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PRODUCTION FUNCTIONS OF EUCALYPTUS FOR THE DESIGN OF SALINE-DRAINAGE WATER REUSE SYSTEMS

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Abstract

Agroforestry has been promoted as a viable "reuse" method for reducing the volumes of saline drainage effluents in California's San Joaquin valley. The effectiveness of eucalyptus at reducing saline drainage volumes is dependent upon its tolerance to the conditions where they are established over the long term, in particular, high concentrations of salts and boron. Consequently we are currently conducting a three-yr study in a large outdoor sand-tank facility at the new US Salinity Lab in Riverside California to determine the potential and limits by which eucalyptus (Eucalyptus camaldulensis, Dehn. Clone 4544) can utilize saline drainage effluent containing variable amounts of boron. A short-term greenhouse study has shown E. calmaldulensis is tolerant to relatively high levels of salinity and that shoot biomass decreased linearly as the EC of the irrigation water increases from 2 to 28 dS/m. In the main experiment, salinity markedly reduced cumulative evapotranspiration and tree height after two months exposure to the various treatments. Boron did not substantially affect these parameters at this time The older leaves on trees treated with high levels of B (25 and 30 mg/L) but relatively low levels of salinity (ECw 2 and 6 dS/m) showed foliar injury characteristic of B toxicity. Leaf B concentrations support this supposition. Injured tissue was found to contain B in excess of 1,500 mg/kg dry wt. No injury was found on trees exposed to the same levels of B but in the presence of high salinity (ECw > 10 dS/m). Leaf B concentrations decreased as salinity increased indicating that salinity reduces leaf-B accumulation.

Leaching and drainage of agricultural lands are prerequisites for sustaining crop productivity in arid and semi-arid regions over the long term but the drainage effluent, which contains dissolved salts, boron and other constituents, must be disposed of or managed to avoid long-term effects on the environment. In California's San Joaquin Valley, trace elements (e.g. Se, Mo, B) are also found in drainage water and their presence have added a new dimension to the management of agricultural drainage effluents (van Schilfgaarde, 1990). Since the closure of the master drain in 1986, use of saline drainage water for irrigation is one of only a few on-farm water management options available to growers in this area as a temporary means of reducing their effluent volumes (San Joaquin Valley Drainage Program, 1990).

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The concept of drainage water reuse through agroforestry (i.e. eucalyptus) has been promoted as part of an environmentally-sound method for the reduction of saline drainage effluents in the San Joaquin valley (Cervinka, 1994; San Joaquin Valley Drainage Program, 1990). The drainage water reuse concept proposes sequential use of drainage water on progressively more salt-tolerant crops where application of concentrated effluents to eucalyptus trees is the second to the last crop, preceding halophytes, in the sequence. However the effectiveness of eucalyptus trees in reducing drainage volume is dependent upon their ability to tolerate high levels of salinity and boron over the long term.

Eucalyptus trees have been found to reduce dryland salinization in areas cleared of native vegetation in western Australia (Bar-i and Schofield, 1992). Re vegetation with eucalyptus trees reduces ground water recharge and lowers raised saline-water tables thereby reducing salinization of the upper portion of the soil profile (Morris and Thomson, 1983).

Over the past decade, eucalyptus plantations have been established throughout California's San Joaquin valley for the purpose of reducing the volume of drainage water that needs ultimate disposal. Often the poorest or most problematic fields such as those with high saline water tables or those that are poorly drained are selected for the eucalyptus trees. Eucalyptus camaldulensis has been an attractive species due to it's relatively high tolerances to salinity (Donaldson et al., 1983; Marcar and Termaat, 1990) and waterlogging (Marcar, 1993; van der Moezel et al., 1988).

The extent to which eucalyptus can reduce drainage volumes depends on maintaining high rates of evapotranspiration. In non-stressed environments, the literature reports crop coefficients (Kc) for a full cover of eucalyptus trees between 1.2 to 1.5 (Stribbe, 1975; Sharma, 1984). However at one site in the San Joaquin valley where Eucalyptus camaldulensis was irrigated with saline drainage water (EC = 10 dS/m and 12 mg/L B), evapotranspiration (ET) was estimated using two energy balance methods and Kc values were 0.83 (i.e. ET of eucalyptus was 0.83 reference crop ET) (Dong et al., 1992). This lower Kc value was attributed to combined salt and B stress.

The feasibility of utilizing eucalyptus to reduce drainage volumes over the long term is dependent upon salt-tolerance, resistance to ion toxicities and water use under saline conditions. Basic information on boron and salt-tolerance, water use and ion accumulation and partitioning in the tree has not been adequately determined for irrigated eucalyptus. Therefore we have initiated a multi-year study that will expand our knowledge in these areas.

