# Tree Production in the Sonoran Desert Using Effluent and Water Harvesting

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In arid areas of the world, including Israel and the southwestern United States, water must be used wisely. A key step in improving land management practices is to minimize soil erosion, successfully establish and grow vegetation having potential commercial and environmental value, and reclaim nonproductive or severely disturbed lands, while still maintaining acceptable water quality standards for surface and ground waters.

In the arid desert environment of the southwestern United States, efficient use of the limited water supply is critical. Municipal reclaimed effluent water combined with rainfall harvested from a water-harvesting system can be utilized for the restoration of degraded lands while, at the same time, enhancing the growth of vegetation having commercial and environmental value. Rapid population growth in the metropolitan areas and many rural communities of the Southwest has increased the availability and amounts of treated effluent. However, the availability of potable water for irrigated plantations may decrease in the future because of increasing demands for domestic uses and resulting increases in costs. A study established in 1996 is assessing the potential of growing trees using several mixtures of potable and treated effluent water as well as harvested rainwater for irrigation. This study is part of a collaborative research program among the University of Arizona, the Volcanic Center, Bet-Dagan, Israel, and the USDA Forest Service. The joint effort is funded by the International Arid Lands Consortium. The main study objectives are (a) to determine the benefits of water-harvesting techniques used in conjunction with wastewater irrigation on trees, (b) to evaluate the ability of the selected tree species to absorb minerals and pollutants found in effluent, and (c) to study the effects of effluent irrigation on tree growth and production.

Tree species used in the study are Mondell pine (*Pinus eldarica*), eucalyptus (*Eucalyptus camaldulensis*), native cottonwood (*Populus fremontii*), black willow (*Salix nigra*), sycamore (*Platanus wrightii*), and ash (*Fraxinus veluntia*). The trees, established from seedlings or cuttings, are being grown and studied both in the field and in containers.

The immediate objective of this presentation is to review first-year observations from the experiments at the University of Arizona. The study concentrates on tree survival and growth under different irrigation mixes. Analyses of soil and plant nutrient tissue data will be presented in subsequent reports. The research partners believe that information gained from their studies in Israel and the United States can be used as the basis for developing guidelines for restoring degraded uplands or reestablishing vegetation in riparian areas, while at the same time providing support for vegetation having commercial and ecological value. The results should be applicable to other arid regions of the world.

The working hypothesis of this study is that the use of municipal effluent for irrigation of trees will enhance the growth of these plants when compared to the growth that can be achieved by irrigating solely with potable water. In addition, there would be no significant uptake of harmful constituents from the effluent water by the trees or adverse impacts upon the soil.

## The Effect of Sewage Effluent on Forest Trees

It is generally accepted that trees can absorb large quantities of water and minerals. Therefore, trees can be effective biological sieves that prevent percolation of the water to the underground reservoirs and the accumulation of minerals in the soil. Irrigation with sewage water has been shown not only to increase tree growth (Dighton and Jones 1991), but also to increase the total amount of minerals in the foliage (Brister and Schultz 1981; Neilsen et al. 1989). Research in Australia (Hop-

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mans et al. 1990) indicates that tree species differ widely in their ability to absorb minerals. The differential accumulation of toxic elements by freshwater plants has been reviewed recently in a comprehensive report by Outridge and Noller (1991). Information on the accumulation of toxic compounds by tree species exposed to effluent is limited. A major factor that needs to be considered when trees are used to dispose of effluent is the variation among species.

Secondary sewage effluent generated from domestic use contains mainly organic matter and minerals. Organic matter often accumulates under effluent irrigation, and organic nitrogen has been found to increase under a wide range of climatic, water, and soil conditions (Brar et al. 1978; Feigin et al. 1978). Organic C and organic N increased four- to five-fold in the upper 3 inches of the soil layer (Brar et al. 1978). Feigin and coworkers (1978) calculated that approximately 7 percent of the amount of nitrogen applied remained in the soil. The buildup of organic matter contributes eventually to all of the elemental cycles in the soil. Organic matter content and composition, together with the environmental conditions, determine the rate of nutrient uptake by plants.

