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# Water Stress and Afforestation: A Contribution to Ameliorate Forest Seedling Performance During the Establishment

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## 1. Introduction

For hundreds of years, forest ecosystems have been supplying human needs with timber and non-timber products such as oils, resins, tannins and other goods like wood or medicine. Beyond material goods, forests also provide a range of other relevant environmental benefits. The accelerating loss of forests represents one of the major environmental challenges. Intensive commercial logging focused mainly on timber products cause unfortunately degradation of extensive areas and, at the same time, the conversion of forest land for commercial agriculture, subsistence farming and logging for fuel wood are considered the main factors of deforestation. Both degradation and deforestation lead to a considerable reduction in the world forest resources. In the last decades worldwide concern about the necessity to protect native forests emerged and a shift in silviculture occurred, changing into a broader concern where environmental values and diversified interests are becoming more important (Food and Agriculture Organization of the United Nations [FAO], 2009, 2010).

Historically, an increase in economic growth and population has been the main force fuelling global wood consumption. The expected increase in world population in the next years and the rise in the standards of living will increase wood demand. As this additional wood demand cannot come from further increases in the harvest of natural forests, it must come from planted forests. Reforestation and afforestation seem to be effective alternatives to increase forest production land, thus covering those timber needs and at the same time contributing to reduce timber extraction in many natural forests (FAO, 2009, 2010; Paquette & Messier, 2010; United Nations Framework Convention on Climate Change [UNCCC]).

Commercial plantations can provide large quantities of timber to keep up with the increasing demand of forest products (sawmills, pulp and particle board industries mainly), and can also be used to provide environmental benefits. It is important to consider that the potential supply of wood arising from forest plantations will depend on the capacity to

maintain the rate of new planting and forest productivity. Forest plantations have greater structural diversity than agricultural crops (Lindenmayer et al., 2003; Viglizzo et al., 2011); they can reduce wind and soil erosion (Kort et al., 1998) and are particularly important for carbon sequestration, contributing to climate change mitigation (Laclau, 2005; Vitousek, 1991). Apart from these plantations benefits and according to environmental conditions of the site, some trade-offs need to be considered (Jackson et al., 2005; Jobbágy & Jackson, 2004).

Forest productivity is determined by genetic potential and is closely linked with environmental resources. Both genetic and environmental factors control plant physiological processes regulating the biomass production of forest stands. The growth depends on solar energy captured by the canopy and water and nutrients provided by the soil for converting CO<sub>2</sub> to photoassimilates (Kozłowski & Pallardy, 1997). Unfortunately, the environment imposes many resource limitations to growth; therefore, forest stands can rarely achieve their potential productivity for extended periods. Indeed, over a wide range of climatic and soil conditions there is a large variation in forest net primary productivity around the world (Gowers et al., 1992; Kozłowski, 2002; Perry et al., 2008; Waring & Schlesinger, 1985).

Plantation performance is commonly hindered by both biotic and abiotic factors. The rapid growth rates of the species used in commercial plantations (like *Pinus*, *Eucalyptus*, *Populus*) are based on their high water demands (Braatne et al., 1992; Florence, 1996; Monclus et al., 2006; Whitehead & Beadle, 2004). But the availability of water, one of the main factors related to plant growth, varies both seasonally and from year to year, regulating forest productivity. During the rotation cycle trees are often subjected to periods of soil and atmospheric water deficit but the effects on plant performance are more serious during the establishment period because they may not only reduce seedlings growth but also compromise their survival. Besides climatic factors, soil water availability is determined by soil factors, stand density and levels of understory competition.

It is crucial to understand the physiological processes that determine growth and survival during the establishment and the response of tree seedling to environmental stimuli because they deeply influence future productivity. Nowadays, all of these issues face new challenges which are expected to come out in the actual context of climate change. In the future an increase in the frequency of drought events is predicted even outside semi-arid and arid areas (Intergovernmental Panel on Climate Change [IPCC], 2007). Under stressful and/or unexpected weather conditions a careful silvicultural planning is essential to ensure success. Silvicultural decisions including the selection of high quality plant material and practices applied during the establishment are tightly connected with plantation performance (Smith et al., 1997).

In this chapter, among the multiple factors that influence growth during the forest establishment, we chiefly discuss the importance of water supply on tree growth and how water stress compromises plant performance. We take into account the interactions between water deficiencies and other abiotic and biotic factors that in fact modulate survival and plant growth. We analyze the potential mechanisms that tree seedlings exhibit to overcome serious stressful conditions during the establishment phase and the effects of nursery techniques applied to produce good quality stock, particularly those imposed to acclimate seedlings to water stress before outplanting. We include results of several studies in species of great importance in afforestation programs.

## 2. Water stress on tree function and growth

Water is an essential resource for plant function and growth. Most of physiological processes are directly or indirectly regulated by tissue water content. Water is solvent of gases, salts and solutes within and among cells and from organ to organ; it is required to provide a substrate and a medium for biochemical reactions and for the transport of mineral ions, as well as to maintain cell turgor for cell enlargement, stomatal opening and the maintenance of the form of young leaves and slightly lignified structures. Only a small fraction of water that passes through the plant and is lost by transpiration during its whole life remains in plant tissue. When leaving the plant through transpiration, chiefly from the leaves, water has an additional cooling effect that allows a plant to maintain a temperature suitable for metabolic reactions and life (Kozloswki & Pallardy, 1997). Zhaner (1968) reviewed the importance of an adequate water supply for woody plants. There is a very high correlation between the amount of wood production and the available soil moisture. As a matter of fact, a large proportion of the variation in diameter growth can be attributed to variation in the availability of water. Although it is one of the most abundant substances in the environment, there is a great temporal and spatial variation in water supply for plants. Water deficit is mainly caused by droughts that refer to periods in which rainfall fails to keep up with potential evaporation, generating the exhaustion of soil water content. Insufficient water supply to plant leaves can also arise in response to other circumstances, either abiotic or biotic. For instance when, despite the existence of adequate water in the soil, there is large air humidity deficit (Hirasawa & Hsiao, 1999; Levin et al., 2009). Regardless of the amount of precipitation, water may not be available because it is frozen. Several soil properties, like soil texture, salinity and/or hydraulic conductivity reduce water supply. Plants can have difficulties in obtaining water from the soil if salts are present in the root zone (osmotic effect). Generally, the need of energy to allow water uptake is greater when the soil solution is saline than when it is not. Competition of neighboring vegetation is also another cause of water depletion to the tree crop (Nielsen & Orcutt, 1996; Passioura, 1996). When soil water availability is scarce, the magnitude of plant transpiration losses is usually greater than root absorption and therefore plants are prone to experience water stress, which is mainly evidenced through a lowering in the plant relative water content and/or in the water potential, decreasing tissue turgor and compromising cellular expansion. Stomatal closure has been identified also as an early response to water deficit that limits the photosynthesis rate leading to a limitation in plant carbon fixation. It is still under debate whether stomatal closure is triggered by chemical signals synthesized in dehydrating roots or by changes in plant hydraulic conductivity (Brodribb, 2009; Brodribb & McAdam, 2011; Cochard et al., 2002; Davies et al., 1986). The depression in gas exchange also reduces water loss leading generally to higher water use efficiency, but the lowering in the photosynthesis rate as well as the decrease in plant leaf area due to leaf desiccation and shedding causes a reduction in plant growth (Chaves et al., 2003; Hsiao, 1973; Kozlowski, 1982; Kramer & Boyer, 1995). Excess of radiation constitutes another concomitant type of stress under water limited conditions. As water stress reduces the rate of photosynthesis, the absorption of light exceeds its utilization. If plants lack the ability to dissipate that excess of energy through external and internal mechanisms of protection, they undergo photoinhibition, i.e. the oxidative damage in the photosynthetic apparatus (Adir et al., 2003; Chaves et al., 2003; Powles, 1984).

As well as affecting plant growth, water scarcity modifies the pattern of carbon allocation (Cannell & Dewar, 1994; Turner, 1986a). More photoassimilates are transferred to belowground components, especially to the fine roots and higher root-shoot ratios can be found in plants experiencing water stress in comparison to plants under high water availability (Guarnaschelli, 2009; Guarnaschelli et al., 2006; Li et al., 2009). In addition, droughts may change diverse morphological and anatomical characteristics. For example, leaves are usually smaller, thicker, more cutinized and their vessels diameter, whereas cell walls are thicker and more lignified. Plant chemical composition may be altered, which means that it can influence the way plants protect themselves against other stressful factors. Plant vigor and overall resistance to stress from insects and/or diseases are influenced by water status (Kozlowski, 1982; Kozlowski & Pallardy, 1997).

Tree species differ in their optimal water requirements and in their susceptibility to water stress. Certain stages of plant growth are more sensitive to water stress than others. While some species are well-adapted to short period of water deficit, they become vulnerable to prolonged water deficit decreasing stomatal conductance and leaf area, changing the pattern of biomass allocation and reducing stemwood production. Water stress compromises cambial growth in different ways. It slows or stops the production of xylem cells and influences the seasonal duration of xylem production and the time of initiation and duration of the latewood production (Kozlowski & Pallardy, 1997). Besides differences among species, the effects and the magnitude of loss caused by droughts vary among provenances or clones (Arend et al., 2011; Guarnaschelli, 2009; Guarnaschelli et al., 2010b) and depend on the season in which the water deficiency occurs (Guarnaschelli, 2009), as well as the intensity and duration of drought (Guarnaschelli et al., 2003c; Guo et al., 2010; Osório et al., 1998). Damage is also linked to the health and vigour of the plants previous to the drought. Plants with healthy root systems and adequate carbohydrate reserves will behave much better during and after a drought period (Kozlowski, 1992; Marshall, 2006).

### 3. Problems during the forest establishment

Planting has become the main method of reforestation in many parts of the world. It is more predictable and reliable than natural regeneration and allows a more effective control of stand density. When planting nursery grown seedlings or cuttings, the most critical processes of natural regeneration, from seed production to the early seedling developmental phase, are skipped (Stoneman, 1994; Tappeiner & Helms, 1973). Forest plantation area has increased considerably in the last years and today includes different species selected due to the good availability of planting material, clear silvicultural management techniques and high productivity. In South America, for instance, forest plantations consist of different introduced species like *Eucalyptus* (*Eucalyptus grandis*, *Eucalyptus globulus*, *Eucalyptus camaldulensis*, *Eucalyptus urophylla* as well as interspecific hybrids), *Pinus* (*Pinus taeda*, *Pinus elliottii*, *Pinus caribaea*, *Pinus ponderosa*), *Populus* (*Populus deltoides*, *Populus xcanadensis*), *Salix*, *Gmelina*, *Toona* among others. The development of forest nurseries, which can produce large quantities of tree seedlings annually, allowed the possibility of establishing large areas of forest plantations.

Planted material is generally exposed to, and has to overcome stressful conditions after planting. Several factors are found to affect the early establishment of forest plantations. However, among abiotic ones, water deficiency is the most common limitation for seedlings from outplanting and all over the establishment (Burdett, 1990; Close et al.,



2005; Margolis & Brand, 1900). Water limitations, derived from periods of soil and/or atmospheric water deficiencies, affect plantations both directly by reduced growth and increased mortality, and indirectly by increased susceptibility to, or damaged by, other abiotic and/or biotic stress factors.

Immediately after being planted, seedlings are subjected to transplant shock, a phenomenon characterized by a depression in the physiological status mainly associated with moisture stress. The alteration in plant water status, caused by limited contact between roots' seedlings and soil, impairment of seedling root function, high evaporative demand, low hydraulic conductance of suberized roots and/or root confinement, constitutes the main constraint for plant survival and growth after planting (Burdett, 1990; Grossnickle, 2005; Kozlowski & Davies, 1975; Rietveld, 1989; Sands, 1984). Low root-soil contact can occur even if soil water potential is near to zero. Therefore transplant shock is not necessarily associated with the soil water status, but low water availability or post-planting droughts intensifies that condition and aggravates it.

The first physiological symptom of transplanting shock is the lowering in predawn water potential. As water potential becomes more negative, other physiological symptoms appear like reduced stomatal conductance, photosynthesis, transpiration and growth (Grossnickle, 1988; Guehl et al., 1989; Jacobs et al., 2009; Sands, 1984). These symptoms were observed by Mena-Petite et al. (2005) after transplanting seedlings of *Pinus radiata* both under drought and under well-watered conditions. Reduced leaf area, leaf shedding, shoot growth and needle length area are the principal morphological symptoms (Haase & Rose, 1993; Struve & Joly, 1992).

The improvement in root-soil contact is mediated by the extension of new root growth. The ability to regenerate new roots after planting is a key process to reduce the effects of transplanting shock and assure plant survival after planting (Rietveld, 1989; Sands, 1987). It has been observed in some Conifer species that new root growth is largely dependent on current photosynthesis (Maillard, 2004; Phillipson, 1998; van den Driessche, 1987), also in some Hardwoods species (Sloan & Jacobs, 2008). Seedlings that develop their root systems after planting reestablish a proper water balance. With a favorable water status they can have a cycle of root growth supported by photosynthesis and photosynthesis supported by root growth. Therefore, high seedling water potential during the outplanting is a favorable condition to initiate new root growth. All plant attributes that ensure a better water balance will benefit the process of transplanting by granting more resistance to water stress (Burdett, 1990).

Bare root plantings are specially accompanied by specific transplanting stress. When plants are lifted for transplanting, a large percentage of the absorbing roots are severed and/or damaged, therefore, the newly transplanted tree suffers from water stress. Even trees that have been grown in containers and could retain their whole root system suffer from some degree of transplant shock. However, container seedlings have proved to have better performance than bare root plants, especially when conditions are more stressful (Barnett & McGilvray, 1993).

When transplanting shock has been overcome, additional drought events that may occur several times along the rest of the establishment period may cause depression in plant function and growth. Forest sites are frequently subjected to periodic droughts. On drought-prone sites a successful regeneration will depend mainly on the ability of plants to tolerate moisture stress.

As mentioned above, other abiotic factors can affect independently or interact with the water availability and cause serious damage in recently planted tree seedlings. Usually several stress act simultaneously with droughts such as heat and high irradiance intensifying moisture deficiencies. By contrast low temperatures may arise. Freezing temperatures induce cell dehydration, which is the most common damage. In specific tissue and organs damage can occur for other reasons, like cell death, separation of cell layers, creation of cavities and frost cracks, xylem embolism among other (Pearce, 2001). Drought as well as low temperature and water-logging reduce water uptake and hence the rate of photosynthesis. An increase in irradiance may cause photoinhibition. Nevertheless, photoinhibition may arise indirectly from the action of all stress factors that cause a reduction in photosynthesis and induce excess light absorption. The effects of competing vegetation, restricting resource availability and herbivory damaging leaf tissues on seedlings performances are discussed later (Burdett, 1990; Close et al., 2005).

#### **4. Strategies to cope with water deficiencies during the establishment**

As the establishment of forest plantations requires long-term investments, it is crucial to select the best management options in order to improve forest productivity in site-specific conditions and to make cost-effective decisions. Moreover, when stressful and/or unexpected weather conditions are predicted, careful silvicultural planning is essential to ensure success. Silvicultural decisions including the selection of high quality plant material and the application of adequate site preparation techniques, proper planting and plantation maintenance practices are the key to a successful establishment and are tightly connected with plantation performance (Blum, 2003; Smith et al., 1997; Tappeiner et al., 2007). In fact, they may be adjusted to withstand water stressful conditions since transplanting generates a severe physiological shock and moisture conditions exclude the establishment of trees. There are many textbooks on Silviculture and availability of information that discuss thoroughly the effects of alternative cultural practices before and after plantation. Our analysis will focus mainly on the strategies to improve seedling quality.

The use of high quality seedlings as well as the application of several cultural practices before and after planting can help to overcome stressful conditions and enhance plantation performance. Regarding particularly outplanting stress, although some level of transplant shock is unavoidable, stock with high performance will minimize the event (Burdett, 1990; Close et al., 2005; Grossnickle, 2005; Rietveld, 1989).

The quality of seedlings is the result of its genotype, growing conditions and cultural practices applied in nurseries. In the context of transplanting process, the utilization of provenances or clones that have been tested as drought tolerant and that have been subjected to appropriate nursery management will show a better performance.

##### **4.1 Mechanisms associated with drought tolerance**

Chaves et al. (2003) suggested that it is essential to have a holistic understanding of plant resistance to water stress to improve crop management and breeding techniques. As originally defined by Ludlow (1989), under drought conditions there are physiological processes and morphological attributes that could extend the period of active growth by controlling water uptake, water loss and hence cell turgor. Water loss can be effectively controlled by stomatal closure and, ultimately, by leaf shedding. To maintain to some extent

cell turgor and stomatal conductance and a sizeable photosynthesis rate under drought conditions, plants have developed particular physiological processes. Species possessing these attributes are very sensitive to dehydration and avoid water deficits when soil moisture limitation occurs. Conversely, other species tolerate dehydration mainly through osmotic adjustment or changes in tissue elasticity.

Drought avoidance, a strategy held by many tree species, is characterized by relatively high lethal water potential or high relative water content with relatively little osmotic adjustment, while drought tolerance species have lower lethal water status values and relative water content and display much more active changes in osmotic potential when subjected to drought conditions. Not all plants fit closely in one category or another but the division in plant responses helps to understand consequences for the species like survival, potential for carbon fixation, maintenance of growth under drought, and metabolic costs of drought resistance mechanisms (Ludlow, 1989).

Schulte & Hinckley (1987) observed that the ability of stomatal closure varied among *Populus* species and their interspecific hybrids, and some of them required a large change in tissue water content for stomatal closure. For example, *P. deltoides* and its hybrids display a large number of strategies avoiding water deficiencies. Among them a reduction in stomatal conductance and transpiration (Marron et al., 2002; Silim et al., 2009), leaf abscission, and decreases in shoot-root ratio (Liu & Dickman, 1992).

For some species, greater biomass allocation to roots relative to shoots, that increase root growth and reduced leaf area, as well as stomatal regulation seem to be effective mechanisms to resist moisture stress (Jacobs et al., 2009). As it has been suggested, plants respond to shifts in resource supply by allocating carbon to the organ involved in capturing the limited resource. Root development is fundamental under water and nutrient deficiency, resulting in plants that have lower shoot:root ratios and greater capacity to absorb water and minerals relating to the shoots that must be supported. The possession of a deep and thick root is considered highly important because it allows access to water deep in the soil profile. The investment of carbon in a deep root system may have, however, a yield implication due to lost carbon allocation to the shoot.

Under water stress, plants of *Alnus rubra* may show leaf senescence and shedding. These processes lead to a favorable decrease in shoot:root ratio and high survival, whereas the reduction in the photosynthetic area resulted in a reduced shoot growth (Pezeshki & Hinkley, 1988).

Thus, mechanisms that allow plants to avoid water deficiencies present some disadvantages because they imply a reduction in leaf area and gas exchange, then the photosynthetic capacity is reduced and at the same time the change in the pattern of carbon allocation favoring root growth reduces shoot growth.

Among the drought tolerance mechanisms, osmotic adjustment implies the accumulation of organic and inorganic solutes in the cell that reduces water potential and allows plants to obtain water from a lower water potential medium and sustain the physiological processes. The capability of osmotic adjustment appears to be controlled by only one or two genes and is simply inherited (Morgan & Condon, 1986). This mechanism may be an advantageous strategy to maintain cell water status (Ashraf et al., 2011; Morgan, 1984). The maintenance of cellular turgor by lowering the osmotic potential in plants exposed to low water conditions is considered to be one of the most important mechanisms of plant adaptation to environmental stresses (Turner, 1986a, 1986b; Turner & Jones, 1980).



The drought induced lowering in osmotic potential has been observed in many coniferous tree species (Edwards & Dixon, 1995; Nguyen-Queyrens & Bouchet Lannat, 2003) as well as in hardwood species (Abrams, 1990; Arndt et al., 2000; Marron et al., 2002; Tschaplinski et al., 1998). In some cases the magnitude of adjustment was related to the maintenance of plant growth rate (Johnsen & Major, 1999; Meier et al., 1992; Pita & Pardos, 2001; Tan et al., 1992).

Considerable variation in the osmotic adjustment capacity has been observed. Among *Eucalyptus* species Lemcoff et al. (1994, 2009) detected different magnitude of osmotic adjustment among seedlings of *E. grandis*, *Eucalyptus tereticornis*, *Eucalyptus viminalis* and *E. camaldulensis*. Other studies that considered different species of *Eucalyptus* reached similar results confirming genetic variability for this mechanism (Merchant et al., 2006; Merchant et al., 2007; White et al., 2000). Variability is also present among provenances of a single species (Guarnaschelli et al., 2001; Guarnaschelli et al., 2006; Tuomela, 1997) or among clones (Pita & Pardos, 2001). Guarnaschelli (2009) compared the response to drought conditions in 13 provenances of *E. globulus* and found differences both among subspecies and also among provenances within some of the subspecies.

As originally stated by Turner (1986a), osmotic adjustment would only represent a useful strategy to tolerate drought if it also develops in the root system (Merchant et al., 2006; Nguyen & Lamant, 1989; Parker & Pallardy, 1988). Guarnaschelli & Lemcoff (2001) detected osmotic adjustment in both shoot and roots of *E. globulus* subsp. *maidenii* provenances and difference in the capacity to adjust cell-wall elasticity.

Gebré & Tschaplinski (2000) indicated that drought tolerance in *Populus* is not only related to the capacity of solute accumulation, but also to low values of osmotic potential itself. Consistent with this statement, Guarnaschelli et al. (2010b), evaluating the drought tolerance of several *P. deltoides* clones, recently showed that they have low osmotic adjustment capacity but in contrast there were consistent differences in osmotic potential among them.

Osmotic adjustment has been recognized as an important cellular drought-responsive trait and, despite past speculations, there is no definitive proof that the osmotic adjustment capacity entails a compromise to potential crop yield (Blum, 2005). Moreover, after stress relief it has been observed greater capacity of stem diameter and height growth in seedlings of *E. globulus* subsp. *globulus* that had shown higher osmotic adjustment capacity (Guarnaschelli, 2009), results that present similarities with those of Osorio et al. (1998).

Although the maintenance of leaf turgor is often linked to osmotic adjustment, changes in tissue elasticity may also contribute to turgor maintenance in plants with (Guarnaschelli, 2009; Lemcoff et al., 2002; Pita & Pardos, 2001) and without osmotic adjustment. The regulation of cell-wall elasticity, generally called elastic adjustment and measured as the change in maximum bulk modulus of elasticity, also aids some species to maintain tissue hydration (Pita & Pardos, 2001; Prior & Eamus, 1999; Stoneman et al., 1994).

Under moderate water stress an increase in tissue elasticity would allow the maintenance of tissue turgor and physiological functions and growth (Fan et al., 1994; White et al., 1996). But also a decrease could represent a useful strategy to overcome low water availability (Nielsen & Orcutt, 1996) while conditioning a decrease in plant water potential, increasing the water potential gradient between plant and soil allowing water uptake. An additional consequence of this kind of cell-wall adjustment, and the concomitant rapid lowering in the water potential, is the closure of stomata that prevents severe water deficit conditions (Dumbroff, 1999; Lemcoff et al., 2002). It has been observed that under moisture stress some

species increase cell-wall elasticity while others decrease it (White et al., 1996; White et al., 2000); this behavior was also detected among provenances of a single species (Guarnaschelli, 2009). A decrease in cell-wall elasticity has been associated with tissue maturation (Bowman & Roberts, 1985; Parker et al., 1982), which commonly occurs during fall and winter. Water stress conditions of similar intensity and duration may exert different responses in cell-wall elasticity, like was observed in subspecies and provenances of *E. globulus* (Guarnaschelli et al., 2001; Guarnaschelli, 2009).

It is important to highlight that the expression of drought tolerance mechanisms may vary if multiple stress factors are simultaneously affecting plants, phenomenon which in fact occurs quite often in nature. Some studies under controlled conditions assessed the responses of several *Eucalyptus* provenances and *Salix* clones submitted to different water and light availability regimes, analyzing the genetic contribution as well as the level of restriction and the interaction effects. In saplings of *Salix* submitted to drought conditions, a decrease in osmotic potential at full turgor and at the turgor loss point occurred in plants growing under full sunlight but also in those that were growing under moderate shade conditions (Guarnaschelli et al., 2010b). These results contrast with those that argue that only dryness and high sunlight trigger a lowering in osmotic potential, stating that under high irradiance conditions there is a higher capacity to accumulate solutes and where osmotic adjustment can take place (Aranda et al., 2005; Uemura et al., 2000). Thus, osmotic adjustment contributed to turgor maintenance processes, allowing an increase in the drought tolerance under full sunlight and moderate shade conditions, without a compromise between the plants adjustments to cope with those two kinds of stress factors (Smith & Huston, 1989). These responses indicate that shade could alleviate the effects of drought (Guarnaschelli et al., 2007; Guarnaschelli et al., 2008), although this is not always the case. Recently lower water potential values were observed in droughted seedlings of *E. grandis* and *E. grandis* x *E. camaldulensis* clones that were growing under shade conditions in contrast to those that were under full sunlight. All shaded plants displayed high plasticity increasing their leaf area as an strategy to increase the uptake of light, but the decrease in shoot:root ratio observed in water stressed plants was not as effective as the change that occurred in water stress plants growing under full sunlight, which allowed better water acquisition under moisture deficit conditions (Guarnaschelli et al., unpublished data).

### **Breeding for drought tolerance**

Tree selection can be a relevant component when dealing with moisture stress. In fact, species, provenances and/or clones genetically adapted to certain levels of water deficiencies can overcome soil and atmospheric water deficits. Plants originating from drier sites are more likely to survive drought than those from mesic sites because they have different mechanisms that help them to tolerate low water availability.

As discussed previously, trees possess a varied number of mechanisms to compensate for water limitation that allow the acquisition of water resources or limit water loss, and indeed represent useful tools in the context of the establishment. Genetic variability in the responses to water stress has been tested in different tree species, among populations or even clones of a single species. It is accepted that high levels of genetic variation within any species improve the potential to withstand abiotic stress, such as droughts and biotic stress as well. However, the ability of plants to sense stressful conditions and environmental change through plastic responses is part of this genetic variation. Trees may also exhibit certain level of physiological and/or morphological change, which is defined as the capacity of

organisms to produce different phenotypes according to environmental changes (Schlichting, 1986; Valladares, 2006). Phenotypic plasticity has been recognized now as a heritable characteristic and can be genetically controlled (Bradshaw, 2006; Lande, 2009). It has a great potential importance in plant evolution (Nicotra et al., 2010).

Mechanisms or traits that avoid or tolerate the dry conditions include a variety of morphological, physiological and biochemical attributes at biochemical, cellular, tissue and whole-organism levels, as discussed previously. Most of them are dependent on other mechanisms; in fact, a sequence of adjustments occurs simultaneously in plants.

Breeding for drought stress tolerance in forest trees should be given high research priority in plant biotechnology programs. Plant response to abiotic stress like water deficiency involves many genes and biochemical-molecular mechanisms. Plant modification to enhanced stress tolerance is based on manipulation of genes that protect and maintain the function and the structure of the cellular components. Due to the complex responses to stress it is more difficult to control and engineer in contrast to traits of engineered resistance to pests or herbicides. Although the improvement of stress tolerance by gene transformation has resulted in important achievements, the complexity of the mechanisms involved makes this task very difficult.

Despite the existence of multiple traits related to drought resistance, the selection of improved growth in water limited environments may not be generalized because it may lead to a trade-off between traits related to both drought resistance and growth. The selection of drought-resistant and productive material may not be simple to achieve, as we mentioned previously. Some species exhibit numerous drought resistance strategies that may impact on productivity differently, like lower leaf area, leaf abscission, enhanced root growth, stomatal closure among others as has been noted before.

But although drought tolerance may be considered as a penalty towards potential productivity, it is not necessarily the case (Blum, 2005). To maintain growth and productivity under water limited conditions, plants have to exercise specific tolerance mechanisms. Plant breeders have improved the performance of crops by breeding for improved yield or quality under conditions of water shortage; however the selection of this kind of plant material is nowadays becoming more important. The development of new tools for monitoring and understanding plant responses to water deficit, ranging from molecular, plant and ecosystem, will allow a better understanding of plant performance under stress, which will be very useful to breeding programs (Chaves et al., 2003).

Pita et al. (2005) discussed the use of particular physiological traits in breeding programs for improved yield under drought conditions focusing mainly in *E. globulus* experience in southern Spain. They explained that *E. globulus* must be considered a species with avoidance capacity because high survival and growth were observed through lower water use efficiency and embolism tolerance. They highlighted the relevance of several hydraulic characteristics, like maximum permeability, maximum leaf conductivity and vulnerability to cavitation and its relationship to stomatal conductance. Osmotic adjustment capacity, a drought tolerance strategy, has also been observed in this species (Guarnaschelli, 2009; Guarnaschelli et al., 2003; Guarnaschelli et al., 2006; Pita & Pardos, 2001; White et al., 1996).

#### 4.2 Nursery conditions and culture

Nursery conditions and culture affect the structural and functional characteristics of tree seedlings. They can produce planting stock of different size and physiological state;

however, each ecological condition needs a different type of plant according to it. If field site conditions where seedlings are going to be transplanted differ from those at nurseries, they may be severely stressed because the process of acclimation in the field occurs over several days, or even weeks. Therefore, it is necessary to use plants suited to the environmental restrictions in which they will be planted (Burdett, 1990).

Nurseries adapt their environmental conditions and cultural practices to produce target seedlings that will assure survival and growth according to the species and site conditions. The alternative methods of seedling production are outlined in several manuals, which cover all phases of production from seed collection to seedling storage and provide detailed information about nursery practices, allowing to secure high quality material (Duryea & Landis, 1984; Landis et al., 1989, 1990, 1992).

Characteristics of target seedlings include height, stem diameter, root volume, root growth potential, plant water status, drought resistance and frost hardiness among others (Rose et al., 1990). Seedlings' height and stem diameter, the most common traits used to assess seedling quality are not always accurate predictors of performance after outplanting. As stated by Burdett (1990), it appears that the central processes in plantation establishment are root growth and photosynthesis in mutual dependence. All attributes that assure a better seedling water balance favor the maintenance of photosynthesis and root growth and benefit the process of transplanting shock in coping with water stress.

In the context of establishment commonly hindered by water stress, plants with root systems of high morphological and physiological standards enable them to establish rapidly and succeed upon outplanting. Large root volume, high root fibrosity and an increased number of first-order lateral roots have shown some correlation with improved field performance (Landis, 2010). Leaf area, shoot:root ratio, the capacity to regulate stomatal conductance as well as the development of osmotic and elastic adjustment will help seedlings performance. Water and nutrient regimes are of particular importance during seedlings production because they control both the rate and type of growth and hence have relevant impact on morphological and physiological attributes mentioned above (Duryea & Landis, 1984; Landis et al., 1989).

### **Drought acclimation**

Plant drought acclimation is a process that results after the exposure to stress conditions that induce structural and functional adjustments, allowing the acquisition of tolerance to drought. Acclimation is a process that occurs spontaneously in nature, helping plants to survive and grow under stress. For example, many plants increase their freezing tolerance at the end of summer and fall upon exposure to low non-freezing temperatures and short days, a phenomenon known as cold acclimation that increases their cold tolerance. At the beginning of spring, when temperatures are rising, this process is reversed. Other plants experience drought acclimation when exposed to moisture stress (Kozłowski & Pallardy 2002; Yordanov et al., 2000).

Drought preconditioning or drought hardening is a common practice applied in nurseries, which entails exposure to sublethal stress and allows seedlings to trigger plastic responses associated with drought acclimation, finally resulting in protection against lethal stress. Submitting tree seedlings to nursery stress conditions may render them more protected from injuries or reduced growth when environmental stresses are abruptly imposed than plants not previously stressed. It is accepted that drought preconditioning helps seedlings to improve their performance, competitiveness and productivity under field conditions. The



process of acclimation occurs over days or weeks. In contrast, poor drought acclimated seedlings will exacerbate transplanting shock.

Drought preconditioning consists in withholding irrigation or restricting the amount of water supplied for short periods. It is generally applied during the last weeks of seedlings production (Landis et al., 1989; Vilagrosa et al., 2006). An irrigation regime that restricts the water availability will induce adjustments in several morphological attributes such as aerial growth and the pattern of dry matter partitioning, reducing leaf area and shoot:root ratio (Lamhamedi et al., 2001; Stewart & Lieffers, 1993). Stock types with low leaf area and shoot:root ratio perform better under drought conditions, since a more favorable balance between water uptake and loss is reached (Cregg, 1994). In addition, physiological adjustments like stomatal regulation, osmotic adjustment and/or elastic adjustment may also contribute to better performance after planting. Several Conifer species deliberately exposed to water deficit displayed drought hardiness and were able to maintain more favorable water status and gas exchange (Edward & Dixon, 1995; van den Driessche, 1991; Zine El Abidine et al., 1994; Zwiazek & Blake, 1989), and greater survival after plantation compared to non-conditioned plants (van den Driessche, 1992).

Among hardwood species, in several *Salix* cultivars drought acclimation was manifested in decreased stomatal conductance, osmotic potential and leaf area to vessel internal cross-sectional area ratio, and increased shoot hydraulic conductance. An increase resistance to stem xylem cavitation was observed in only one clone (Wikberg & Ogren, 2007). Seedlings of three provenances of *E. globulus* that were submitted during one month to drought cycles of 6 and 9 days, considered as moderate and severe stress, displayed plastic changes: osmotic adjustment and reduced leaf area. The extent of osmotic adjustment was influenced by the degree of drought preconditioning; osmotic potential at full turgor in severe stressed plants was significantly lower than in moderate stressed plants. Thus, the magnitude of the adjustment increased with the intensity of water stress, suggesting an additive effect in this drought tolerance mechanism. When non conditioned plants (daily irrigated) and drought conditioned were all evaluated under a new drought cycle, the last showed higher water status and stomatal conductance (Guarnaschelli et al., 2003c). Similar results were observed with three representative Mediterranean species (Vilagrosa et al., 2003; Villar-Salvador et al., 2004).

Plants may display different phenotypic plasticity in their attributes according to the intensity of the drought preconditioning (Guarnaschelli et al., 2003c). Medium and moderate levels of water stress induced a higher level of hardiness in comparison with severe water stress conditioning (Villar Salvador et al., 2004). It is important to highlight that severe water stress preconditioning is likely to induce some level of tissue damage and a higher decrease in growth due to the high dehydration experienced or low growth rate after transplanting.

As for bareroot seedlings, the control of water irrigation may be more difficult to achieve, preconditioning includes root pruning. After being root-pruned, seedling of *Quercus rubra* and *Juglans nigra* experienced water stress, which triggered many changes in growth as well as morphological and physiological attributes. Undercutting reduced seedling growth and shoot:root ratio and increased the number of first order lateral roots, which increased field survival (Schultz & Thompson, 1997). These results show that drought preconditioning triggers morphological and physiological adjustments associated with an increase in drought tolerance.

Several studies have also tested the effects of preconditioning on growth and survival after planting. Some of them indicate that there is a positive effect on survival (Guarnaschelli et



al., 2003a; Guarnaschelli et al., 2006; van den Driessche, 1992), whereas only a few show a positive effect on growth (Arnott et al., 1993).

Guarnaschelli et al. (2006) evaluated the effect of drought preconditioning after transplanting. Three provenances of *E. globulus* subsp. *bicostata* were subjected to moderate water deficit conditions. They evidenced drought acclimation capacity showing osmotic adjustment, a reduction in seedlings size, leaf area, shoot:root ratio and stomatal conductance. After being transplanted under moisture stress conditions, drought preconditioned plants showed better water status, gas exchange capacity and higher levels of survival than well irrigated plants. It was observed that midday relative water content (RWC) was closely correlated with survival as also found by Mena-Petite et al. (2005), while survival was inversely correlated with shoot:root biomass ratio. Both RWC and shoot:root ratio could be considered reliable indicators of potential initial survival and are closely associated with establishment success (Grossnickle & Folk, 1993).

Several processes involved in drought tolerance confer also an increase in cold tolerance (Bigras & Dumais, 2005; Moraga et al., 2006). It has been observed that drought resistant genotypes of *E. globulus* showed greater cold tolerance than drought susceptible ones (Costa e Silva et al., 2009). The application of drought hardening treatments may also increase cold tolerance. The accumulation of solutes that commonly occurs under water stress decreases the osmotic potential and may cryoprotect freezing labile cell structures. Coopman et al. (2010) applied two drought hardening treatments to different genotypes of *E. globulus* subsp. *globulus* under nursery conditions that resulted in an increase in the seedlings drought tolerance but also in their freezing tolerance. They observed that the freezing tolerance varied with the genotypes and the level of water stress preconditioning.

### **The interactive effects of water and other factors during seedlings production**

When dealing with a process of drought acclimation, many other factors can influence plant responses to drought preconditioning, as is the case of nutrition, age and/or growing media conditions. In fact the nutrient regime as well as the growing media used to produce forest containerized seedlings can strongly affect plant during the drought preconditioning period and their performance after outplanting.

The growing media usually consists of a mix of organic materials, like sphagnum peat moss, composted pine bark, coco fiber or other local organic products with inorganic components as perlite, vermiculite or sand. The mix is selected in order to obtain a growing media of slightly acid pH, high cation exchange capacity, low inherent fertility, adequate porosity, and freedom of pests, all characteristics that allow the production of healthy seedlings. Both the water-holding and nutrient supplying properties are functions of the different growing medium components; therefore the irrigation and fertilization have to be adjusted according to their characteristics (Landis et al., 1990). Artificial mixes dry out much more rapidly than surrounding soil, so watering is very important. Verdaguer et al. (2011) observed that when seedlings of *Quercus coccifera* were grown in natural soil compared to standard nursery growing medium growth rates were higher. Results suggest that the former were acclimated to the soil and higher photosynthetic rate, transpiration and stomatal conductance were observed in those seedlings.

Besides irrigation regime, fertilization can have important effects on plant quality modifying their performance under drought during the establishment. Harvey & van den Driessche (1999) observed that increasing nitrogen (N) supply under dry conditions increase leaf loss

and decrease water potential in *Populus trichocarpa*, making them more vulnerable to cavitation. The effects of N fertilization on drought and cold acclimation were assessed on several forest Mediterranean species. High N level decreased frost hardiness in *Pinus* species. In all species high N increased shoot:root ratio and in some of them stomatal conductance, which might impair seedlings water balance if soil water content is low after planting (Villar Salvador et al., 2005).

van Den Driessche (1992) analyzed the responses of *Pseudotsuga menziesii*, *Pinus contorta* and *Picea glauca* seedlings that were grown in containers in a greenhouse and submitted to two N treatments and three potassium (K) treatments with three drought treatments. A positive relation between shoot:root ratio and survival in *P. contorta* and *P. glauca* indicated that increase in N increased both shoot growth and drought resistance over the N range investigated, while *P. menziesii* showed an interaction between drought and N treatment and a small response in both survival and dry weight to potassium (K) application.

K plays important physiological functions in plants. It regulates cell membrane activity, it is an enzyme cofactor and one of the main ions that contribute to plants osmoregulation, improving the tissue water content and regulating stomatal closure among others (Morgan, 1984; Taiz & Zeiger, 2002). While high N fertilization stimulates rapid soft growth, adequate K promotes firmer tissue. K addition increases water uptake, decreases transpiration losses, leaf area ratio and desiccation damage. It has been shown that K, with calcium and magnesium, increases leaf waxes, protecting plants during the hardening process. Thicker cuticles also protect to insect feedings and penetration fungi (Cakman, 2005; Landis, 2005). Nurseries have traditionally applied extra K as part of the hardening process.

Several studies showed that K fertilized seedlings had better performance under water stress conditions (Garau et al., 2004a; Garau et al. 2004b). The responses of *E. camaldulensis* and *E. globulus* seedlings submitted to different treatments of fertilization and water availability were analyzed at the nursery stage and after plantation. Nursery treatments involved two levels of K and two levels of water availability. Results indicated that drought conditioning and K fertilization in nursery improve seedlings growth after plantation (Garau et al., 2005).

Guarnaschelli et al. (2010b) observed a decrease in the osmotic potential in water stressed and K fertilized plants of *E. globulus*, which would imply an increase in the water potential gradient between the plant and the soil, facilitating water uptake. In addition, treated plants showed higher relative water content and stomatal conductance.

Recently, Oddo et al. (2011) analyzed the effects of short-term K fertilization on plants of *Laurus nobilis*. They observed an enhancement in hydraulic conductance following short-term K fertilization; phenomenon that can be quite advantageous for maintaining cell turgor, stomatal aperture and gas exchange rates under moderate drought stress.

Apart from previous results, Römheld & Kyrkby (2010) argued that it is still necessary to explore the influence of K on plants under stressful conditions. In fact, there is no clear evidence that K addition may increase cold tolerance as well.

## **5. Effects of vegetation competition and herbivory during the tree establishment**

### **5.1 Weed competition: The main biotic cause of water and resource deficiencies**

During plantation establishment conditions of high levels of light and, sometimes, increased availability of water and nutrients favor the development of opportunistic, fast-growing

herbaceous and/or woody species that invade the disturbed site from wind-blow seeds, seeds stored in the seed soil-bank or by sprouting. Although the surrounding vegetation may play important functions in the forest system (reduce soil erosion, retain and recycle nutrients, add organic matter to the soil) and in certain environments can facilitate the growth of tree seedlings, it commonly interferes and captures resources at the expense of trees seedling performance (Cannell & Grace, 1993; Nambiar & Sands, 1993). Only shade tolerant tree species can become established beneath such vegetation. Herbaceous and/or woody vegetation which limits resource availability, hindering seedlings' expected growth and survival has been cited as one of the main causes of low plantation success (Smith et al., 1997; Close et al., 2005; Tappeiner et al., 2007).

Weed vegetation reduces the levels of water availability in the soil and affects negatively seedling water status (Dinger & Rose, 2009, 2010; Löf & Welander, 2004; Picon-Cochard et al., 2006), representing the main biotic cause of water stress (Lamhamedi et al., 1998; Picon-Cochard et al., 2001). Differences in weed density (Florentine & Fox, 2003; Garau et al., 2008b) and growth forms (Balandier et al., 2006; Coll et al., 2004; Provendier & Balandier, 2008) may cause variations in water restriction. Nevertheless, weeds will significantly interfere with forest seedlings only during "the critical period" (Adams et al., 2003).

Plant responses to competition are similar to those that allow coping with abiotic resource deficiencies and involve several physiological and/or morphological adjustments. Seedlings of shade intolerant trees, commonly used in many commercial plantations, are generally characterized by a great physiological plasticity that enables them to better utilize the higher light levels of open environments, and to withstand better the associated environmental stresses (Peltzer & Köchy, 2001; Picon-Cochard et al., 2006). Some responses are rapid and potentially lead to greater survival (i.e. stomatal closure), whereas others are delayed for hours or days, representing new capabilities and allocation patterns, providing some degree of resistance to the stress.

Numerous studies demonstrated that tree seedlings responded to weed imposed water deficit by anticipating stomatal closure and showing a reduction in leaf water potential (Coll et al., 2004; Dinger & Rose, 2009, 2010; Garau et al., 2008b; Picon-Cochard et al., 2001, 2006; Provendier & Balandier, 2008; Rey Benayas et al., 2003; Watt et al., 2003). Even with high soil water availability, the presence of weeds produced a significant decrease in leaf stomatal conductance (Garau et al., 2008b; Watt et al., 2003). Reductions between 30 and 80% in seedlings stomatal conductance reflect a useful response to limit water loss under soil water deficit (Garau et al., 2008b; Picon-Cochard et al., 2001).

Changes in tissue water relation parameters can help to withstand water stress induced by weed competition. A higher bulk modulus of cell wall elasticity and a lower osmotic potential or both were found in tree seedlings in response to neighboring competition (Rey Benayas et al., 2003). Garau et al. (2008b) observed that the restriction of soil water by weeds induced an osmotic adjustment of 0.38 MPa in seedlings of *E. globulus* subsp. *maidenii* and of 0.65 MPa when, additionally, a water restriction condition was imposed. Similarly, a cell wall stiffening of 8.0 MPa was induced independently of the level of water availability. Together, both strategies ensure water uptake while maintaining both cell turgor and volume. These features also allowed the maintenance of higher rates of gas exchange at low soil water content, being crucial for the establishment of tree seedlings (Lopez et al., 2009; Rodriguez-Calcerrada et al., 2010; Serrano & Peñuelas, 2005).

Some studies showed an increase in the intrinsic tree seedlings water-use efficiency (WUE) in response to soil dehydration caused by weed competition. Stomatal closure enabled seedlings to limit water stress, and since the decrease in stomatal conductance was faster than the decrease in CO<sub>2</sub> assimilation rate, an increase in the intrinsic WUE occurred (Garau et al., 2008b; Picon-Cochard et al., 2001; Picon-Cochard et al., 2006).

Other morphological adjustments that imply the postponement of dehydration by lessening the loss and increasing the uptake of water allow withstanding the low water availability. The presence of neighbouring vegetation may reduce seedlings above and below ground biomass to values 60- 80% lower than those obtained without competition (Garau et al., 2008b; Picon-Cochard et al., 2006; Watt et al., 2003). Under such conditions tree seedlings show lower leaf area and shoot:root ratio (Coll et al., 2004; Garau et al., 2008b; Picon-Cochard et al., 2006; Shipley & Meziane, 2002; Watt et al., 2003).

It is not possible to have water stress through competition without having some degree of nutrient stress, and although water stress has been implicated as the main regulator of seedlings performance, it is likely that competition for light also occurs. In fact, weeds are considered “multiple stressors” that compete not only for water but also for nutrients and light (Adams et al., 2003; Caldwell et al., 1995; Nambiar & Sands, 1993). Significant reductions in nutrients (mainly N) and light availability were observed in several studies attributed to competing vegetation (Cogliastro et al., 2006; Davis et al., 1999; Powell & Bork, 2004). Garau et al. (2008b) found a 50-75% reduction in photosynthetically active radiation when eucalypt seedlings were growing under a 100% of weed cover, condition that triggered the greatest leaf osmotic adjustment capacity. Significant increases in free amino acids that contribute to osmoregulation were observed in response to water stress and shade conditions (Showler, 2002; Valladares & Pearcy, 2002). Their synthesis may be associated with increasing weed competition.

### **Implication for plantation establishment**

It is possible to mitigate the effects of competition effectively by selecting plant material and applying cultural practices during the establishment (Adams et al., 2003; Jacobs et al., 2004). There are species or genotypes that during the critical initial stage of plantation establishment can demonstrate a “strong tolerance ability” (Goldberg, 1996) because they can maintain a high water status, particularly in the presence of weed competition. Physiological and morphological differences within species can thus form a basis for matching plant material to site, although survival and growth will ultimately depend on the levels of water stress experienced.

As discussed above, differences in the response of water-relations parameters to water stress induced by weeds can potentially be used to match genetic material to specific sites. Net solute accumulation could hence favor drought-tolerance beyond the seedling stage and be used as preliminary prediction for genetic screening studies and of field performance studies (Lemcoff et al., 1994; López et al., 2009). As observed by Garau et al. (2008b) seedlings with greater capacity for osmotic adjustment and cell wall stiffening were able to maintain a higher water status under severe weed cover. Garau (2003) found that although two provenances *E. globulus* subsp. *maidenii* presented similar drought-tolerance mechanisms, they have different capacity of acclimation. Murrabrine seedlings showed a higher water-stress threshold (a better combination of processes for “reduced water loss” and “maintenance of water uptake”) than Tantawanglo, which allowed Murrabrine seedlings to maintain higher rates of growth under weed competition.



In addition to genetic characteristics, nursery practices and silvicultural techniques can have an important effect on the seedling's growth and competition effects. Planting large seedlings allows withstanding competition from herbaceous or shrubby vegetation and minimizes the period of susceptibility to competition and also to animal damage (Noland et al., 2001; South et al., 2005). Cuesta et al. (2010) observed that large, nitrogen enriched seedlings of *Pinus halepensis* in the presence of weeds had higher water potential, gas exchange, and root growth and had finally a better transplanting performance.