Methods

A short-term study was conducted using a recirculating sand tank facility in a greenhouse at the new USDA-ARS Salinity Laboratory to test the salt tolerance of 7 clones of Eucalyptus camaldulensis, Dehn. and one clone of Eucalyptus rudis. Eight salinity treatments were replicated 3 times to test the salt tolerance of these eucalyptus saplings. The salinity treatments consisted of a mixture of salts that were added to nutrient solution in proportion to those found in the saline drainage effluents. Targeted EC values of the irrigation solution were 2 (control), 4, 8, 12, 16, 20, 24 and 28 dS/m. After seven weeks exposure to the different saline treatments, shoots were harvested and leaves were removed from each of the upper, upper-middle, lower-middle and lower quarters of the shoot. Leaves were dried, ground and analyzed for the major inorganic ions.

For the main experiment, an elaborate outdoor recirculating sand-culture facility has recently been constructed and is used for this study. Each of the 24 sand tanks are 7.2 m^3 and each are irrigated from and drained into 4000L storage-reservoirs underground. These large sand tanks are used as lysimeters and are automated to quantify water use. Reservoirs are replenished automatically each day with tap water and volume replacements (i.e. ET) are recorded. Serial communication data acquisition modules in conjunction with solenoid valves, level switches and water meters are controlled from a remote location with a PC computer installed with data acquisition software.

Two eucalyptus saplings (Eucalyptus camaldulensis Dehn. Clone 4544) were planted to each tank in mid June and were irrigated with nutrient solution until trees were 2 m in height (21 Sept) at which time treatments began. Simulated saline-drainage treatments consisted nutrient solution with variable amounts of B and/or salts added to the solution in amounts characteristic of drainage water in the area. Sodium and sulfate are the dominate ions in the salinized treatments but the salinizing solution also contains the other common ions in proportion to those found in the effluent. There are 6 salinity treatments (ECw 2, 6, 10, 15, 22 and 28 dS/m) and 6 boron treatments (1, 4, 8, 15, 25 and 30 mg/L). Because of the limited number of sand tanks, the experiment was designed as a two-way factorial layout with partial replication. The extreme treatments were replicated as were several of the intermediate treatments. Surface regressions and two-way ANOVA analyses will be performed on the data.

Trees are routinely measured for height, trunk, main branch, and primary-stem diameter as well as percent canopy cover. One tree will be harvested after 6 to 12 months and will be used to determine the effects of treatment on the allometric relationships of the plant parts to biomass. The allometric relationships can be used to accurately estimate plant foliar biomass based on trunk and branch diameters in subsequent studies. Tissue samples are collected routinely and analyzed for B and the major ions. Visual symptoms of phytotoxicity are recorded regularly.

We propose to determine these parameters in order to provide a rationale for management that will optimize the reuse of saline drainage water, minimize drainage volumes requiring ultimate disposal, sustain crop and land resources, and provide growers with greater economic viability.

Results and Discussion

Results from the short-term study that screened the salt-tolerance of different clones of Eucalyptus camaldulensis indicate that salt-tolerance within this species is rather variable. A non-linear crop response model described by van Genuchten and Hoffman (1984) was used to fit the relative yield data. The response for Clone 4544 (the clone used in the large outdoor facility) was for the most part linear (Fig. 1). According to the guidelines by Ayers and Westcot (1985), E. camaldulensis falls within the moderately-tolerant to tolerant range. A direct classification is difficult since salt-tolerance data are usually reported as a function of ECe Our data are reported as EC of the soil solution and the 2: 1 approximation between EC soil water and ECe (Ayers and Westcot, 1985) may not be appropriate for coarse sand.

Marcar and Termaat (1990) evaluated the salt-tolerance of E. camaldulensis using sand cultures. These investigators reported that 100 mol/m^3 NaCl and nutrient solution concentrated to an equivalent osmotic potential reduced shoot growth by 35% . In our study a similar salt level (i.e. ECw = 9 dS/m) reduced shoot growth by only 25%. The differences in studies may be due to lower leaching fractions used in the study by Marcar and Termaat (1990).

In the main experiment, high levels of salinity (28 dS/m) reduced tree height and trees were affected immediately after salinity was imposed on 21 July (Julian day 264) (Fig.2). In the non-salinized controls, tree height increased nearly linearly into the month of December. High levels of B have not yet affected tree height so values for the various B treatments at each salinity level were averaged and plotted.

No attempts at constructing production functions will be made until after the destructive harvest of one of the two trees. However data on cumulative water use for the month of December is presented in a 3-D plot in figure 3. Salinity has already had a profound affect on evapotranspiration. Evapotranspiration from tanks with trees irrigated with 28 dS/m water were nearly half those irrigated with non-salinized nutrient solution. Since cumulative evapotranspiration is often linearly related to biomass (Howell, 1990) a 50% reduction in cumulative ET might translate into a 50% reduction in the growth rate of the tree. To date, B has had little to no adverse affect on cumulative water use.

While B had little affect on ET, high irrigation water boron caused a substantial increase in leaf-B accumulation (Fig. 4). Leaf samples taken in December have shown that there is a strong interaction between salinity and boron in the irrigation water on leaf B accumulation. Increasing B in the irrigation water from 1 to 25 mg/L at 2 dS/m increased leaf B from 152 to 1043 mg/kg dry. This is nearly a 7 fold difference. However at 22 dS/m, leaf B concentrations increased approximately only 4 fold. Salinity apparently has a strong influence on reducing leaf B.

From the data collected so far it is impossible to determine how salinity is reducing B. Salinity has substantially reduced transpiration so it is possible that the net flux of B from the root to the shoot is also reduced. Calcium additions to the substrate have been shown to decrease leaf B concentrations (Gupta and MacLeod, 1981) as well as alleviate B toxicity in Prunus species (El-Motaium, 1993). Evidently Ca increases B retention in root tips thereby reducing translocation to the stem and leaves and that B and Ca were quantitatively associated with each other in cell wall material (El-Motaium, 1993).

Other cations have also showed this effect. In a rather old study conducted on a sandy loam soil, Mg hydroxide additions resulted in a greater while Na hydroxide additions resulted in a lesser reduction of leaf B (Wolf, 1940). In our study, increased salinity is associated with increased Ca but only up to the 15 dS/m level. Beyond that salt level, Ca increases in the irrigation water were negligible. Therefore reduction in leaf B concentrations at high salinity could be related to interaction of B with other cations or other factors (e.g. reduction of ET as salinity increases).

The older leaves of trees treated with high concentrations of B and low levels of salinity showed injury characteristic of B toxicity. Injury began to show as dark red color (anthocyanins) on the tips and margins and those portions of the leaves began to burn as injury became more acute. Injured leaves were separated into anthocyanotic, burned and uninjured tissue. In leaves that showed anthocynanins and no burn, the B in the anthocynatic leaf margins were about twice that of the uninjured tissue. In the burned leaves, the burned margins of the leaves contained nearly twice the amount of B as anthocynatic margins but their uninjured portions were about half the concentration as the uninjured leaves only showing anthocynins. Although data are limited as this time, it appears as if B in the middle uninjured portion of the leaves continues to move out towards the tips and margins as injury becomes more severe.

Conclusions

After three months from initiation of the irrigation treatments, salinity has dramatically reduced evapotranspiration and boron has accumulated in older leaves of E. camaldulensis treated with high B and low salinity to the extent where severe injury developed on leaf-margins and tips. There is pronounced interaction between salinity and B where salinity reduces leaf B accumulation. E. camaldulensis appears relatively tolerant to this sulfate-dominated saline water but it is not known what long-term effects will be.

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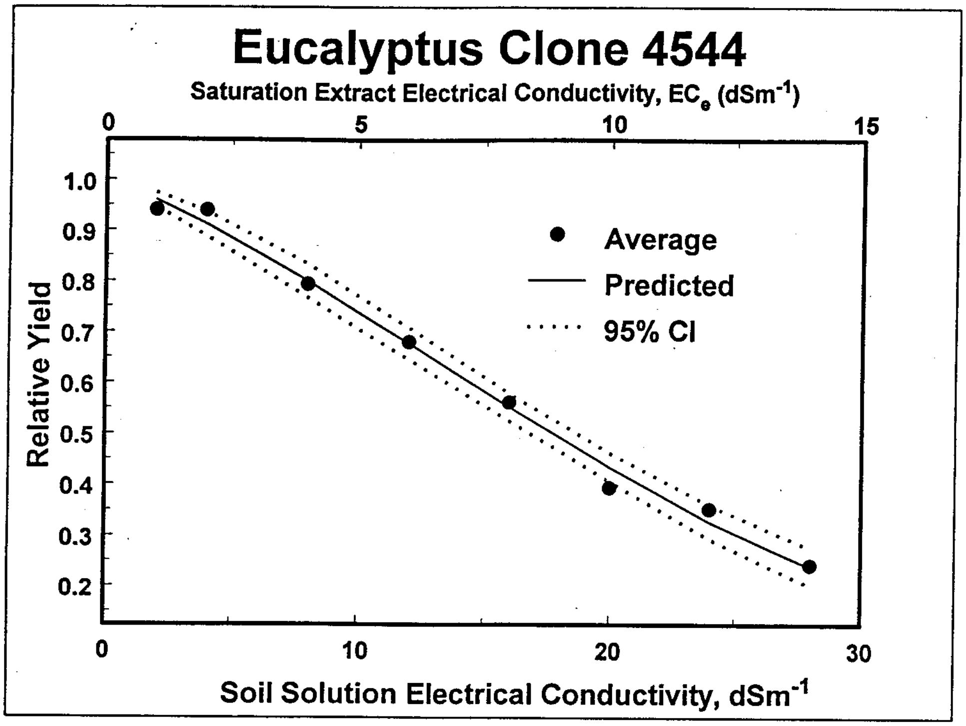