*Eucalyptus camaldulensis*, introduced into Israel many years ago, has proven to be a fast-growing tree species. Eucalyptus has the capacity of absorbing large quantities of water and minerals. Mature eucalyptus trees can evaporate up to 15 gallons of water per day (Walker et al. 1991). It is hypothesized that irrigating with sewage water in the proper quantities might compensate for the loss of water through evaporation, and also stimulate tree growth. Eucalyptus has a very branched root system that is active all year, contributing to the efficiency of this species. A two-fold increase in tree growth following irrigation with sewage water compared to control trees has been recorded for woody species such as *Populus* (Bialkirwicz 1978), *Pinus* (Cromer et al. 1983; Attiwill and Cromer 1982), *Eucalyptus*, and *Casuarina* (Stewart and Flinn 1984).

## Water Harvesting and Effluent As a Supplemental Source

Increasing competition for water in arid and semiarid regions has stimulated interest in a wide range of techniques for increasing water availability. Researchers at the University of Arizona have actively explored the use of water-harvesting techniques for agriculture in the arid and semiarid regions (Karpiscak et al. 1987; Matlock 1986; Matlock and Dutt 1986; Matlock 1983; Dutt et al. 1981).

Using effluent as a source of supplemental water for creating and enhancing wetlands and riparian areas in Arizona and throughout the entire southwestern United States is proving to be an important management technique (Tellman 1992). The creation of additional wetlands and riparian areas is important because in the southwestern United States, riparian areas occupy only about 1 percent of the land surface. However, these areas are valuable for many reasons. The issue of effluent use in the major metropolitan areas of Phoenix and Tucson was discussed in a paper by Lieuwen (1990). Interest in the United States in treating municipal wastewater using plant systems has increased as an ecologically and economically viable alternative to traditional treatment methods (Hammer 1989; Reed et al. 1995; Karpiscak et al. 1996; Kadlec and Knight 1996).

## Riparian Area Management in the Southwestern United States

More than 800 vertebrate species, many (250+) threatened, endangered, and sensitive, reside in the Southwestern Region of the USDA Forest Service. A majority of these animals are either obligate inhabitants of riparian areas or utilize them at some stage of their life cycle. Because of the cool environment provided by these riparian areas, they attract many recreationists. They also are important areas for livestock watering and local water supplies. However, the past misuse of riparian areas throughout the southwestern United States has resulted in vegetation destruction, both in the riparian areas and in the surrounding watershed (DeBano and Schmidt 1989). Vegetation removal and soil compaction on the watersheds have increased surface runoff from these areas and concentrated the resulting streamflow in channels where it has caused downcutting and subsequent dewatering of the riparian areas, thereby upsetting the hydrologic regimes necessary to sustain many of these former riparian areas. Implementing methods of rehabilitating and enhancing these degraded riparian areas in partnership with private and public land owners is an important goal for USDA Forest Service managers (Tellman et al. 1992). Reversing such degradation will require establishing a regulated streamflow. Both effluent additions and water-harvesting techniques provide opportunities for developing the more regulated streamflow regimes necessary for rehabilitating many of these degraded riparian ecosystems.

## Methods

The sites in Arizona include a field plot at a University of Arizona research farm near Tucson, and an area for the container experiments at the nearby Constructed Ecosystems Research Facility (CERF), supported by the Pima County Wastewater Management Department. The field plot consists of about 1.3 hectares (3.2 acres) that can be irrigated with both potable and reclaimed water as well as harvested natural rainfall. After receiving permission to proceed at the research farm, 15-foot-wide catchments were graded perpendicular to the slope of the field.