Several measures are used also to regulate competition: weeding, plowing and application of herbicides (Smith et al., 1997; Tappeiner et al., 2007). Alternative methods of weed control are very effective because a greater number of seedlings can be established on treated sites. Different herbicides have been used to keep plantations weed-free. However, restrictions on the use of herbicides and worries about their environmental effects are generating some changes in silvicultural decisions. It has been agreed that it is necessary to adopt a new approach to weed control towards and "integrated vegetation management". For example, reducing the area of weed control according to the tree crop and weed growth habit characteristics seems to be an appropriate and effective option which causes less environmental impact and at the same time is less expensive (Garau et al., 2008a).

## 5.2 Herbivory and its interaction with water deficiencies

Trees are subjected to the negative impact of herbivory that removes biomass that might be allocated to grow and increases mortality. Different insect, rodent and mammalian species affect seedlings establishment both in natural forests and in commercial plantations (Becerra & Bustamante, 2008; Dulamsuren et al., 2008; Meiners et al., 2000). They are known to affect tree seedlings, especially during their first year of growth, but the intensity of damage is related to the population density of herbivores and to habitats' food offer. Plantation productivity is reduced due to the decrease in seedling growth, seedling survival and the development of multiple leaders. In Central and South America leaf-cutting ants are one of the main plagues that threaten seedlings growth and survival during the establishment (Della Lucia, 1993; Forti & Castelli Boaretto, 1997; Vasconcelos & Cherrett, 1997).

Plants have developed different kinds of defences, which allow their successful survival against herbivores. Some species have physical barriers (such as thorns and trichomes) or biomechanical properties in their leaves (such as strength and toughness) as anti-herbivore defences. Other plants produce chemical defences; mostly secondary metabolites like alkaloids, glucosinolates, terpenes, phenols, hydroxamic acids, tiophenes, and cyanogenic glycosides, among others. Secondary metabolites represent adaptive characters that have been subjected to natural selection during evolution and are thus important for plant survival and reproductive fitness (Benett & Walsgrove, 1994; Thies & Lerda, 2003; Wink, 2003). For instance, *Eucalyptus* species contain high concentrations of monoterpenic and sesquiterpenic compounds in their foliage, which have proved to be responsible for their ability towards different herbivores (Marsaro et al., 2004; Moore et al., 2004).

Genetic and environmental factors contribute to modulate the level at which different types of defence responses occur in plant species. Guarnaschelli et al. (2000) observed significant differences in leaf thickness and toughness among seedlings of provenances of *E. globulus* subsp. *maidenii*. Leaf-cutting ants caused higher damage in the provenance with lower toughness. Although nutritional quality of plant tissue can influence herbivore host choice, the structural and chemical defences are the major determinants of leaf and twigs



palatability. Most of those attributes are under genetic control (Raymond, 1995) and inter- and intra-provenance variation in resistance to insect damage has been reported in *Eucalyptus* sp. (Floyd et al., 1995).

Abiotic stresses such as drought can have important effects on plant-herbivore interactions, modifying herbivore population dynamics and anti-herbivore defences. Different hypotheses predict how plants under stress should respond to herbivory. However, it is difficult to generalize the effects of abiotic stress on host quality and herbivore damage (Wise & Abrahamson, 2007) since, although some herbivores are favored by unstressed plants, others are favored by moderately stressed plants or by severely stressed plants. Caffarini et al. (2006) observed in seven provenances of three subspecies of *E. globulus* that droughted plants or leaves (field and lab tests, respectively) were preferred by the leaf cutting ant *Acromyrmex lundii* to unstressed ones, overriding subspecies or provenance.

The decreased performance of herbivores on water stressed plants may be caused by several non-exclusive reasons: an increase in plant defense levels, a decrease of carbohydrate levels and/or a decrease in foliar water content (Scheirs & De Bruyn, 2006). But drought may increase or decrease secondary metabolism, increasing or decreasing host quality of trees for insect herbivores. For example, in several *Eucalyptus* species Muller da Silva et al. (2006) observed that water restriction decreased essential oil production while Stone & Bacon (1994) reported no modifications in total terpenoids yield.

The concentration of total phenolic glycosides increased in leaves of poplars that were growing under water stress conditions, however the growth of only one species of herbivore was negatively affected (Hale et al., 2005).

Sometimes the impact of herbivory is often greater if other original stress damage and lead to important tree losses. In young plantations of *E. camaldulensis* stressed by moisture deficit and in two young plantations of *E. dunnii* stressed by flooding and weed competition, Stone (2001) observed that the stress-inducing agents reduced canopy growth rates and architecture so that the proportion of leaf tissue damage by insects increased and the tree's ability to tolerate that damage decreases in all three cases.

Herbivory is thought to increase on water stress plants due to induced changes in plant physiology, specifically N availability. Water stress mediates N availability and then modifies the quality of the leaves and the population dynamics of insect herbivores (Huberty & Denno, 2004). Self-pruning of old leaves in combination with a reduction in leaf area of new leaves may allow the reallocation of foliar proteins to young leaves, explaining the enhanced foliar protein concentration in water stressed plants (Scheirs & De Bruyn, 2005). It was found that a greater availability of nutrients increased total essential oil and cineole levels in eucalypt leaves (Close et al., 2003; O'Reilly-Wapstra, 2005), however complex the effects of nutrients and secondary compounds on herbivores responses may be esteemed.

The susceptibility of pinyon pine (*Pinus edulis*) to the stem-and cone-borer increased in sites with intense water and nutrient deficiencies and the release from stress led to increased resistance to insect attack (Coob et al., 1997). *Eucalyptus* plants with high levels of fertilization showed higher levels of herbivory (Paine & Hanlon, 2010). Similarly, *Eucalyptus* seedlings, which had higher foliage N, lower tanin and higher essential oil levels were more browsed (Close et al., 2004).

Other abiotic stresses such as shade can affect the levels of damage by herbivores. A number of studies have reported lower tolerance of herbivory under shade conditions (Baraza et al.,

2004; McGraw et al., 1990; Norghaver et al., 2008; Salgado-Luarte & Gianoli, 2011). Differential herbivory in contrasting light environments may reflect light-induced differences in plant defensive traits such as leaf toughness and carbon-based secondary compounds. Plants' resistance may be greater in the sun probably due to their lower specific leaf area (SLA) (Salgado-Luarte & Gianoli, 2011). While comparing several characteristics in *Eucalyptus* seedlings growing under different levels of light, Guarnaschelli et al. (2003a, 2003b) found higher levels of herbivory damage in shaded plants, which had lower leaf thickness and toughness associated with higher SLA. Although Nichols-Orians (1991) detected much higher foliar concentrations of condensed tannins in plants growing in full sunlight compared to those growing in the understory, leaf-cutting ants found these leaves more acceptable because of the higher concentrations of foliar nutrients that override the benefits of increased concentrations of tannins. In other studies shade affected the chemical defences of *Acer*, *Quercus* and *Pinus* seedlings lowering the levels of total phenols and condensed tannins and increasing the levels of N (Baraza et al., 2004; Baraza et al., 2010). Moreover, plant resistance to herbivory can be influenced not only by the independent effects of plant genotype and environmental variation, but also by interactions between the two. A significant genotype x fertilizer interaction was found in the defensive compounds of *E. globulus* and their resistance to mammalian herbivores (O'Reilly-Wapstra et al., 2005). Some differences were recently found in the levels of leaf damage caused by *Leptocybe invasa* in seedlings of several clones of *E. grandis* and *E. grandis* x *E. camaldulensis* that were growing under alternative water and light availability regimes. Attacks were concentrated only in plants of *E. grandis* x *E. camaldulensis* clones, particularly in plants under drought, shade and drought plus shade conditions (Guarnaschelli et al., unpublished data).

### Management options

Interestingly enough, induction of intra-specific herbivore resistance is possible through manipulation of light, nutrients and water in the nursery environment or water and nutrient availability during the establishment. In fact, the potential of nursery preconditioning to enhance survival chances of future trees by reducing palatability or attracting beneficial insects as a result of changes in physical and/or chemical defences seems to be promising. Water availability manipulation during the nursery period of *E. camaldulensis* seedlings modified leaves essential oil composition, and drought triggered a significant increase in several oxygenated terpenes production (particularly linalool and 1,8-cineole) known to repel different defoliator species (Leicah et al., 2010).

Seedlings of *E. globulus* and *E. nitens* with high-fertilizer nursery treatment were browsed more than the low-fertilizer nursery treatment, the results being consistent with their differences in foliar N and tannins (Close et al., 2004). Similarly, the young foliage of *E. nitens* seedlings that receive medium and high levels of nutrient regime was intensively consumed. High levels of N in young leaves outweighed the presence of sideroxylonals and essential oils that generally act as deterrents to herbivores (Loney et al., 2006).

In contrast, low nutritional quality seems to be a plant defence against herbivores. Haukioja et al. (1991) demonstrated that the low nutritional quality is a potential active defence against herbivory in the mountain birch (*Betula pubescens* subsp. *tortuosa*), especially when it is correlated with repellent allelochemicals. In field trials Paine & Hanlon (2010) found that *Eucalyptus* trees treated with higher levels of irrigation and no fertilization demonstrated lower levels of damage by a psyllid.

Therefore, manipulation of seedlings or saplings chemistry through the application of particular fertilizer regimes as well as the regulation of water availability are useful tools for managers wishing to decrease damage by herbivory during the establishment. Alleviating tree stress through improved silvicultural practices or improved site selection techniques may indirectly reduce the impact of insect herbivory. In resource-limiting environments, an alternative approach may be planting species of slower growth that are predicted to have better defended foliage. Manipulation of these natural antiherbivore plant strategies is not exclusive of other management approaches, such as the genetic selection of natural insect resistance and selective chemical control techniques (Stone, 2001).

## 6. Conclusions

Water stress is the main cause of alteration of plant physiological processes and reduction of plant growth, which affects considerably tree seedlings performance immediately after plantation and during the whole establishment stage, causing serious losses and affecting tree regeneration and, consequently, future stand productivity. Water stress, itself and together with other abiotic and biotic factors, affects the dynamics of forest establishment, having an enormous impact on seedling performance. Multifactor stress conditions or sometimes the impact of secondary factors are often greater than the original drought effects, leading to greater tree losses. The enhancement of forest regeneration is a key process to ensure high forest productivity to supply timber needs in the present scenario of increasing demand of forest products. As discussed above, successful establishment depends on several management aspects. Breeding for drought tolerance should be given high priority in all research programs, considering genetic variation and phenotypic variation. In order to mitigate the transplanted shock, we also highlighted the importance of regulating water and nutrient regimes in nursery as useful tools not only to modify drought tolerance but also to reduce seedling's palatability, and hence herbivory damage in plantation forestry. Previous exposure to stress conditions, or a natural hardening period, can markedly influence future plant responses. Drought resistant seedling, nursery hardened, suited to the particular environmental condition, will have better field performance.

Some of the factors associated with successful forest establishment which have not been reviewed here, such as cultural practices applied before and over the establishment, have been widely studied; however, it is still necessary to foster new research in other areas. More information concerning seedling physiology is required, especially in relation of how seedlings adapt to particular plantation environments. The effects of water deficit and freezing temperatures, as well as the mechanisms that govern plant drought and frost tolerance, closely related to plant survival and growth during the establishment, have been analyzed in depth due to their great economic impact and relevance to stand productivity. Nowadays, climate change is altering environmental conditions. It is expected that drought conditions will become more frequent in extended areas. Changes in water availability and temperature will probably interact with other abiotic and biotic factors that may have a high effect during the forest establishment and the whole rotation. Under this environmental challenge it will be necessary for any species, provenances and clones, to understand the physiological basis of plant responses to water stress and together with interacting stressful factors that will be crucial also for predicting forest productivity. At the same time, nurseries' managers will be requested to adapt their cultural techniques in order to produce

high quality stock seedlings according to good field performance. Irrigation and nutritional protocols at nurseries should also be adjusted not only taking into account their influence on abiotic stress tolerance but also considering their impact on plant nutritional status and the host quality of trees for insect herbivores. It is necessary to establish relationships between field performance and physiological and morphological properties of nursery stock for each species, which will allow the implementation of the most adequate practices to produce stock of high quality. Finally, foresters will be requested to adapt the silvicultural planning to the present environmental concerns applying low impact practices and implementing integrative vegetation and pests control programs according to the principles of sustainable management.

## 7. References

- Abrams, M. D. (1990). Adaptations and responses to drought in *Quercus* species of North America. *Tree Physiology*, Vol.7, No.1-2-3-4, (December 1990), pp. 227-238, ISSN 0829-318X.
- Adams, P. R.; Beadle, C. L. & Mendham, N. J. (2003). The impact of timing and duration of grass control on growth of a young *Eucalyptus globulus* Labill. plantation. *New Forests*, Vol.26, No.2, (September 2003), pp. 147-165, ISSN 0196-4286.
- Adir, N.; Zer, H.; Shochat, S. & Chad, I. (2003). Photoinhibition - a historical perspective. *Photosynthesis Research*, Vol.76, No.1-3, (April 2003), pp. 343-370, ISSN 0166-8595.
- Aranda, I.; Castro, L.; Pardos, M.; Gil, L. & Pardos, J. A. (2005). Effects of the interaction between drought and morphological traits in cork oak (*Quercus suber* L.) seedlings. *Forest Ecology and Management*, Vol.210, No.1-3, (May 2005), pp. 117-129, ISSN 0378-1127.
- Arend, M.; Kuster, T.; Günthardt-Goerg, M. S.; Dobberty, M. & Abrams, M. (2011). Provenance-specific growth responses to drought and air warming in three European oak species (*Quercus robur*, *Q. petraea* and *Q. pubescens*). *Tree Physiology*, Vol.31, No.3, (April 2011), pp. 287-297, ISSN 0829-318X.
- Arndt, S. K.; Wanek, W.; Clifford, S. C. & Popp, M. (2000). Contrasting adaptations to drought stress in field-grown *Ziziphus mauritiana* and *Prunus persica* trees: water relations, osmotic adjustment and carbon isotope composition. *Functional Plant Biology*, Vol.27, No.11, (November 2000), pp. 985-996, ISSN 1445-4408.
- Arnott, J. T.; Grossnickle, S. C.; Puttonen, P.; Mitchell, K. A. & Folk, R. S. (1993). Influence of nursery culture on growth, cold hardiness and drought resistance of yellow cypress. *Canadian Journal of Forest Research*, Vol.23, No.12, (December 1993), pp. 2537-2547, ISSN 0045-5067.
- Ashraf, M.; Akram, N. A.; Al-Qurainy, F. & Foolad, M. R. (2011). Drought tolerance: roles of organic osmolytes, growth regulators, and mineral nutrients. *Advances in Agronomy*, Vol.111, (April 2011), pp. 249-296, ISBN 012-0007-95-9.
- Balandier, P.; Collet, C.; Miller, J.; Reynolds, P. & Zedaker, S. (2006). Designing forest vegetation management strategies based on the mechanisms and dynamics of crop tree competition by neighbouring vegetation. *Forestry*, Vol.79, No.1, (January 2006), pp. 3-27, ISSN 0015-752X.
- Baraza, E.; Gómez, J.; Hódar, J. & Zamora, R. (2004). Herbivory has a greater impact in shade than in sun: responses of *Quercus pyrenaica* seedlings to multifactorial



- environmental variation. *Canadian Journal of Botany*, Vol.82, No.3, (March 2004), pp. 357-364, ISSN 1916-2790.
- Baraza, E.; Zamora, R. & Hódar, J. (2010). Species-specific responses of tree saplings to herbivory in contrasting light environments: An experimental approach. *Ecoscience*, Vol.17, No.2, (June 2010), pp. 156-165, ISSN 1195-6860.
- Barnett, J. P. & McGilvray, J. M. (1993). Performance of container and bareroot Loblolly pine seedlings on bottomlands in South Carolina. *Southern Journal of Applied Forestry*, Vol.17, No.2, (May 1993), pp. 80-83, ISSN 0148-4419.
- Becerra, P. I. & Bustamante, R. O. (2008). The effect of herbivory on seedling survival of the invasive exotic species *Pinus radiata* and *Eucalyptus globulus* in a Mediterranean ecosystem of Central Chile. *Forest Ecology and Management*, Vol.256, No.9 (October 2008), pp. 1573-1578, ISSN 0378-1127.
- Bennett, R. N. & Wallsgrove, R. M. (1994). Secondary metabolites in plant defence mechanisms. *New Phytologist*, Vol.127, No.4, (August 1994), pp. 617-633, ISSN 1469-8137.
- Bigras, F. J. & Dumais, D. (2005). Root-freezing damage in the containerized nursery: impact on plantation sites - A review. *New Forests*, Vol.30, No.2-3, (September 2005), pp. 167-184, ISSN 0196-4286.
- Blum, A. (2005). Drought resistance, water-use efficiency, and yield-potential-are they compatible, dissonant, or mutually elusive? *Australian Journal of Agricultural Research*, Vol.56, No.11, (November 2005), pp. 1159-1168, ISSN 0004-9409.
- Braatne, J. H.; Hinckley, T. M. & Stettler, R. F. (1992). Influence of soil water on the physiological and morphological components of plant water balance in *Populus trichocarpa*, *Populus deltoides* and their F1 hybrids. *Tree Physiology*, Vol.11, No.4, (December 1992), pp. 325-339, ISSN 0829-318X.
- Bradshaw, A. D. (2006). Unraveling phenotypic plasticity - why should we bother? *New Phytologist*, Vol.170, No.4, (June 2006), pp. 644-648, ISSN 1469-8137.
- Brodribb, T. J. (2009). Xylem hydraulic physiology: The functional backbone of terrestrial plant productivity. *Plant Science*, Vol.177, No.4, (October 2009), pp. 245-251, ISSN 0168-9452.
- Brodribb, T. J. & Mc Adam, S. A. (2011). Passive origins of stomatal control in vascular plants. *Science*, Vol.331, No.6017, (February 2011), pp. 582-585, ISSN 0036-8075.
- Burdett, A. N. (1990). Physiological processes in plantation establishment and the development of specification for forest planting stock. *Canadian Journal of Forest Research*, Vol.20, No.4, (April 1990), pp. 415-427, ISSN 0045-5067.
- Caffarini, P.; Pelicano, A.; Carrizo, P. & Lemcoff, J. H. (2006). Impacto del estrés hídrico y la procedencia de *Eucalyptus globulus* Labill. sobre el comportamiento de herbivoría de *Acromyrmex lundii* Guérin. *Idesia*, Vol.24, No.1, (April 2006), pp. 7-11, ISSN 0073-4675.
- Caldwell, J.; Sucoff, E. & Dixon, K. (1995). Grass interference limits resource availability and reduces growth of juvenile red pine in the field. *New Forests*, Vol.10, No.1, (July 1995) pp. 1-15, ISSN 0196-4286.
- Cakman, I. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *Journal of Plant Nutrition and Soil Science*, Vol.168, No.4, (August 2005), pp. 521-530, ISSN 1522-2624.



- Cannell, M. G. R. & Grace, J. (1993). Competition for light: detection, measurement, and quantification. *Canadian Journal of Forest Research*, Vol.23, No.10, (October 1993), pp. 1969-1979, ISSN 0045-5067.
- Cannell, M. G. R. & Dewar, R. C. (1994). Carbon allocation in trees: a review of concepts for modeling, In: M. Begon & H. A. Fitter, (Eds.), pp.59-104. *Advances in Ecological Research* 25, Academic Press Ltd., ISBN 978-012-0139-25-5, London, UK.
- Chaves, M. M.; Maroco, J. P. & Pereira, J. S. (2003). Understanding plant responses to drought: from genes to whole plant. *Functional Plant Biology*, Vol.30, No.3, (March 2003), pp. 239-264, ISSN 1445-4408.
- Close, D. J.; McArthur, C.; Paterson, S.; Fitzgerald, H.; Walsh, A. & Kincade, T. (2003). Photoinhibition: a link between effects of the environment on eucalypt leaf chemistry and herbivory. *Ecology*, Vol.84, No.11, (November 2003), pp. 2952-2966, ISSN 0012-9658.
- Close, D. J.; McArthur, C.; Pietrzykowski, E.; Fitzgerald, H. & Paterson, S. (2004). Evaluating effects of nursery and post-planting nutrient regimes on leaf chemistry and browsing of eucalypt seedlings in plantation. *Forest Ecology and Management*, Vol.200, No.1-3, (October 2004), pp. 101-112, ISSN 0378-1127.
- Close, D.; Bail, I.; Hunter, S. & Beadle, C. L. (2005). Effects of exponential nutrient-loading on morphological and nitrogen characteristics and on after-planting performance of *Eucalyptus globulus* seedlings. *Forest Ecology and Management*, Vol.205, No.1-3, (February 2005), pp. 397-403, ISSN 0378-1127.
- Close, D. J.; Beadle, C. L. & Brown, P. H. (2005). The physiological basis of containerized tree seedlings 'transplant shock': a review. *Australian Forestry*, Vol.68, No.2, (June 2005), pp. 112-120, ISSN 0004-9158.
- Cochard, H.; Coll, L.; Le Roux, X. & Améglio, T. (2002). Unraveling the effects of plant hydraulics on stomatal closure during water stress in walnut. *Plant Physiology*, Vol.128, No.1, (January 2002), pp. 282-290, ISSN 0032-0889.
- Cogliastro, A.; Benjamin, K. & Bouchard, A. (2006). Effects of full and partial clearing, with and without herbicide, on weed cover, light availability, and establishment success of white ash in shrub communities of abandoned pastureland in southwestern Québec, Canada. *New Forests*, Vol.32, No.2, (September 2006), pp. 197-210, ISSN 0196-4286.
- Coll, L.; Balandier, P. & Picon-Cochard, C. (2004). Morphological and physiological responses of beech (*Fagus sylvatica*) seedlings to grass-induced belowground competition. *Tree Physiology*, Vol.24, No.1, (January 2004), pp. 45-54, ISSN 0829-318X.
- Coob, N. S.; Mopper, S.; Gehring, C. A.; Caouette, M.; Christensen, K. M. & Whitman, T. G. (1997). Increased moth herbivory associated with environmental stress of pinyon pine at local and regional levels. *Oecologia*, Vol.109, No.3, (February 1997), pp. 389-397, ISSN 0029-8549.
- Coopman, R. E.; Jara, J. C.; Escobar, R.; Corcuera, L. J. & Bravo, L. A. (2010). Genotypic variation in morphology and freezing resistance of *Eucalyptus globulus* seedlings subjected to drought hardening in nursery. *Electronic Journal of Biotechnology*, Vol.13, No.1, (January 2010), 9 pp., Available at: <http://www.ejbiotechnology.info/index.php/ejbiotechnology/index>.

- Costa e Silva, F.; Shvaleva, A.; Broetto, F.; Ortuño, M. F.; Rodrigues, M. L.; Almeida, M. H.; Chaves, M. M. & Pereira, J. S. (2009). Acclimation to short-term low temperatures in two *Eucalyptus globulus* clones with contrasting drought resistance. *Tree Physiology*, Vol.29, No.1, (January 2009), pp. 77-86, ISSN 0829-318X.
- Cregg, B. M. (1994). Carbon allocation, gas exchange, and needle morphology of *Pinus ponderosa* genotypes known to differ in growth and survival under imposed drought, *Tree Physiology*, Vol.14, No.7-8-9, (July 1994), pp. 883-898, ISSN 0829-318X.
- Cuesta, B.; Villar-Salvador, P.; Puértolas, J.; Jacobs, D. J. & Rey Benayas, J. M. (2010). Why do large, nitrogen rich seedlings, better resist stressful transplanting conditions? A physiological analysis in two functionally contrasting Mediterranean forest species. *Forest Ecology and Management*, Vol.260, No.1, (June 2010) pp. 71-78, ISSN 0378-1127.
- Davies, W. J.; Metcalfe, J.; Lodge, T. A. & da Costa, A. R. (1986). Plant growth substances and the regulation of growth under drought. *Australian Journal of Plant Physiology*, Vol.13, No.1, (January 1986), pp. 105-125, ISSN 1445-4408.
- Davis, M.; Wrage, K.; Reich, P.; Tjoelker, M.; Schaeffer, T. & Muermann, C. (1999). Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology*, Vol.145, No.2, (December 1999), pp. 341-350, ISSN 1385-0237.
- Della Lucia, T. M. C. (Ed.). (1993). *As formigas cortadeiras*, De Folha da Viçosa, ISBN , Minas Gerais, Brazil.
- Dinger, E. & Rose, R. (2009). Integration of soil moisture, xylem water potential, and fall-spring herbicide treatments to achieve the maximum growth response in newly planted Douglass-fir seedlings. *Canadian Journal of Forest Research*, Vol.39, No.7, (July 2009), pp. 1401-1414, ISSN 0045-5067.
- Dinger, E. & Rose, R. (2010). Initial fall-spring vegetation management regimes improve moisture conditions and maximize third-year Douglass-fir seedling growth in a Pacific Northwest plantation. *New Zealand Journal of Forestry Science*, Vol.40, No.1, (July 2010), pp. 93-108, ISSN 0048-0134.
- Dulamsuren, C.; Hauck, M. & Mühlenberg, M. (2008). Insect and small mammal herbivores limit tree establishment in northern Mongolian steppe. *Plant Ecology*, Vol.195, No.2, (April 2008), pp. 143-156, ISSN 1385-0237.
- Duryea, M I. & Landis, T. D. (Eds.). (1984). *Forest Nursery manual: Production of bareroot seedlings*, Martinus Nijhoff/Dr M. Junk Publisher, ISBN 978-902-4729-13-5, The Hague, Netherlands.
- Edwards, R. R & Dixon, M. D. (1995). Mechanisms of drought response in *Thuja occidentalis* L. I. Water stress conditioning and osmotic adjustment. *Tree Physiology*, Vol.15, No.2, (February 1995), pp. 121-127, ISSN 0829-318X.
- Fan, S.; Blake, T. J. & Blumwald, E. (1994). The relative contribution of elastic and osmotic adjustment to turgor maintenance of woody species. *Physiologia Plantarum*, Vol. 90, No.2, (February 1994), pp. 414-419, ISSN 0031-9317.
- Food and Agriculture Organization of the United Nations (FAO). (2009). *State of the world's forests 2009*, FAO. ISBN 978-925-1060-57-5, Rome, Italy.
- Food and Agriculture Organization of the United Nations (FAO). *Global Forest Resource Assessment 2010*, FAO. ISBN 978-925-3066-54-4, Rome, Italy.
- Florence, R. G. (1996). *Ecology and Silviculture of eucalypt forest*. CSIRO Publishing, ISBN 978-064-3057-99-9, Collinwood, Victoria, Australia.

- Florentine, S. & Fox, J. (2003). Competition between *Eucalyptus victrix* seedlings and grass species. *Ecological Research*, Vol.18, No.1, (January 2003), pp. 25-39, ISSN 0912-3814.
- Floyd, R. B.; Farrow, R. A. & Neumann, F. G. (1995). Inter- and intra-provenance variation in resistance to insect feeding. *Australian Forestry*, Vol.57, No.1, (March 1995), pp. 45-48, ISSN 0004-9158.
- Folgarait, P. J.; Dyer, L. E.; Marquis, T. J. & Braker, H. E. (1996). Leaf-cutting ant preferences for five native tropical plantation tree species growing under different light conditions. *Entomologia Experimentalis et Applicata*, Vol. 80, No.3, (September 1996), pp. 521-530, ISSN 0013-8703.
- Forti, L. C. & Castellani Boaretto, M. A. C. (1997). Formigas cortadeiras. Biologia, ecologia, danos e controle. Botucatu, San Pablo, Brazil.
- Garau, A. M. (2003). Estrategias de tolerancia al estrés hídrico provocado por la competencia con malezas durante el período de implantación de eucalipto. M.Sc. Thesis, Facultad de Agronomía, Universidad de Buenos Aires, Argentina.
- Garau, A. M.; Caccia, F. D. & Guarnaschelli, A. B. (2008a). Impact of standing vegetation on early establishment of willow cuttings in the flooded area of the Parana River Delta. *New Forests*, Vol.36, No.1, (July 2008), pp. 79-91, ISSN 0196-4286.
- Garau, A. M.; Guarnaschelli, A. B.; Mema, V. & Lemcoff, J. H. (2004a). Tissue water relations in *Eucalyptus* seedlings: effects of species, K fertilization and drought. *Proceedings of International IUFRO Eucalyptus in a Changing World*, Aveiro, Portugal, October 11-15, 2004.
- Garau, A. M.; Guarnaschelli, A. B.; Prystupa, P. & Lemcoff, J. H. (2004b). Relaciones hídricas en plantines de *Eucalyptus* sp. Sujetos a la interacción de fertilización nitrogenada y potásica con restricción hídrica. *Proceedings XXV Reunión Argentina de Fisiología Vegetal*. p.97, San Rosa, La Pampa, Argentina. September 22-24, 2004.
- Garau, A. M.; Lemcoff, J. H.; Ghersa, C. M. & Beadle, C. L. (2008b). Water stress tolerance of *Eucalyptus globulus* Labill. subsp. *maidenii* (F.Muell.) saplings induced by water restriction imposed by weeds. *Forest Ecology and Management*, Vol.255, No.7, (April 2008), pp. 2811-2819, ISSN 0378-1127.
- Garau, A. M.; Guarnaschelli, A. B.; Prystupa P.; Niveyro, I.; Landi, L.; Zorza, F. & Lemcoff, J. H. (2005). Fertilización y restricción hídrica en plántulas de *Eucalyptus camaldulensis*: modificaciones morfológicas y sus efectos sobre el estrés de plantación. *CD Proceedings Tercer Congreso forestal Argentino y Latinoamericano*, ISSN 1669-6786, Corrientes, Argentina, September 6-9, 2005.
- Goldberg, D. (1996). Simplifying the study of competition at the individual plant level: consequences of distinguishing between competitive effect and response for forest vegetation management. *New Zealand Journal of Forestry Science*, Vol.26, No.1/2, pp. 19-38, ISSN 0048-0134.
- Gower, S. T.; Vogt, K. A. & Grier, C. C. (1992). Carbon Dynamics of Rocky Mountain Douglas-Fir: Influence of Water and Nutrient Availability. *Ecological Monographs*, Vol.62, No.1, (March 1992), pp. 43-65, ISSN 0012-9615.
- Grossnickle, S. C. (1988). Planting stress in newly planted jack pine and white spruce. 2. Changes in tissue water potential components. *Tree Physiology*, Vol.4, No.1, (March 1988), pp. 85-97, ISSN 0829-318X.
- Grossnickle, S. C. (2005). Importance of root growth in overcoming planting stress. *New Forests* Vol.30, No.2-3, (September 2005), pp. 273-294, ISSN 0196-4286.

- Grossnickle, S. C. & Folk, R. S. (1993). Stock quality assessment: Forecasting survival or performance on a reforestation site. *Tree Planter's Note*, Vol.44, No.3, (Summer 1993), pp. 113-121. Available from <http://www.rngr.net/publications/tpn>.
- Guarnaschelli, A. B. (2009). Efecto del ajuste osmótico y la elasticidad de la pared celular sobre el crecimiento de *Eucalyptus globulus* durante el establecimiento. M.Sc. Thesis, Facultad de Agronomía, Universidad de Buenos Aires, Argentina.
- Guarnaschelli, A. B. & Lemcoff, J. H. (2001). Shoot and root osmotic adjustment in seedlings of *E. globulus* subsp. *maidenii*. *Proceedings The 6<sup>th</sup> ISRR Symposium. Roots: The Dynamic Interface between plants and the earth*, pp. 480-481, ISBN 493-1358-07-1, Nagoya, Japan, November 11-15, 2001.
- Guarnaschelli, A. B.; Garau, A. M. & Lemcoff, J. H. (2001). Tissue water relations in *Eucalyptus globulus* subsp. *maidenii*. *Proceedings IUFRO International Symposium Developing Eucalypts for the Future*, pp. 65, Valdivia, Chile, September 10-15, 2001.
- Guarnaschelli, A. B.; Prystupa, P. & Lemcoff, J. H. (2006). Drought conditioning improves water status, stomatal conductance and survival of *Eucalyptus globulus* subsp. *bicostata*. *Annals of Forest Science*, Vol.63, No.8, (December 2006), pp. 941-950, ISSN 1286-4560.
- Guarnaschelli, A. B.; Erice, F.; Battaglia, A. & Lemcoff, J. H. (2003a). Respuestas a la sequía y a la sombra en plantines de *Eucalyptus grandis*. *CD XVIII Jornadas Forestales de Entre Ríos*. ISSN 1667-9253, Concordia, Entre Ríos, Argentina, October 23-24, 2003.
- Guarnaschelli, A. B.; Garau, A. M.; Caccia, F. D. & Cortizo, S. C. (2008). Physiological responses to shade and drought in young willow plants. *Proceedings 23rd Session of the International Poplar Commission. Poplars, willows and people's wellbeing*, Available from <ftp://ftp.fao.org/docrep/fao/011/k3334e/k3334e.pdf>, pp. 75 Beijing, China, October 26-30, 2008.
- Guarnaschelli, A. B.; Garau, A. M.; Cortizo, S. C. & Lemcoff, J. H. (2010a). Differences in the ability of *Salix* clones to cope with water and light restriction. *IPS-V Books of Abstracts IUFRO Fifth International Poplar Symposium. Poplars and willows: research models to multipurpose trees for biobased society* (Available from <http://ocs.entecra.it/index.php/IPS/index/pages/view/material>), pp. 183, Orvieto, Italia, September 20-25, 2010.
- Guarnaschelli, A. B.; Garau, A. M.; Lemcoff, J. H. & Pathauer, P. (2007). Impacto de la sombra y la sequía sobre especies fisiológicas y de crecimiento en diversos orígenes de *Eucalyptus globulus* subesp. *globulus*. *CIDEU Bulletin, Bulletin of Forest and Environmental Topic*, Vol.3, No.1, (March 2007), pp. 91-98, ISSN 1885-5237.
- Guarnaschelli, A. B.; Gutiérrez G.; Garau, A. M. & Lemcoff, J. H. (2003b). Aclimatación a la sombra en plántulas de *E. globulus* subesp. *globulus*. *Proceedings Primer Simposio Iberoamericano de Eucalyptus globulus*, Montevideo, Uruguay, October 30-31, 2003.
- Guarnaschelli, A. B.; Lemcoff, J. H.; Prystupa, P. & Basci, S. O. (2003c). Responses to drought preconditioning in *Eucalyptus globulus* Labill. provenances. *Trees*, Vol.17, No.6, (November 2003), pp. 501-509, ISSN 0931-1890.
- Guarnaschelli, A. B.; Garau, A. M.; Mendoza, E. M.; Zivec, V. & Cortizo, S. C. (2010b). Influence of drought conditions on morphological and physiological attributes of *Populus deltoides* clones. *IPS-V Book of Abstracts IUFRO Fifth International Poplar Symposium. Poplars and willows: research models to multipurpose trees for biobased society*, Available from



- <http://ocs.entecra.it/index.php/IPS/index/pages/view/material>, pp. 155, Orvieto, Italia, September 20-25, 2010.
- Guarnaschelli, A. B.; Mantese, A.; Baraño, J. J.; De Haro, A. M. & Lemcoff, J. H. (2000). Anatomical leaf characteristics related to herbivory in *Eucalyptus globulus* subesp. *maidenii* seedlings, In: *The tree, L'Abre 2000*, I. Quentin, (Ed.) pp. 59-63, IQ Collectif Institut de Recherche en Biologie Végétale, ISBN 292-2417-21-2, Montréal, Canada.
- Guarnaschelli, A. B.; Ruiz Nuñez, J.; Chiavassa, J. A.; Fedotova, N. & Garau, A. M. (2010c). Aclimatación en vivero en plantas de *Eucalyptus* por restricción hídrica y fertilización potásica. CD XXIV Jornadas Forestales de Entre Ríos, ISSN 1667-9253 Concordia, Entre Ríos, Argentina, October 28-29, 2010.
- Guehl, J. M.; Aussenac, G. & Kaushal, P. (1989). The effects of transplanting stress on photosynthesis, stomatal conductance and leaf water potential in *Cedrus atlantica* Manetti seedlings: the role of root regeneration. *Annals of Forest Science*, Vol.46, No.Supplemental, pp. 464-468, ISSN 1286-4560.
- Guo, X. Y.; Zhang, X. S. & Huang, Z. Y. (2010). Drought tolerance in three hybrid poplar clones submitted to different watering regimes. *Journal of Plant Ecology*, Vol.3, No.2, (June 2010), pp. 79-87, ISSN 1752-9921.
- Hale, B.; Herms, D.; Hansen, R.; Clausen, T. & Arnold, D. (2005). Effects of drought stress and nutrient availability on dry matter allocation, phenolic glycosides and rapid induced resistance of poplar to two Lymantriid defoliators. *Journal of Chemical Ecology*, Vol.31, No.11, (November 2005), pp. 2601-2620, ISSN 0098-0331.
- Harvey, H. P. & van den Driessche, R. (1999). Nitrogen and potassium effects on xylem cavitation and water-use efficiency in poplars. *Tree Physiology*, Vol.19, No.14, (December 1999), pp. 943-950, ISSN 0829-318X.
- Haukioja, E.; Ruohomaki, K.; Suomela, J. & Vuorisalo, T. (1991). Nutritional quality as a defense against herbivores. *Forest Ecology and Management*, Vol.39, (1991), pp. 237-245, ISSN: 0378-1127.
- Hirasawa, T. & Hsiao, T. C. (1999). Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field. *Field Crops Research*, Vol. 62, No.1, (June 1999), pp. 53-62, ISSN 0378-4290.
- Hsiao, T. C. (1973). Plant responses to water stress. *Annual Review of Plant Physiology*, Vol.24, (June 1973), pp. 519-570, ISSN 0066-4294.
- Huberty, A. & Denno, R. (2004). Plant water stress and its consequences for herbivores insects: a new synthesis. *Ecology*, Vol.85, No.5, (May 2004), pp. 1383-1398, ISSN 0012-9658.
- Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M. L. Parry; O. F. Canziani; J. P. Palutikof; P. J. van der Linden & C. E. Hanson, C. E. (eds.). Cambridge University Press, ISBN 978-052-1705-97-7, Cambridge, UK.
- Jacobs, D. F.; Ross-Davis, A. L. & Davis, A. S. (2004). Establishment success of conservation tree plantation in relation to silvicultural practices in Indiana, USA. *New Forests*, Vol.28, No.1, (July 2004), pp. 23-36, ISSN 0196-4286.
- Jacobs, D. F.; Salifu, K. F. & Davis, A. S. (2009). Drought susceptibility and recovery of transplanted *Quercus rubra* seedlings in relation to root system morphology. *Annals of Forest Science*, Vol. 66, No.6, (November 2009), 504, 12 pp., ISSN 1286-4560.



- Jackson, R. B.; Jobbágy, E. G.; Avissar, R.; Roy, S. B.; Barrett, D. J.; Cook, C. W.; Farley, K. A.; le Maitre, D. C., McCarl, B. A. & Murray, B. C. (2005). Trading Water for Carbon with Biological Carbon Sequestration. *Science*, Vol.310, No.5752, (November 2005), pp. 1944-1947, ISSN 0036-8075.
- Jobbágy, E. G. & Jackson, R. B. (2004). Groundwater use and salinization with grassland afforestation. *Global Change Biology*, Vol.10, No.8, (August 2004), pp. 1299-1312, ISSN 1354-1013.
- Johnsen, K. H. & Major, J. E. (1999). Shoot water relations of black spruce families displaying a genotype x environment interaction in growth rate. I. Family and site effects over three growing seasons. *Tree Physiology*, Vol.19, No.6, (May 1999), pp. 367-374, ISSN 0829-318X.
- Kort, J.; Collins, M. & Ditsch, D. (1998). A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy*, Vol.14, No.4, (April 1998), pp. 351-359, ISSN 0961-9534.
- Kozlowski, T. T. (1982). Water supply and tree growth. I Water deficits. *Forestry Abstracts*, Vol.43, pp. 57-95, ISSN 0015-7538.
- Kozlowski, T. T. (1992). Carbohydrate sources and sinks in woody plants. *Botanical Review*, Vol.58, No.2, (April 1992) pp. 107-222, ISSN 0006-8101.
- Kozlowski, T. T. (2002). Physiological ecology of natural regeneration of harvested and disturbed stands: implications for forest management. *Forest Ecology and Management*, Vol.158, No.1-3, (March 2002), pp. 195-221, ISSN 0378-1127.
- Kozlowski, T. T. & Davies, D. (1975). Control of water balance in transplanted trees. *Journal of Arboriculture*, Vol.1, No.1, (January 1975), pp. 1-10, Available from [http://joa.isa-arbor.com/browse.asp?Journals\\_ID=1](http://joa.isa-arbor.com/browse.asp?Journals_ID=1).
- Kozlowski, T. T. & Pallardy, S. G. (1997). *Physiology of woody plants*, Second edition, Academic Press, ISBN 012-4241-62-X, San Diego, California, USA.
- Kozlowski, T. T. & Pallardy, S. G. (2002). Acclimation and adaptive responses of woody plants to environmental stresses. *Botanical Review*, Vol.68, No.2, (April 2002), pp. 270-334, ISSN 0006-8101.
- Kramer, P. J. & Boyer, J. S. (1995). *Water relations of plants and soils*, Academic Press, ISBN 012-4250-60-2, San Diego, California, USA.
- Laclau, P. (2003). Biomass and carbon sequestration of ponderosa pine plantations and native cypress forests in northwest Patagonia. *Forest Ecology and Management*, Vol.180, No.1-3, (July 2003), pp. 317-333, ISSN 0378-1127.
- Lamhamedi, M. S.; Bernier, P.; Hebert, C. & Jobdon, R. (1998). Physiological and growth responses of three sizes of containerized *Picea Mariana* seedlings out planted with and without vegetation control. *Forest Ecology and Management*, Vol.110, No.1-3, (October 1998), pp. 13-23, ISSN 0378-1127.
- Lamhamedi, M. S.; Lambany, G.; Margolis, H.; Renaud, M.; Veilleux, L. & Bernier, P. Y. (2001). Growth, physiology, root architecture and leaching of air-slit containerized *Picea glauca* seedlings (1+0) in response to time domain reflectrometry control irrigation regime. *Canadian Journal of Forrest Research*, Vol.31, No., pp. 1968-1980, ISSN 0045-5067.
- Lande, R. (2009). Adaptation to an extraordinary environment by evolution of phenotypic plasticity and genetic assimilation. *Journal of Evolutionary Biology*, Vol.22, No.7, (July 2009), pp. 1435-1446, Online ISSN 1420-9101.

- Landis, T. D. (2005). Macronutrients. Potassium. *Forest Nursery Notes*. Winter 2005. pp. 5-11, Available from <http://www.rngr.net/publications/fnn>.
- Landis, T. D.; Tinus, R. W.; McDonald, S. E. & Barnett, J. P. (Eds.) (1989). *The Container Tree Nursery Manual*, Vol. 4, *Seedling nutrition and irrigation*, USDA, Forest Service, Agricultural Handbook 674, Washington D.C, USA. Available from <http://www.rngr.net/publications/ctnm>.
- Landis, T. D.; Tinus, R. W.; McDonald, S. E. & Barnett, J. P. (Eds.), (1990). *The Container Tree Nursery Manual*, Vol. 2, *Containers and Growing media*, USDA, Forest Service, Agricultural Handbook 674, Washington D.C., USA. Available from <http://www.rngr.net/publications/ctnm>.
- Landis, T. D.; Tinus, R. W.; McDonald, S. E. & Barnett, J. P. (Eds.). (1992). *The Container Tree Nursery Manual*, Vol. 3, *Atmospheric environment*, USDA, Forest Service, Agricultural Handbook 674, Washington D.C., USA. Available from <http://www.rngr.net/publications/ctnm>.
- Landis, T. D.; Tinus, R. W. & Barnett, J. P. (Eds.). (2010). *The Container Tree Nursery Manual*. Vol. 7. *Seedling Processing, Storage, and Outplanting*, USDA. Forest Service. Agricultural Handbook 674. Washington D.C. Available from <http://www.rngr.net/publications/ctnm>.
- Leicach, S. R.; Garau, A. M.; Guarnaschelli, A. B.; Yaber Grass, M. A.; Sztarker, N. D. & Dato, A. (2010). Changes in *E. camaldulensis* essential oil as a response to drought. *Journal of Plant Interactions*, Vol.5, No.3, pp. 205-210 ISSN 1742-9145.
- Lemcoff, J. H.; Garau, A. M. & Guarnaschelli, A. B. (2009). Afforestation under adverse biotic and abiotic environment. A contribution to ameliorate *Eucalyptus* performance during the establishment: The Argentinean Experience, *Proceedings The Dahlia Greidinger International Symposium on "Crop Production in the 21<sup>st</sup> Century: Global Climate Change, Environmental Risks and Water Scarcity"*, pp. 119-121, Available from <http://dgsymp09.technion.ac.il/>, Haifa, Israel, March 2-5, 2009.
- Lemcoff, J. H.; Guarnaschelli, A. B.; Garau, A. M.; Bascialli, M. E. & Ghera, C. M. (1994). Osmotic adjustment and its use as selection criterion in *Eucalyptus* seedlings. *Canadian Journal of Forest Research*, Vol.24, No.12, (December 1994), pp. 2404-2409, ISSN 0045-5067.
- Lemcoff, J. H.; Guarnaschelli, A. B.; Garau, A. M. & Prystupa, P. (2002). Elastic and osmotic adjustment in rooted cuttings of *Eucalyptus camaldulensis*. *Flora*, Vol.197, No.2, pp. 134-142, ISSN 0367-2530.
- Levin, M.; Resnick, N.; Rosianskey, Y.; Kolotilin, I.; Wininger, S.; Lemcoff, J. H.; Cohen, S.; Galili, G.; Koltai, H. & Kapulnik, Y. (2009). Transcriptional profiling of *Arabidopsis thaliana* plants' response to low relative humidity suggests a shoot-root communication. *Plant Science*, Vol.177, No.4, (November 2009), pp. 450-459, ISSN 0168-9452.
- Li, F. L.; Bao, W. K. & Wu, N. (2009). Effects of water stress on growth, dry matter allocation and water-use efficiency of a leguminous species, *Sophora davidii*. *Agroforestry Systems*, Vol.77, No.3 (November 2009), pp. 193-201, ISSN 0167-4366.
- Lindenmayer, D. B.; Hobbs, R. J. & Salt, D. (2003). Plantation forestry and tree biodiversity conservation. *Australian Forestry*, Vol.66, No.1, (March. 2003), pp. 62-66, ISSN 0004-9158.

