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Research Article

Acclimation of *Artocarpus chaplasha* (Chapalish) seedlings to soil water deficit

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Abstract

The aim of the present work was to investigate the potential acclimation of *Artocarpus chaplasha* (Chapalish) seedlings to soil water deficit. In the nursery of the Institute of Forestry and Environmental Sciences, Chittagong University, seedlings were grown on a mixture of nursery soil and cow dung (3:1) in black polythene tubes. Growth and yield of seedlings, and their shoot water content, declined under soil water limitation. Soil moisture content and shoot water content were highly correlated. Under soil water deficits, total mass production of Chapalish seedlings was negatively affected as indicated by a significant reduction in stem elongation, leaf expansion, and root, stem and leaf mass increment. Moreover, soil moisture content and root dry mass were linearly related. Within two weeks of re-watering, stem elongation, leaf expansion, and total plant and root mass significantly recovered in drought-stressed seedlings.

Keywords Drought resistance, water stress, total plant mass, shoots water content, re-watering

Introduction

In many regions of the world, seasonally irregular and variable rainfalls often result in serious water shortage and periodic drought. A decline in summer precipitation was likely over the central parts of arid and semi-arid Asia, leading to expansion of deserts and periodic severe water stress conditions (Cruz et al. 2007). The type of water status regulation may be a critical factor for plant survival and mortality in the context of climate change (Himmelsbach et al. 2011). Rainfed terrestrial plants often suffer from uncertain soil water availability, particularly in monsoon and savanna climates (Monteith 1977). During the 14 years period (1985 to 1998), a mean temperature increase of about 1°C in May and 0.5 °C in November was observed (Mirza 2002). In the IPCC 2007 report, Cruz et al. (2007) mentioned that in India, Pakistan, Nepal, and Bangladesh, water shortages have been attributed to rapid urbanisation and industrialisation, to population growth and inefficient water use, which are aggravated by changing climate and its adverse impacts on demand, supply and water quality. According to the same report, precipitation decline and droughts in most delta regions of Pakistan, Bangladesh, India and China have resulted in the drying up of wetlands and severe degradation of ecosystems.

Hence, soil water shortage is common in Bangladesh, particularly in the northwestern part of the country, which is currently undergoing a slow process of desertification. Evidence of desertification is obvious in northern part of Bangladesh (Anon 2005) and, especially, in the

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Barind Tract (Gain 2002). Here, every year, millions of nursery raised seedlings of different indigenous and exotic tree species are planted under national reforestation and afforestation program. However, 20-50 % of these seedlings die during dry season from October to April (Hassan 1987). Drought is a major factor affecting survivorship and growth of newly planted seedlings in forest plantations. Hence, knowledge on growth responses of relevant tree species to drought is important for effective selection of species to plant in dry regions.

Germination, seedling stage, and flowering are most critical for water-deficit damage. Stress imposed during these periods drastically affects crop growth, ultimately leading to massive losses in yield and quality (Frederick and Bauer 1996). Tree seedlings, grown in areas prone to periodic drought, may be highly stressed even immediately after planting when their roots did not yet penetrate into deeper soil layers to escape drying of soil close to surface. This stress may be very crucial for survival and growth. Although general patterns of responses to soil water deficit are similar in many species, there are important differences in physiological responses (Ludlow 1980) and development (Angus and Moncur 1977).

Although the influence of soil water on plant growth and physiology is quite well investigated, only few studies on drought stress responses during the establishment phase of forest tree species in forest plantations in Bangladesh have been published (Kabir et al. 2006, Ferdousee et al. 2010). Hence, the present study was conducted to assess the response of *Artocarpus chaplasha* (Chapalish) seedlings to soil water. This large deciduous tree species is indigenous to Bangladesh and may be a species appropriate for afforesting in this specific area. Chapalish is found scattered in moist deciduous and evergreen forests of the Sub-Himalayan tract and ranges from Nepal eastwards to Khasi Hills, lower Burma and Chittagong (Brandis 1906). Besides, the species is widely preferred by the farmers in large scale plantation due to its multipurpose uses. The aim of this study was to evaluate the potential to grow *Artocarpus chaplasha* seedlings under both high and low soil water availability. Furthermore, the ability of seedlings to recover from periodic drought should be established.

