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Title: Effects of soil water stress on *Acacia nilotica* (Linn.), *Pithecellobium duice* (Roxb.) and *Swietenia macrophylla* (King.) during germination and growth

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Programme: Master of Science in Forestry

EFFECTS OF SOIL WATER STRESS ON *Acacia nilotica* (Linn.), *Pithecellobium dulce* (Roxb.) AND *Swietenia macrophylla* (King.) DURING GERMINATION AND GROWTH

M.S.c Thesis

By

Niger Sultana

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
SCHOOL OF LIFE SCIENCE
KHULNA UNIVERSITY
KHULNA-9208
BANGLADESH

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COURSE TITLE: THESIS

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This work has been prepared and submitted to Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh for the partial fulfillment of M.Sc. in Forestry.

Dedicated

To

My Beloved Parents

Abstract

Acacia nilotica, Pithecellobium dulce and *Swieitenia macrophylla* are common species in Khulna, the South-West part of Bangladesh. To investigate the effect of water stress on germination, survival and growth of the three species an experiment was conducted in nursery with ~~four~~ three levels of water (100%, 50% and 25% field capacity) in Khulna University. Germination percent, Survival percent, Root/Shoot ratio, biomass partitioning of the species were investigated. Among the species *Swieitenia macrophylla* could not germinate in 25% field capacity. *Acacia nilotica* showed the highest moisture loss ($P<0.05$). Moisture loss from fresh biomass increased with increasing water stress. Total dry biomass decreased with increased water stress ($P<0.05$).

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DECLARATION

I declare that the work in the thesis entitled 'Effects of moisture variations on germination and growth at nursery stage for *S. macrophylla* (King), *P. dulce* (Roxb.) and *A. nilotica* (Linn).' has been performed by me under direct supervision of Associate professor Md. Sharif Hasan Limon in the Discipline of Forestry and Wood Technology, Khulna University, Khulna and it has not been accepted or submitted for a degree in any other University.

I hereby, give consent for my thesis, if accepted, to be available for any kind of photocopying and for inter library loans.

03.9.13

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APPROVAL

This thesis is submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh, in partial fulfillment for the Masters of Science degree in Forestry. I have approved the style and format of the thesis.

18.09.13

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Climate change is now one of the most concerning issues of forest management. Climate change induced risk is observed all over the world. Unexpected changes of climate become intense. Some countries are believed to suffer by flood and some are by drought. Climate scientists project that the global temperature are going to increase 1.8° C to 6.4° C from average global temperature (Pender, 2008). The temperature increase is faster than predicted. The future projection of climate change indicates that south Asia is very likely to warm up during this century (Parry, 2007). This might induce large scale vegetation change in the affected areas (Overpeck *et al.*, 1990). Tree plantation has been chosen as a climate change adaptation strategy in many climate change adaptation programs. Seasonal rainfall and warm to hot climate affect seed germination, establishment, survival and growth. Researchers have focused less attention about seed germination, recruitment process and growth of tropical dry forest species than mature tree (Khurana and Singh, 2004). Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. Bangladesh will be the most affected country due to climate change as temperature rise has been found for the last 60 years (Agarawal *et al.*, 2003). Increased global temperature and reduced precipitation together producing drought situation in Bangladesh (Selvaraju and Baas, 2007). Variation in temperature and rainfall change the plants growth and establishment in natural colonization and succession.

Water is the most important abiotic elements of plants which is associated with other necessary factor controlling growth of plants (Pallardy, 2008). Plant starts using water since its germination and continues its use throughout its life. Seedling stage is critical because availability of water determines plants success of survival and establishment (Wilson and Witkowski, 1998). Increased dry period and reduced precipitation are potential risk factors for germination, survival and growth of seedlings in such environment. Thus, early stage survival of seedlings has become an important issue for tree plantation in dry environment. Plant shows different adaptations to different level of water stresses and varies from species to species (Kozlowski and Pallardy, 2002). Knowledge on germination and seedling establishment is pivotal to understand plant recruitment and succession and for the management of plant populations (Khurana and Singh, 2001). Species specific knowledge of drought tolerance and adaptation is indispensable to screen species suitable for dry environment (Carventas *et al.*, 1998; Soriano *et al.*, 2011) in Bangladesh.

A. nilotica, and *S. macrophylla* are commonly known plantation and agroforestry tree species in Bangladesh (Mahmood *et al.*, 2009) and *P. dulce* is found in homestead forests, street plantation and in Mangrove as third rotation plant (Hossain *et al.*, 2008; Saenger, 2011). Increase of dry periods is imposing increased moisture stress in Bangladesh. In future how these species response to different water stress is an important issue to predict vegetation change and selection of species for plantation and agroforestry. Most research efforts have focused on the effects of drought on larger size classes and a few have focused on seedling (Bunker and Carson, 2005). However, at seedling stage plant endure or succumb to harsh environment which determines the the future of the species (Dhupper, 2012). Little has been reported on the effect of moisture stress on the germination and seedlings growth of these tree species. In this study, *A. nilotica, P. dulce* and *S. macrophylla* were studied under different moisture levels to evaluate their drought tolerance and drought avoidance.

1.2 Objectives

This study will therefore:

i) Determine the effect of water stress on the germination and growth at nursery stage of *A. nilotica, P. dulce* and *S. macrophylla.*
ii) Evaluate growth of the seedlings exposed to different water stress.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Climate change and Drought

Climate change is the cause and consequence of global effect (Stern, 2007) and is evaluated by measuring change of temperature and rainfall of any region (Islam, 2009). According to IPCC, climate change refers to a change in climate for a decade or longer period that can be identified by statistical test (Watson *et al.*, 2001). Climate change increases the magnitude and intensity of floods, agricultural drought, storm-surges and cyclones, saline ingress and other disasters (e.g. coastal and river bank erosion and landslides triggered by heavy rainfall (Team, 2008; Islam, 2009). The World Bank climate change experts' opinion is that the poorest of the poor in South Asia are the most affected by climate change (Islam, 2009).The world's climate has always been changing between hotter and cooler periods. Climate change in the next hundred years will be significant and by the year 2100 best estimates predict between a 1.8° C and 4 °C rise in average global temperature, although it could possibly be as high as 6.4° C (Pender, 2008). Future scenarios predict frequency and severity of extreme droughts, hot extremes, and heat waves could increase (Allen *et al.*, 2010).

Team (2001) reported, many natural system are being affected by changing regional climate especially temperature increases. Allen *et al.*, (2010), reported that climate change have some positive and negative aspects. It increases forest vigor and growth from CO_2 fertilization, increases water use efficiency and longer growing seasons.

Changed land surface especially reduction of forest cover and land denudation increases reflectivity of earth's surface temperature changing regional climate leads to drought (Desprez-Loustau *et al.*, 2006) . Regions located in the transition zone between major climate zones, e.g., from temperate to dry climates, are particular susceptible to drought and thus to potential changes in climate (van Lanen *et al.*, 2007).

2.2 Drought affected area

Temporary drought occurs in 64% of world's land while 36% of worlds land under semi-arid conditions, receiving only 127mm to 762 mm rainfall annually during crop season (Akıncı, 2012). On a global basis, about one-third of potential arable land suffers from inadequate water supply and the yields of much of the remainder are periodically reduced by drought. Moreover, water deficits may occur during a plant's life cycle outside of arid and semi-arid regions even in tropical rainforests (Zhang, 2011).

Arnell (2004) found that very dry areas increased from 12% global land surface to 30% since 1970s calculated by the Palmer drought severity index (PDSI) over the period 1900 to 2002. Drought occurrence is increased particularly in western and southern Africa, southern Europe and North Africa, south Asia and eastern Australia. Part of this increase followed a large jump due to decreased precipitation in large areas in the 1980s due to El Ñino Southern Oscillation (ENSO) and partly was due to increasing surface temperatures and therefore evaporation. According to Lehner prediction, in Southern Europe that currently occurs on average once every hundred years could have a return period by 2070s. Füssel and Klein (2006) found that net primary productivity (NPP) and net ecosystem productivity (NEP) in large parts of the drought-affected areas are reduced. Tropical dry forest occurs in central and south America, Africa, India, South East Asia and Australia.

Arid condition exclude trees establishment because periodic drought hampers growth and survival of plant, even forest ecosystem (Allen *et al.*, 2010). Plants transplanted to field undergo severe physiological shock due to the decreased capacity for water absorption. The small root could not uptake water to compensate the loss of water in leaves through transpiration (Kozlowski and Pallardy, 2002).

Many of the poorest countries around the world are at the risk of expected damages that are much larger as a percentage of their national output. For countries that have fewer resources with which to fend off the consequences of climate change, the impacts will be devastating (Nayar, 2009). The estimated (damage and lost production) cost to the national economy of natural disasters of Bangladesh over the last 10 years is between 0.5% and 0.3% of GDP (Team, 2008).

2.3 Climate change scenarios of Bangladesh

Climate change projects that drought-prone areas of Bangladesh will face high rainfall variability and sea level rising and major country-wide droughts every five year. Western parts of the country will be at greater risk of drought and more vulnerable to dry spells during both the monsoon and dry seasons. Northwestern regions are particularly vulnerable to droughts (Bass, 2006).

Drought occurs when soil moisture level and relative humidity in air is low while temperature is also high (Zhang, 2011). In Bangladesh, drought is defined as the period when the moisture content of soil is less than the required amount for satisfactory crop growth during the normal crop-growing season (Banglapedia, 2006).

Bangladesh has suffered severe droughts in 1973, 1978, 1979, 1981, 1982, 1992, 1994, 1995, 2000 and 2006. It is a recurrent phenomenon in some parts of the country, but the northwestern region is seriously drought prone because of high rainfall variability (Shahid and Behrawan, 2008). The average annual rainfall in this region is 1,329 mm, whereas that in the northeastern part of the country is 4,338 mm. The meteorological drought is a common phenomenon in this region, which is linked to rainfall pattern and related climatic conditions (Shahid *et al.*, 2005). According to the National Drought Mitigation Center (2006), every year Bangladesh experiences a dry period for 7months, from November to May, when rainfall is normally low. During this period about 2.7 million hectares of land in Bangladesh are vulnerable to annual drought (Pender, 2008).

Bangladesh's drought-prone areas are warmer and drier than they were 50 years ago and current projections suggest that Bangladesh will become hotter, its nights will be warmer and it will face frequent droughts due to increased rainfall variations (Pender, 2008).

Climate change would alter crop water requirement in drought-prone areas. Plant requires large supply of water during hot, dry, windy and sunny periods and the requirement is low during cool, humid and cloudy periods with little wind. Information on the ecological requirements at the seed and seedling stages is vital both for silvicultural and forest management plans (Khurana and Singh, 2001). Moreover, elevated temperature or drought reduces growth and increases mortality. Fresh water resources, namely surface and groundwater, in drought-prone areas are already declining due to over exploitation to support irrigation in the dry months (Team, 2008). Thus, information on the ecological requirements of water during germination and seedling stages is vital both for silvicultural and forest management point of view (Khurana and Singh, 2001).

2.4 Water and plant growth

Plant requires water in its every stage of life and it accounts for over 50% of the fresh weight of woody plants (Zhang, 2011). Lack of soil water during the dry season may limit the survival and growth of plant. Seasonal rainfall and 2-6 months of drought each year affect germination, survival and seedling development during which the ratio of potential evaporation to rainfall is greater than one (Khurana and Singh, 2001). Water is progressively lost from a fully "saturated soil", firstly by draining freely, under the influence of gravity, and the rate of loss gradually slows down until no further water drains away, when the soil is said to be at "field capacity". Further loss of water by evaporation or by absorption by plant roots reduces the moisture content still further, until no further loss from these causes can occur, a stage known as the "wilting point" at which plants can no longer obtain the water necessary to meet their needs and they therefore wilt and die from moisture starvation (Akıncı *et al.*, 2012). Drought may range from moderate and of short duration to extremely severe and prolonged summer drought that has strongly influenced evolution and plant life. Initially plant experience drought in a short time, even under adequate moisture condition and may prevail in certain time of day and normalized after reduction transpiration in night (Zhang, 2011). Water is the most important component for transporting and distribution of polar organic molecule (e.g., sucrose in the phloem), inorganic ion (nutrients from root to leaf, xylem); CO_2 or bicarbonate to the site of photosynthetic fixation of the cell and atmospheric gases (diffusion of oxygen to site of respiration) (Fitter and Hay, 2002). Water potential increases with increasing temperature (Khurana and Singh, 2001). Plants adopt different physiological and ecological adaptation in water shortage by either tolerance or avoidance to shortage. Plant responses roughly may be classified as; i) short term changes related mainly to physiological responses (linked to stomatal regulation); ii) acclimation to the availability of certain level of water (solute accumulation resulted with adjustment of osmotic potential and morphological changes); iii) adaptation to drought conditions (sophisticated physiological mechanisms and specifically modifications in anatomy)(Zhang, 2011).

2.4.1 Germination

Each species has its own water potential threshold temperature under which seeds will not germinate (van Haverbeke, 1963). The first stage of germination is the physical process of imbibition and if water supply is restricted, germination may be delayed or even prevented. More numbered seeds take less time to germinate (Leiva and Fernández-Alés, 1998). Adequate amount of water is required for imbibition and subsequent germination, as well as for seedling establishment. Seeds of drier habitats germinate after getting minimum water under water deficit. Other environmental factor needed for germination along with water. Available water helps to break seed dormancy and hastens germination. Seed dormancy is particularly related with variable rainfall trends and extended dry periods within the annual cycle. Seeds germinate at different times in a dry season. In areas with a long dry season, seedling desiccation may be a major obstacle to recruitment. Rate of germination declines when surrounding soil is dried from the field capacity to matric potential –1 MPa (Fitter and Hay, 2002). Severe drought may change some gene of trees (Fitter and Hay, 2002). In this stage water is important for activation of enzymes responsible for embryo development and utilization of endosperm (Grezeski, 1997).

2.4.2 Growth

Seedling growth forms linked with season. Seedlings of dry-forest grow well during the dry season when irrigated and also suffer far lower dry-season mortality than seedlings of wet-forest (Bunker and Carson, 2005). Higher temperature induces greater tree drought through higher evapotranspiration rates and/or faster depletion of moisture in soil profile. As a result trees get shorter growing season (van Haverbeke, 1963) and persistent drought restricts tree radial growth (Wang *et al.*, 2012). Drought increases with increasing potential moisture limitation (Khurana and Singh, 2001). Mediavilla and Escudero (2004) reported seedling establishment and juvenile growth are critical period for life cycle of tree species. Growth performance of older seedling is better than younger seedling (Zida *et al.*, 2008). Stomatal closure is a common strategy to prevent water loss (Mediavilla and Escudero, 2004). Dry mass allocation to leaves and leaf area in seedlings of several rainforest as well as dry forest trees are decreased in water deficit. The reduced leaf growth prevents water loss resulting increased leaf thickness which in turn increases the ratio of mesophyll area available for CO_2 uptake per unit leaf area and hence the water use efficiency for a given transpiration rate. Seedlings previously exposed in slowly lower drought, the level of dehydration tolerance of the seedlings will increase. *Acacia* and *Eucalyptus* have better control of water loss, as they show drought hardening characteristics to face extreme scarcity. By reducing irrigation of seedlings in nursery, induce budset, dormancy and drought tolerance of seedlings. Plants survive in drought by osmotic adjustment, changing elasticity of tissues and osmotic volume, changing root/shoot allocation of dry matter (Kozlowski and Pallardy, 2002). In the field, plants are normally not deprived of water rapidly. During slowly increasing drought photosynthesis and transpiration usually decrease at similar rates (Zhang, 2011). Nutrient transportation via xylem is prevented in dried condition affecting growth negatively (Fitter and Hay, 2002). Nutrient uptake depends on root absorption and root length. Under water stress essential nutrients act as cofactor or enzymes activators to regulate plant metabolism. Water stress generally favored increases in nitrogen, K+, Ca^2+, Mg^2+, Na+, and Cl- but decreases in phosphorus and iron. Although the many report stated that water stress mostly causes reduction in uptake of nutrients (Akıncı *et. al.*, 2012).

2.4.3 Reproduction

Successful reproduction of plants requires substantial quantity of water (Fitter and Hay, 2002). Drought during squaring and flowering hampers carbohydrate metabolism of reproductive unit. Sever water-deficit affects gas exchange functions, which consequently results in an agitation of carbohydrates and energy production metabolism of reproductive units (Loka and osterhuis, n.d.). Flowering and subsequent phenophase occur early (Kozloski and Pallardy, 2002). Drought shortens the length of reproductive phase. Delayed flowering increases the mortality of plant. Advanced flowering reduces the potential of plant's seed production, quality of seed. Flower size, nectar volume and concentration of nectar concentration are decreased with the increasing drought (Carroll *et al.*, 2001). Flower bud dormancy needs water to break. Drying-irrigation is sometimes provided for cultivation for example in coffee cultivation to shorten harvesting period. A dormant bud on a perennial contains reduced leaves and floral and/or vegetative meristems, and relies on the rest of the plant for water. In some tropical species such as coffee, drought is an alternative cue for breaking flower bud endodormancy. Buds then exist in an ecodormant state ready to respond by rapid floral growth as soon as the first rains fall at the end of the dry season. Seed are the primary means of reproduction (Atwell *et al.*, 1999). Kozloski and Pallardy (2002) revealed that, Drought increases the fruit yields of some species.

2.5 Drought in Tropical forest

Precipitation over tropical land masses has declined during the 20th century. Reduced precipitation, period of dry season and severe drought affect the structure of tropical forests by favoring dry forest species decreasing and overall species diversity (Poorter and Markesteijn, 2007). Tropical forest accounts for 52% of the total forest area of the world of which 42% is dry forest. Decreased rainfall converts gradually wet evergreen forest to dry deciduous rainforest. Severe drought eliminates drought intolerant and rare species and also limits the environmental niche of the rare species. About 63% of the tropical rainforest species produce non-dormant seeds of which only 24% of the dry tropical tree species produce seeds which are not dormant. Physical dormancy is more prevalent in dry tropical species compared to wet tropical species. A number of factors including seedling density, seedling age, temperature and light availability enhance the impact of severe drought on woody seedlings. Light availability increases the deficit of soil moisture. No effect of increasing seedling density on seedling mortality or growth has been found in tropical forest. Growth form interacts with dry season. Size of tropical dry forest becomes smaller that expressed in lower biomass accumulation. Reduction of rainfall increases deciduous species. Moisture deficit limits all phenological activity (flowering, fruiting, leaf production, leaf fall, and tree growth) (Murphy and Lugo, 1986). Area of Tropical forest dominated by dry-forest seedlings grow well during the dry season when irrigated and suffer far lower dry-season mortality than area dominated by wet-forest seedlings (Bunker and Carson, 2005). Seedling recruitment is considered the critical stage in forest dynamics, because of the greater susceptibility to diseases of seedlings than of tree (Bunker and Carson, 2005).

2.6 Effect of water shortage on plants

Plants experience drought when actual evaporation is more than potential evapotranspiration (Brady *et al.*, 1996). Drought changes the plant physiologically and morphologically (Fitter and Hay, 2002). Water deficit may reduce the leaf area of tree because cell extension is highly sensitive to water shortage. Species from drier forest reduce water loss with lower transpiring leaf area per unit plant mass. They capture water by investing more biomass in roots with a high root length or taproot with low root length (Poorter and Markesteijn, 2007) and shorter leaf area make capable plants to continue growth (Leuschner *et al.*, 2001). The capacity of plants to tolerate low leaf water status varies widely among species. Species those able to desiccation tolerate or delay can survive in severe drought (Kursar *et al.*, 2008). Plant water deficit inhibits photosynthesis by the closure of stomata, reduction of leaf area, decrease in hydration of protoplasm and senescence of leaf. With severity and length of drought of leaf photosynthetic activity gradually reduces (Ögren and Öquist, 1985; Fitter and Hay, 2002). The effects of changing water availability in plant are on roots and xylem. As the soil dries, decreased permeability, due to root suberization and/or increased loss of fine roots, can reduce the balance between water extraction capacity and transpiring leaf area. Roots of unwatered plants often grow deeper into the soil than that of plants are watered regularly (Zhang, 2011). Loss of turgor of leaf cell is associated with period of drought and wilting is the final stage of it (Leuschner *et al.*, 2001; Fitter and Hay, 2002). Stomata of plants start to close at drought thereby reducing CO_2 in photosynthetic mesophyll. Severe soil moisture deficit with short period inhibits root growth where longer lasting soil moisture deficit increases root/shoot ratio. Stem diameter growth are more sensitive than leaf area to drought (Leuschner *et al.*, 2001) and decrease root/ shoot ratio with tree age and size (Ritson and Sochacki, 2003). During desiccation continuously losses of xylem causes death because of ceasing water supply (Kursar *et al.*, 2008).

Plants can be classified according to their adaptations to drought. They are

1. Hydrophytes adapted to partial and complete submergence in free water. Such plants cannot grow at soil moisture tensions greater than 500-1000 kpa.
2. Mesophytes are terrestrial plants adapted to moderate water supplies. They can grow at soil moisture tensions of up to 2000 kpa.

3. Plants adapted to arid zones are called Xerophytes. They can grow under moisture tensions as great as 4000 kpa (Kimmins, 1997).

Cordeiro *et al.* (2009) reported that short drought had no effect on height and stem diameter increment of *S. macrophylla* but leaf and leaflet numbers decrease. Therefore, reduced total leaf area is a way to remain alive in drought by decreasing transpiration, net photosynthesis and above ground growth. Young *S. macrophylla* can tolerate short period drought and continue physiological functions when return to normal condition.

2.7 Study species

2.7.1 *Acacia nilotica*

A. nilotica is an evergreen, usually moderate sized (2.5-25 m) tree with a short, thick and cylindrical trunk. It has a strong light requirement.it is drought resistant. Mean annual temperature: 4-47° C. Mean annual rainfall: 200- 1270 mm. Soil type: Grows on a wide variety of soils, seemingly thriving on alluvial soils, black cotton soils, heavy clay soils, and can tolerate poorer soils. (World Agroforestry Centre, 2013).

2.7.2 *Pithecellobium dulce*

Pithecelobium dulce is a fast growing medium sized, spiny tree; height ranges 5-15m. Leaves are paripinnate, deciduous but foliage is persistent, as the new leaves appear while the old ones are being shed. It has been used as reforestation and fuel wood (Parrotta, 1991). *Pithecelobium dulce* grows well both in wet and dry areas under full sunlight and shows variation from its climatic requirement. It grows on poor soil, drought area and brackish soil due to its extensive root system. Mean annual temperature: 0-48° C and mean annual rainfall 250-1650 mm (World Agroforestry Centre, 2013). Germination starts 1 to 2 days after seed sowing and ranges 20-70 percent.

2.7.3 *Swietenia macrophylla*

S. macrophylla is a large deciduous tree with an umbrella-shaped crown. Its height ranges 30 m and diameter at breast height (DBH) more than 1.5 m. Within its ecological range, the optimum annual rainfall is between 1000 and 2500 mm with a dry period of 0–4 months (Krisnawati et al., 2011). Mean annual temperature: (min. 11) 20-28 (max. 35) ° C, Mean annual rainfall: 1600-2500 mm. Soil type: *S. macrophylla* grows best on well-drained sites with medium to heavy soils (World Agroforestry Centre, 2013). The tree prefers rich, deep and well-drained soils, with moisture available most of the year. Seed germination is hypogeal or cryptocotylar. The seeds do not show a latency period and do not require pretreatment. Under favorable conditions (fertile soil, periodic watering, without attacks by pests and diseases at the nursery site), the newly gathered, fresh seeds germinate 10 to 28 days after sowing (Rocas, 2003). *S. macrophylla* is widespread throughout the tropics, found naturally in both tropical dry and tropical wet forest types. The largest plantations of *S. macrophylla* have been reported in South and Southeast Asia. The species has a wide geographical and ecological range, growing naturally in wet and dry tropical forests and on a variety of soil types. It is widely used for avenue planting in some Asian countries. *S. macrophylla* has great potential for reforestation and afforestation, particularly for improving soil. It is also suitable for large-scale timber production plantation (Krisnawati *et al.*, 2011).

2.8 Impact on Agroforestry

Acacia species with a higher root-to-shoot ratio are probably better adapted to deep nutrients and water capture; this may be an important adaptive trait for agroforestry tree growing in drier areas (Masutha *et al.*, 1997). It can fix atmospheric nitrogen by legume (Carventas *et al.*, 1998). *S. macrophylla* is used commercially in Bangladesh and for Potassium and Phosphorus nutrient it is best for agroforestry (Mahmood *et al.*, 2009).

2.9 Survival strategy

Survival of seedlings varied on seed source. Seedlings from dried origin survived the longest time between the interior source survived and coastal region (Cregg and Zhang, 2001). Plants subjected to periods of drought show an acclimation or hardening and are able to survive subsequent drought periods with less damage compared to plants not previously stressed. The mechanisms developed as survival strategies include tolerance and avoidance of drought. The mechanism included (i) drought escape by rapid development, which allows plants to finish their cycle before severe drought; (ii) drought avoidance by, for instance, increasing water uptake and reducing transpiration rate by the reduction of stomatal conductance and leaf area; (iii) drought tolerance by maintaining tissue turgor during drought via osmotic adjustment, which allows plants to maintain growth under drought; and (iv) resisting severe stress through survival mechanisms (Zhang, 2011). Plant have strategies to overcome drought stress normally involve a mixture of tolerance and stress avoidance mechanisms. The tolerance strategies involve immediate physiological and biochemical responses, whereas the avoidance mechanism to involve long developmental and morphological traits. Regular drought-tolerant plants can withstand moderate tissue dehydration of about 30% water loss. Severe drought could not inhibit the growth of seedlings which was exposed to lower drought. By contrast, desiccation-tolerant plants or resurrection plants are tolerant to further cell dehydration (around 90% water loss) and keep the ability to rehydrate successfully (Kozlowski and Pallardy, 2002).

CHAPTER THREE

MATERIALS AND METHOD

3.1 Experimental site

The study was carried out in Forest Nursery in Khulna University. Khulna is in the south western part of the country. The general climate of the district is tropical monsoon climate and mostly characterized as hot summer, mild winter and monsoonal rain. Growing season starts in April continues upto November (Fig.1).

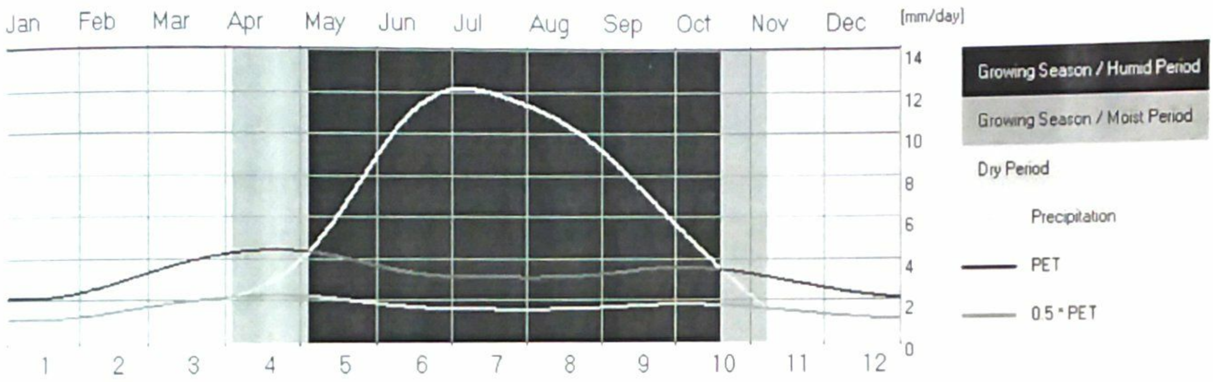


Fig: 3.1: Climate map of Khulna generated by Local Climate Estimator Ver. 1.10 from FAO (2005)

3.2 Soil preparation

Nursery soil was used as a medium of growth. The soil was a mixture of Forest soil and compost. 6x3 inch polybag was used to fill the soil. Each polybag had two perforations just above the bottom of the polybag. Soil of five polybags was oven dried and weighed separately. Average weight of five soil samples was taken to fill the polybag for the experiment. To determine the 100% field capacity of soil, five polybags were watered fully by tap water and kept until the last drop drains out due to gravitation. The wet poly bags were weighed and the oven dry weight was deducted from the weight soil sample resulting amount of water. The average value of the water was considered as the required water for 100% field capacity (FC). Then the amount was estimated according to 50% FC and 25% FC.

Table 3.1 Basic properties of soil

PROPERTIES	VALUE
pH	7.87
EC	236 ms/cm
Available N	23.6×10^{-3} (±.003) mg/gm
Available P	1.2×10^{-4}(±. 00007) mg/gm
Available K	13.99×10^{-2}(±.003) mg/gm
Available Na	18.8×10^{-2}(±.079) mg/gm

Parenthesis indicates value of standard deviation

3.3 Experiment set up

The experiment was carried out in a glass house in Forest nursery of Khulna University from April to July, 2012. Healthy seeds of *A. nilotica, P. dulce* and *S. macrophylla* were collected from healthy trees present in and around Khulna University. Seeds were collected from healthy trees occurring in and around Khulna University. Seeds were checked individually to eliminate visibly damaged and inferior seed. Seeds were soaked 24 hours in water as a pre sowing treatment as well as to reduce seed moisture variability prior to sowing. Each 6x4 inch polybag were filled with the nursery soil weighed approximately 350 gm. Over the experimental period the day time temperatures in the glasshouse was recorded and it ranged from 26° to 45° C. The experiment comprised of three watering regimes (100%, 50% and 25% FC) as treatment and three species as replication with ninety polybags per treatment.

3.4 Water correction

Five polybags were kept as control without seedling to determine the evaporative water loss. Control polybags were weighed by electronic balance. Every alternate day seedlings were watered by averaging the weight of five polybags and corrected the amount of water lost. Water correction was done for germination test and seedling growth.

3.5 Germination test

The polybags were arranged in a completely randomized design (CRD) in cork made boxes. Total 270 polybags were used for four treatments (100%, 50% and 25% FC) for a species and a total of 90 seeds were sown for a single treatment. Germination was recorded every day.

3.6 Seedling growth

Ten polybags containing seedlings of approximately similar height were taken for growth study from a single treatment of a species. The study was continued for three months. After three months seedlings were collected and washed gently in running water and separated into biomass components (root, shoot and leaf) and fresh weight was taken instantly using 4 digit SHIMADZU electric balance. Before placing the samples in an oven, root and shoot length was measured for individual seedlings. The samples were oven dried in 80^0C until they gave constant weight. Length of polybag should be larger for providing enough space to root growth. Soil water potential should be measured and duration of study should be extended for growth.

3.7 Statistical analysis

For germination data were collected every day. Percentage of germination was calculated for individual species. Root/shoot biomass ratio was calculated for individual species for respective treatments and One-Way ANOVA was applied to test significance and for comparison of the means Tukey's test of significance was carried out. The same statistical procedure was followed for biomass components (root, shoot and leaf) and moisture loss. To carry out Statistical analysis, MINITAB 16 (Trial version) was used and graph was produced by Origin pro 8.6 (Trial Version).

CHAPTER FOUR

RESULTS

4.1 Germination

Germination varied with species in different field capacities. Among the species, *Swietenia macrophylla* did not germinate at 25% field capacity. Germination of *S. macrophylla* at 100% and 50% field capacity remained within 55%-60%. Similar pattern was found for *Pithecellobium dulce* at 100% and 50% field capacity. However, at 25% field capacity it germinated more than 100% and 50% field capacity. *Acacia nilotica* on the other hand, showed a decreasing trend of germination with decreasing field capacity (Fig. 4.1).

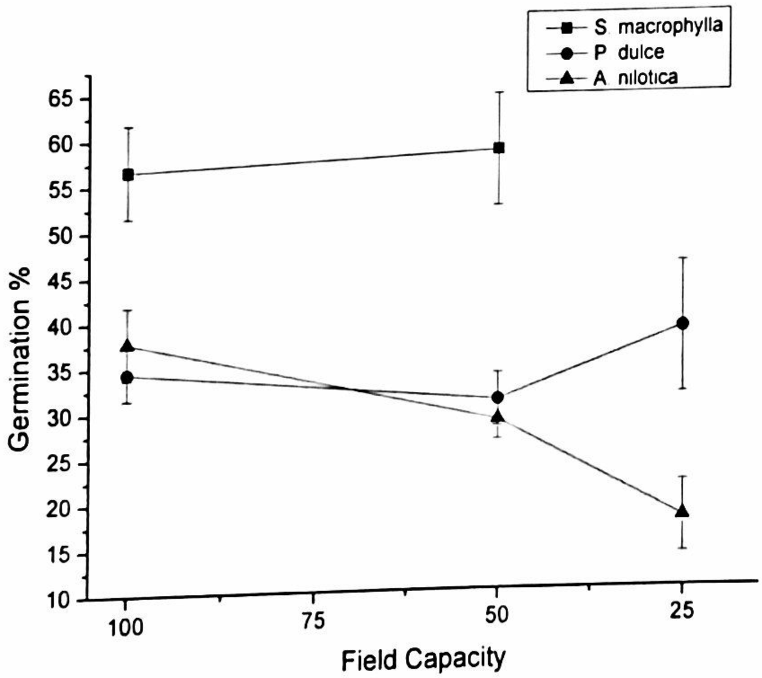
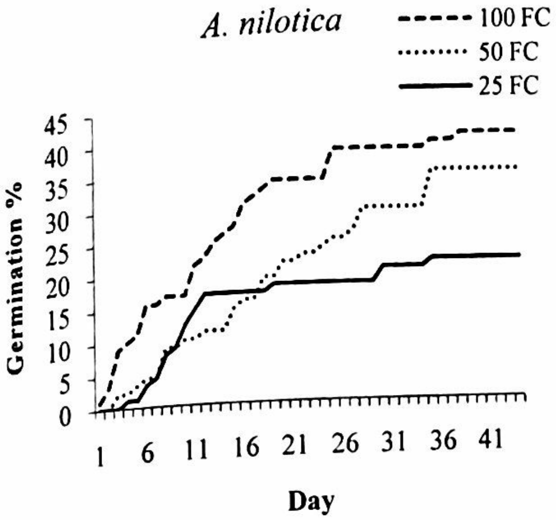
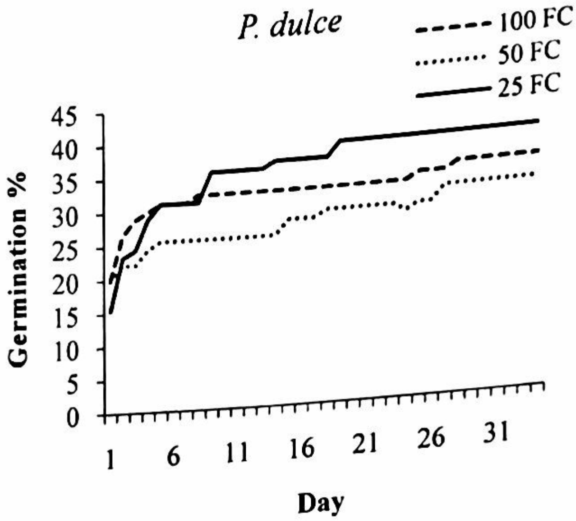


Fig 4.1: Germination of *Acacia nilotica*, *Pithecellobium dulce* and *Swietenia macrophylla* species at different field capacity.

Germination of both *S. macrophylla* and *P. dulce* were found to follow a trend. The highest germination of *S. macrophylla* was found at 50% field capacity and for *P. dulce* at 25% field capacity. It decreased with increasing field capacity. *A. nilotica* showed the reverse order of germination (Fig. 4.2).





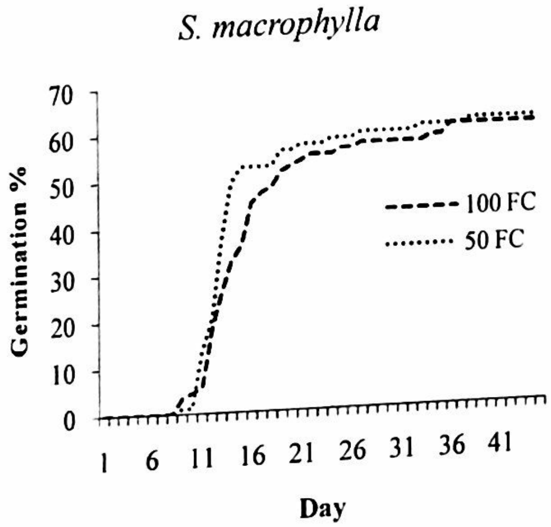


Fig 4.2: Cumulative germination% per day of *A. nilotica, P. dulce and S. macrophylla* at three field capacities.

4.2 Survival

At 50% FC survival achieved 60% or more for all the species (Fig 4.3). Among the three species death of seedlings of *P. dulce* was more at 25% FC. Soil moisture probably went critical at 25% FC for their survival after germination. Though, *A. nilotica* seedling survival dropped from 100% FC, it remained similar that was found at 50% FC and 25% FC. *S. macrophylla* showed increased survival at 50% FC than 100% FC.

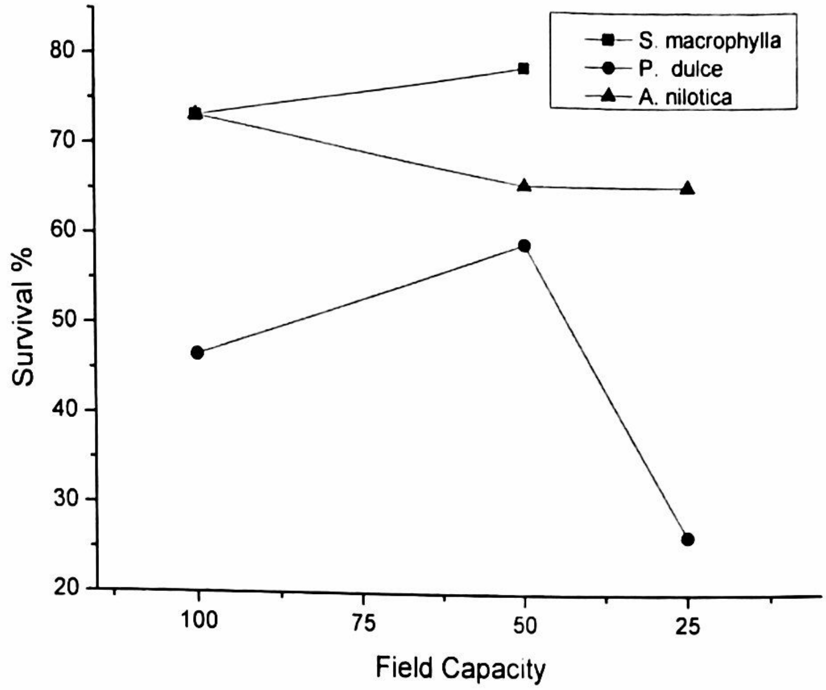


Fig 4.3: Survival percentage of *A. nilotica, P. dulce and S. macrophylla.*

4.3 Root-shoot ratio

Root to shoot dry biomass ratio varied among the species. However, significant variation was observed for *A. nilotica.* Root to shoot dry biomass ratio of *A. nilotica* decreased significantly ($p<0.05$) from 100% FC to 50% FC. The ratio was not significantly different for 50% FC and 25% FC (Fig 4.4). *S. macrophylla* and *P. dulce* showed little response to soil moisture content ($p>0.05$).

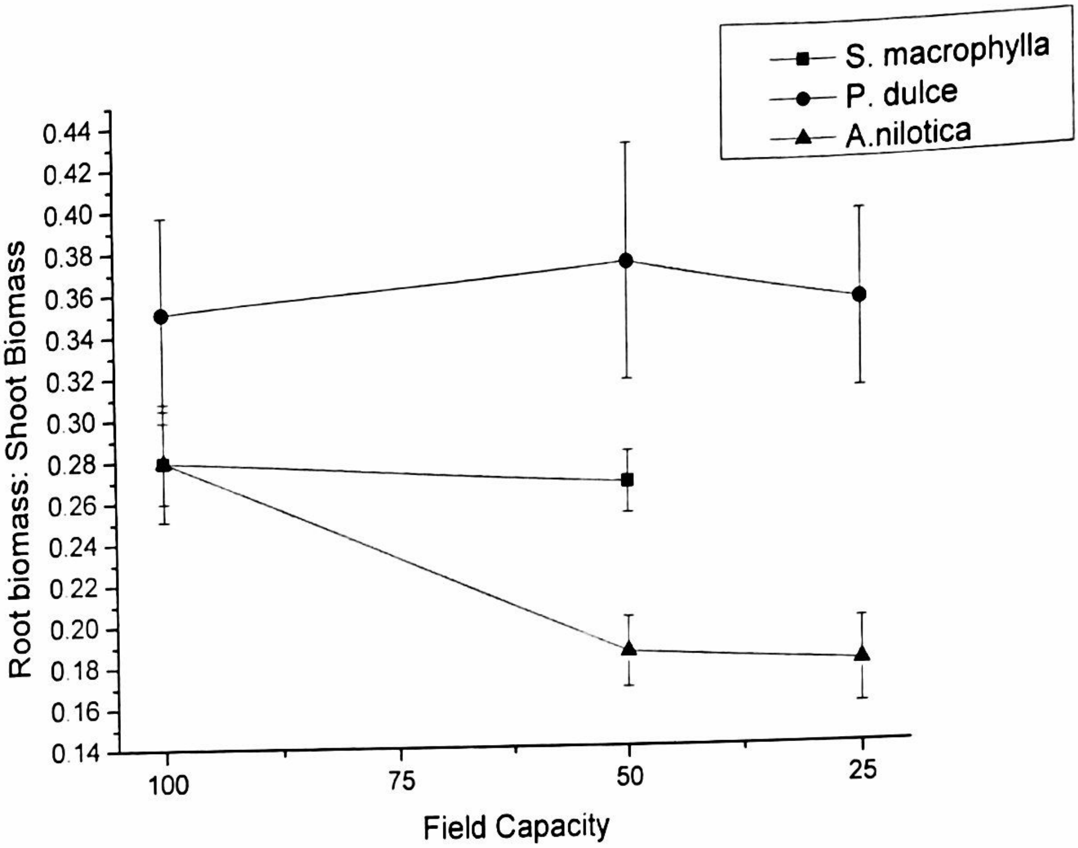


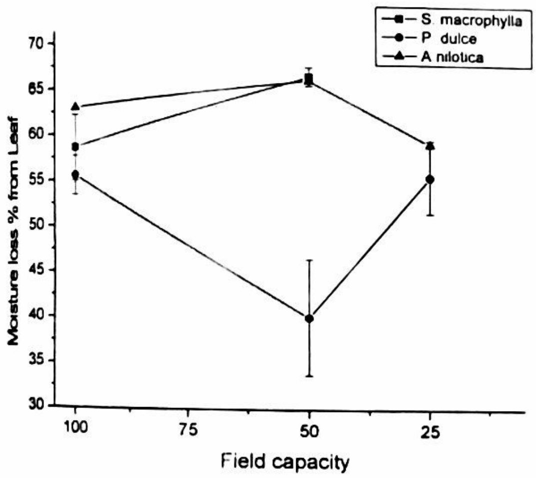
Fig 4.4: Root/shoot biomass ratio of *A. nilotica, P. dulce and S. macrophylla.*

Table 4.1: ANOVA and multiple comparison for Root/shoot biomass ratio of *A. nilotica* and *P. dulce*.

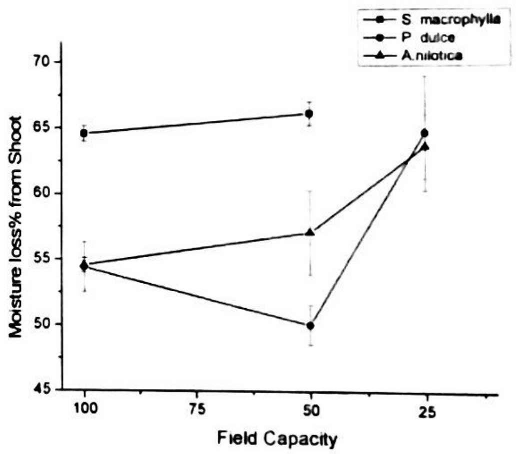
Species	One-Way ANOVA	Grouping Using Tukey Method
A. nilotica	Source DF SS MS F P Tret 2 0.06170 0.03085 5.93 0.007 Error 27 0.14036 0.00520 Total 29 0.20205	Tret N Mean Grouping 100 10 0.27945 A 50 10 0.18643 B 25 10 0.18037 B
P. dulce	Source DF SS MS F P Tret 2 0.0039 0.0019 0.08 0.924 Error 27 0.6537 0.0242 Total 29 0.6575	Tret N Mean Grouping 50 10 0.3776 A 25 10 0.3579 A 100 10 0.3508 A

4.4 Moisture loss from Biomass components

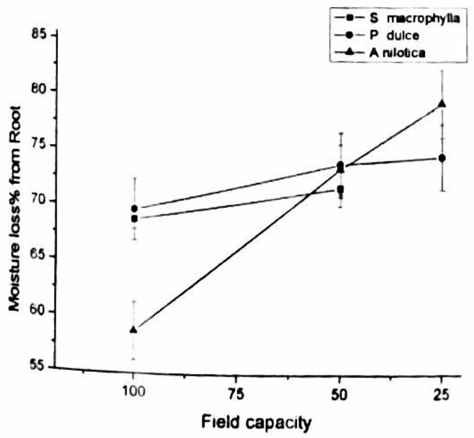
Moisture loss was found to vary among different biomass components (leaf, shoot and root). In case of moisture loss from leaf biomass, *P. dulce* lost the highest moisture content at 25% FC and the lowest at 50% FC. *A. nilotica* lost low moisture at 25% FC in comparison to 100% FC and 50% FC. *S. macrophylla* lost more moisture at 50% FC than 100% FC (Fig. 4.5a). Moisture loss from shoot biomass for both *A. nilotica* and *P. dulce* was the highest at 25% FC. *A. nilotica* lost less moisture from shoot at 50% FC than *P. dulce*. *S. macrophylla* did not loss significant moisture from shoot at 100% FC to 50% FC (Fig 4.5b). Root moisture loss was found to increase significantly ($p<0.05$) from 100% FC to 25% FC for *A. nilotica*. However, for *P. dulce and S. macrophylla* root moisture loss was not significant ($p>0.05$) (Fig. 4.5c).



(a)



(b)



(c)

Fig 4.5: Moisture loss from leaf (a) shoot (b) and root (c) biomass from *A. nilotica, P. dulce and S. macrophylla* under different soil moisture level.

Table 4.2: ANOVA and multiple comparision for moisture loss from shoot biomass of *A. nilotica* and *P. dulce*.

Species	One-Way ANOVA						Grouping Using Tukey Method			
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
A. nilotica	Tret	2	444.7	222.3	4.04	0.029	25	10	63.741	A
	Error	27	1486.1	55.0			50	10	57.163	A B
	Total	29	1930.8				100	10	54.600	B
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
P. dulce	Tret	2	1141.8	570.9	6.85	0.004	25	10	64.792	A
	Error	27	2250.3	83.3			100	10	54.435	B
	Total	29	3392.1				50	10	50.084	B

Table 4.3: ANOVA and multiple comparision for moisture loss from root biomass of *A. nilotica* and *P. dulce*.

Species	One-Way ANOVA						Grouping Using Tukey Method			
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
A. nilotica	Tret	2	2219.1	1109.6	15.82	0.000	25	10	79.245	A
	Error	27	1894.2	70.2			50	10	73.349	A
	Total	29	4113.3				100	10	58.782	B
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
P. dulce	Tret	2	132.9	66.5	0.82	0.451	25	10	74.434	A
	Error	27	2186.5	81.0			50	10	73.764	A
	Total	29	2319.4				100	10	69.671	A

Table 4.4: ANOVA and multiple comparision for moisture loss from leaf biomass of *A. nilotica* and *P. dulce*.

Species	One-Way ANOVA						Grouping Using Tukey Method			
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
A. nilotica	Tret	2	236	118	0.66	0.523	50	10	65.67	A
	Error	27	4806	178			100	10	62.92	A
	Total	29	5042				25	10	58.84	A
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
P. dulce	Tret	2	1578	789	3.98	0.030	100	10	55.53	A
	Error	27	5348	198			25	10	55.28	A
	Total	29	6926				50	10	40.02	A

4.5 Biomass

4.5.1 Total dry matter

Total dry matter production varied among the treatments for a species (Fig 4.6). The significant variation of dry biomass reduction was observed in case of 25% Field capacity. Moisture stress was prominent at this stage. At 100% FC individually all species contained high dry biomass. At 50% FC total dry biomass reduction was insignificant ($p>0.05$). However, at 25% FC biomass reduction was significant ($p<0.05$) in comparison to 100% FC and 50% FC for *A. nilotica* and *P. dulce*.

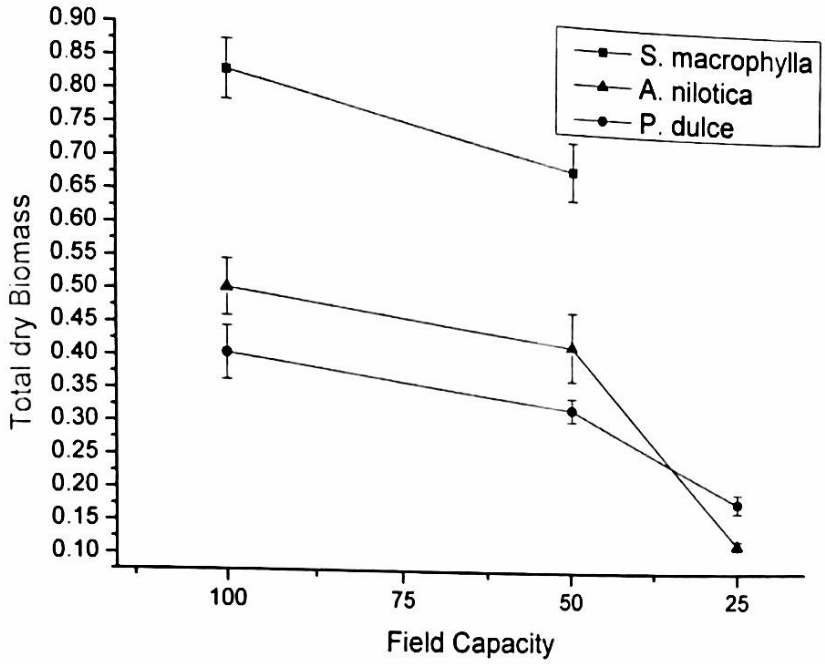


Fig 4. 6: Total dry matter (gm) of *A. nilotica, P. dulce* and *S. macrophylla* at all treatment.

4.6 Above ground dry biomass

4.6.1 Shoot Biomass

Leafless dry stem is considered as dry shoot biomass which varied with treatments among the species. *A. nilotica* and *P. dulce* showed a decreasing trend of shoot biomass with increasing soil moisture stress. Significant variation was observed at 25% FC for both this two species ($p<0.05$). *S. macrophylla* showed no significant variation between 50% FC and 100% FC ($p>0.05$) (Fig. 4.7).

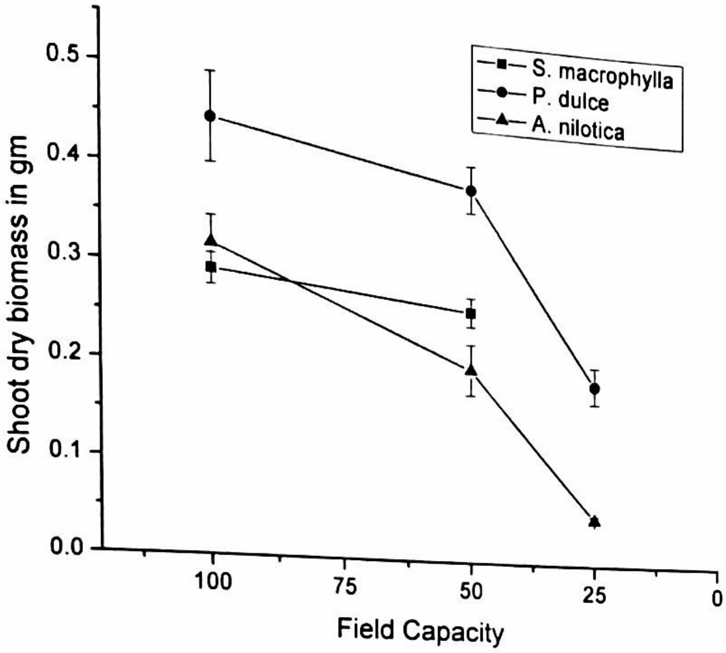


Fig 4.7: Dry shoots biomass for *S. macrophylla, A. nilotica* and *P. dulce.*

Table 4.5: ANOVA and multiple comparison for dry shoot biomass of *A. nilotica* and *P. dulce.*

Species	One-Way ANOVA						Grouping Using Tukey Method			
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
A. nilotica	Tret	2	0.36943	0.18472	36.48	0.000	100	10	0.32150	A
	Error	27	0.13671	0.00506			50	10	0.20750	B
	Total	29	0.50614				25	10	0.05080	C
	Source	DF	SS	MS	F	P	Tret	N	Mean	Grouping
P. dulce	Tret	2	0.11981	0.05991	20.41	0.000	100	10	0.20850	A
	Error	27	0.07924	0.00293			50	10	0.19800	A
	Total	29	0.19905				25	10	0.06950	B

4.6.2 Leaf biomass

The highest dry leaf biomass was observed for *S. macrophylla* in all the treatments. The highest dry biomass was found in 100% FC for all the species, only *A. nilotica* showed it in 50% FC. *P. dulce* produced less biomass among the species of the study. Significantly less leaf biomass was produced for *P. dulce* in 50% FC than *A. nilotica* and *S. macrophylla* (4.8).

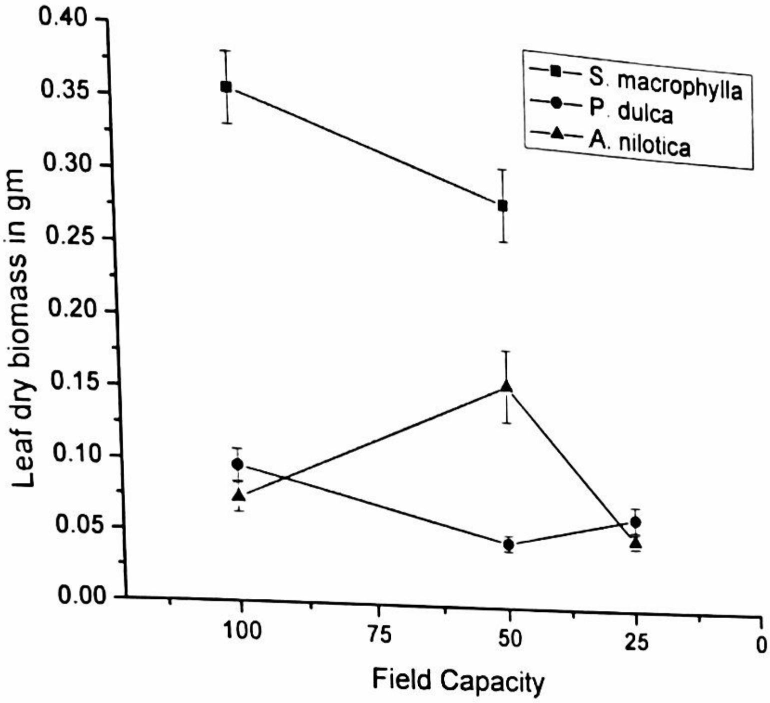


Fig 4.8: Dry leaf biomass for *S. macrophylla*, *A. nilotica* and *P. dulce*.

Table 4.6: ANOVA and multiple comparison for dry leaf biomass of *A. nilotica* and *P. dulce*.

Species	One-Way ANOVA: Source	DF	SS	MS	F	P	Grouping Using Tukey Method: Tret	N	Mean	Grouping
A. nilotica	Tret	2	0.06945	0.03472	12.85	0.000	50	10	0.16400	A
	Error	27	0.07299	0.00270			100	10	0.07420	B
	Total	29	0.14244				25	10	0.05300	B
P. dulce	Tret	2	0.011827	0.005914	6.90	0.004	100	10	0.09700	A
	Error	27	0.023137	0.000857			25	10	0.06960	A B
	Total	29	0.034964				50	10	0.04850	B

4.7 Below ground dry biomass

4.7.1 Root biomass

The highest dry root biomass was observed for *S. macrophylla* in all the treatments. *A. nilotica* produced less biomass among the species of the study in all the treatment except 100% FC. *P. dulce* showed little variation in root biomass from 100% to 50% FC. At 25% FC, both *A. nilotica* and *P. dulce* produced significantly less biomass at 25% FC ($p<0.05$) (Fig 4.9).

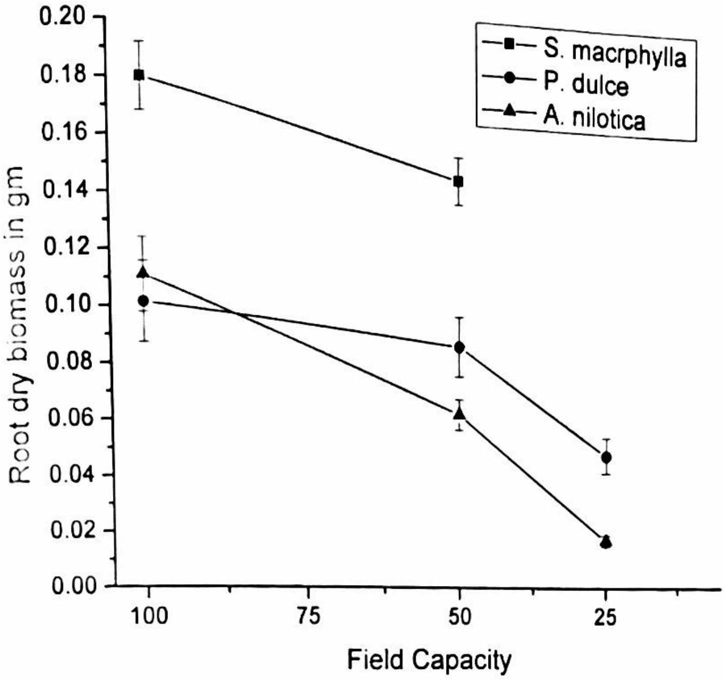


Fig 4.9. Dry roots biomass for *S. macrophylla*, *A. nilotica* and *P. dulce*.

Table 4.7: ANOVA and multiple comparison for moisture loss from root biomass of *A. nilotica* and *P. dulce*.

Species	One-Way ANOVA					Grouping Using Tukey Method			
	Source	DF	SS	MS	F P	Tret	N	Mean	Grouping
A. nilotica	Tret	2	0.043247	0.021623	31.41 0.000	100	10	0.11100	A
	Error	27	0.018590	0.000689		50	10	0.06400	B
	Total	29	0.061837			25	10	0.01800	C
	Source	DF	SS	MS	F P	Tret	N	Mean	Grouping
P. dulce	Tret	2	0.01438	0.00719	5.94 0.007	100	10	0.10150	A
	Error	27	0.03269	0.00121		50	10	0.08870	A
	Total	29	0.04707			25	10	0.05000	B

CHAPTER FIVE

Discussion

Water stress influenced germination and growth of *Acacia nilotica*, *Pithecellobium dulce* and *Swietenia macrophylla*. Less than 50% FC produced significant (P<0.05) and negative effect on biomass accumulation. Effect of soil water stress found in our experiment has been discussed in the following sections.

5.1 Germination

Moisture is one of the major requirements for seed germination. Success of germination is strongly influenced by the availability of moisture. In this experiment, response of seeds to moisture was found species specific. No significant variation in germination of *S. macrophylla* was found between 50% FC and 100% FC but failed to germinate any seed at 25% FC. This might be due to the quick desiccation of the seed. Morris *et al.* (2000) reported that viability of *S. macrophylla* is lost quickly due to desiccation. Though seeds in this experiment received irrigation, the amount of moisture probably was not enough to prevent desiccation at 25% FC. Morris *et al.* (2000) also reported that seeds of *S. macrophylla* sown close to rainy season had high germination which indicates influence of continuous wet weather for successful germination of the species. Non-linear germination was found for *P. dulce*. At 25% field capacity *P. dulce* germinated more than it was found at 50% and 100% field capacity. Non-linearity is not uncommon in nature as species differ somehow in resource requirement in order to co-exist in a community (Bazzaz, 1987). *Acacia nilotica* showed a decreasing trend in germination with decreasing moisture. Generally this trend is common for seed germination which has been reported by Khurana and Singh (2001) and Cavalcante and Perez (1995). In this experiment, *A. nilotica, P. dulce and S. macrophylla* showed different responses to moisture and this trend has been reported by Poorter *et al.* (2012) for other tree species. In general, in this study low soil water potential reduced germination except *P. dulce*.

5.2 Survival

After germination, the seedlings of *A. nilotica, P. dulce* and *S. macrophylla* responded to applied moisture levels. The both *P. dulce* and *S. macrophylla* showed increased survival at 50% FC than in 100% FC. The survival percentage of *P. dulce* dropped sharply from 50% FC to 25% FC. The moisture level at 25% FC probably was critical for *P. dulce* seedling survival. Though *P. dulce* is reported to tolerate aridity (World Agroforestry Centre, 2013), it is generally found in the tropical coastal region. Besides, origin of seeds also influence how the species will perform in a particular environment (Cregg & Zhang, 2001, Baskin & Baskin, 1998). The seeds of *P. dulce* were collected from Khulna and the climate of Khulna is wet and humid. *A. nilotica* showed little decrease in survival from 100% FC to 50% FC and maintained the similar trend for 25% FC as well. Among these three species *A. nilotica* showed tolerance to 25% FC indicating its tolerance to low moisture regime.

5.3 Root-shoot biomass ratio

Generally it is believed that root growth is less restricted than shoot growth under water limiting condition. For this, root to shoot ratio has been considered as primary indication for drought tolerance (Bartelink, 1998; Atwell *et al.*, 1999; Shipley & Meziane, 2002; Kozloski & Pallardy, 2002; Yardanov *et al.*, 2006). Root to shoot biomass ratio of *S. macrophylla* and *P. dulce* did not show any significant variation . However, *A. nilotica* showed decreased root to shoot biomass ratio with decreasing moisture. Generally root to shoot ratio is influenced by plant traits, rooting media, rhizosphere zone available and radial growth of the roots (Lindsey and Kilgore, 2013). In this study, rooting depth was limited for the species. Though root to shoot ratio is considered as one of the key indicators, Mc Michael and Quisenberry (1991) and Lloret et al., (1999) found no correlation between root to shoot biomass ratio and drought tolerance as there is differences in water absorbing capacity of the root system.

5.4 Moisture loss from biomass components

General trend of losing more moisture with increasing moisture stress from root and shoot biomass indicates storing of water as limiting resources (Kozloski and Pallardy, 2002). This is a common phenomenon for plant as it preferably allocates more limiting resources in different organs to reduce imbalance by storing limiting soil resource. The tendency to increase water storage in plant in response to water stress is a common phenomenon and varies from species to species (Schwinning and Ehleringer, 2001). *A. nilotica* in this experiment lost significantly more water from root with increasing water stress indicating its strategy to store more water at water stressed condition. *P. dulce* stored less water in root than in shoot biomass. It is found as a common survival strategy of seedlings for the most species to response water stressed condition.

5.5 Biomass production

5.5 Total dry biomass

Total dry matter production for all the species decreased with increasing moisture stress. The lowest dry biomass Fig (4.6) was produced in the highest moisture stress. Reduction in biomass production due to moisture is well established (Kimmins, 1987). Reduction in growth is considered the principal effect of drought (Silva *et al.*, 2010). The variable response to moisture stress results variable reduction of dry matter production (Greco and Cavagnaro 2002, Rawat and Singh 2000). The highest dry biomass was produced by *S. macrophylla* as this species has different morphology than other two species viz, large leaves and initial high shoot development. *Acacia nilotica* and *Pithecellobium dulce* showed similar reduction of dry matter production (Rawat and Singh 2000) due to moisture stress as they both show close morphological traits.

Shoot biomass:

All the species showed decreasing trend of shoot biomass reduction with decreasing moisture level Fig (4.7). This trend is also confirmed by other authors as plant experience reduced photosynthesis due to low moisture and CO_2 (Pallardy et al, 2008; Dhupper, 2012). *A. nilotica* was found to differ significantly among the treatments. On the contrary, *P. dulce* produced the least biomass at 25% FC (Table 4.5).Plants subjected to moderate water stress are often very nearly the same size as well watered plants (Poorter *et al.*, 2012). The result of about dry shoot and root biomass of *P. dulce* demonstrated that 100% and 50% FC showed no reduction while only 25% FC showed significant variation.

Leaf biomass

Khurana and Singh (2001) observed that trees response in water shortage by reducing dry leaf biomass. In this experiment, though moisture level reduction resulted less leaf biomass for all the species, convincing trend was absent (Fig. 4.8, Table 4.6). It warrants further investigation of leaf morphology and anatomy in water stressed condition which was not part of this experiment.

Root biomass

Root biomass decrease was evident in this study. Significant variation of root biomass reduction was observed in case of *A. nilotica* indicates its response to low moisture. *P. dulce* on the other hand responded at 25% FC (Fig.4.9, Table 4.7). Though, it is believed plant invest more in root in drought condition, it was not evident in this study. This might be due to limited rooting media used in this study used. Root growth was also found to vary due to plant traits, rooting media, rhizosphere zone available and radial growth of the roots (Lindsey and Kilgore, 2013; Mc Michael and Quisenberry, 1991; Lloret et al., 1999).

CHAPTER SIX

Conclusion

In this study, *A. nilotica* was found to respond to moisture stress efficiently. It adjusted its growth behavior with available resources. *P. dulce* depicted a different niche as it is equally capable of maintaining growth at intermediate moisture stress. On the other hand, *S. macrophylla* was found to be intolerant to low moisture. All the species increased moisture storage with increasing moisture stress and it is accepted as a survival strategy against dry environment. Therefore, both *A. nilotica* and *P. dulce* can thrive into low moisture regime.

Recommendations

- This study should be extended for at least a year.
- Larger pot should be use to provide seedlings more belowground space.
- Rate of photosynthesis, chlorophyll content and leaf area in response to water stress should be studied.
- Soil water potential should be determined.

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