in relation to water supply (Cowan, 1981; Jones, 1992).

5.2. Biometric observations

In the current study, the seedlings inoculated with AMF recorded higher shoot height than non-inoculated ones. Among the different AMF used, seedlings inoculated with *G. etunicatum* showed higher shoot lengths while, non-inoculated ones showed lower shoot height. At 60 days, seedlings inoculated with *R. intraradices* recorded higher shoot height while, those inoculated with *F. mosseae* showed the lowest shoot height. The control seedlings recorded higher shoot height while, the treatment IW/ET=0.4 had lower height in mahogany seedlings. The effect of interaction between AMF and irrigation regimes was not significant at 120, 150 and 180 days. Higher shoot height was observed for seedlings inoculated with *R. intraradices* and *G. etunicatum* under control treatment and treatment IW/ET=1.0. Sneha *et al.* (2012) in teak seedlings found that treatments IW/ET=1 and IW/ET=0.6 had more height; while in IW/ET=0 and IW/ET=0.3, seedling height was less. Increased shoot height was observed for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). Seedling height increased due to AMF inoculation in several studies (Rajan *et al.*, 2000; Binu *et al.*, 2015). *F. mosseae* was found to be the most promising AMF symbiont for *Azadirachta indica* seedlings in the nursery (Sumana and Bagyaraj, 2003). They found that plant height, number of leaves and stem girth were significantly higher in seedlings inoculated with *F. mosseae* when compared to non-inoculated seedlings. In the same studies, plant biomass was found to be enhanced by about 70 per cent and shoot-root biomass was also significantly higher. These findings are in agreement with the results of current study. Many reports suggest the negative impact of water stress in plant growth (Anjum *et al.*, 2003; Bhatt and Rao, 2005; Shao *et al.*, 2008). After 15 days of exposure to water stress, reduction in plant height up to 40 per cent was observed in eucalyptus and casuarina seedlings (Nautiyal *et al.*, 1994) compared to well irrigated seedlings. Six month old seedlings of *Casuarina glauca*, under moderate and severe water stress, recorded a decrease in height by 23 and 32 per cent respectively than that of well irrigated control seedlings (Albouchi *et al.*, 2003). The reduction may be due to the reduction of cell water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth, during drought stress. However, seedling height was not influenced by restricted irrigation treatments in mahogany seedlings (Sneha *et al.*, 2013).

In the present study, longer roots were observed for IW/ET=1 treatment. The shortest roots were observed for the treatment IW/ET=0.4. No significant variations were observed for taproot length at 180 days. The seedlings inoculated with *R. intraradices* recorded a significantly longer taproot till 90 days after the inoculation. After 90 days, the seedlings inoculated with *G. etunicatum* had longer length of taproot. The non-inoculated seedlings maintained the least growth with respect to taproot length for the whole duration of experiment. The increase in root length is considered as an adaptive response against water stress as it helps seedlings to absorb more water during stress period. This was not found to be true in the present study. The effect of interaction was significant at 30 and 60 days. Higher taproot length was observed for seedlings inoculated with *R. intraradices* at IW/ET=0.8. The lower taproot dry weight of the drought treated seedlings, compared with the controls, indicates that the longer roots of the drought-treated seedlings were thinner than the corresponding roots of the control seedlings. The present results are on par with the experiment on drought-treated young cotton (*Gossypium hirsutum*) seedlings, which had a significantly greater taproot length than the controls (Pace *et al.*, 1999). Increased root length can be considered as an efficient mechanism of seedlings to explore deeper layers of soil and hence to absorb more water to cope up with water stress. At the end of the drought period, the length of the taproot was greater in the drought-treated seedlings than in the controls. In seedlings of mahogany (Sneha *et al.*, 2013) and teak (Sneha *et al.*, 2012), IW/ET=0.3 had the maximum root length at the end of six months. A slight increase in root length due to water stress was observed in *Leucaena leucocephala* seedlings, (El-Juhany and Aref, 1999). In ten week old seedlings of *Acacia mangium,* increased root growth capacity was observed due to water stress (Awang and Chavez, 1993).

Water stress in mahogany seedlings also caused reduction in collar girth. While considering the various irrigation regimes, the irrigation control seedlings had higher collar diameter than the rest of treatment along with IW/ET=1. The treatment IW/ET=0.4 showed lower collar girth during the course of the study along with IW/ET=0.6. The effect of interaction was found to be significant for 30, 60 and 120 days. Higher collar girth was observed for seedlings inoculated with *G. etunicatum* and *R. intraradices* of treatment IW/ET=1 and control. The results are similar to Sneha *et al.* (2012), where collar diameter of teak seedlings was highest in treatment IW/ET=1. In the increasing levels of drought treatments, water stress might have influenced the physiological processes and may have resulted in poor performance of seedlings. Cell division, being a turgor dependent activity is one of the first physiological process affected consequent to water stress. Singh and Singh (2009) reported that the collar diameter of two year old seedlings of *D. sisoo* was reduced by 38 per cent at low irrigation level. Increased collar girth was observed for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). Use of different AMF strains did not produce any significant variation in the collar girth of the seedlings after 30 days of treatment. However, higher collar girths were observed from seedlings inoculated with *R. intraradices* for the rest of the period. After 150 days of treatment, seedlings inoculated with G. *etunicatum* also had significantly higher values. *Azadirachta indica* seedlings in the nursery when inoculated with *F. mosseae* showed significantly higher stem girth when compared to non-inoculated seedlings (Sumana and Bagyaraj, 2003). Similar observations were also reported in *D. sisoo* inoculated with *G. fasciculatum* (Sumana and Bhagyaraj, 1996). A 50 per cent reduction in collar diameter was observed in eucalyptus hybrid seedlings in response to water stress (Nautiyal *et al.*, 1994). El-Juhany and Aref (1999) reported 23 and 35 per cent reduction in diameter in *Leucaena leucocephala* under moderate and severe water stress respectively. Inoculation with three different AMF species (*G. occultum, G. mosseae* and *G. aggregatum*) resulted in significant increase in shoot height, collar diameter and leaf area of *Acacia mangium* seedlings. Seedlings inoculated with *G. occultum* had higher biomass than seedlings inoculated with other AMF species (Ghosh and Verma, 2006).

It was found that the leaf area of the mahogany seedlings under different treatments over a period of time showed significant variations. The irrigation control seedlings recorded larger leaf area than others throughout the period of study. The treatment IW/ET=0.4 showed smaller leaf area along with IW/ET=0.6. No significant variation was observed for leaf area for seedlings inoculated with different AMF species after 30 days of treatment. Highest leaf area was observed for seedlings inoculated with *G. etunicatum* throughout the duration of study, along with those inoculated with *R. intraradices* on 60 and 120 days after treatment. Non- inoculated seedlings along with *F. mosseae* recorded smaller leaf area. The effect of interaction was found to be significant throughout the period of study. Higher leaf area was observed for seedlings inoculated with G. *etunicatum* and *R. intraradices* under daily irrigation control treatment. Theoretically, the loss of leaf area is an important stress avoidance strategy and is considered as a defensive mechanism against drought stress (Levitt, 1980). Sufficient soil water availability through higher levels of irrigation probably helps to maintain cell turgidity and leads to increased leaf size and the overall biomass (Souch and Stephens, 1998). During water stress, depending on the intensity and duration of the drought, seedlings tend to minimize transpirational water loss by reducing their number of leaves and leaf area (Jones and Cortlett, 1992), which was the case in the current study also. The results are in conformity with the studies of Rajan *et al.* (2000), who screened selected AMF for their symbiotic efficiency with *Tectona grandis*. Teak seedlings grown in the presence of AMF showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils not inoculated with AMF. The leaf area was significantly more in seedlings grown in the presence of *G. leptotichum*. They concluded that increased leaf area and enhanced nutrient content in seedlings colonized by *G. leptotichum* have probably resulted in significantly higher biomass compared to other treatments. Leaf area was higher for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). Zokaee-Khosroshah *et al.* (2014) found that in various species of *Prunus*, the reduction in leaf area was due mainly to leaf abscission and the reduction in number of leaves per plant, under high levels of drought stress. Leaf area was less in the drought-treated young cotton seedlings than in the controls (Pace *et al.*, 1999).

A significant increase in the production of leaves in the control treatment as well as the treatment IW/ET=1 was recorded in the current investigation. It was also observed that the treatment IW/ET=0.4 had the least production of leaves throughout the experiment. Application of different AMF species and irrigation regimes had generally a significant effect on the production of leaves. All of the three AMF species positively influenced the production of leaves at 30 days. Seedlings inoculated with *R. intraradices* and *G. etunicatum* showed a higher production of leaves significantly than the rest. The effect of interaction was found to be significant throughout the period of study. All seedlings under the control irrigation treatment recorded higher values. Defoliation is a quick response and a morphological adaptation to reduce water loss and redistribute resources under severe drought stress condition. Drought tolerant species are characterized by more number of leaves with smaller size to keep rate of photosynthesis intact while reducing transpiration. Drought stress caused significant reductions inoculated with G. *etunicatum* and *R. intraradices* under daily irrigation control treatment. Theoretically, the loss of leaf area is an important stress avoidance strategy and is considered as a defensive mechanism against drought stress (Levitt, 1980). Sufficient soil water availability through higher levels of irrigation probably helps to maintain cell turgidity and leads to increased leaf size and the overall biomass (Souch and Stephens, 1998). During water stress, depending on the intensity and duration of the drought, seedlings tend to minimize transpirational water loss by reducing their number of leaves and leaf area (Jones and Cortlett, 1992), which was the case in the current study also. The results are in conformity with the studies of Rajan *et al.* (2000), who screened selected AMF for their symbiotic efficiency with *Tectona grandis*. Teak seedlings grown in the presence of AMF showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight as against those grown in soils not inoculated with AMF. The leaf area was significantly more in seedlings grown in the presence of *G. leptotichum*. They concluded that increased leaf area and enhanced nutrient content in seedlings colonized by *G. leptotichum* have probably resulted in significantly higher biomass compared to other treatments. Leaf area was higher for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). Zokaee-Khosroshah *et al.* (2014) found that in various species of *Prunus*, the reduction in leaf area was due mainly to leaf abscission and the reduction in number of leaves per plant, under high levels of drought stress. Leaf area was less in the drought-treated young cotton seedlings than in the controls (Pace *et al.*, 1999).

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in the leaf number of seedlings in different species of almond (Zokaee-Khosroshahi *et al.*, 2014). Water stress decreased the leaf number of black locust seedlings; however, colonization with AMF led to an increased number of leaves in water stress treatments (Yang *et al.*, 2014). Sumana and Bagyaraj (2003) found that the number of leaves was significantly higher in the *Azadirachta indica* seedlings inoculated with *F. mosseae* when compared to non-inoculated seedlings. Similar observations were reported in *D. sisoo* inoculated with *G. fasciculatum* (Sumana and Bhagyaraj, 1996). Number of leaves was least in the water stressed seedlings of teak (Sneha *et al.*, 2012).

A higher production of lateral roots in AMF inoculated seedlings was also recorded in the present study. Seedlings inoculated with *R. intraradices* and *G. etunicatum* generally, indicated a higher production of lateral roots. After six months, it was observed that seedlings inoculated with *G. etunicatum* had a higher production of lateral roots. Non inoculated seedlings were found to have lower lateral root production during the period of study. A significant increase in the production of lateral root can be observed in the control as well as IW/ET=1 treatment throughout the period of time. It was also found that the treatment IW/ET=0.4 had the least production of lateral roots in the experiment. The effect of interaction was significant at 30 and 90 days. The seedlings inoculated with *G. etunicatum* under the control treatment had higher production of lateral roots. Higher number of lateral roots was observed for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). The development of an efficient root system resulting from AMF inoculation can be helpful for successful establishment of many plant species. Analysis of root system development was done to define relationships between lateral root order dynamics, arbuscular mycorrhiza development, and the physiological state of the symbiotic fungus *G. fasciculatum* in a woody plant species *Platanus acerifolia*. The result showed that AMF induced modifications in root development in *P. acerifolia*. It was also observed that AMF colonization was closely related to the appearance of different root orders. Third-order lateral roots dominated in arbuscular mycorrhizal seedlings, while second-order laterals were most numerous in non-mycorrhizal systems (Tisserant *et al.*, 1996).

In the present study, a significant reduction in the fresh weight of leaves, roots and shoots was observed for non-inoculated seedlings. The daily irrigated control seedlings had higher values for fresh weight of leaves and shoot throughout the experiment. The lowest values for fresh weight of shoot was observed generally for the treatments IW/ET=0.6 and IW/ET= 0.4. Reduction in shoot weight in response to water stress might be due to a shift in dry matter allocation. Under water deficit the plant may tend to allocate more dry matter towards roots than aboveground parts. The lowest values for fresh weight of leaves were recorded for IW/ET=0.6 and IW/ET=0.4. For fresh weight of roots, the highest values were recorded for the control and IW/ET=1 treatment. The treatment IW/ET=0.4 showed lowest values for the fresh weight of roots. Between the three AMF species, seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher values for fresh weight of leaves. No significant variation was observed with respect to fresh weight of roots for seedlings inoculated with AMF species at 30 days. The highest values for fresh weight of roots and shoots were observed for seedlings inoculated with *G. etunicatum*. The effect of interaction for fresh weight of leaves was significant throughout the period of study except for 120 days. Higher fresh weight of leaves was recorded for seedlings inoculated with *G. etunicatum* and *R. intraradices* under the control treatment. The effect of interaction was found to be significant throughout the period of study for fresh weight of roots and shoots. Higher value was observed for seedlings inoculated with *G. etunicatum* under treatment IW/ET=0.6 and under control irrigation treatment. Seedlings inoculated with *G. etunicatum* under the control irrigation treatment and treatment IW/ET=1 recorded higher values. Allocation of dry matter to the root system leads to increased root biomass, increased root respiration and mycelial biomass; which could explore a larger volume of soil for nutrient, and consequently resulting in higher uptake rates (Jakobsen *et al.,* 1992). It has been observed that mycorrhizal seedlings absorb water more efficiently under water deficit environment (Khalvati *et al.*, 2005); which might be due to the modification in root architecture, that in turn contributes to a better root growth with numerous branching (Berta *et al.*, 2005). Reduced number of leaves under water stress was observed in seedlings of casuarina (Nautiyal *et al.,* 1994). Significant reduction in shoot weight was observed by Sneha *et al.* (2012) among teak seedlings provided with different irrigation regimes. At the end of six months of irrigation treatment, seedlings of IW/ET=1 showed maximum shoot weight while, seedlings of IW/ET=0.3 showed least shoot weight Under moderate and severe drought, reduction in stem weight of *Leucena leucocephala* treatments was found to be 52 per cent and 65 per cent respectively (El-Juhany and Aref, 1999). Reduction in number of leaves in IW/ET=0.3 and IW/ET=0 also affected the shoot growth of mahogany seedlings negatively (Sneha *et al.,* 2013). Enhancement in growth was observed for

Acacia holosericea seedlings, when inoculated with *G. intraradices* (Duponnois and Plenchette, 2003) and *G. aggregatum*. *D. sissoo* seedlings when inoculated with AMF, encouraged growth under glasshouse conditions, which could be of great importance with respect to its survival and growth in natural conditions (Bisht *et al.*, 2009).

In the current study, the highest dry weights for leaves were recorded for the daily irrigated seedlings. No significant difference between the treatments IW/ET= 0.6 and IW/ET=0.4 was observed, for which, the lowest values were observed at 30, 60 and 150 days. The treatment IW/ET=0.4 had lowest values throughout the experiment. This shows that depending on the increasing intensity and duration of the drought stress, seedlings tend to minimize transpirational water loss by reducing their number of leaves and leaf area. Higher leaf dry weights were observed for seedlings inoculated with *R. intraradices* and *G. etunicatum*. The effect of interaction was found to be significant except at 120 and 180 days. Seedlings inoculated *R. intraradices*, *G. etunicatum* and *F. mosseae* belonging to irrigation control treatment. Non inoculated seedlings had lowest values for dry weight of leaves. According to Pace *et al.* (1999), the dry weights of the leaves and stems were less in the drought-treated young cotton (*Gossypium hirsutum* L.) seedlings than in the controls, at the end of the drought and recovery period. Zhu *et al.* (2012) found that the leaf dry weight was significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. Yang *et al.* (2014) found that drought stress decreased the dry weight of the leaves, in both mycorrhizal and non mycorrhizal seedlings. However, the dry weights of the leaves, was higher in mycorrhizal seedlings than non-mycorrhizal seedlings for all treatments.

The irrigation control seedlings had higher dry weight of root along with IW/ET=1 at 60 and 120 days. The treatments IW/ET=0.6 and IW/ET=0.4 showed lower values of root dry weight during the course of the study. The seedlings inoculated with AMF (*R. intraradices* and *G. etunicatum*) had higher dry weight of roots after 30 and 60 days after treatment, while, *G. etunicatum* recorded highest values at 90 and 180 days. No significant variation was noted for dry weight of roots for seedlings inoculated with different AMF species after 120 and 150 days of treatment. The effect of interaction was found to be significant throughout the period of study. Higher dry weight of roots was recorded for seedlings inoculated *R. intraradices* under the control irrigation treatment. Higher dry weight of roots was also recorded for seedlings inoculated with *G. etunicatum* under the control irrigation treatment. On the contrary, Sneha *et al.* (2012) observed that in severely water stressed teak seedlings of treatments IW/ET=0 and IW/ET=0.3, more biomass was allocated more towards roots than to shoots. However, no significant variations in root dry weight were observed among the seedlings of mahogany under different levels of irrigation (Sneha *et al.*, 2013). Pace *et al.* (1999) found that in the drought-treated young cotton seedlings, increase in root length at the expense of root thickening happened as a response to stress. El-Juhany and Aref (1999) estimated the reduction in root dry weight by 21 per cent under moderate and 29 per cent under severe water stress in *Leucaena leucocephala* seedlings.

In the present study, there was no significant variation with respect to the dry weight of shoot at 30, 90 and 120 days after inoculation. Seedlings inoculated with *R. intraradices* and *G. etunicatum* showed higher dry weight of shoot at 60 and 150 days after inoculation. After six months, the seedlings inoculated with *G. etunicatum* showed an increased dry weight of shoot while, the non-inoculated ones showed lower dry weight of shoot. The irrigation regimes however maintained a consistent trend where the daily irrigated seedlings exhibited maximum accumulation of dry weight of shoot and the treatment IW/ET=0.4 displayed the minimum throughout the study. These results suggest that increasing levels drought adversely affected the shoot growth of seedlings significantly and is in agreement with the following studies. The effect of interaction was found to be significant except at 120 days. Higher values were observed for seedlings inoculated with *R. intraradices, G. etunicatum* and *F. mosseae* under control irrigation. But after 180 days, seedlings inoculated with *G. etunicatum* under control irrigation had higher dry weight of shoot. Zhu *et al.* (2012) in their study found that shoot dry weights were significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. Pace *et al.* (1999) proposes that drought affected the shoot growth of cotton plants more than it did their root growth. At the end of the drought and recovery periods, all measures of shoot growth, including height, leaf area, nodes, and the dry weights of the leaves and stems, were less in the drought-treated seedlings than in the controls. The *F. mosseae* inoculated melon seedlings showed the highest shoot dry weight and root dry weight than those inoculated with *G. versiforme* and *R. intraradices*, regardless of water conditions (Huang *et al.*, 2011). Plant height and stem diameter decreased significantly under drought stress in both mycorrhizal and non-mycorrhizal black locust seedlings (Yang *et al.*, 2014). Plant height and stem diameter of mycorrhizal seedlings were larger than those of non-mycorrhizal seedlings under mild and severe drought stress treatments. The seedlings inoculated with *R. intraradices* had larger plant height than the seedlings inoculated with *F. mosseae* under well watered treatment. However, the reverse was observed under severe stress treatment.

In this study, no significant variation with respect to total fresh weight was observed at 30 days, due to the application of different AMF species. Seedlings inoculated with *G. etunicatum* generally, recorded higher values for total fresh weight while, non-inoculated seedlings showed a significant reduction in the total fresh weight throughout the experiment. At 90 and 120 days, however, higher values were recorded for seedlings inoculated with *R. intraradices*. While considering the different irrigation regimes, the highest values were mainly recorded for the control treatment. The lowest values were both observed for treatments IW/ET=0.6 and IW/ET= 0.4. After six months, the treatment IW/ET=0.4 had the lowest values for total fresh weight. It is widely accepted that AMF symbiosis affects plant growth and biomass. The interaction effect was significant throughout the period of study except for at 120 and 180 days. Seedlings inoculated with AMF under the control irrigation treatment recorded higher. Zhu *et al.* (2012) in his study, observed that total fresh weight were significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. The effect of two AMF species; *G. fasciculatum* and *G. macrocarpum* on shoot and root fresh weights and nutrient content of *Cassia siamea* was evaluated (Giri *et al.*, 2005). Under nursery conditions, mycorrhizal inoculation improved growth of seedlings. It was also found that root and shoot weights were higher in mycorrhizal than non-mycorrhizal seedlings.

In the present study, the highest values for total dry weight were observed for the control treatment. There was no significant difference between the control and the treatment IW/ET=1 at 120 days for both of which the highest values were recorded. This decrease in dry matter may be due to the considerable reduction of photosynthesis and plant growth under drought conditions (Shao *et al.*, 2008). Changing resource pools (e.g., water or nutrient availability) may also affect this distribution of biomass. At 30, 90 and 150 days, the lowest values were both observed for treatments IW/ET=0.6 and IW/ET= 0.4. A significant reduction in the total dry weight of the non- inoculated seedlings was also observed in this study, when compared to that of inoculated ones. Highest values were recorded for seedlings inoculated with *G. etunicatum.*

Seedlings inoculated with *R. intraradices* also had higher values for first 90 days of treatment. The lowest values were recorded for the seedlings not inoculated with AMF. The interaction effect was significant throughout the period of study. Seedlings inoculated with *R. intraradices* and *G. etunicatum* under the control irrigation treatment recorded higher values. Total biomass accumulated was higher for mahogany seedlings inoculated with *R. intraradices* (Ajeesh, 2015). Zhu *et al.* (2012) demonstrated that total dry weight was significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. Under well watered, moderate and severe water stress conditions, mycorrhizal inoculation significantly increased total plant dry weight by 15 per cent, 17 per cent and 20 per cent, respectively, compared to non-mycorrhizal seedlings (Beltrano and Ronco, 2008).

Shoot- root length ratio was highest for non-inoculated seedlings throughout the course of study. Both *R. intraradices* and *G. etunicatum* generally had the lowest values. However, after six months, seedlings inoculated with *G. etunicatum* documented the lowest values. No significant variation in shoot-root length ratio was observed between the treatments at 60 days. The treatment IW/ET=0.4 demonstrated the lowest values through the course of study. The effect of interaction was found to be significant throughout the period of study. Higher shoot-root length ratio was recorded for seedlings not inoculated with AMF under the treatment IW/ET=0.6 and seedlings inoculated *F. mosseae* under the control treatment recorded higher values. Shoot-root ratio appears to be governed by a functional balance between water uptake by the root and photosynthesis by the shoot which in turn increases the root growth. This functional balance is affected by water stress and more biomass is allocated towards roots to increase more water absorption. At the end of the drought and recovery period, shoot- root ratio was less in drought-treated young cotton seedlings than the controls (Pace *et al.*, 1999). The drought-treated young cotton seedlings retained a significantly greater taproot length than the controls. The results indicate that drought affected the shoot growth of cotton cultivars more than it did their root growth. This result was similar to the observation of McMichael and Quisenberry (1991) where, drought decreased the shoot-root ratio. The same pattern was observed in drought affected saplings of eucalyptus (Rose *et al.*, 1990; Ngugi *et al.*, 2004) and sandal (Hiremath, 2004). According to Sneha *et al.* (2012), teak seedlings of treatment IW/ET=0 was superior throughout the experimental period in terms of shoot root length and biomass ratio. In contrast to these findings, the control treatments showed significantly higher values in our study.

In the present study, the shoot- root biomass ratio of mahogany seedlings when treated with different AMF species showed no significant variations except at 30 and 60 days after inoculation. The highest values were recorded for non-inoculated seedlings, along those inoculated with *F. mosseae.* The seedlings inoculated with *R. intraradices* and *G. etunicatum* recorded lowest values at 30 and 60 days respectively. The interaction effect was not significant throughout the period of study. Seedlings not inoculated with AMF under the control treatment had higher shoot root biomass ratio at 30 days. At 120 and 180 days, seedlings inoculated with *G. etunicatum* had higher shoot root biomass ratio under the irrigation treatment IW/ET=0.6. At 150 and 180 days, higher values were observed for seedlings inoculated with seedlings inoculated with *R. intraradices* under control irrigation treatment. The effect of AMF on shoot-root ratio is likely due to more water and nutrient uptake, higher root hydraulic conductivity, and higher photosynthetic rate under drought stress treatments. Therefore, mycorrhizal seedlings were probably less deprived of essential nutrients compared with non-mycorrhizal seedlings, and maintained a high growth rate even though under drought stress. AMF colonization increased the shoot- root biomass ratio under all well watered treatments, by improving aboveground biomass accumulation primarily (Wright *et al.,* 1999). A significant reduction was observed in shoot-root biomass ratio of teak seedlings in IW/ET=0 after six weeks (Sneha *et al.,* 2012). In the present study, the highest values were noted for control seedlings while IW/ET=0.4 recorded lower values. Reduction in shoot root biomass ratio is due to allocation of more biomass in the roots than the shoot in search of water under drought stress. Rao *et al.* (2005) also reported reduced performance of teak seedlings under severe water stress in shoot-root biomass ratio. Same result was reported in *Hopea odorata* and *Mimusops elengi* seedlings (Zainudin *et al.*, 2003); and in seedlings of *Dalbergia sissoo* (Singh and Singh, 2006). In mahogany seedlings (Sneha *et al.,* 2013), however, no significant change in shoot- root biomass ratio was observed among different treatments. The levels of irrigation might not be sufficient to impart water stress in treatments IW/ET=1, 0.6 and 0.3. Container-grown two-year-old uniform maples (*Acer campestre L*), little-leaf linden (*Tilia cordata Mill.),* and pedunculate oak (*Quercus robur L.*) was inoculated with a mixture of infected roots and mycelium of native selected mycorrhizal inoculum and grown in well watered or water shortage conditions (Fini *et al.,* 2011). Water shortage reduced plant biomass and shoot root ratio decreased under water shortage in linden and oak. Higher shoot root ratios are commonly observed in mycorrhizal plants (Berta *et al.*, 2005). The improvement in shoot root ratio has been attributed to the ability of the fungus to substitute for the relatively greater amounts of root matter required by non-mycorrhizal plants for P uptake, and this may allow mycorrhizal plants to allocate a greater proportion of assimilates to shoot production (Bethlenfalvey *et al.*, 1985).

The vigour index I of the seedlings is calculated based on the seedling length. In the present study, higher index values were obtained for seedlings inoculated with different AMF species, when compared to that of the non-inoculated ones. This is due to the superior height of the AMF inoculated seedlings. Generally, seedlings inoculated with *R. intraradices* and *G. etunicatum* recorded higher index values. However, after 90 days, seedlings inoculated with *G. etunicatum* had the highest index values. This shows that the seedlings inoculated with *G. etunicatum* was far more superior in growth and suitable to the host. The non-inoculated seedlings maintained their lower values throughout the period of study. Among the different irrigation regimes, the highest values were documented for the control and IW/ET=1 for 90 days, due to the higher seedling height which is also confirmed in this study. After 120 days, however, the highest values were recorded only for the seedlings with the control treatment. The treatment IW/ET=0.4 maintained lowest values throughout the experiment. The effect of interaction was not significant at 120, 150 and 180 days. Higher index values were observed for seedlings inoculated with *G. etunicatum* under control treatment and the treatment IW/ET=1. Many reports suggest the negative impact of water stress in plant growth (Anjum *et al.*, 2003; Bhatt and Rao, 2005; Kusaka *et al.*, 2005; Shao *et al.*, 2008). Water stressed citrus seedlings showed 25 per cent reduction in plant height (Wu *et al.*, 2008). An increase in seedling height was reported in AMF inoculated seedlings by Vasanthakrishnan *et al.* (1995) in *Casuarina equisetifolia* and Rajan *et al.* (2000) in teak. Similar observations were reported in *D. sisoo* inoculated with *Glomus fasciculatum* (Sumana and Bhagyaraj, 1996). An increment of 2.82 per cent was observed in vigour indexes for mahogany seedlings inoculated with different AMF species (with *F. mosseae* and *R. intraradices*) (Ajeesh, 2015).

In the present study, no significant variations for vigour index II were observed when treated with different AMF species, at 30, 120 and 150 days. Vigour index II is calculated based on the seedling dry weight. Seedlings inoculated with *R. intraradices* and *G. etunicatum* recorded significantly higher vigour index II values at 60 days. After six months, seedlings inoculated with *G. etunicatum* showed the highest vigour index II values. The non-inoculated seedlings recorded the smallest vigour index II values consistently. Non-significant variations were demonstrated for seedlings at 30, 120 and 150 days after applying the irrigation treatments. At 60, 90 and 180 days the control seedling showed higher vigour index values while the treatment IW/ET=0.4 showed lower index values. The effect of interaction was not significant at 60, 120 and 180 days. Seedlings inoculated with *R. intraradices* had higher values under control treatment and the treatment IW/ET=1. Seedlings inoculated with *G. etunicatum* under the control irrigation treatment also recorded higher values. Zhu *et al.* (2012) found that the leaf dry weight was significantly lower for drought-stressed maize seedlings than those for well-watered seedlings. Yang *et al.* (2014) found that stress treatments decreased the dry weight of the leaves, both in mycorrhizal and non mycorrhizal seedlings. However, the dry weights of the leaves, was higher in mycorrhizal seedlings than non-mycorrhizal seedlings for all treatments. Pace *et al.* (1999) observed that drought affected the shoot growth of cotton plants more than it did their root growth. At the end of experiment, all measures of shoot growth, including height, leaf area, nodes, and the dry weights of the leaves and stems, were less in the drought-treated seedlings than in the controls.

5.3. Quality assessment

Seedling quality index of mahogany seedlings when subjected to different AMF species showed no significant variations at 30, 120 and 150 days after inoculation. At the end of the study, highest values for seedling quality index were recorded for seedlings inoculated with *G. etunicatum*; whereas, lowest values were observed for non- inoculated seedlings. This may be due to the increased dry biomass of seedlings inoculated with AMF. No significant variations were observed with respect to irrigation regimes at 30, 120 and 150 days. Generally, the highest values were obtained for control seedlings; while, IW/ET=0.4 showed lowest values. The effect of treatments on interaction was significant throughout the experiment. Higher values were observed for seedlings inoculated with *G. etunicatum*, *R. intraradices* and *F. mosseae* under control treatment. Quality index is a quantitative measure of young plant quality. It is determined only using morphological measurements and does not include physiological or performance attributes (Currey *et al.*, 2012). The quality index has a non-destructive nature and thus facilitates and enables experimentation in forest nurseries. The lower quality index attributes to the sensitivity in seedling growth as a response to water stress. While studying seedling quality in

Trema micrantha, Fonseca *et al.* (2002) reported that quality index is highly correlated with all morphological parameters, agreeing with results in this study. Higher seedling quality index was observed for mahogany seedlings inoculated with *F. mosseae* and *R. intraradices* (Ajeesh, 2015). Inoculation with *R. intraradices* improved the seedling quality in *Azadirachta indica* seedlings by 104, 25 and 93 percent (Muthukumar *et al.*, 2001) over non-inoculated controls. The biovolume index and quality index were significantly more in seedlings inoculated with *F. mosseae;* while, non-inoculated seedlings recorded the lowest biovolume and quality indices (Sumana and Bagyaraj, 2003).

Biovolume index calculates the above-ground portion of tree seedlings. In this study, inoculation with AMF brought about an increase in biomass production. Seedlings inoculated with *R. intraradices* had the highest index values; whereas, non-inoculated seedlings showed lowest values till 90 days. At 120 days, higher values were recorded for both *R. intraradices* and *G. etunicatum*; while, the non-inoculated seedlings displayed minimum values. At 150 and 180 days, seedlings inoculated with *G. etunicatum* showed highest values while, non-inoculated seedlings maintained their trend. The effect of treatments on interaction was not significant at 90, 150 and 180 days. Higher biovolume index was observed for seedlings inoculated with *G. etunicatum* of treatment IW/ET=1.0. Such high values of biovolume index and quality index indicates a sturdier stem and a proportionate dry weight, which are desirable qualities among nursery seedlings (Hatchell, 1985). Teak seedlings inoculated *G. leptotichum* showed a greater biovolume index and quality index compared to all other treatments and this increase was up to an extent of 68 and 66.7 per cent, respectively, over non-inoculated seedlings (Rajan *et al.*, 2000). Inoculation with *G. claroideum* brought about an important increase in biomass production, which might be attributable to increased dependence of wheat on AMF for water uptake (Al-Karaki *et al.*, 2004).

In the present study, the non-inoculated seedlings had the lowest mycorrhiza use efficiency (MUE) throughout the study. Seedlings inoculated with *G. etunicatum* and *R. intraradices* demonstrated higher values mostly. However, after six months, seedlings inoculated with *G. etunicatum* had highest values for MUE. Considering various irrigation regimes, higher efficiency was shown by all except IW/ET=0.4 at 30 days. At 60 days, higher efficiency was recorded for IW/ET=0.6 and IW/ET=0.4 while, the lowest was recorded for control treatment.

Highest values were recorded for all except control and IW/ET=0.4 after six months. The effect of interaction of treatments was significant throughout the experiment. Higher mycorrhiza efficiency index was observed for seedlings inoculated with *G. etunicatum* and *R. intraradices* under the treatment IW/ET=0.6. Mycorrhizal use efficiency is a direct measurement of efficiency of AMF inoculation. Cruz *et al.* (1992) categorized the MUE in three groups: 40 per cent and above: high efficiency; 10-40 per cent: moderate efficiency; below 10 per cent; no efficiency. The high MUE value suggested that inoculation with AMF would be useful in the production of vigorous seedlings in the nursery (Ghosh and Verma, 2006), that may establish better in the field and withstand drought or nutrient deficiency and pathogenic infections. The ranking of the three AMF species for mycorrhizal dependency in melon seedlings, for different water conditions, was as follows: *F. mosseae* >*G. versiforme* >*R. intraradices* (Huang *et al.*, 2011). The *Acacia mangium* seedlings, when inoculated with *G. occultum* showed 57 per cent efficiency; while, those inoculated with *F. mosseae* and *Glomus aggregatum* recorded 47 per cent and 46 per cent respectively (Ghosh and Verma, 2006).

5.4. Percentage of AMF association

In the present study, the highest colonization percentage at 150 and 180 days was observed for *G. etunicatum*, while the lowest was observed for non-inoculated seedlings. Mycorrhizal colonization was more adversely affected by severe stress than moderate stress. The treatment IW/ET=1 showed highest values; while, the lower values were demonstrated by IW/ET=0.6 and IW/ET=0.4. From this, it is evident that that increasing drought stress causes reduction in AMF colonization. The effect of treatments on interaction was not significant at 150 and 180 days (Figure 36). It is established that root colonization is improved during drought period under field conditions (Auge, 2001). In potted plants, the results are however contrasting. Some authors found an increase in root colonization, while others described a decrease. The effect of mycorrhizal colonization on host water relations has been analyzed by many researchers (Auge, 2001). The enhancement of growth and nutrient uptake, mainly P, resulting from mycorrhizal colonization leads to a modification of host water relations (Safir *et al.*, 1972). Microscopic assessment confirmed that increasing drought stress brought a significant decline of AMF colonization, from 83.86 to 54.41 per cent for *F. mosseae* and *R. intraradices,* respectively

(Yang *et al.*, 2014). Under well watered conditions roots colonized by *G. claroideum* showed a significantly higher percentage of colonization compared to water stressed seedlings (Beltrano and Ronco, 2008). The melon (*Cucumis melo* L.) seedlings inoculated with F. mosseae showed significantly higher root AM colonization, than those inoculated with *G. versiforme* and *R. intraradices* under both water conditions (Huang *et al.*, 2011). Wu and Xia (2006) observed that AMF colonization of citrus was higher under well watered treatment compared with a drought stress treatment. They also concluded that increasing drought stress causes decline in AMF colonization. The mycorrhizal infection of *Azadirachta excelsa* seedlings was high (81.25 per cent) with *F. mosseae*. This was probably because *A. excelsa* possesses coarse root and relatively fewer root hairs. Plant species with coarse rooting system and few root hairs appear to be more dependent on mycorrhiza for mineral nutrient uptake (Huat *et al.*, 2002).The colonization percentage was found to be the highest in *Anacardium occidentale* seedlings inoculated with *F. mosseae* (Ananthakrishnan *et al.*, 2004).

In the present study, high total spore count was observed for both *R. intraradices* and *G. etunicatum* at 150 days. However, *G. etunicatum* recorded the highest total spore count at 180 days. Among the irrigation regimes, after six months, IW/ET=1documented high spore count; while, control showed least count. The effect of treatments on interaction was significant at 150 and 180 days. Highest spore count was observed for seedlings inoculated with *R. intraradices* and *G. etunicatum* under treatment IW/ET=1. Inoculation with AMF showed an increase in percentage of colonized root for sandal seedling which increased with time (Binu *et al.*, 2015). The control seedlings recorded a lower spore count. Drought stress significantly decreased AMF colonization in maize plants under well-watered and drought stress and (Zhu *et al.*, 2012). Rajan et al. (2000) observed that a significantly higher percentage of teak roots were colonized with *G. margarita*, while screening different AMF for their symbiotic efficiency with *T. grandis*. However, spore numbers were highest in soil samples inoculated with *G. leptotichum*, indicating the better proliferating ability of this fungus with teak as the host. Sumana and Bagyaraj (2003) reported that highest root colonization and spore numbers were observed in seedlings inoculated with *F. mosseae* and the lowest colonization and spore numbers were experienced by non-inoculated neem seedlings.

A significant reduction in the performance of mahogany seedlings was observed with the increasing levels of drought stress. Seedlings inoculated with AMF recorded better morphological and physiological parameters when compared to that of the non-inoculated seedlings. Among the three AMF species, *R. intraradices* and *G. etunicatum* showed a better suitability with mahogany seedlings during the course of study. Between these two AMF species, *G. etunicatum* is highly recommended for the production of superior planting stock of mahogany seedlings in the nursery.

Summary

6. SUMMARY

An experiment was conducted to analyze the effect of various levels of water stress and different species of arbuscular mycorrhiza fungi (AMF) on the growth and development of *Swietenia macrophylla* seedlings in nursery. The experiment was laid out in a completely randomized design with two factors and replicated four times at College of Forestry tree nursery, Vellanikkara. Four different irrigation levels at IW (irrigation water)/ET (cumulative crop evapotranspiration) =1, 0.8, 0.6 and 0.4; and a control with daily irrigation were applied as the first factor. As the second factor, an arrangement of three AMF species, viz; *Funneliformis mosseae*, *Glomus etunicatum,* and *Rhizophagus intraradices* and a non-inoculum as a control were used.

The salient findings of the study are given below.

1. Mahogany seedlings with daily irrigation (control) recorded higher shoot height, collar girths and leaf area. Longer roots were observed for control seedlings as well as the treatment IW/ET=1. A significant increase in the production of leaves and lateral root was also be observed in the control as well as IW/ET=1 treatment throughout the study period. The treatment IW/ET=0.4 had lower shoot height, taproot length, collar girth, leaf area, least production of leaves and lateral roots. The seedlings inoculated with AMF recorded increased shoot height, taproot length, collar girth, and leaf area, number of leaves and number of lateral roots when, compared to non-inoculated ones. Seedlings inoculated with *G. etunicatum* showed higher shoot, taproot lengths, collar girths and leaf area. Non- inoculated seedlings and those inoculated with *F. mosseae* recorded smaller leaf area and collar girth. Seedlings inoculated with *R. intraradices* and *G. etunicatum* showed a higher production of leaves and lateral roots, while non- inoculated seedlings had lower number of leaves and lateral root production during the period of study.
2. The daily irrigated control seedlings had higher values for fresh weight of leaves and shoot throughout the experiment while, the highest values for fresh weight of roots were recorded for the control and IW/ET=1 treatments. The lowest values for fresh weight of shoot and leaves were both recorded for treatments IW/ET=0.6 and IW/ET=0.4 whereas, treatment IW/ET=0.4 alone showed lower values for the fresh weight of roots. Between the three AMF species, seedlings inoculated with *R. intraradices* and *G. etunicatum* had

higher values for fresh weight of leaves. The highest values for fresh weight of roots and shoots were observed for seedlings inoculated with *G. etunicatum*. The highest total fresh weight was recorded for the control treatment. The lowest total fresh weight were both observed for treatments IW/ET=0.6 and IW/ET= 0.4. Highest total fresh weight was recorded for seedlings inoculated with *G. etunicatum*. The lowest values were recorded for the seedlings not inoculated with AMF.

3. Dry weights for leaves, shoot and roots were higher for seedlings inoculated with *R. intraradices* and *G. etunicatum* while, highest total dry weight was recorded for seedlings inoculated with *G. etunicatum*. Non inoculated seedlings had lowest values for dry weight. The highest dry weights for leaves, shoots, roots and total dry weight were recorded for the daily irrigated treatment. The treatment IW/ET=0.4 had lowest dry weights throughout the experiment.
4. Highest values for shoot- root length ratio and biomass ratio were observed for non-inoculated seedlings throughout the course of study. Seedlings inoculated with *R. intraradices* and *G. etunicatum* recorded the lowest shoot- root length and biomass ratios. The daily irrigated treatment recorded the highest shoot- root length and biomass ratios while, IW/ET=0.4 showed the lowest values through the course of study.
5. Higher values for vigour index I and II were recorded for seedlings inoculated with different AMF species, when compared to that of the non-inoculated seedlings. Among the different AMF used, the seedlings inoculated with *G. etunicatum* recorded higher index values while, non-inoculated seedlings maintained lower values throughout the period of study. Among the different irrigation regimes, the highest values were documented for the daily irrigated control while, the treatment IW/ET=0.4 maintained lowest values throughout the experiment.
6. The seedlings inoculated with *R. intraradices* and *G. etunicatum* showed highest leaf area ratio, whereas, the non-inoculated seedlings and those inoculated with *F. mosseae* showed lowest leaf area ratios. The highest values were recorded for the control treatment while, IW/ET=0.4 showed lowest leaf area ratios. Those seedlings inoculated with *R. intraradices* had higher leaf weight ratios while; non-inoculated seedlings had the lowest leaf weight ratios. After six months, higher leaf weight ratios were observed for all treatments except IW/ET=0.4.

7. The non- inoculated seedlings maintained the highest specific leaf area (SLA) while, those inoculated with *R. intraradices* and *G. etunicatum* recorded the lowest SLA values. The control seedlings had higher SLA while, the lower SLA was recorded for treatment IW/ET=0.4 and IW/ET=0.6. The treatment IW/ET=0.4 showed higher the specific leaf weight (SLW) throughout the period. The control seedlings mostly had lower SLW values. Seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher SLW values while, the lowest values were observed for non-inoculated seedlings.
8. Higher absolute growth rates were observed for daily irrigated control, IW/ET=0.8 and IW/ET=0.6 while, IW/ET=0.4 showed the lowest. The seedlings inoculated with *G. etunicatum* had higher absolute growth rates, whereas non-inoculated seedlings had lower growth rates. Seedlings inoculated with *R. intraradices* and *G. etunicatum* had higher relative growth rates and net assimilation rates, while, non-inoculated seedlings had lower relative growth rates. The treatment IW/ET=0.8 and IW/ET=0.6 had highest values for relative growth rates while, IW/ET=0.4 recorded the lowest. Highest net assimilation rates were recorded for IW/ET=0.6 and seedlings inoculated with *R. intraradices* and *G. etunicatum*; while, IW/ET=0.4 and non-inoculated seedlings recorded the least net assimilation rates.
9. It was also found that the rate of photosynthesis and stomatal conductance was significantly lower for the non- inoculated seedlings, when compared to the inoculated ones. Seedlings inoculated with *G. etunicatum* showed highest rate of photosynthesis and stomatal conductance. The daily irrigated control treatment and IW/ET=1 had higher rates of photosynthesis and stomatal conductance, while IW/ET=0.4 showed lowest rates throughout the experiment.
10. The treatments IW/ET=1 and IW/ET=0.8 generally recorded higher values of transpiration rate, while IW/ET=0.4 had lower values. Mahogany seedlings inoculated with *G. etunicatum* recorded higher rates of transpiration compared to non- inoculated seedlings. The daily irrigated seedlings and treatment IW/ET=1 maintained lower leaf temperatures, while the treatment IW/ET=0.4 exhibited higher temperature consistently. The leaf temperature of mahogany seedlings, when inoculated with different AMF species had significantly lower values than the non-inoculated seedlings. Among the

various AMF species used, leaf temperature was significantly lower for those seedlings inoculated with *G. etunicatum.*

11. Higher chlorophyll content was recorded mostly from seedlings inoculated with *G. etunicatum* and *R. intraradices.* The lowest chlorophyll content was observed for non-inoculated seedlings. The daily irrigated control seedlings recorded higher chlorophyll content, while the treatment IW/ET=0.4 had lower values.
12. The control seedlings demonstrated the highest relative water content (RWC) and water potential whereas, the treatment IW/ET=0.4 had the lowest values. The non-inoculated seedlings showed a lower RWC and water potential throughout the period of the experiment. Seedlings inoculated with *G. etunicatum* displayed a better percentage of relative water content and water potential throughout the studies.
13. Highest values for seedling quality index, biovolume index and mycorrhizal use efficiency were recorded for seedlings inoculated with *G. etunicatum*; whereas, lowest values were observed for non- inoculated seedlings. Highest values were obtained for daily irrigated control seedlings; while, IW/ET=0.4 showed lowest values. The highest values for mycorrhizal use efficiency was observed for IW/ET=0.8 while, IW/ET=0.4 recorded lowest values.
14. The highest colonization percentage and total spore count was observed for seedlings inoculated with *G. etunicatum*, while the lowest was observed for non-inoculated seedlings. The treatment IW/ET=1 showed high spore count and highest root colonization percentage while, the lower values for colonization percentage were demonstrated by IW/ET=0.6 and IW/ET=0.4. The least total spore was recorded for the daily irrigated control treatment.

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Efficacy of arbuscular mycorrhizal fungi for drought tolerance in *Swietenia macrophylla* king. seedlings

By

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ABSTRACT

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ABSTRACT

An experiment was carried out to analyze the influence of four different levels of water stress ((IW (irrigation water)/ET(cumulative crop evapotranspiration)=1, 0.8, 0.6 and 0.4) and three different species of arbuscular mycorrhizal fungi (AMF), viz; *Funneliformis mossae*, *Glomus etunicatum,* and *Rhizophagus intraradices* on the growth and development of *Swietenia macrophylla* seedlings in nursery. Seedlings that were irrigated daily and the seedlings not inoculated with AMF were maintained as controls. Drought stress was found to affect the growth and physiology of mahogany seedlings significantly. The daily irrigated (control) seedlings recorded higher shoot height, collar girth, leaf area, fresh weight of shoot, fresh weight of leaves, total fresh weight, dry weight of leaves, dry weight of shoot, dry weight of root, total dry weight, shoot- root length ratio, shoot- root biomass ratio, vigour index I and vigour index II. Physiological attributes such as leaf area ratio (LAR), specific leaf area (SLA), absolute growth rate (AGR), chlorophyll content, relative water content (RWC) and water potential were also found to be higher in the irrigation control treatment while, lower values were observed for specific leaf weight (SLW). The irrigation control seedlings also had higher seedling quality index and biovolume index. However, higher values for taproot length, number of leaves, number of lateral roots, fresh weight of roots and lower leaf temperature were observed for both the irrigation control and treatment IW/ET=1. The treatment IW/ET=1 showed higher rate of photosynthesis, stomatal conductance, root colonization percentage and total spore count. However, higher transpiration rates was observed for the seedlings of treatment IW/ET=0.8 too. Highest mycorrhizal use efficiency (MUE) was recorded for the treatment IW/ET=0.8. The treatment IW/ET=0.8 and IW/ET=0.6 both had higher relative growth rate (RGR) while, the treatment IW/ET=0.6 recorded higher net assimilation rate (NAR). Performance of the seedlings were poorest in the treatment IW/ET=0.4. It had lowest shoot height, taproot length, collar girths, leaf area, number of leaves, lateral roots, fresh weight of roots, dry weight of leaves, dry weight of shoot, dry weight of roots total dry weight, shoot- root length ratio, shoot- root biomass, vigour index I, vigour index II, LAR, leaf weight ratio (LWR), SLA, AGR, RGR, NAR, rate of photosynthesis, stomatal conductance, transpiration rate, chlorophyll content, RWC, water potential, seedling quality index, biovolume index and MUE, colonization percentage and total spore count; and higher leaf temperature and SLW.

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Colonization with AMF, especially with *G. etunicatum* significantly improved the biometric as well as the physiological attributes of the seedlings. These seedlings recorded higher shoot height, taproot length, collar girth, leaf area, fresh weight of shoot, fresh weight of root, total dry weight, vigour index I, vigour index II, seedling quality index, biovolume index, MUE, root colonization percentage and total spore count. Seedlings inoculated with *G. etunicatum* also had lower leaf temperature and higher values of AGR, rate of photosynthesis, stomatal conductance, transpiration rate, RWC and water potential. The seedlings inoculated with *R. intraradices* and *G. etunicatum* both showed an increased number of leaves, lateral roots, fresh weight of leaves, dry weight of leaves, dry weight of shoot, dry weight of roots, shoot- root length ratio, shoot- root biomass ratio, LAR, LWR, SLW, RGR, NAR, chlorophyll content and lower SLA values. Inoculated seedlings were found to perform better compared to non-inoculated seedlings under higher levels of water stress. Among the various species of AMF used, *F. mosseae* was found to have the lower suitability with the host plants. The non-inoculated seedlings and the seedlings inoculated with *F. mosseae* both recorded lower leaf area and LAR. The non- inoculated seedlings not only demonstrated lower fresh weight of leaves, fresh weight of roots, fresh weight of shoot, total fresh weight, vigour index I, vigour index II; but also, higher shoot- root length ratio and shoot- root biomass ratio. This treatment also had lower values for physiological parameters like rate of photosynthesis, stomatal conductance, transpiration rate, chlorophyll content, RWC, water potential LWR, SLW, AGR, RGR, NAR, and higher values for SLA. Seedling quality index, biovolume index and MUE were also found to be lower in the non- inoculated seedlings. These seedlings also recorded lower root colonization percentage and total spore count in the rhizosphere soils. From the experiment, it was apparent that the performance of inoculated seedlings was better than the non-inoculated ones. The application of AMF was found to influence the production of quality planting stock of mahogany positively. Inoculation with AMF was also observed to impart drought tolerance to the seedlings. Among the three different AMF species used, *G. etunicatum* was the most beneficial and suitable one for the mahogany seedlings.

APPENDIX – I

Commercial production of AMF biofertilizer

Arbuscular mycorrhizal fungi have great potential as biofertilizers in forestry. The ultimate objective of the greenhouse studies is to extend them to field on a commercial basis. Being biotrophs, AMF is difficult to cultivate on a synthetic medium. They also need the symbiotic association with plant for proliferation. For large scale production, one of the choices available is to develop a dual culture of host roots and AMF. For this, it is mandatory to select an efficient AMF, suitable host and substrate.

Materials required

1. Efficient AMF strains (vermipaste based pure cultures, spores and hyphae mixture etc.)
2. Suitable host plant (onion, leek, maize, sorghum etc.)
3. Potting medium (vermiculite, soil:sand (1:1) mixture, sterile soil etc.)
4. Grow bags
5. Growth conditions (clean growth chamber or greenhouse devoid of contamination)

Procedure

1. Grow bags having a capacity of 5 kg are filled with autoclaved sterile vermiculite.
2. 25 g of the pure culture is then added to each of the grow bags.
3. *Zea mays* seeds are taken and then surface sterilized with 0.1% Sodium hypochlorite for 5 minutes. After washing thoroughly with distilled water, these seeds are then sown in vermiculite.
4. Daily irrigation should be carried out in the grow bags with sterile water.
5. At every 10 day interval, 50 ml of Hoagland's solution was applied to the grow bags.
6. After 45 days, the maize roots are then tested for root colonization. When the root colonization percentage was found to be 80 % or above, the shoots of the maize plants are harvested and removed.
7. The root portion along with vermiculite, after mixed up thoroughly, was then stored in a cool place before inoculation.

APPENDIX – II

Commercial production and maintenance of mycorrhizal mahogany seedlings

By inoculation, the nursery period of seedlings can be brought down to three months. The polybags are filled with potting mixture of sand, soil and cow dung in the ratio 1:2:1. The expenditure of production of 1000 mycorrhizal mahogany seedlings in nursery is estimated to be Rs. 9745.00. Each mahagony seedlings can be sold at a rate of Rs. 15.00. From the sale of 1000 seedlings, the income is estimated about 15,000.00. The benefit cost ratio is calculated at 1.54 and the payback period is estimated at 3 months.

Cost of production of 1000 seedlings in polybag and maintaining for a period of three months.

Commercial production of AMF				
Sl. No.	**Materials required**	**Quantity**		**Cost (Rs.)**
1	Pure inoculum	50 g		2500.00
2	Vermiculite	10 kg		450.00
3	Maize seeds	4 packets		20.00
4	Grow bags	5 Nos.		75.00
	Total			2545.00
Production of AMF seedlings				
Sl. No.	**Materials required**	**Quantity**	**Unit Cost**	**Cost for 1000 polybags**
6	Red earth	2 unit	5000.00	500.00
7	Riverine sand	1 unit	7000.00	700.00
8	Cow dung	1 unit	2500.00	250.00
9	Polybag (4.5”x 6”)	4 kg	250.00	1000.00
10	Seeds	1 kg	350.00	350.00
	Total			2800.00
Maintenance for 150 days of nursery period				
11	Irrigation			500.00
12	Labour (Male)	5 labour day	450.00	2250.00
13	Labour (Female)	5 labour day	330.00	1650.00
	Total			4400.00
	Grand total			**9745.00**