Material and methods

The experiment was carried out at the nursery of the Institute of Forestry and Environmental Sciences, University of Chittagong, Chittagong, Bangladesh (Fig. 1), experiencing tropical monsoon climate, i.e. hot, humid summer and cool, dry winter. Average monthly temperature varies between 21.8 °C and 29.2 °C maximum and 15 °C to 26 °C minimum; relative humidity is generally lowest (64 %) in February and highest (95 %) in June-September.

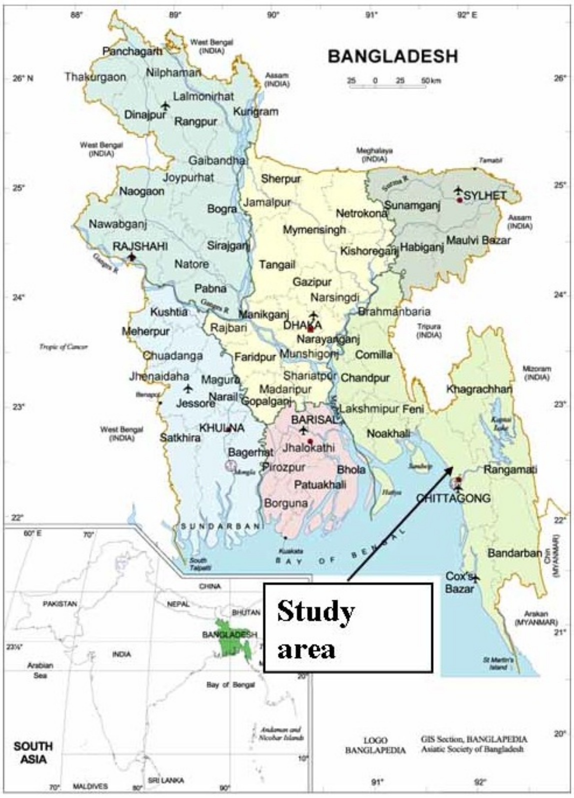

Fig. 1: Study area (Source: Banglapedia, National Encyclopedia of Bangladesh)

In Fig. 2, mean monthly maximum and minimum temperatures, total monthly rainfall, and mean monthly humidity at noon of Chittagong region is shown for the experimental period. Sixty-five, about 6 weeks old seedlings of Chapalish (*Artocarpus chaplasha* Roxb.) were transplanted

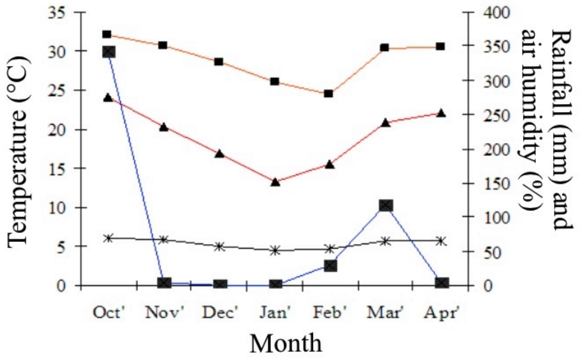

Fig. 2: Mean maxium temperature (--■--), mean minimum temperature (--▲--), rainfall (--■--), and air humidity (--*--) during the experiment.

into black polythene bags (diameter: 20 cm; depth: 50 cm) filled up to 48 cm with a mixture of nursery soil and cow dung (3:1). All bags were watered daily until seedlings had established as indicated by formation of new leaves. In the following experiment, batches of seedlings were either watered daily (controls, W_e; 30 plants) or exposed to drought for 40 to 42 d by withholding watering (W_n, 30 plants). After the drought cycle, 5 stressed seedlings (W_{res}) were continuously watered every day for additional 7 d, and other 5 stressed seedlings were watered for additional 14 d to study their potential to recover from stress.

During drying cycle, soil water content, stem length, leaf length, leaf dry mass, and stem and root mass were recorded at regular intervals (10 d) on 5 plants from each group. Soil water content was determined at two different layers (0-20 cm and 20-48 cm) of soil column (4 replications each) by measuring fresh (FM) and oven dry (at 70 °C for 72 h) mass (DM) of soil. Soil water content (g g^{-1}) was calculated as (FM - DM)/DM. Increase in stem length of seedlings was calculated by subtracting the initial length from the length of the following measurements. Stem length was measured after re-watering from the end of drying cycle for 10 d. Length of young growing leaves of both watered and un-watered seedlings was recorded in five replications at each sampling date. Leaf length was converted into leaf area, using following regression equation y (area) = -4.537+8.314 * x (leaf length) developed by plotting actual leaf area (measured by square grid method) against the length of 20 leaves. In addition, area of all leaves was measured using an image scanner (Canon-D2400U, Canon, Tokyo, Japan) and a imaging software (Scion Image, Scion Corporation, Frederick, USA).

At each sampling date, roots of each individual seedling were collected and root dry mass (dried at 70°C for 72 h) was measured. For the measurement of their mass, stems and leaves were separated during harvesting and their fresh and dry mass (at 70°C for 72 h) were recorded. Total mass was calculated summing leaf, stem and root mass of individual seedling.

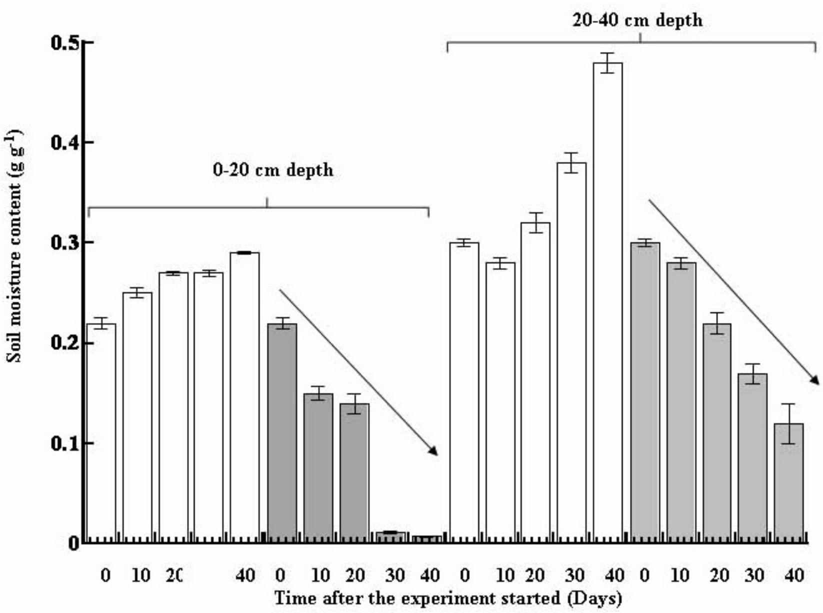

Fig. 3: Soil moisture content (SMC) at various depths at different point of time during the drying cycle of the experiment. In the figure white blank bar indicates W_e (Irrigated) and Gray bar indicates W_n (Non Irrigated)

From these data, specific shoot mass (SSM, shoot dry mass/shoot length), shoot mass ratio (SMR, shoot dry mass/total plant dry mass), leaf mass ratio (LMR, leaf dry mass/total plant dry mass), root mass ratio (RMR, root dry mass/total plant dry mass) and root to shoot ratio (R/S, root dry mass/shoot dry mass) were derived following Briggs et al. (1920).

Treatment differences were explored by two way analysis of variance and least significant difference test using Microsoft Excel and KaleidaGraph (Synergy Software, Reading, USA).

Results and Disussion

During drying cycle, soil water content of non-irrigated samples gradually declined (Fig. 3). Reduction was larger in the top (0-20 cm) layer than in the bottom (20-48 cm) layer as already found by Mohiuddin (1992), Kabir et al. (2006) and Ferdousee et al. (2010). This indicates that during progressing drying, plants must exploit moisture from ever deeper layers. Shoot water content of non-irrigated seedlings was also gradually and significantly reduced (Fig. 4). Shoot water content is of prime importance in detecting the influence of soil drying on shoot performance. As soil dries, the soil water potential is reduced, resulting in declining shoot water potential and the reduction of turgor (Sharp and Davies 1979). Due to the fact that shoot water content of non-irrigated seedlings gradually declined with soil water, a strong relationship between soil moisture content and shoot water content (R^2 = 0.78) was found in the present study.

Artificial drought significantly decreased growth of *A. chaplasha*. Stem elongation gradually ceased with the duration of drought. After six weeks of experiment, leaves completely wilted and the stem increment was 9 cm (Fig. 5a), which was almost half that of irrigated control plants (17 cm). However, growth of stressed plants fully recovered within two weeks of re-watering (Fig. 5b). Although stressed plants showed symptoms of recovery, their height was still significantly lower than that of constantly irrigated plants at the end

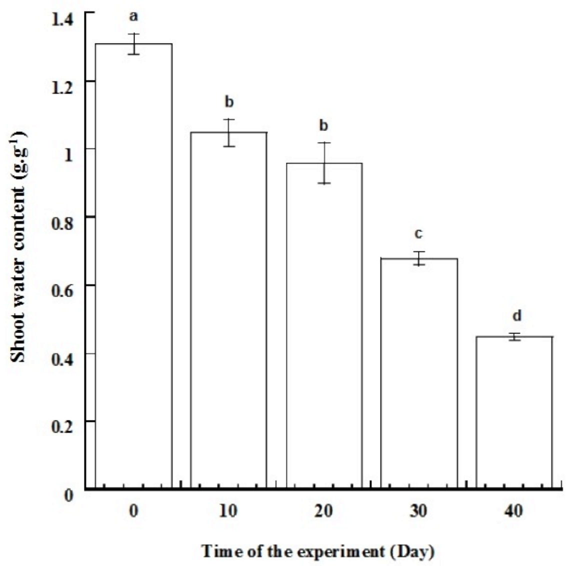

Fig. 4: Shoot water content in non-irrigated seedlings of *Artocarpus chaplasha* during the drying cycle of the experiment. Given are means ± SE (n=5); different letters indicate significant ($P < 0.05$) differences.

of the experiment (Fig 5c). Most of the measured growth parameters (dry mass of leaf, stem, roots and leaf area) were significantly lower in non-irrigated seedlings than in control plants during 6 weeks of drying cycle (Table 1, Fig. 6a). In contrast, differences for leaf area were not significant (Fig. 6b). So, total leaf area was not affected by the water regimes. Similar results were reported for poplar plants (Mohiuddin 1992) and *Chickrassia velutina* stem cuttings (Kabir et al. 2002) except for plant height. In a comparable experiment, Ferdousee et al. (2010) found the same trend in plants of *Acacia auriculiformis*. Ahmed et al. (2010) reported significant positive response of root and shoot length in watered Seriphidium quettense compared to stressed plants. In non-irrigated seedlings, reduction in leaf, stem and root dry mass resulted in gradually reduced total mass production. This lower total mass in non-irrigated seedlings compared to control plants is in agreement with the result of Pace et al. (1999), Cakir (2004), Villagra and Cavagnaro (2006). Although roots were more distributed to deeper soil layers (35-40 cm) in stressed than in control plants (20-30 cm), root dry mass production was significantly higher in

Table 1: Shoot dry mass (SDM), root dry mass (RDM), leaf dry mass (LDM) and total dry mass (TDM) measured at different phases.