The field and container experiments in Arizona include six tree species: cottonwood, black willow, Mondell pine, sycamore, velvet ash, and eucalyptus. Cottonwood, black willow, sycamore, and ash are important southwestern riparian tree species, and Mondell pine and eucalyptus are popular ornamental species in the metropolitan areas of Arizona. The eucalyptus species is being used in the experiments in Israel. Trees for the field and container studies were started from poles except for Mondell pine and eucalyptus. These species were planted as transplants from plastic sleeves and 4 inch pots, respectively. Ash and sycamore were replanted because of poor survival after the initial planting. The field experiments focus on five treatments that reflect a range of water mixtures:

1. Control only, with water from harvested rainfall and potable municipal water equal to 100 percent of pan evaporation.
2. Irrigation to 100 percent of pan evaporation with 25 percent of water being reclaimed municipal effluent.
3. Irrigation to 100 percent of pan evaporation with 50 percent of water being reclaimed municipal effluent.
4. Irrigation to 100 percent of pan evaporation with 75 percent of water being reclaimed municipal effluent.
5. Irrigation to 100 percent of pan evaporation with 100 percent of water being reclaimed municipal effluent.

Separate drip irrigation supply lines for potable and reclaimed water are equipped with separate timers to ensure that the proper amount of irrigation water, either potable or reclaimed, is supplied to the individual plants. Supplemental irrigation is provided by a drip system.

Fifty individuals each of six tree species were planted in a randomized complete block design in the water-harvesting field system. Ash and sycamore were planted as poles obtained from trees at Fort Huachuca, Arizona. Black willow and cottonwood were planted from cuttings collected from trees at the nearby CERF facility, and eucalyptus and pine were purchased commercially. Planting of all species in the field was completed in December 1996. Height measurements of pine and eucalyptus were begun in December 1996 and of the other four species in May 1997. Tree diameter at breast height (DBH) measurements were started in September 1997.

The individual trees in the field plots were fenced to protect them from rodents and rabbits until they had achieved enough growth and size to survive browsing by animals. The field plots are periodically treated to control weeds.

Soil samples were collected from the field plots prior to planting in 1996 and again in December 1997. The first tissue samples will be collected from the field plants in late spring 1998 after they have achieved sufficient size to sustain the harvesting of 100 to 125 grams of leaf and stem tissue. The tissue will be analyzed for selected parameters such as sodium, chloride, phosphate, nitrate, and copper.

Containers are used to avoid the influence of differences in field soils using the same tree species as those planted in the field water-harvesting system. The container studies are conducted using 10 replicates of each plant species. These experiments were started at CERF in April 1997 by filling 120 plastic 32-gallon containers with clean mortar sand. Two drip lines were installed to each of the containers, one to deliver potable water and one to deliver treated effluent. Each container is supplied with either 100 percent potable water or 100 percent effluent water. A chlorinization unit was placed in the effluent line so that all plants would receive water containing chlorine. Trees and emitters were placed randomly in the containers. Pine and eucalyptus were planted as seedlings in May 1997 and cottonwood and black willow as poles in June 1997. The remaining two species, ash and sycamore, were planted as poles in August 1997.

Data are logged into an IBM computer using Quattro Pro software to create a spreadsheet. Because field and pot experiments are conducted in a randomized complete block design, any of the variables that are measured only once during the experiment will be subjected to an analysis of variance for the randomized complete block design. Any trends in the characteristics over time will be estimated for each of the treatments. If the characteristics change over time, then the differences in trends among the treatments will be tested for statistical significance. The 5 percent level will be used to determine significance unless otherwise stated. However, as this is a preliminary report on tree survival and initial growth, no statistical analysis will be discussed at this time because of the short growing time since planting.

## Results and Discussion

Tree survival at the field site is shown in Figure 1. Note the nearly 100 percent survival rate for eucalyptus and pine, planted as transplants, and for cottonwood and willow, which were planted as pole cuttings, regardless of the water mixture. Ash and sycamore, also planted from pole cuttings, had about an 80 percent survival rate. Initial survival was lowest for sycamore (20 percent) when treated with pure effluent (0P/4E), and ash (60 percent) when treated with one-quarter effluent (3P/1E). These rates for ash and sycamore are improved from the 30 and 50 percent rates observed previously (August 1997). It appears that pole plants of these two species are slower to take root and show a growth response compared to willow and cottonwood.

Survival data for the container trees are shown in Figure 2. Note that no cottonwood pole plants survived the initial June transplanting to the containers, in contrast to the nearly 100 percent survival obtained in the field planting. This finding also is in contrast to the survival of similar transplants in the gravel-filled subsurface constructed wetland cells at CERF. Cottonwood poles were replanted in containers in early November 1997, and thus no data were available on their survival in November or December 1997. It was difficult to determine the survival of some ash and sycamore plants in December, because they were typically small individuals that had dropped their leaves.

Plant survival in the field appeared to be the same for willow and cottonwood (poles) and for eucalyptus and pines (transplants) whether irrigated with 100 percent potable or 100 percent effluent water (Figure 3). Survival for sycamore and ash (poles), however, appeared to be lower when irrigated with effluent water in the field. This observation seemed to be the case particularly for sycamore, whose survival rate decreased over time (Figure 3) when compared to surviving sycamore irrigated with only potable water.

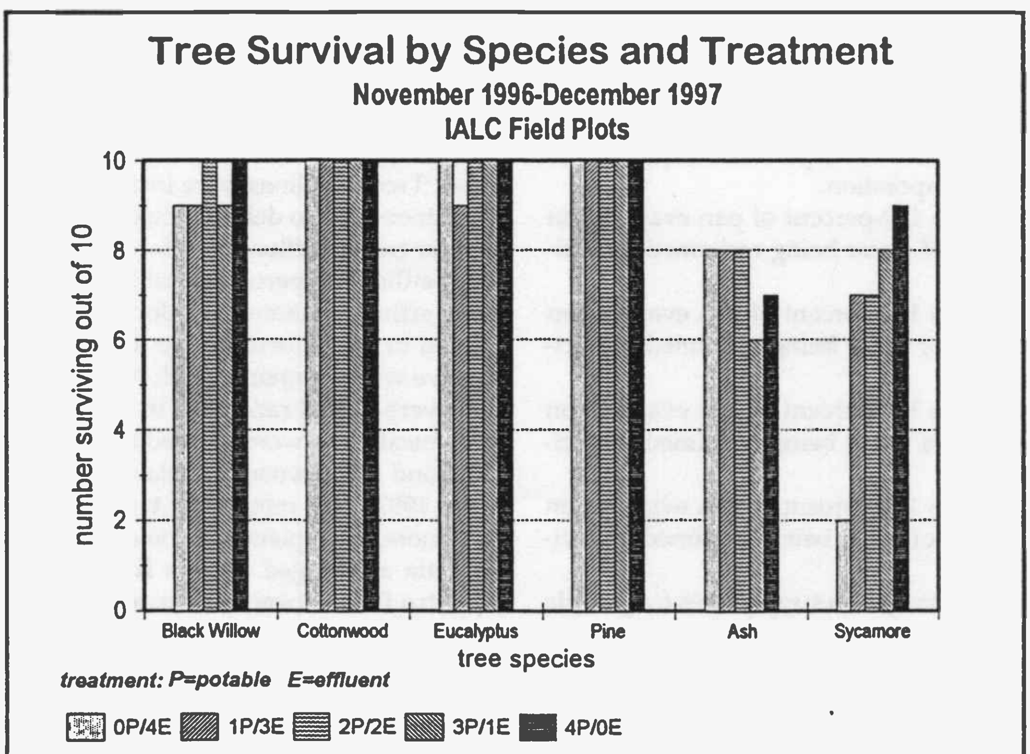
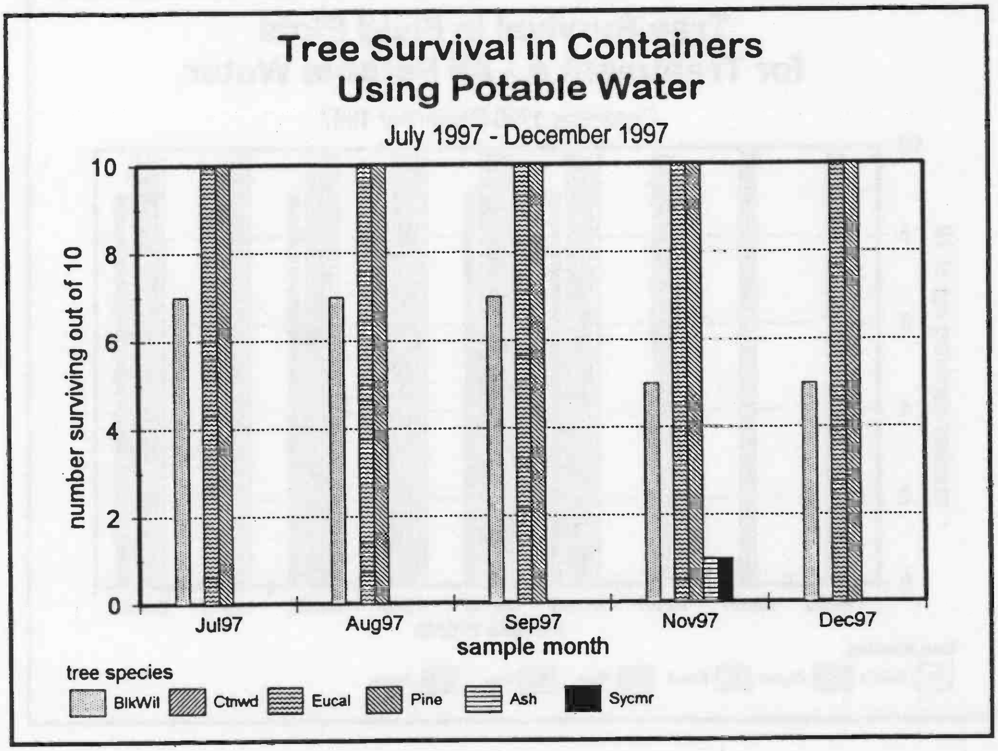



Figure 1. Tree survival by species and treatment.



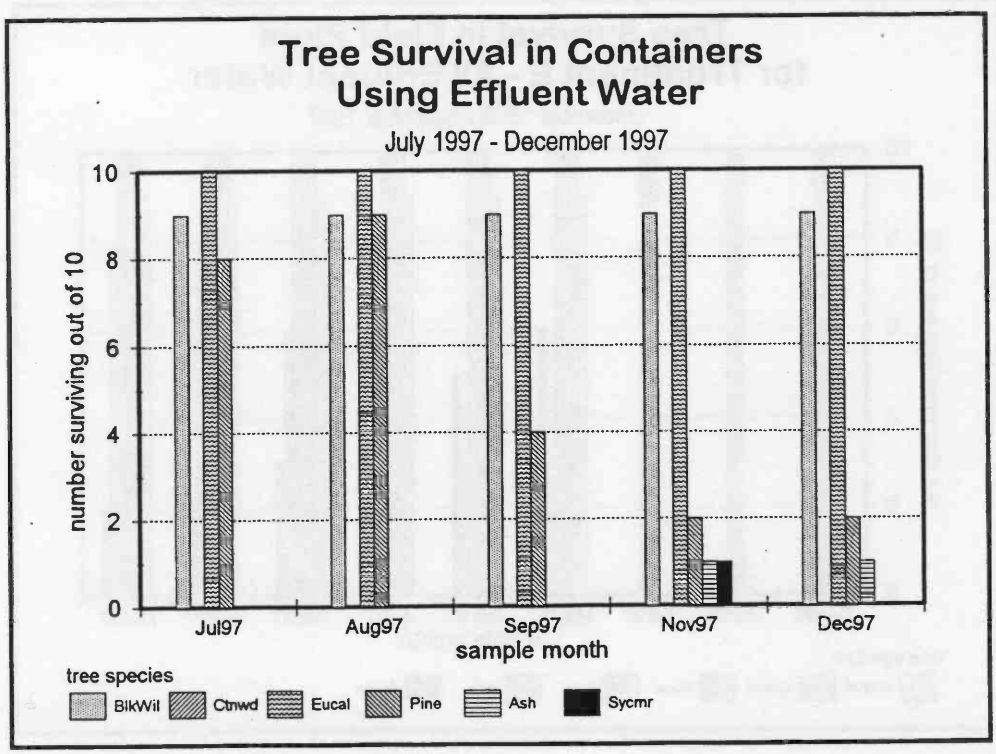
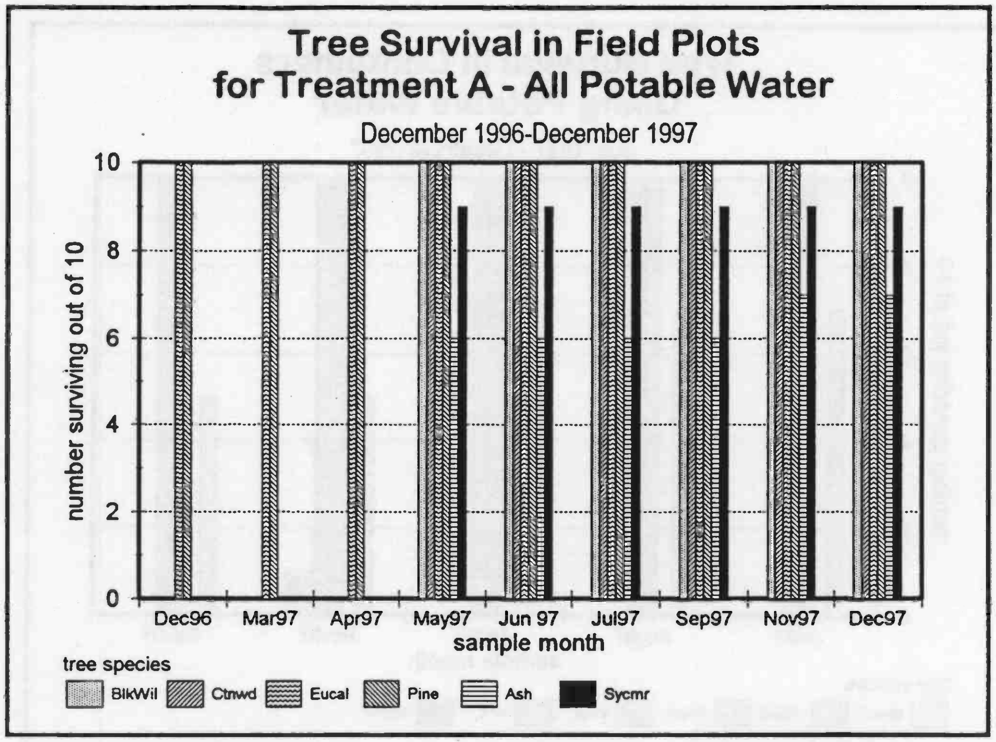




Figure 2. Tree survival in containers using potable and effluent water.



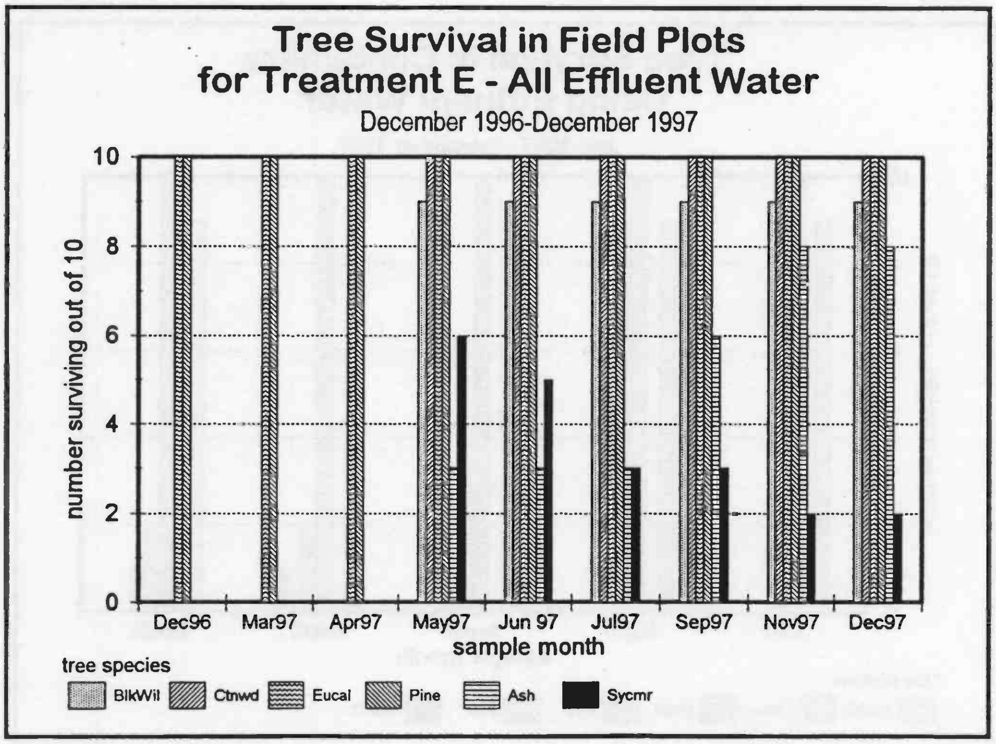
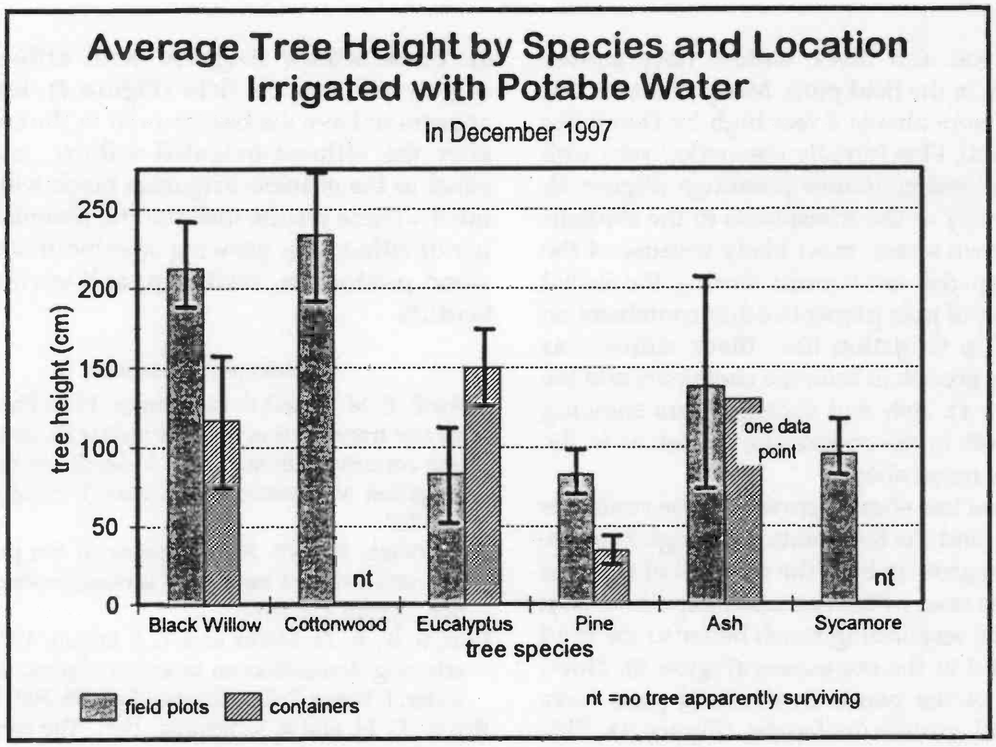




Figure 3. Tree survival in field plots using potable and effluent water.



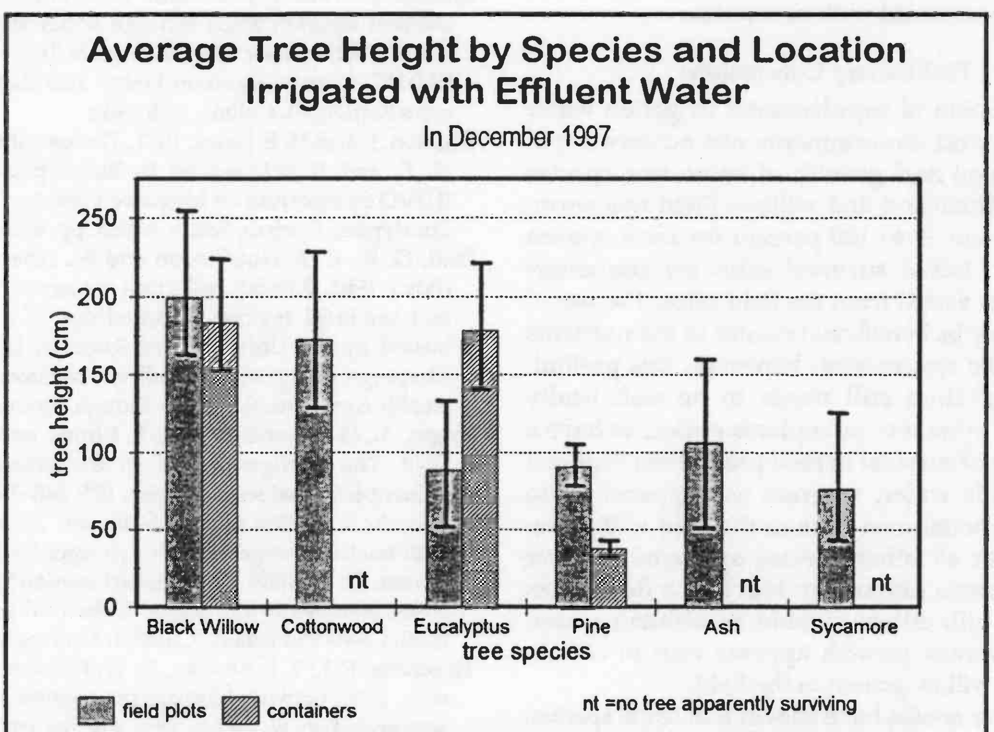




Figure 4. Average tree height by species and location irrigated with potable and effluent water.

Cottonwood and black willow have shown rapid growth in the field plots. Many of the cottonwood trees were almost 8 feet high by December 1997 (Figure 4). Pine initially responded very well in both field and container plantings (Figure 4). However, many of the transplants to the containers have shown stress, most likely because of the need to keep the sand moist during the initial transplanting of pole plants in other containers on the same drip irrigation line. Black willow has shown rapid growth in both the containers and the field (Figure 4). Ash and sycamore are showing slower growth in the containers, as well as in the field plots as noted above.

Eucalyptus has shown growth in the container experiments and the field plots. Although this species seems to grow in both the clay soil of the field plots and the sand of the container experiments, it appears to be responding much better to the sand culture found in the containers (Figure 4). However, some of the plants in the field plots have shown rapid growth in height (Figure 4). This finding supports the results found by our Israeli team members. One of the most interesting issues was the failure of any of the cottonwood and sycamore pole plants (some 60 cuttings of each species) to become established in the containers. These plants were replaced with new poles.

## Preliminary Conclusions

The application of supplemental irrigation water to trees in arid environments can achieve rapid establishment and growth of some tree species such as cottonwood and willow. Field tree survival rates were 90 to 100 percent for most species (Figure 3). Initial survival rates for container-grown trees varied from the field rates. The use of effluent may be beneficial because of the nutrients found in the wastewater. However, this preliminary observation still needs to be statistically evaluated. Sycamore pole-plants appear to have a higher rate of survival in field plots when supplied with potable water, whereas ash appears to do somewhat better over time in the field with effluent. Almost all other species appeared to have about the same rate of survival in the field when supplied with either potable or effluent water. Overall average growth appears best in cottonwood and willow grown in the field.

First-year results have shown that some species, especially cottonwood and willow in the field, grew to a height of 6–8 feet within 12 months of planting (Figure 4). Pine and black willow had their most rapid growth in the field plots (Figure 4). