# Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 10 (5): 294-300, 2011
ISSN 1682-3974 / DOI: 10.3923/ajps.2011.294.300


# Effects of Different Soil Moisture Regimes on Leaf Area Index, Specific Leaf Area and Water use Efficiency in Eucalyptus (*Eucalyptus camaldulensis* Dehnh) under Dry Climatic Conditions

[1]M.H. Rad, [2]M.H. Assare, [3]M.H. Banakar and [4]M. Soltani
[1]Member of Scientific Board, Agricultural and Natural Resource Research Center of Yazd Province, P.O. Box 89165-571, Azadegan Bulvar., Yazd, Iran
[2]Member of Scientific Board, Research Institute of Forests and Rangelands, P.O. Box 13185-116, Tehran, Iran
[3]Member of Scientific Board, National Salinity Research Center, P.O. Box 89195-315, Azadegan Bulvar., Yazd, Iran
[4]Researcher of Agricultural and Natural Resource Research Center of Yazd Province, P.O. Box 89165-571, Azadegan Bulvar., Yazd, Iran

**Abstract:** *Eucalyptus camaldulensis* Dehnh is one of the most important planted species in Iran, because of its fast growth and resistant to drought stress. Nonetheless, drought stress limited the suitable growth and decreases the pulp qualities and quantity. The aim of this study was to get information about the effects of drought stress on *Eucalyptus camaldulensis* Dehnh behavior of morph-physiology characteristics. Changes in Leaf Area Index (LAI), Specific Leaf Area (SLA) and Water Use Efficiency (WUE) of three-years old trees under three soil moisture regimes (100, 70 and 40% of field capacity) under lysimeteric conditions were studied. The trials were carried out during the years of 2006-2008 in Shahid Saduqi Desert Research Station of Yazd, Iran. Results showed that a significant reduction of soil moisture effects on the reduction of biomass production and leaf area index. Water use efficiency and specific leaf area significantly increased with increasing stress; however, not significant difference was observed between treatments of 70 and 40% of field capacity. Severe drought (40% of field capacity) reduced water use efficiency in wood production without any significant differences to 100% of field capacity treatment. This implied that a moderate level of drought stress improved water use efficiency in this species of eucalyptus in an arid climate. Severe drought stress induced a reduction in water use efficiency. Therefore, it can be concluded that appropriate growth of this species and an economic production of wood depends thoroughly on soil moisture content. As a result, severe drought stress will impair many morphological and physiological behaviors.

**Key words:** Eucalyptus, drought stress, biomass components, leaf area index, specific leaf area, water use efficiency

## INTRODUCTION

Plants can absorb maximum water from the soil and minimal water loss from their leaves to cope with drought stress (Arndt *et al*., 2001). For drought resistance, several morphological, physiological and biochemical mechanisms are used (Sanchez-Blanco *et al*., 2009; Mefti *et al*., 2008; Zhang *et al*., 2005; Lei *et al*., 2007). This strength is based on adaptability and stability under drought conditions. Some plants are able to keep their water status in good conditions and delay the negative effects of drought stress (Levitt, 1980). Other plants are able to tolerate relatively prolonged periods of drought stress. High osmotic adjustment, high root to shoot ratio, high transpiration efficiency and high water use efficiency, are some adaptability strategies to drought tolerance. Plants are able to keep their high water potential and avoid the negative effects of drought stress (Xoconostle-Cazares *et al*., 2010; Sanchez-Blanco *et al*., 2009; Gebre and Tschaplinski, 2000).