Figure 1. Relative yield (shoot biomass) of E. camaldulensis as affected by increased salinity of the irrigation water.

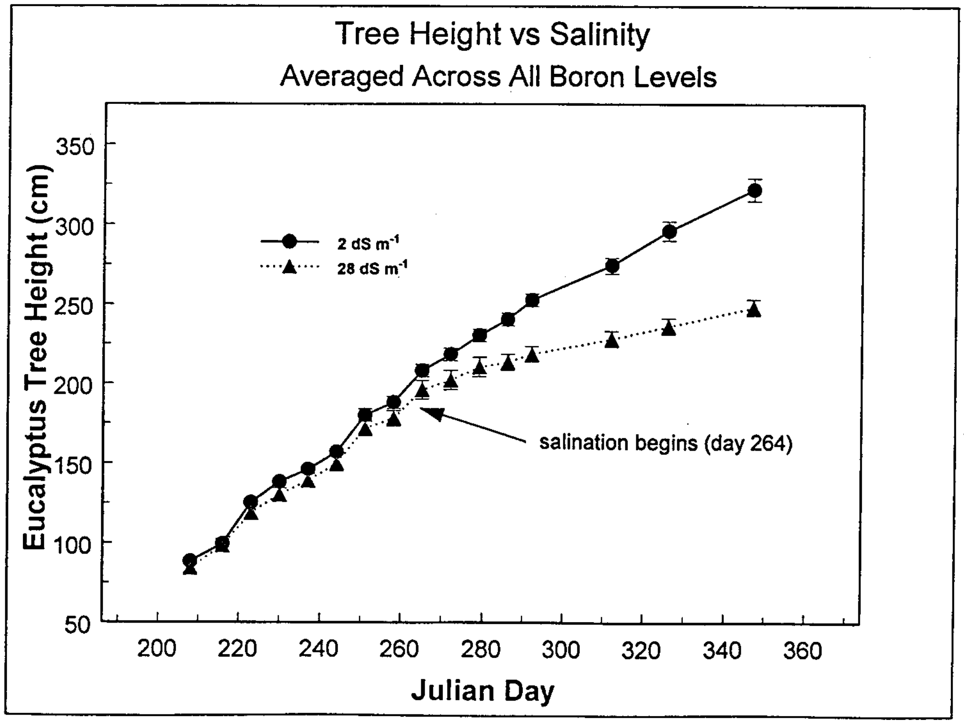

Figure 2. Tree height measured at various times in plots irrigated with low (2 dS/m) and high levels (28 dS/m) of salinity. Each value is the average across B treatments.