- Liu Z. & Dickmann, D. I. (1992). Responses of two hybrid poplar clones to flooding, drought and nitrogen availability. I. Morphology and growth. *Canadian Journal of Botany*, Vol.70, No.11, (November 1992), pp. 2265-2270, ISSN 1916-2790.
- Loney, P. E.; McArthur, C.; Sanson, G. D.; Davies, N. W.; Close, D. C. & Jordan, G. J. (2006). How do soil nutrients affect within-plant patterns of herbivory in seedlings of *Eucalyptus nitens*? *Oecologia*, Vol.150, No.3, (December 2006), pp. 409-420, ISSN 0029-8549.
- Löf, M. & Welander, N. (2004). Influence of herbaceous competitors on early growth in direct seeded *Fagus sylvatica* L. and *Quercus robur* L. *Annals of Forest Science*, Vol.61, No.8, (December 2004), pp. 781-788, ISSN 1286-4560.
- Lopez, R.; Rodríguez-Calcerrada, J. & Gil, L. (2009). Physiological and morphological response to water deficit in seedlings of five provenances of *Pinus canariensis*: potential to select variation in drought-tolerance. *Trees*, Vol.23, No.3, (June 2009), pp. 509-519, ISSN 0931-1890.
- Ludlow, M. M. (1989). Strategies in response to water stress. In: *Structural and functional responses under: water shortage*, K. H. Krebs, H. Richter & T. M. Hinckley, (Eds.), pp. 269-281, SPB Academic Press, ISBN 905-1030-27-4, The Hague, The Netherlands.
- Maillard, P. D.; Garriou, E.; Deléens, P. G. & Guehl, J. M. (2004). The effect of lifting on mobilization and new assimilation of C and N during regrowth of transplanted Corsican pine seedlings. A dual <sup>13</sup>C and <sup>15</sup>N approach. *Annals of Forest Science*, Vol.61, No.8, (December 2004), pp. 795-805, ISSN 1286-4560.
- Margolis, H. & Brand, D. (1990). An ecophysiological basis for understanding plantation establishment. *Canadian Journal of Forest Research*, Vol.20, No.4, (April 1990), pp. 375-390, ISSN 0045-5067.
- Marron, N.; Delay, D.; Petit, J. M.; Dreyer, E.; Kalham, G.; Delmotte, F. M. & Brignolas, F. (2002). Physiological traits of two *Populus x eucamericana* clones, Louisa Avanzo and Dorskamp, during a water stress and a re-watering cycle. *Tree Physiology*, Vol.22, No.12, (August 2002), pp. 849-858, ISSN 0829-318X.
- Marsaro, A.; Souza, R.; Della Lucia, T.; Fernandes, J.; Silva, M. & Vieira, P. (2004). Behavioural changes in workers of the leaf-cutting ant *Atta sexdens rubropilosa* induced by chemical components of *Eucalyptus* leaves. *Journal of Chemical Ecology*, Vol.30, No.9, (September 2009), pp. 1771-1780, ISSN 0098-0331.
- Marshall, J. D. (1985). Carbohydrates status as a measure of seedling quality. In: *Evaluating seedling quality: Principles, procedures and predictive abilities of major tests*, *Proceedings of the Workshop Held October 16-18, 1984*, M. Duryea (Ed.), pp. 49-58, Forest Research Laboratory, Oregon State University, ISBN 9780874370003 Corvallis, Oregon, USA.
- Marshall, J. G. & Dumbroff, E. B. (1999). Turgor regulation via cell wall adjustment in white spruce. *Plant Physiology*, Vol.119, No.1, (January 1999), pp. 313-319, ISSN 0032-0889.
- McGraw, J.; Gottschalk, K.; Vavrek, M. & Chester, A. (1990). Interactive effects of resources availabilities and defoliation on photosynthesis, growth and mortality of red oak seedlings. *Tree Physiology*, Vol.7, No.1-2-3-4, (December 1990), pp. 247-254, ISSN 0829-318X.
- Meiners, S. J.; Handel, S. N. & Pickett, S. T. A. (2000). Tree seedling establishment under insect herbivory: edge effect and inter-annual variation. *Plant Ecology*, Vol.151, No.2, (December 2000), pp. 161-170, ISSN 1385-0237.

- Mena Petite, A.; Muñoz-Rueda, A. & Lacuesta, M. (2005). Effects of cold storage treatments and transplanting stress on gas exchange, chlorophyll fluorescence and survival under water limiting conditions of *Pinus radiata* stock-types. *European Journal of Forest Research*, Vol.124, No.2, (June 2005), pp. 73-82, ISSN 1612-4669.
- Merchant, A.; Tausz M.; Arndt, S. K. & Adams, M. A. (2006). Cyclitols and carbohydrates in leaves and roots suggest contrasting physiological responses to water deficits. *Plant, Cell and Environment*, Vol.29, No.11, (November 2006), pp. 2017-2029, Online ISSN 1365-3040.
- Merchant, A.; Callister, A.; Arndt, S.; Tausz, M. & Adams, M. (2007). Contrasting physiological responses of six *Eucalyptus* species to water deficits. *Annals of Botany*, Vol.100, No.7, (December 2007), pp. 1507-1515, ISSN 0305-7369.
- Meier, C. E.; Newton, R. J.; Puryear, J. D. & Sean, S. (1992). Physiological responses of Loblolly pine (*Pinus taeda* L.) seedlings to drought stress: osmotic adjustment and tissue elasticity. *Journal of Plant Physiology*, Vol. 140, No.6, pp. 754-760, ISSN 0176-1617.
- Monclus, R.; Dreyer, E.; Villar, M.; Delmotte, F. M.; Delay, D.; Petit, J. M.; Barbaraux, C.; Le Thiec, D.; Bréchet, C. & Brignolas, F. (2006). Impact of drought on productivity and water use efficiency in 29 clones of *Populus deltoides* x *Populus nigra*. *New Phytologist*, Vol.169, No.4, (February 2006), pp. 765-777, ISSN 1469-8137.
- Moore, B.; Wallis, I.; Pala-Paul, J.; Brophy, J.; Willis, R. & Foley, W. (2004). Antiherbivore chemistry of *Eucalyptus*- Cues and deterrents for marsupial folivores. *Journal of Chemical Ecology*, Vol. 30, No.9, (September 2009), pp. 1743-1769, ISSN 0098-0331.
- Moraga, P.; Escobar, R. & Valenzuela, S. (2006). Resistance to freezing in three *Eucalyptus globulus* Labill. subspecies. *Electronic Journal of Biotechnology*, Vol.9, No.3, (June 2006) pp. 310-314, Available from <http://www.ejbiotechnology.info/index.php/ejbiotechnology/index>.
- Morgan, J. M. (1984). Osmoregulation and water stress in higher plants. *Annual Review of Plant Physiology*, Vol.35, (June 1984), pp. 299-319, ISSN 0066-4294.
- Morgan, J. M. & Cordon, A. G. (1986). Water use, grain yield and osmoregulation in wheat. *Australian Journal of Plant Physiology*, Vol.13, No.4, (August 1986), pp. 523-532, ISSN 1445-4408.
- Muller da Silva, P.; Brito, J. & da Silva, F. (2006). Potential of eleven *Eucalyptus* species for the production of essential oils. *Scientia Agricola* Vol. 63, No.1, (Jan./Feb.2006), pp. 85-89, ISSN 0103-9016.
- Nambiar, E. K. S. & Sands, R. (1993). Competition for water and nutrients in forests. *Canadian Journal of Forest Research*, Vol.23, No.10, (October 1993), pp. 1955-1968, ISSN 0045-5067.
- Nguyen, A. & Lamant, A. (1989). Variation in growth and osmotic regulation of roots of water-stressed maritime pine (*Pinus pinaster* Ait.) provenances. *Tree Physiology*, Vol.5, No.1, (March 1989), pp. 123-133, ISSN 0829-318X.
- Nguyen-Queyrens, A. & Bouchet Lannat, F. (2003). Osmotic adjustment in three-year-old seedlings of five provenances of maritime pine (*Pinus pinaster*) in response to drought. *Tree Physiology*, Vol.23, No.6, (April 2003), pp. 397-404, ISSN 0829-318X.
- Nicotra, A. B.; Atkin, O. K.; Bonser, S. P.; Davidson, A. M.; Finnegan, E. J.; Marthensius, U.; Poot, P.; Purugganan, M. D.; Richards, C. L.; Valladares, F. & van Kleunen, M.



- (2010). Plant phenotypic plasticity in a changing climate. *Trends in Plant Science*, Vol.15, No.12, (December 2010), pp. 684-692, ISSN 1360-1385.
- Nielsen, E. T. & Orcutt, D. M. (1996). *The physiology of plants under stress. Abiotic factors*. J. Wiley & Sons, ISBN 047-1035-12-6, New York, USA.
- Noland, T. L.; Mohammed, G. H. & Walter, R. G. (2001). Morphological characteristics associated with tolerance to competition from herbaceous vegetation for seedlings of jack pine, black spruce and white pine. *New Forests*, Vol.21, No.2, (May 2001), pp. 199-215, ISSN 0196-4286.
- Norghaver, J.; Malcom, J. & Zimmerman, B. (2008). Canopy cover mediates interactions between a specialist caterpillar and seedlings of a neotropical tree. *Journal of Ecology*, Vol.96, No.1, (January 2008), pp. 103-113, ISSN 1365-2745.
- Oddo, E.; Inzerillo, S.; La Bella, F.; Grisafi, F.; Salleo, S.; Nardini, A. & Goldstein, G. (2011). Short-term effects of potassium fertilization on the hydraulic conductance of *Laurus nobilis* L. *Tree Physiology*, Vol.31, No.2, (February 2011), pp. 131-138, ISSN 0829-318X.
- O'Reilly-Wapstra, J.; Potts, B.; McArthur, C. & Davies, N. (2005). Effects of nutrient variability on the genetic-based resistance of *Eucalyptus globulus* to a mammalian herbivore and on plant defensive chemistry. *Oecologia*, Vol.142, No.4, (May 2005), pp. 597-605, ISSN 0029-8549.
- Osório, J.; Osório, M. L.; Chaves, M. M. & Pereira, J. S. (1998). Water deficits are more important in delaying growth than in changing patterns of carbon allocation in *Eucalyptus globulus*. *Tree Physiology*, Vol.18, No.6, (June 1998), pp. 363-373, ISSN 0829-318X.
- Paine, T. & Hanlon, C. (2010). Integration of tactics for management of *Eucalyptus* herbivores: influence of moisture and nitrogen fertilization on red gum lerp psyllid colonization. *Entomologia Experimentalis et Applicata*, Vol.137, No.3, (December 2010), pp. 290-295, Online ISSN 1570-7458.
- Paquette, A. & Messier, C. (2010). The role of plantations in managing the world's forests in the Anthropocene. *Frontiers in the Ecology and Environment*, Vol.8, No.1, (February 2010), pp. 27-34, ISSN 1540-9295.
- Parker, W. C. & Pallardy, S. G. (1988). Leaf and root osmotic adjustment in drought-stressed *Quercus alba*, *Q. macrocarpa*, and *Q. stellata* seedlings. *Canadian Journal of Forest Research*, Vol.18, No.1, (January 1988), pp. 1-5, ISSN 0045-5067.
- Passioura, J. B. (1996). Drought and drought tolerance. *Plant Growth Regulation*, Vol.20, No.2, (December 1996), 79-83, ISSN 0169-6903.
- Peltzer, D. & Köchy, M. (2001). Competitive effects of grasses and woody plants in mixed-grass prairie. *Journal of Ecology*, Vol.89, No.4, (August 2001), pp. 519-527, ISSN 1365-2745.
- Perry, D. A.; Oren, R. & Hart, S. C. (2008). *Forest Ecosystems. Second Edition*. The John Hopkins University Press. ISBN 978-080-1888-40-3, Maryland. USA.
- Pezeshki, R. & Hinckley, T. M. (1988). Water relation characteristics of *Alnus rubra* and *Populus trichocarpa*: responses to field drought. *Canadian Journal of Forest Research*, Vol.18, No.9, (September 1988), pp. 1159-1166, ISSN 0045-5067.
- Phillipson, J. (1988). Root growth in Sitka Spruce and Douglas-fir transplants: dependence on the shoot and stored carbohydrates. *Tree Physiology*, Vol.4, No.2, (June 1988), pp. 101-108, ISSN 0829-318X.

- Picon-Cochard, C.; Nsourou-Obame, A.; Collet, C.; Guehl, J. & Ferhi, A. (2001). Competition for water between walnut seedlings (*Juglans regia*) and rye grass (*Lolium perenne*) assessed by carbon isotope discrimination and  $\delta^{18}\text{O}$  enrichment. *Tree Physiology*, Vol.21, No.2-3, (June 2001), pp. 183–191, ISSN 0829-318X.
- Picon-Cochard, C.; Coll, L. & Balandier, P. (2006). The role of below-ground competition during early stages of secondary succession: the case of 3-year-old Scots pine (*Pinus sylvestris* L.) seedlings in an abandoned grassland. *Oecologia*, Vol.148, No., pp. 373–383, ISSN 0029-8549.
- Pita, P. & Pardos, J. A. (2001). Growth, morphology, water use and tissue water relations of *Eucalyptus globulus* clones in response to water deficit. *Tree Physiology*, Vol.21, No.9, (June 2001), pp. 599–607, ISSN 0829-318X.
- Pita, P.; Cañas, I.; Soria, F.; Ruiz, F. & Toval, G. (2005). Use of physiological traits in tree breeding for improved yield in drought-prone environments. The case of *Eucalyptus globulus*. *Investigaciones Agrarias. Sistemas y Recursos Forestales*, Vol.14, No.3, pp. 383–393, ISSN 1131-7965.
- Powell, G. & Bork, E. (2004). Above- and below-ground effects from alfalfa and marsh reedgrass on aspen seedlings. *Forest Ecology and Management*, Vol.199, No.2-3, (October 2004), pp. 411–422, ISSN 0378-1127.
- Powles, S. B. (1984). Photoinhibition of photosynthesis induced by visible light. *Annual Review of Plant Physiology*, Vol.35, No., pp. 15–44, ISSN 0066-4294.
- Provendier, D. & Balandier, P. (2008). Compared effects of competition by grasses (Graminoids) and broom (*Cytisus scoparius*) on growth and functional traits of beech saplings (*Fagus sylvatica*). *Annals of Forest Science*, Vol.65, No., pp. 510–508, ISSN 1286-4560.
- Prior, L. D. & Eamus, D. (1999). Seasonal changes in leaf water characteristics of *Eucalyptus tetrodonta* and *Terminalia ferdinandiana* saplings. *Australian Journal of Botany*, Vol.47, No.4, pp. 587–599, ISSN 0067-1924.
- Raymond, C. A. (1995). Genetic variation in *Eucalyptus regnans* and *Eucalyptus nitens* for level of observed defoliation caused by *Eucalyptus* leaf beetle, *Chrysophtharta bimaculata* Olivier, in Tasmania. *Forest Ecology and Management*, Vol.72, No.1, (March 1995), pp. 21–29, ISSN 0378-1127.
- Rey Benayas, J.; Espigares, T. & Castro-Diez, P. (2003). Simulated effects of herb competition on planted *Quercus faginea* seedlings in Mediterranean abandoned cropland. *Applied Vegetation Science*, Vol.6, No.2, (December 2003), pp. 213–222, ISSN 1402-2001.
- Rietveld, R. J. (1989). Transplanting stress in bareroot conifer seedlings: its development and progression to establishment. *Northern Journal of Applied Forestry*, Vol.6, No.3, (September 1989), pp. 99–107, ISSN 0742-6348.
- Rodríguez-Calcerrada, J.; Pardos, J. & Aranda, I. (2010). Contrasting responses facing peak drought in seedlings of two co-occurring oak species. *Forestry*, Vol.83, No.4, (October 2010), pp. 369–378, ISSN 0015-752X.
- Römheld V. & Kirkby, E. A. (2010). Research on potassium in agriculture: needs and prospects. *Plant and Soil*, Vol.335, No.1-2, (October 2010), pp. 155–180, ISSN 0032-079X.
- Rose, R.; Campbell, S. & Landis, T. D. (Eds.). (1990). *The Target seedling Symposium: Proceedings, Combined Meeting of the Western Forest Nurseries Associations, August 13-*