For short-term deficiencies (e.g., at noon), balances between water uptake and water loss is caused through stomatal closure (Kramer and Boyer, 1995; Banon *et al*., 2004). In this case, the $CO_2$ absorption rate is limited and

**Corresponding Author:** M.H. Rad, Member of Scientific Board, Agricultural and Natural Resource Research Center of Yazd Province, P.O. Box 89165-571, Azadegan, Bulvar., Yazd, Iran Tel: +98 351 7212414 -15 Fax: +98 351 7222261

net photosynthesis decreased (Maricle *et al*., 2008). For long-term deficiencies, adaption is obtained by increasing root to shoot ratio (Bacelar *et al*., 2007; Li and Wang, 2003). High root to shoot ratio may be very effective in adaptation to drought stress (Li and Wang, 2003; Gazal and Kubiske, 2004; Bargali and Tewari, 2004). Drought stress perhaps affect the ratio of transpiration surface area and soil water absorbing surface area (ratio of shoot to root) which might be the cause for reduced evapotranspiration rate (Sarker and Hara, 2004). In other words, in arid regions, the first and most common feature of plant growth is increasing of root to shoot ratio, although the ratio is controlled genetically. Under drought conditions, root development takes place through the transfer of nutrients from leaves and stems to roots (Dias *et al*., 2007). It seems that increasing in soil moisture increases the weight of shoot portions, whereas in water stress conditions, the weight of shoot is more affected than roots. Hence, under water stress conditions, root growth is stunted shoots ahead. This situation will increase the ratio of root to shoot (Chiatante *et al*., 2006).

Very large majority of industrial forests in the world are planted with 10 species of Eucalyptus of which *E. camaldulensis* is one of the most important species. *E. camaldulensis* is one of the best species for land reclamation, especially lands with high groundwater table where soil is saline and alkali. Butcher and Southerton (2007), noted that *E. camaldulensis* is naturally distributed in regions with 250-1600 mm of rainfall.

In Iran, arid and semi-arid regions are vastly distributed. Aridity and salinity are the most adverse environmental factors limiting crop vegetation. Selecting of tolerant plant species to improve vegetation and economic exploitation of these areas has always been considered. Hence, planting of eucalyptus species has started from 1931 in the northern area of Iran. The species is now allocated to north, center and south areas of the country at a significant level (Sardabi, 1998). Among all eucalyptus species, most attention has been paid to *E. camaldulensis* due to having high resistance to adverse environmental conditions. Despite large plantation of *E. camaldulensis* all over the country, little information is available about the morphological and physiological behaviors. The aim of the present experiment was to study some morphological and physiological behaviors of *E. camaldulensis* under drought stress conditions.

## MATERIALS AND METHODS

**General description of the site:** This research was carried out during the years of 2006-2008 in Shahid Saduqi Desert Research Station of Yazd, Iran. This station located at 54°11′ 9′′ East longitude and 22°4′ 30′′ North latitude with an elevation of 1158 m above sea level. The site has an average annual precipitation of 70 mm and a maximum wind speed of 120 km $h^{-1}$. The climate of the site is described as a cold hyper-arid climate.

**Procedure:** In this experiment, a total number of nine weighing cylindrical lysimeters with an internal diameter of 121 and a height of 160 cm were used. All lysimeters were made of galvanized iron covered with fiber glass and glass wool to reduce temperature exchanges. The bottom of each lysimeter had a slope of 2 cm to drain excess water into an outlet tube. For this purpose a 10 cm layer of coarse sand covered with a 5 cm layer of fine sand were placed into the bottom of lysimeters. All lysimeters filled with a silty-loam soil having a bulk density of 1.58 g $cm^{-3}$, an electrical conductivity of 4.1 dS $m^{-1}$ and a pH of 7.1.

After preparing lysimeters, a 1-year old seedling was planted in each lysimeter irrigated with 50 liters of water (1.07 dS $m^{-1}$) every 15 days. One year later, soil moisture regimes including 100, 70 and 40% of field capacity were treated in the form of complete randomized design with three replications. All lysimeters were weighed to determine soil moisture. Soil moisture was also measured by TDR (TRIME Model) at different soil depths (20, 40, 60, 80, 100 cm).

**Measured properties:** Shoot weight: At the end of experiment, the aerial portion of trees was cut at the soil surface, weighed rapidly, placed in oven at 70°C for 48 h and then weighed again (Yin *et al*., 2005).