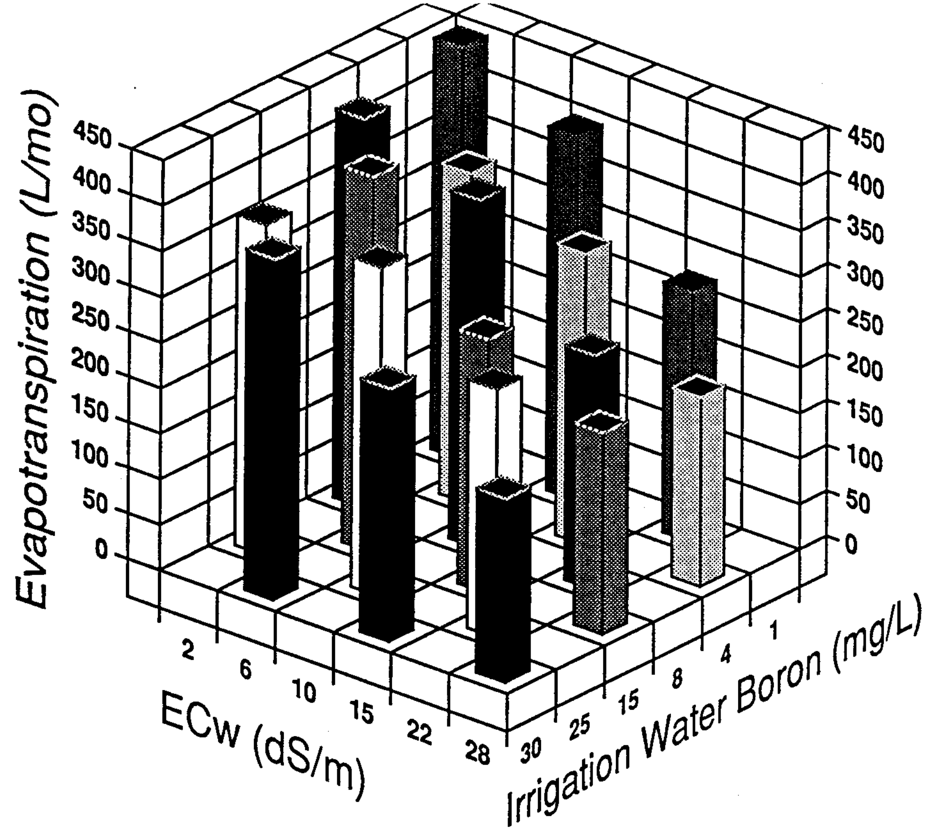

Figure 3. Evapotranspiration from lysimeters treated with variable levels of salinity and B in the irrigation water.

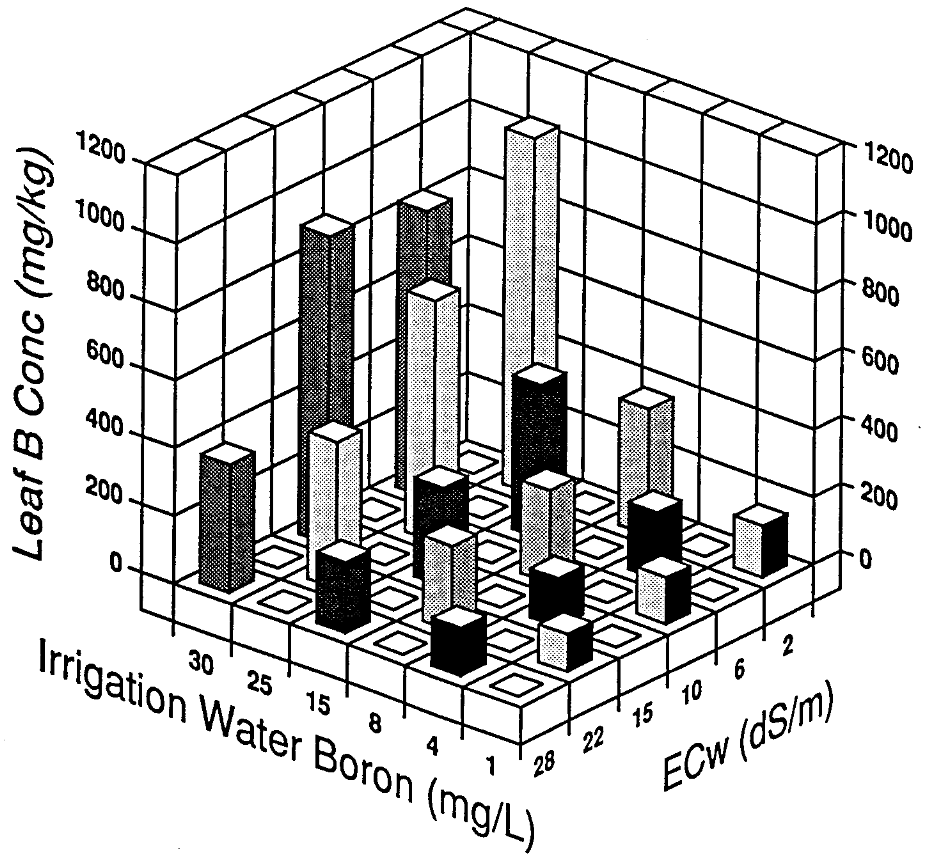

Figure 4. Leaf B concentration as affected by the salinity and concentration of B in the irrigation water.