	Stress Phase		Recovery Phase	
Parameter	W_e Watered daily	W_n Non-irrigated	W_e Watered daily	W_{res} Rewatered
SDM (g)	13.32 ± 0.23	9.86 ± 0.51	14.92 ± 0.14	14.77 ± 0.25
RDM (g)	11.98 ± 0.36	10.41 ± 0.33	14.37 ± 0.43	14.02 ± 0.37
LDM (g)	10.65 ± 0.33	8.08 ± 0.28	12.78 ± 0.37	11.95 ± 0.33
TDM (g)	35.95 ± 0.82	28.35 ± 0.99	42.07 ± 0.72	40.74 ± 0.90

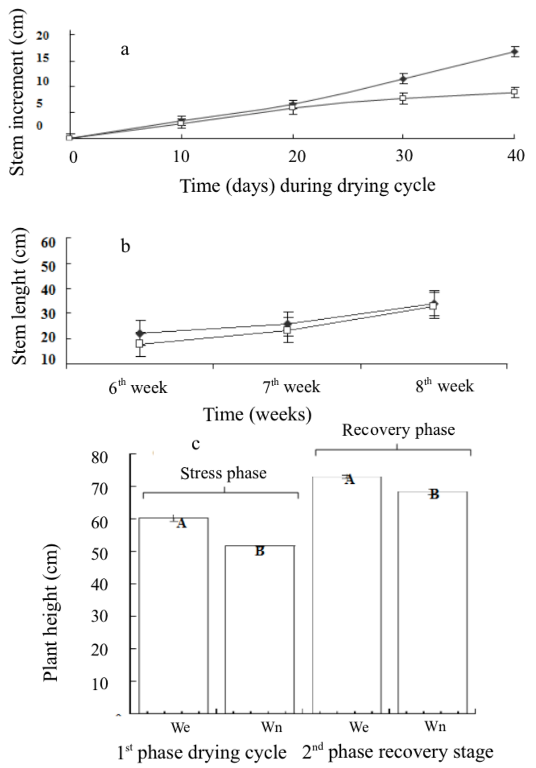

Fig. 5: Stem length (cm) and plant height (cm) of irrigated (♦) and non-irrigated (□) seedlings of *Artocarpus chaplasha* (a) after 40 d of drying cycle and (b) after re-watering as well as plant height (cm) of irrigated (W_e) and non-irrigated (W_n) *A. chaplasha* seedlings at the end of drought phases and after re-watering. Given points are means ± SE (n=5); different letters indicate significant (P < 0.05) differences.

continuously irrigated plants, obviously reflecting their better growth conditions.

As shown in Table 2, specific shoot mass (SSM) significantly decreased with reduction in watering frequencies. SSM was highest (0.221 g cm-1) in We and lowest (0.188 g cm^{-1}) in Wn. However, SSM of recovered plants (0.215 g cm^{-1}) was found higher than that of well-watered plants (0.204 g cm^{-1}). Shoot mass ratio but not leaf mass ratio was significantly reduced in non-irrigated plants during six weeks of drought. In contrast, both root mass ratio and root to shoot ratio significantly increased in stressed plants.

The decrease of total plant dry mass was due to lower root, shoot and leaf dry masses. This finding reflects those of Mohiuddin (1992), who reported significant reduction of total mass production with limited water supply in poplar. Phytomass production in plants is directly related to photosynthesis. Partial or complete inhibition of photosynthesis due to a decline in the photosynthetic capacity, and stomatal closure as a result of water stress has long been known.

Leaf area per plant was not significantly affected by drought. This result contradicts common observation that water shortage may inhibit leaf growth (Srinivas-Rao and Bhatt 1988). Reduced leaf water potential, resulting from limited water supply, may decrease net photosynthesis, so leaf growth is inhibited, as reported in sorghum (Shearman et al. 1972). Closure of stomata, in response to limited soil water supply, inhibits carbon dioxide uptake and

Table 2: Specific shoot mass (SSM), shoot mass ratio (SMR), leaf mass ratio (LMR), root mass ratio (RMR) and root shoot ratio (R/S) measured at different phases.

	Stress Phase		Recovery Phase	
Parameter	W_e Watered daily	W_n Non-irrigated	W_e Watered daily	W_{res} Rewatered
SSM	0.22	0.19	0.20	0.22
SMR	0.37	0.35	0.36	0.36
LMR	0.30	0.29	0.30	0.29
RMR	0.33	0.37	0.34	0.35
RSR	0.49	0.58	0.52	0.52

results in reduced supplies of assimilates available for allocation to the growing leaves. Thus, leaf growth is adversely affected, as reported for wheat (Masle and Passioura 1987). In contrast, some plants may acclimate to soil drying by increasing the concentration of solutes in the symplast, which may help to maintain turgor at low tissue water potentials. This also facilitates the continuous extraction of water from dry soil. In addition, turgor maintenance allows cell expansion (Turner 1986) to be continued in leaves with no significant decrease in total leaf area. It seems highly probable that Chapalish might, indeed, maintain turgor in cells of expanding leaves, potentially being the reason for the insignificant effects of drought on leaf area change per plant in Chapalish.

Plant height was significantly affected by water shortage, while specific shoot mass (SSM) significantly decreased in non-irrigated plants. This means that shoot length was affected with less material under drought stress conditions. Soil drying induces stomatal closure before any change in leaf water status occurs (Gollan et al. 1986). Stomatal closure protects plants against excessive water loss but also reduces carbon dioxide uptake and, hence, net photosynthesis (Downton et al. 1988; Metcalfe et al. 1989, Seiler and Cazell 1990).

Leaf area ratio (LAR) increased (data not shown because the difference was not significant) in non-irrigated plants with simultaneous increase in specific leaf area (SLA) but almost no change in leaf mass ratio (LMR). Such increase in SLA in water-limited plants was reported for some *Eucalyptus* species (Bachelard 1986) and for poplar (Mohiuddin 1992). Increased SLA indicated that plants, growing under conditions of low water supply, produced thinner leaves. In other words, the same leaf area was produced with less material. This might be related to leaf development and limited carbon dioxide fixation under drought conditions (Michael et al. 1988).

The root to shoot ratio significantly increased with limited water supply (Table 2). It is reported that mechanism of acclimation to soil drying involves a shift in the allocation of assimilates from shoot to root. Soil drying stimulates root growth and proliferation deep into the soil profile (Molyneux and Davies 1983). Such structural changes in rooting are generally correlated with a reduction in shoot growth (Kramer 1983), resulting in an increase in root growth in absolute terms (Khalil and Grace 1992) or relative to shoot growth (Osonubi and Fasehun 1987). However, extreme soil drying ultimately reduces root growth (Seiler and Cazell 1990).

Most of the measured growth parameters (leaf area, stem length, root dry mass, total dry mass) of non-irrigated seedlings almost completely recovered within two weeks of re-watering (Fig. 5c, 6, Table 1 and 2). Similar results were reported by Mohiuddin et al. (1994). After re-watering, total dry mass, root dry mass, stem elongation

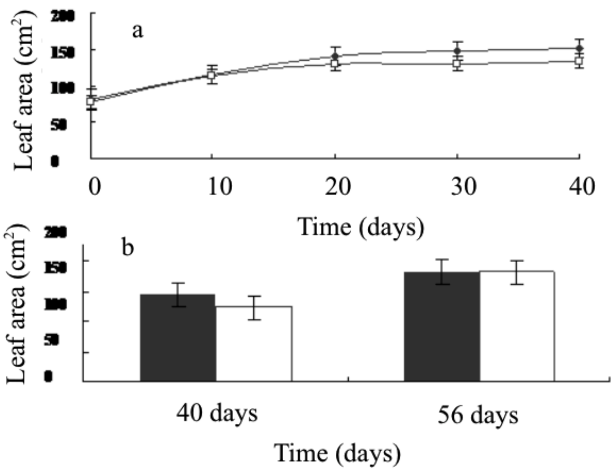

Fig. 6: Leaf area (cm^2) of growing seedlings of *Artocarpus chaplasha* (a) after 40 d of drying cycle and (b) after rewatering. Given are means ± SE (n=5), different letters indicate significant ($P < 0.05$) differences; irrigated control (♦); non-irrigated (□).

and leaf elongation of the stressed, wilted seedlings significantly increased probably because the accumulated solutes allowed these plants to absorb more water from the soil. As a result, stressed seedlings nearly completely recovered growth within 14 d after re-watering.

Conclusion

The results suggest that *Artocarpus chaplasha* can acclimate to drying of soil with significant decrease in total plant biomass. The results also suggest that *A. chaplasha* has a high drought tolerance and, thus, the capability to survive long periods of drought (almost six weeks). The growth and physiological behaviour of plants in an environment, particularly in controlled environment, may be used to predict the performance of the species in the field under similar conditions. Accuracy of prediction should be tested through small scale experiments in the field under the similar conditions. In *A. chaplasha,* increment in root system, seedling growth and development, leaf elongation, stem length and total dry mass depends on soil moisture content. At the same time, the recovery of growth traits with re-watering suggests that in the areas where drought periods do not exceed 6 weeks Chapalish may be successfully grown. In a nutshell, *A. chaplasha* has excellent potential to be one of the best plantation species in Bangladesh. The result of the present study also adds another criterion to make it popular for mass scale plantation and detailed field level research.

References

Ahmad, S., Gul, S., Achakzai, A.K.K., Islam, M., 2010. Seedling growth response of *Seriphidium quettense* to water stress and non-water stress conditions. Int. J. Exp. Bot. (ΦYTON) 79, 19-23.

Angus, J.F., Moncur, M.W., 1977. Water stress and phenology in wheat. Aust. J. Agr. Res. 28, 177-181.

Anon, 2005. National Action Programme (NAP) for Combating Desertification in Bangladesh. Department of Environment, Ministry of Environment and Forest, Government of the Peoples Republic of Bangladesh and IUCN – The World Conservation Union Bangladesh Country Office. Bangladesh.

Bachelard, E.P., 1986. Effects of soil moisture stress on the growth of seedlings of three Eucalyptus species. II. Growth effects. Aust. Forest Res. 16, 51-61.

Briggs, G.E., Kidd, F., West, C., 1920. A quantitative analysis of plant growth, II. Ann. Appl. Biol. 7, 202-223.

Brandis, D., 1906. Indian trees. International Book Distributors, Dehra Dun, pp. 489-491.

Cakir, R., 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Res. 89, 1-16.

Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin Y., Punsalmaa, B., Honda Y., Jafari, M., Li, C., Huu Ninh, N., 2007. Asia. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.): Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 469-506.

Downton, W.J.S., Loveys, B.R., Grant, W.J.R., 1988. Non-uniform stomatal closure induced by water stress causes putative nonstomatal inhibition of photosynthesis. New Phytol. 110, 503-510.

Ferdousee, N., Ahmed, R., Kabir, M.A., Hoque, A.T.M.R., Mohiuddin, M., 2010. Growth and yield performance of growing seedlings of

Acacia auriculiformis (Fabaceae) under limitation of soil water. Res. on Crops 11, 187-194.

Frederick, J.R., Bauer, P.J., 1996. Winter wheat responses to surface and deep tillage on the south eastern coast plain. Agron. J. 88, 829-833.

Gain, P [Ed], 2002. Bangladesh environment, Facing the 21st Century [2nd edition]. Society for environmental and Human Development (SHED), Bangladesh.

Gollan, T., Passioura, J.B., Munns, R., 1986. Soil water status affects the stomatal conductance of fully turgid wheat and sunflower leaves. Aust. J. Plant Physiol. 13, 459-464.

Hassan, M.M., 1987. Working depth for tree planting in relation to soil moisture control section and texture. Ind. J. For. 10, 89-93.

Himmelsbach, W., Treviño-Garza, E.J, González-Rodríguez, H., González-Tagle, M.A.,Gómez Meza, M.V., Aguirre Calderón, O.A., Estrada Castillón, A.E.,Mitlöhner,R., 2011. Acclimatation of three co-occurring tree species to water stress and their role as site indicators in mixed pine-oak forests in the Sierra Madre Oriental, Mexico. Eur. J. Forest. Res. (Online first viewed) DOI 10.1007/s10342-011-0507-3.