**Root weight:** All roots were removed from the soil, rinsed thoroughly with water and then weighed as described above.

**Leaf area index:** At the end of experiment, 30 leaves of each tree from different parts were cut randomly. The area of each leaf was measured with a leaf area meter (AM200, Bioscientific Co.). To calculate the leaf area of the tree, the number of leaves multiplied by the average leaf area. Leaf area index is defined as the leaf area of tree per the area of canopy (Burton *et al*., 1991; Cutini *et al*., 1998).

**Specific leaf area:** Specific leaf area is defined as a mean area of leaf surface which is equivalent to one gram. To calculate specific leaf area, the third leaves of four lateral branches were cut, measured by leaf area meter, oven dried at 70 for 24 h and weighed (Cutini *et al*., 1998).

**Water use efficiency:** The water use efficiency of each treatment calculated by below Eq.:

$$WUE=\frac{D}{W}$$

where, WUE was water use efficiency, D was total aerial dry matter production and W was the volume of consumed water. In the present study, the water use efficiency for wood production was also determined.

**Data analysis:** SAS statistical software was used for data analysis, correlations and all mean comparisons (Duncan). A p-value of 0.05 was considered statistically significant. All graphs were drawn using Microsoft office excel.

## RESULTS

**Biomass production:** Analysis of variance results for shoot dry weight showed that there was a significant difference ($p<0.001$) among all soil moisture regimes (Table 1).

As shown in Table 1, there is a very significant difference for dry matter between treatments of field capacity 100 or 70% and field capacity 40%. Analysis of variance for other yield components including leaves, main and lateral branches showed a significant difference among all treatments at $p<0.001$. On the other word, increasing soil moisture or decreasing drought stress increased all components of shoot dry weight.

Results given in Table 1 also showed that root dry weight increased significantly with increasing soil moisture content. The same trend was observed for root to shoot ratio ($p<0.001$). On the other word, reduction in soil moisture content was more effective in decreasing of root to shoot ratio.

Results given in Table 1 showed no significant difference of branch to leaf ratio among all soil moisture treatments. The relationship of shoot dry weight and their components with roots indicated a positive correlation between them as shown in Fig. 1.

**Specific leaf area:** Results given in Table 1 showed that there was a significant difference of specific leaf area

Table 1: Total biomass yield, yield components, root to shoot ratio, branch to leaf ratio, special leaf area and leaf area index of *E. camaldulensis* under different soil moisture regimes

| | Dry matter (g) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatments (%) | Leaf | Lateral branch | Main branch | Root | Total | Root/branch | Branch/leaf | SLA ($cm^2 gr^{-1}$) | LAI |
| 100 FC | 1570.25[a] | 423.27[a] | 1602.38[a] | 4288.30[a] | 7884.30[a] | 1.19[a] | 1.29[a] | 68.34[b] | 3.85[a] |
| 70 FC | 1091.20[b] | 251.57[b] | 1022.19[b] | 2381.70[b] | 4746.66[b] | 0.99[b] | 1.16[b] | 75.10[a] | 2.92[b] |
| 40 FC | 602.20[c] | 193.01[c] | 253.09[c] | 525.70[c] | 1574.00[c] | 0.51[c] | 0.74[c] | 81.08[a] | 0.85[c] |

Means followed by the same letter are not significantly different (p = 0.001)

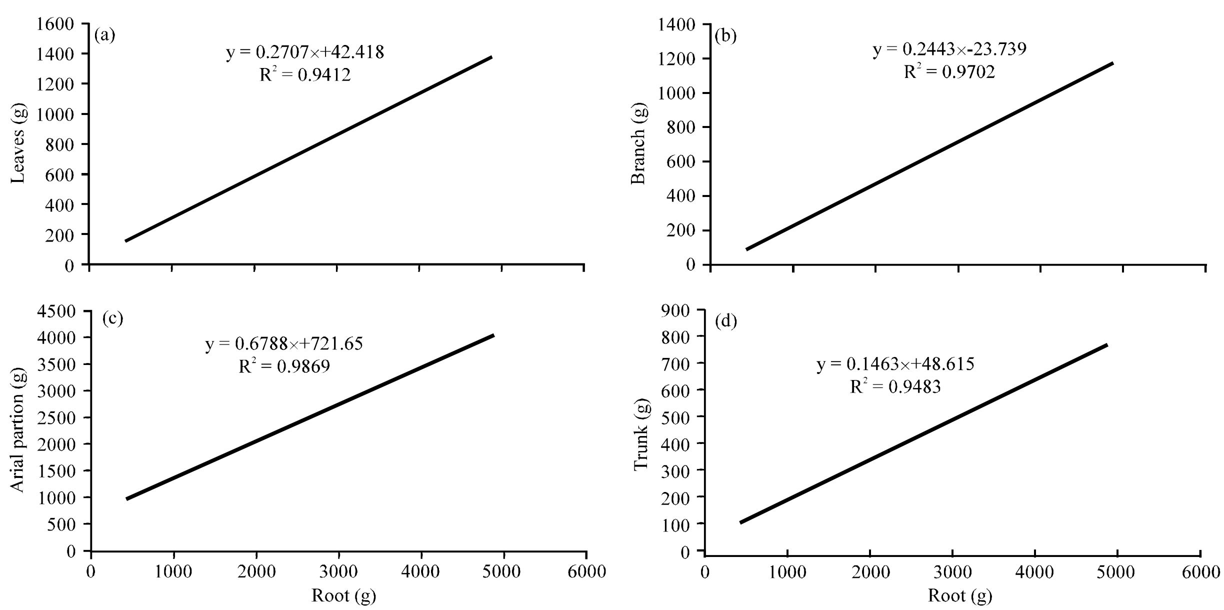


Fig. 1 (a-d): The relationship between root dry weight and all shoot components

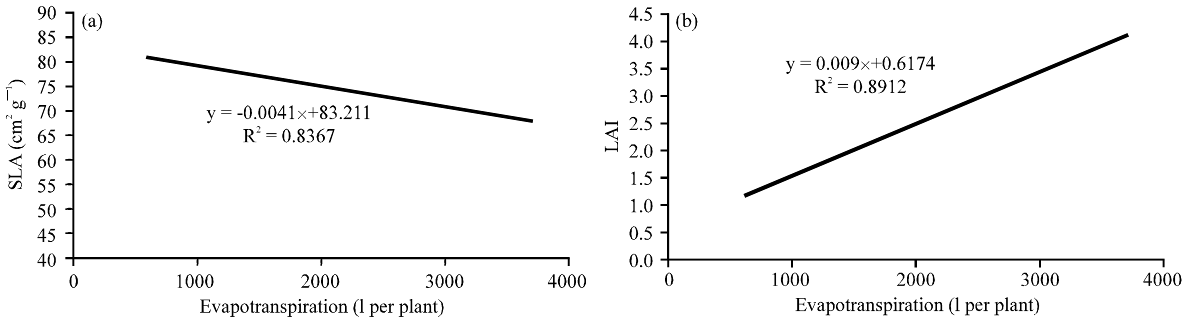


Fig. 2 (a-b): The relationship between special leaf area, leaf area index and the rate of evapotranspiration

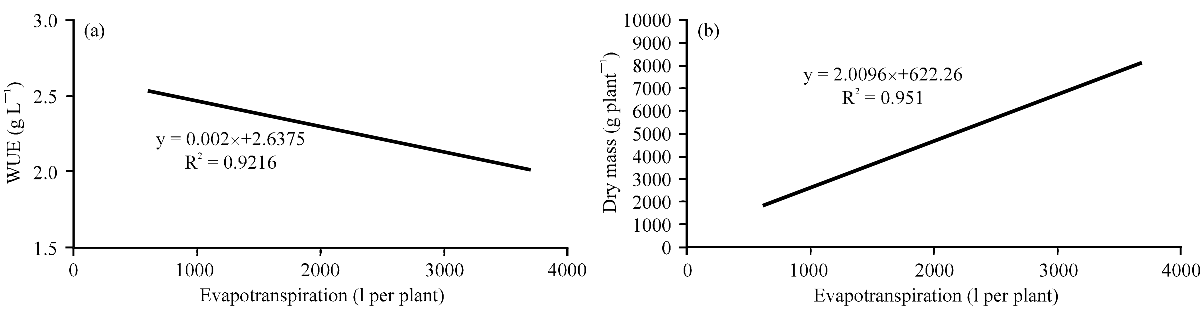


Fig. 3 (a-b): The relationship between dry mass, water use efficiency and the rate of evapotranspiration

among all soil moisture regimes ($p<0.001$). The relationship between specific leaf area and the rate of evapotranspiration is shown in Fig. 2.

**Leaf area index:** Results given in Table 1 showed that leaf area index increased significantly with increasing soil moisture content. The relationship between leaf area index and the rate of evapotranspiration is shown in Fig. 2.

**Water use efficiency:** Water use efficiency is defined as the amount of dry matter production (Root and shoot) per unit of water consumed (evapotranspiration). Detail on the amount of water consumed (evapotranspiration), dry matter production (Root and shoot) and the amount of wood production is given in Table 2. There is no significant difference between the water use efficiency (based on total dry matter production) of 70 and 100% field capacity treatment as shown in Table 2. The water use efficiency decreased with decreasing the amount of evapotranspiration and this effect was highly significant in the treatment of 40% of field capacity. Result showed that the water use efficiency (based on wood production) improved under moderate stress (70% field capacity) which was very significant to others. This means that the water use efficiency of 70% field capacity treatment is 0.48 g $L^{-1}$ under moderate stress where as 100 and 40% of field capacity treatment produce 0.34 and 0.36 g $L^{-1}$ water use efficiency respectively.

Table 2: The rate of evapotranspiration and water use efficiency of *E. camaldulensis* for different soil moisture regimes

| Treatments | 40%FC | 70%FC | 100%FC |
|---|---|---|---|
| Evapotranspiration (L) | 4345.00$^{a}$ | 2133.50$^{b}$ | 690.60$^{b}$ |
| Total dry biomass (g) | 7884.30$^{a}$ | 4746.66$^{b}$ | 1574.00$^{b}$ |
| Total WUE (g $L^{-1}$) | 1.81$^{b}$ | 2.23$^{a}$ | 2.28$^{a}$ |
| Wood biomass (g dry matter) | 1602.38$^{a}$ | 1022.19$^{b}$ | 235.00$^{b}$ |
| Wood WUE (g $L^{-1}$) | 0.36$^{b}$ | 0.48$^{a}$ | 0.34$^{b}$ |

Means followed by the same letter are not significantly different ($p = 0.001$)

**Relationship between evapotranspiration and measured parameters:** Results showed that increasing in evapotranspiration had a positive effect on dry matter production where as a reverse effect of evapotranspiration was observed for water use efficiency as shown in Fig. 3. This feature was also showed a positive correlation with leaf area index. However, evapotranspiration had a negative effect on and special leaf area (Fig. 2).

## DISCUSSION

The effect of drought stress through reductions in growth and biomass production can be occurred. Results of this experiment showed that different soil moisture regimes had different effects on dry matter production in both shoots and roots. Many studies indicate that increasing in drought stress could decrease all plant dry weight (Omidi, 2010; Jongrungklang *et al.*, 2008; Abdalla and El-Khoshiban, 2007; Hamada, 1996).

However, Kameli and Losel (1996) reported that drought stress may increase root weight and decrease shoot weight. The absorption of nutrients from the soil depends on the availability of water to roots. It is reported that soil water deficit may reduce root growth and limit nutrient uptake by roots (Arndt *et al*., 2001). With continued stress, closure of the stomata, reducing of transpiration rate and carbon fixation will occur. This may induce a reduction in photosynthesis rate and more reduction in biomass production (Kramer and Boyer, 1995). Results of this experiment showed a Significant reduction of dry matter in all different parts of drought-treated trees including leaves, main branches, lateral branches and roots. A reduction in root dry weight of 4288.3 to 525.7 g of field capacity 40% indicated the significant effect of drought stress on root production.

Results of this experiment showed that drought stress reduced root to shoot ratio (R/S) from 1.2 to 0.51. The ratio was 0.98 in the field capacity of 70% treatment. In other words, the plant can also produce enough roots at 30% of drought stress. More stress caused a reduction in root growth, water uptake, mineral deficit and finally stop the growth. Gindaba *et al*. (2004) reported a root to shoot ratio of 0.76 for Eucalyptus seedlings under greenhouse conditions.

Li and Wang (2003), Gazal and Kubiske (2004), Bargali and Tewari (2004) consider a high root to shoot ratio as a drought tolerant parameter. They have emphasized that the first and most common feature of plant growth is increasing of root to shoot ratio in arid regions.

Susiluoto and Berninger (2007) had attributed the increasing of root to shoot ratio of *E. microtheca* as a drought resistance strategy. In this case, it appears that the species is not resistant to drought, because of low root to shoot ratio under drought stress. Merchant *et al*. (2007) classified *E. microtheca* as a Phreatophytic species. These plants grow their roots to maximize water up take from the soil.

Drought stress has a significant effect on growth and accumulation of organic matter in various parts of tree leaves by reducing the rate of photosynthesis. Results of this experiment showed the least amount of specific leaf area for 100% of field capacity treatment in comparison to others. In this study, mean specific leaf area ranged from 68.4 to 81.1 $cm^2$ $g^{-1}$. These variations are due to different soil moistures treatments. This feature increased significantly with decreasing soil moisture.

In Australia, the amount of special leaf area was reported between 20 to 80 $cm^2$ $g^{-1}$ for Eucalyptus forests (Specht and Rundel, 1990). Specht and Rundel (1990) also noted that the least amount of specific leaf area was for natural forests with dry conditions whereas most of the planting forests with high soil moisture had the maximum special leaf area. New leaves naturally have a great amount of special leaf area. At the end of the growing season, this feature greatly reduced. It should be noted that specific leaf area is affected by several factors other than availability to water including nutrient status and accessibility to light.

Results of this study showed that increasing in soil moisture decreased the amount of water use efficiency. This may be due to opening the stomata and more water loss from their leaves. In this experiment, increasing soil moisture resulted in increasing the number of leaves indicating the ability of plant to improve transpiration surface. Increasing in transpiration rate due to increasing leaf area index and special leaf area may result in decreasing water use efficiency. This is one of the most effective ways to up take more water from the soil.

Results showed that treatments of 70 and 40% of field was improved capacity resulted in a yield reduction of 39 and 80%, respectively. However, water use efficiency improved in 70% of field capacity treatment (2.23 g $L^{-1}$) with out any significant difference to 40% of field capacity treatment. As a result, it can be concluded that the maximum drought stress having a yield reduction of 61% in comparison to 100 of field capacity treatment is 30% under water deficit conditions. Continuing the stress resulted in more reduction in yield and water use efficiency. However, moderate drought stress improved water use efficiency. Severe drought stress reduces significantly water use efficiency through stomatal closure and low rate of $CO_2$ diffusion. Gindaba *et al*. (2004), in a greenhouse experiment reported a decrease in water use efficiency for *Cordia Africana*, *Croton macrostachyus*, *E. camaldulensis*, *E. globulus* and *Millettia ferruginea* under drought stress. They also reported the amount of water use efficiency for *E. camaldulensis* 1.8, 4, 4.5 and 4.9 g $L^{-1}$ under 25, 50, 75 and 100% of field capacity, respectively. Although these results are inconsistent with the results presented by Davidson (1989), who reported 1.27 g $L^{-1}$ of water use efficiency for Eucalyptus trees, Li (1999) studied the water use efficiency of three Eucalyptus accessories under three levels of drought stress and found that there was a strong relationship between growth and water use efficiency. He believed that the growth rate of Eucalyptus depended on the rate of transpiration.

## CONCLUSION

Aridity is one of the most important environmental factors affecting plant growth yield and yield components. Results showed that increasing in yield components of Eucalyptus species obtained under optimum environment conditions.

**REFERENCES**


Abdalla, M.M. and N.H. El-Khoshiban, 2007. The influence of water stress on growth, relative water content, photosynthetic pigments, some metabolic and hormonal contents of two *Triticium aestivum* cultivars. J. Applied Sci. Res., 3: 2062-2074.

Arndt, S.K., S.C. Clifford, W. Wanek, H.G. Jones and M. Popp, 2001. Physiological and morphological adaptation of the fruit tree *Ziziphus rotundifollia* in response to progressive drought stress. Tree Physiol., 21: 705-715.

Bacelar, E.A., J.M. Moutinho-Pereira, B.C. Goncalves, H.F. Ferreira and C.M. Correia, 2007. Changes in growth, gas exchange, xylem hydraulic properties and water use efficiency of three olive cultivars under contrasting water availability regimes. Environ. Exp. Bot., 60: 183-192.

Banon, S.J.A., J.A. Fernandez, A. Franco, J.J. Torrecillas, A. Alarcon and M.J. Sanchez-Blanco, 2004. Effects of water stress and night temperature preconditioning on water relation and morphological and anatomical changes of *Lotus creticus* plants. Sci. Hortic., 101: 333-342.

Bargali, K. and A. Tewari, 2004. Growth and water relation parameters in drought-stressed *Coriaria nepalensis* seedlings. J. Arid Environ., 58: 505-512.

Burton, A.J., K.S. Pregitzer and D.D. Reed, 1991. Leaf area and foliar biomass relationships in northern hardwood forests located along an 800 km acid deposition gradient. J. For. Sci., 37: 1041-1059.

Butcher, P.A. and S. Southerton, 2007. Marker-Assisted Selection in Forestry Species. In: Marker-Assisted Selection in Crops, Livestock, Forestry and Fish: Current Status and the Way Forward, Guimaraes, E.P., J. Ruane, B.D. Scherf, A. Sonnino and J.D. Dargie (Eds.). FAO Press, Rome, Italy, pp: 283-306.

Chiatante, D., A. Di-Iorio, S. Sciandra, G. Stefania and S. Mazzoleni, 2006. Effect of drought and fire on root development in *Quercus pubescens* Willd. and *Fraxinus ornus* L. seedlings. J. Environ. Exp. Bot., 56: 190-197.

Cutini, A., G. Matteucci and G.S. Mugnozza, 1998. Estimation of leaf area index with the Li-cor LAI 2000 in deciduous forests. J. For. Ecol. Manage., 105: 55-65.

Davidson, J., 1989. The eucalyptus dilemma: Arguments for and against eucalyptus planting in Ethiopia. The Forestry Research Centre Seminar Note Series No. 1.A.A.

Dias, P.C., W.L. Araujo, G.A.B.K. Moraes, R.S. Barros and F.M. DaMatta, 2007. Morphological and physiological responses of two coffee progenies to soil water availability. J. Plant Physiol., 164: 1639-1647.

Gazal, R.M. and M.E. Kubiske, 2004. Influence of initial root length on physiological responses of cherry bark oak and shumard oak seedling to field drought conditions. J. For. Ecol. Manage., 189: 295-305.

Gebre, G.M. and T.J. Tschaplinski, 2000. Role of osmotic adjustment in plant productivity. A Summary Report and Review of Current Literature, Environmental Sciences Division Publication No. 4961. http://www.ornl.gov/~webworks/cpr/v823/rpt/101884.pdf

Gindaba, J., A. Rozanov and L. Negash, 2004. Response of seedlings of two Eucalyptus and three deciduous tree species from Ethiopia to severe water stress. J. For. Ecol. Manage., 201: 119-129.

Hamada, A.M., 1996. Effect of NaCl, water stress or both on gas exchange and growth of wheat. Biol. Plant., 38: 405-412.

Jongrungklang, N., B. Toomsan, N. Vorasoot, S. Jogloy, T. Kesmala and A. Patanothai, 2008. Identification of peanut genotypes with high water use efficiency under drought stress conditions from peanut germplasm of diverse origins. Asian J. Plant Sci., 7: 628-638.

Kameli, A. and D.M. Losel, 1996. Growth and sugar accumulation in durum wheat plants under water stress. New Phytol., 132: 57-62.

Kramer, P.J. and J.S. Boyer, 1995. Water Relation of Plants and Soils. Academic Press, London.

Lei, Y., C. Yin and C. Li, 2007. Adaptive responses of *Populus przewaskii* to drought stress and SNP application. Acta Physiol. Plant., 29: 519-529.

Levitt, J., 1980. Responses of Plants to Environmental Stresses. Water, Radiation, Salt and Other Stresses. II. Academic Press, New York.

Li, C. and K. Wang, 2003. Differences in drought responses of three contrasting *Eucalyptus microtheca* F. Muell populations. J. For. Ecol. Manage., 179: 377-385.

Li, C., 1999. Carbon isotope composition, water-use efficiency and biomass productivity of *Eucalyptus micotheca* populations under different water supplies. J. Plant Soil, 214: 165-171.

Maricle, B.R., D.R. Cobos and C.S. Campbell, 2008. Biophysical and morphological leaf adaptations to drought and salinity in salt marsh grasses. J. Environ. Exp. Bot., 60: 458-467.

Mefti, M., H. Bouzerzour, A. Abdelguerfi and H. Nouar, 2008. Morphological and growth characteristics of perennial grass cultivars grown under semi-arid conditions of the Algerian high plateaus. J. Agron., 7: 138-147.

Merchant, A., A. Callister, S. Arndt, M. Tausz and M. Adams, 2007. Contrasting physiological responses of six eucalyptus species to water deficit. Ann. Bot., 100: 1507-1515.

Omidi, H., 2010. Changes of proline content and activity of antioxidative enzymes in two canola genotype under drought stress. Am. J. Plant Physiol., 5: 338-349.

Sanchez-Blanco, M.J., S. Alvarez, A. Navarro and S. Banon, 2009. Changes in leaf water relations, gas exchange, growth and flowering quality in potted geranium plants irrigated with different water regimes. J. Plant Physiol., 160: 1016-1025.

Sardabi, H., 1998. Adjustment of eucalyptus and pine species in coastal areas and low elevation of Mazandaran east province. Res. Inst. For., 192: 133-133.

Sarker, B.C. and M. Hara, 2004. Periodic drought stress effect on evapotranspiration, root hydraulic conductance and fruit yield efficiency of eggplant. Asian J. Plant Sci., 3: 132-139.

Specht, R.L. and P.W. Rundel, 1990. Sclerophyll and foliar nutrient status of Mediterranean-climate plant communities in Southern Astralia. J. Aust. Bot., 38: 459-474.

Susiluoto, S. and F. Berninger, 2007. Interactions between morphological and physiological drought responses in *Eucalyptus microtheca*. Silva Fenn., 41: 221-233.

Xoconostle-Cazares, B., F.A. Ramirez-Ortega, L. Flores-Elenes and R. Ruiz-Medrano, 2010. Drought tolerance in crop plants Am. J. Plant Physiol., 5: 241-256.

Yin, C., X. Wang, B. Duan, J. Luo and C. Li, 2005. Early growth, dry matter allocation and water use efficiency of two sympatric *Populus* species as affected by water stress. Environ. Exp. Bot., 53: 315-322.

Zhang, X., N. Wu and C. Li, 2005. Physiological and growth responses of *Populus davidiana* ecotypes to different soil water contents. J. Arid Environ., 60: 567-579.