- 17, 1990, Roseburg, Oregon, General Technical Report GTR-RM-200. Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, Available from <http://www.rngr.net/publications/proceedings/1990/WFCNA>, Fort Collins, Colorado, USA.
- Salgado-Luarte, C. & Gianoli, E. (2011). Herbivory may modify functional responses to shade in seedlings of a light-demanding tree species. *Functional Ecology*, Vol.25, No.3, (June 2011), pp. 492-494, Online ISSN 1365-2745.
- Sands, R. (1984). Transplanting stress in radiate pine. *Australian Forest Research*, Vol.14, pp. 67-72, ISSN 0004-914X.
- Scheirs, J. & De Bruyn, L. (2005). Plant-mediated effects of drought stress on host preference and performance of a grass miner. *Oikos*, Vol.108, No.2, (August 2005), pp. 371-385, Online ISSN 1600-0706.
- Schlichting, C. D. (1986). The evolution of phenotypic plasticity in plants. *Annual Review of Ecology and Systematics*, Vol.17, pp. 677-693, ISSN 0066-4162.
- Schulte, P. J. & Hinckley, T. M. (1987). The relationships between guard cell water potential and the aperture of stomata of *Populus*. *Plant Cell and Environment*, Vol.10, No.4, (June 1987), pp. 313-318, ISSN 1364-1344.
- Schultz, R. C. & Thompson, J. R. (1997). Effect of density control and undercutting on root morphology on 1+0 bareroot hardwood seedlings: five year field performance or root-graded stock in the central USA. *New Forests*, Vol.13, No.1-3, (May 1997), pp. 301-314, ISSN 0196-4286.
- Scheirs, J. & De Bruyn, L. (2005). Plant-mediated effects of drought stress on host preference and performance of a grass miner. *Oikos*, Vol.108, No.2, (February 2005), pp. 371-385, Online ISSN 1600-0706.
- Serrano, L. & Peñuelas, J. (2005). Contribution of physiological and morphological adjustments to drought resistance in two Mediterranean tree species. *Biologia Plantarum*, Vol.49, No.4, (December 2005), pp. 551-559, ISSN 1573-8264.
- Shipley, B. & Meziane, D. (2002). The balanced-growth hypothesis and the allometry of leaf and root biomass allocation. *Functional Ecology*, Vol.16, No.3, (June 2003), pp. 326-331 Online ISSN 1365-2745.
- Showler, A. (2002). Effects of water deficit stress, shade, weed competition, and kaolin particle film on selected foliar free amino acid accumulations in cotton, *Gossypium hirsutum* (L.). *Journal of Chemical Ecology*, Vol.28, No.3, (March 2002), pp. 631-651, ISSN 0098-0331.
- Silim, S.; Nash, R.; Reynard, D.; White, B. & Shroeder, W. (2009). Leaf gas exchange and water potential responses to drought in nine poplar (*Populus* spp.) clones with contrasting drought tolerance. *Trees*, Vol.23, No.5, (October 2009), pp. 959-969, ISSN 0931-1890.
- Sloan, J. L. & Jacobs, D. F. (2008). Carbon translocation patterns associated with new root growth proliferation during episodic growth of transplanted *Quercus rubra* seedlings. *Tree Physiology*, Vol.28, No.7, (July 2008), pp. 1121-1126, ISSN 0829-318X.
- Smith, D. M.; Larson, B. C.; Kelty, M. J. & Ashton, P. M. S. (1997). *The practice of Silviculture: Applied Forest Ecology*, 9<sup>th</sup> Edition, John Wiley & Sons Inc, ISBN 047-1109-41-X, New York, USA.
- Smith T. & Huston, M. (1989). A theory of the spatial and temporal dynamics of plant communities. *Vegetatio*, Vol.83, No.1-2, (October 1989), pp. 49-69, ISSN 0042-3106.

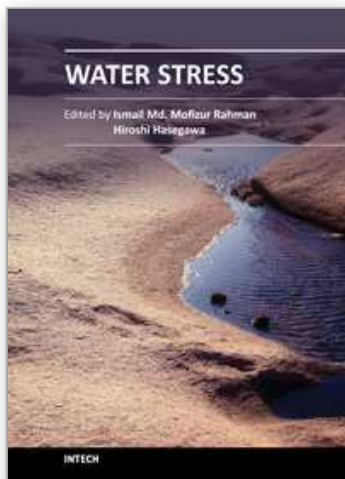
- South, D. B.; Harris, S. W.; Barnett, J. P.; Hains, M. J. & Gjerstad, D. H. (2005). Effect of container type and seedling size on survival and early height growth of *Pinus palustris* seedlings in Alabama, U.S.A. *Forest Ecology and Management*, Vol.204, No.2-3, (January 2005), pp. 385-398, ISSN 0378-1127.
- Stone, C. (2001). Reducing the impact of insect herbivory in eucalypt plantations through management of extrinsic influences on tree vigor. *Austral Ecology*, Vol.26, No.5, (October 2001), pp. 482-488, ISSN 1442-9985.
- Stone C. & Bacon, P. E. (1994). Relationships Among Moisture Stress, Insect Herbivory, Foliar 1,8-cineole Content and the Growth of River Red Gum *Eucalyptus camaldulensis*. *Journal of Applied Ecology*, Vol.31, No.4, (November 1994), pp. 604-612, ISSN 1365-2664.
- Stoneman, G. L. (1994). Ecology and physiology of establishment of eucalypt seedlings from seed: A review. *Australian Forestry*, Vol.57, No.1, (March 1994), pp. 11-30, ISSN 0004-9158.
- Stoneman, G. L.; Turner, N. C. & Dell, B. (1994). Leaf growth, photosynthesis and tissue water relations of greenhouse-grown *Eucalyptus marginata* seedlings in response to water deficits. *Tree Physiology*, Vol.14, No.6, (June 1994), pp. 633-646, ISSN 0829-318X.
- Stewart, J. D. & Lieffers, V. J. (1993). Preconditioning effects of nitrogen addition rate and drought stress on container-grown lodgepole seedlings, *Canadian Journal of Forest Research*, Vol.23, No.8, (August 1993), pp. 1663-1671, ISSN 0045-5067.
- Taiz, L. & Zeiger, E. (2002). *Plant Physiology. Third edition*. Sinauer Associates Inc. Publishers, ISBN 087-8938-23-0 Sunderland, Massachusetts, USA.
- Tan, W.; Blake, T. J. & Boyle, T. B. (1992). Drought tolerance in faster- and slower-growing black spruce (*Picea mariana*) progenies: II. Osmotic adjustment and changes of soluble carbohydrates and amino acids under osmotic stress. *Physiologia Plantarum*, Vol. 85 No.4, (August 1992), pp. 645-651, ISSN 0031-9317.
- Tappeiner, J. C. & Helms, J. A. (1971). Natural regeneration of Douglas fir and white fir in exposed sites in the Sierra Nevada of California. *American Midland Naturalist*, Vol. 86, No.2, (October 1971), pp. 358-370, ISSN 1938-4238.
- Tappeiner, J. C.; Maguire, D. A. & Harrington, T. B. (2007). *Silviculture and Ecology of Western U. S. Forests*. Oregon State University Press, ISBN 978-087-0711-87-9, Corvallis, Oregon, USA.
- Theis, N. & Lerdau, M. (2003). The evolution of function in plant secondary metabolites. *International Journal of Plant Sciences*, Vol.164, No.S3, (May 2003), pp. S93-S102, ISSN 1058-5893.
- Tschaplinski, T. J.; Tuskan, G. A.; Gebré, G. M. & Todd, D. E. (1998). Drought resistance of two hybrid *Populus* clones grown in a large-scale plantation. *Tree Physiology*, Vol.18, No.10, (October 1998), pp. 653-658, ISSN 0829-318X.
- Tuomela, K. (1997). Leaf water relations in six provenances of *Eucalyptus microtheca*: a greenhouse experiment. *Forest Ecology and Management*, Vol.92, No.1-3, (May 1995), pp. 1-10, ISSN 0378-1127.
- Turner, N. C. (1986a). Adaptation to water deficit: A changing perspective. *Australian Journal of Plant Physiology*, Vol.13, No.1, pp. 175-190, ISSN 1445-4408.
- Turner, N. C. (1986b). Crop water deficits: a decade of progress. *Advances in Agronomy*, Vol.39, pp. 1-51, ISBN 012-0007-95-9.



- Turner, N. C. & Jones, M. M. (1980). *Turgor maintenance by osmotic adjustment: a review and evaluation*. In: *Adaptation of Plants to Water and High Temperature Stress*, N. C. Turner & P. J. Kramer, (Eds.), pp. 78–103, John Wiley & Sons, ISBN 978-047-1053-72-9, New York, USA.
- Uemura, A.; Ishida, A.; Nakano, T.; Terashima, I.; Tanabe, H. & Matsumoto, Y. (2000). Acclimation of leaf characteristics of *Fagus* species to previous-year and current-year solar irradiance. *Tree Physiology*, Vol.20, No.14, (Agosto 2000), pp. 945-951, ISSN 0829-318X.
- United Nations Framework Convention on Climate Change (UFCCC). (2007). Investment and financial flows to address climate change. 273 pp.
- Valladares, F.; Vilagrosa, A.; Peñuelas, J.; Ogaya, R.; Camarero, J. J.; Corcuera, L.; Siso, S. & Gil-Pelegrin, E. (2004). *Estrés hídrico: Fisiología y escalas de la sequía*, In: *Ecología del bosque mediterráneo en un mundo cambiante*, F. Valladares, (Ed.), pp. 163-190, Ministerio de Medio Ambiente, EGRAF. S.A., ISBN 84-8014-552-8, Madrid, España.
- Valladares, F.; Sánchez-Gómez, D. & Zavala, M. A. (2006). Quantitative estimation of phenotypic plasticity: bringing the gap between the evolutionary concept and its ecological applications. *Journal of Ecology*, Vol.94, No.6, (November 2006), pp. 1103-1116, ISSN 1365-2745.
- van den Driessche, R. (1987). Importance in current photosynthate to new root growth in planted conifer seedlings. *Canadian Journal of Forest Research*, Vol.17, No.8, (August 1989), pp. 776-782, ISSN 0045-5067.
- van den Driessche, R. (1991). Influence of container nursery regimes on drought resistance of seedlings following planting. II. Stomatal conductance, specific leaf area and root growth capacity. *Canadian Journal of Forest Research*, Vol.21, No.5, (May 1995), pp. 566-572, ISSN 0045-5067.
- van den Driessche, R. (1992). Changes in drought resistance and root growth capacity of container seedlings in response to nursery drought, nitrogen and potassium treatments. *Canadian Journal of Forest Research*, Vol.22, No.5, (May 1992), pp. 740-749, ISSN 0045-5067.
- Vasconcelos, H. L. & Cherrett, J. M. (1997). Leaf-cutting ants and early forest regeneration in central Amazonia: effects of herbivory on tree seedling establishment. *Journal of Tropical Ecology*, Vol.13, No.3, (May 1997), pp. 357-370, ISSN 0266-4764.
- Verdaguer, D.; Vilagran, J.; Lloansi, S. & Fleck, I. (2011). Morphological and physiological acclimation of *Quercus coccifera* L. Seedlings to water availability and growing medium. *New Forests*, Vol.42, No.3, pp. 363-381, (November 2011), ISSN 0196-4286.
- Viglizzo, E. F.; Frank, F. C.; Carreño, L. V.; Jobbágy, E. G.; Pereyra, H.; Clatt, J.; Pincén, D. & Ricard, M. F. (2011). Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Global Change Biology*, Vol.17, No.2, (February 2011), pp. 959-973, ISSN 1354-1013.
- Vilagrosa, A.; Cortin, J.; Gil-Pelegrin, E. & Bellot, J. (2003). Suitability of drought-preconditioning techniques in Mediterranean climate. *Restoration Ecology*, Vol.11, No.2, (June 2003), pp. 208-216, Online ISSN 1526-100X.
- Vilagrosa, A.; Villar-Salvador, P. & Puértolas, J. (2006). *El endurecimiento en vivero de especies forestales mediterráneas*. In: *Calidad de planta forestal para la restauración en ambientes mediterráneos*. Estado actual de conocimientos, J. Cortina, J. L. Peñuelas, J. Puértolas, R.

- Savé & A. Vilagrosa, (Eds.), pp. 119-140, DGB Ministerio de Medio Ambiente, Serie Forestal, ISBN 848-0146-70-2, Madrid, España.
- Villar-Salvador, P.; Planelles, R.; Oliet, J.; Peñuelas, J. L.; Jacobs, D. F. & M. González. (2004). Drought tolerance and transplanting performance of holm oak (*Quercus ilex*) seedlings after drought hardening in the nursery. *Tree Physiology*, Vol.24, No.10, (October 2004), pp. 1147-1155, ISSN 0829-318X.
- Villar-Salvador, P.; Puértolas, J.; Peñuelas, J. L. & Planelles, R. (2005). Effects of nitrogen fertilization in the nursery on the drought and frost resistance of Mediterranean forest species. *Investigación Agraria. Sistemas y Recursos Forestales*, Vol.14, No., pp. 408-418, ISSN 1131-7965.
- Vitousek, P. M. (1991). Can planted forests counteract increasing atmospheric carbon dioxide? *Journal of Environmental Quality*, Vol.20, No.2, (April-June 1991), pp. 348-354, ISSN 0047-2425.
- Waring, R. H. & Schlesinger, W. H. (1985). *Forest Ecosystems. Concepts and management*. Academic Press Inc., ISBN 012-7354-40-9, New York, USA.
- Watt, M.; Whitehead, D.; Mason, E.; Richardson, B. & Kimberley, M. (2003). The influence of weed competition for light and water on growth and dry matter partitioning of young *Pinus radiata* at a dryland site. *Forest Ecology and Management*, Vol.183, No.1-3, (September 2003), pp. 363-376, ISSN 0378-1127.
- White, T. C. (1969). An index to measure weather-induced stress by trees associated with outbreak of psyllids in Australia. *Ecology*, Vol.50, No.5, (September 1969), pp. 905-909, ISSN 0012-9658.
- White, D. A.; Beadle, C. L. & Worledge, D. (1996). Leaf water relations of *Eucalyptus globulus* and *E. nitens*: seasonal, drought and species effects. *Tree Physiology*, Vol.16, No.5, (May 1996) pp. 469-476, ISSN 0829-318X.
- White, D. A.; Turner, N. C. & Galbraith, J. H. (2000). Leaf water relations and stomatal behavior of four allopatric *Eucalyptus* species planted in Mediterranean southwestern Australia. *Tree Physiology*, Vol.20, No.17, (November 2000), pp. 1157-1165, ISSN 0829-318X.
- Whitehead, D. & Beadle, C. L. (2004). Physiological regulation of productivity and water use in *Eucalyptus*: a review. *Forest Ecology and Management*, Vol.193, No.1-2, (May 2004), pp. 113-140, ISSN 0378-1127.
- Whiteman, A. & Brown, C. (1999). The potential role of forest plantations in meeting future demands for industrial wood products. *International Forestry Review*, Vol.1, No.3, (September 1999), pp. 143-152, ISSN 1465-5489.
- Wikber, J. & Ogren, R. (2007). Variation in drought resistance, drought acclimation and water conservation in four willow cultivars used for biomass production. *Tree Physiology*, Vol.27, No.9, (September), pp. 1339-1346, ISSN 0829-318X.
- Wink, M. (2003). Evolution of secondary metabolites from an ecological and molecular phylogenetic perspective. *Phytochemistry*, Vol.64, No.1, (September 2003), pp. 3-19, ISSN 0031-9422.
- Wise, M. J. & Abrahamson, W. G. (2007). Effects of resource availability on tolerance of herbivory: a review and assessment of three opposite models. *American Naturalist*, Vol.169, No.4, (April 2007), pp. 443-454, ISSN 00030147.

- Yordanov, I.; Velikova, V. & Tsonev, T. (2000). Plants responses to drought, acclimation and stress tolerance. *Photosynthetica*, Vol.38, No.2, (June 2002), pp. 171-186, ISSN 0300-3604.
- Zine El Abidine, A.; Bernier, P. Y.; Stewart, J. D. & Plamondon, A. P. (1994). Water stress preconditioning of black spruce seedlings from lowland and upland sites, *Canadian Journal of Botany*, Vol.72, No.10, (October 1994), pp. 1511-1518, ISSN 1916-2790.
- Zwiazek, J. J. & Blake, T. J. (1989). Effects of preconditioning on subsequent water relations, stomatal sensitivity, and photosynthesis in osmotically stressed black spruce. *Canadian Journal of Botany*, Vol.67, No.8, (August 1989), pp. 2240-2244, ISSN 1916-2790.



## **Water Stress**

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Plants experience water stress either when the water supply to their roots becomes limiting, or when the transpiration rate becomes intense. Water stress is primarily caused by a water deficit, such as a drought or high soil salinity. Each year, water stress on arable plants in different parts of the world disrupts agriculture and food supply with the final consequence: famine. Hence, the ability to withstand such stress is of immense economic importance. Plants try to adapt to the stress conditions with an array of biochemical and physiological interventions. This multi-authored edited compilation puts forth an all-inclusive picture on the mechanism and adaptation aspects of water stress. The prime objective of the book is to deliver a thoughtful mixture of viewpoints which will be useful to workers in all areas of plant sciences. We trust that the material covered in this book will be valuable in building strategies to counter water stress in plants.

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