Kabir, M.A., Kamaluddin, M., Miah, M.D., 2002: Acclimation of *Chickrassia velutina* Wight et. Arn. stem cuttings to water stress. The Indian Forester 128, 439-444.

Kabir, M.A., Hoque, A.T.M.R., Kamaluddin, M., 2006. Acclimation of acacia hybrid (*Acacia mangium* × *Acacia auriculiformis*) vegetative propagules to soil water deficits. Dendrobiol. 56, 37–43.

Khalil, A.A.M., Grace, J., 1992. Acclimation to drought in *Acer pseudoplatanus* L. (Sycamore) seedlings. J. Exp. Bot. 43, 1591-1602.

Kramer, P.J., 1983: Water relations of plants. Academic press, Inc. New York.

Ludlow, M.M., 1980: Adaptive significance of stomatal responses to stress. In: Turner, N.C., Kramer, P.J. (Eds.): Adaptations of plants to water and high temperature stress. Wiley and Sons, New York, pp. 123-138.

Molyneux, D.E., Davies, W.J., 1983: Rooting pattern and water relations of three pasture grasses growing in drying soil. Oecologia 58, 220-224.

Masle, J., Passioura, J.B., 1987: The effects of soil strength on the growth of young wheat plants. Aust. J. Plant Physiol. 14, 643-656.

Metcalfe, J.C., Davies, W.J., Pereira, J.S., 1989: Effects of water deficit on leaf growth and initiation of fast growing tree species. Ann. Sci. For. Suppl. 46, 366-368.

Michael, D.A., Isebrands, J.G., Dickmann, D.I., Nelson, N.D., 1988. Growth and development during the establishment year of two *Populus* clones with contrasting morphology and phenology. Tree Physiol. 4, 139-152.

Mirza, M.Q., 2002. Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. Global Environ. Chang. 12, 127-138.

Mohiuddin, M., 1992. Plant water relations in a model agroforestry system. Ph.D. thesis, University of Edinburgh, UK.

Mohiuddin, M, Jarvis, P.G., Russell, G., 1994. Effect of different levels of soil water stress on root development of Bean and Poplar in a simulated agroforestry. Bangladesh J. For. Sci. 23, 32-37.

Monteith, J.L., 1977. Climate. In: Alvim, Pde.T, Kozlowski, T. (Eds.): Ecophysiology of tropical crops. Academic Press, New York and London, pp. 1-27.

Osonubi, O., Fasehun, F.E., 1987. Adaptations to soil drying in woody seedlings of African locust bean. Tree Physiol. 3, 321-330.

Pace, P.F., Cralle, H.T., El-Halawany, S.H.M., Cothren, J.T., Sensaman, S.A., 1999: Drought-induced changes in shoot and root growth of young cotton plants. J. Cotton Sci. 3, 183-187.

Seiler, J.R., Cazell, B.H., 1990: Influence of water stress on the physiology and growth of red spruce seedlings. Tree Physiol. 6, 69-77.

Sharp, R.E., Davies, W.J., 1979: Solute regulation and growth by roots and shoots of water-stressed maize plants. Planta. 142, 43-49.

Shearman, L.L., Eastin, J.D., Sullivan, C.Y., Kinbacher, E.J., 1972: Carbon dioxide exchange in water stressed sorghum. Crop Sci. 12, 406-409.

Srinivasa-Rao, N.K., Bhatt,R, 1980. Photosynthesis, transpiration, stomatal diffusive resistance, and relative water content of *Capsicum* (Bell Pepper) grown under water stress. Photosynthetica 22, 377-382.

Srivastava, J.P., Tyagi, D.N., 1999. Advances in water relation and moisture stress studies of plants. In: Passarakli, M. (Ed.): Handbook of plant and crop stress. Marcel Dekker Inc., New York, Basel, pp. 1029-1039.

Turner, N.C., 1986: Adaptation to water deficits: a changing perspective. Aust. J. Plant Physiol.13, 175-190.

Villagra, P.E, Cavagnaro, J.B., 2006: Water stress effects on the seedling growth of *Prosopis argentina* and *Prosopis alpataco*. J. Arid Environ. 64, 390-400.

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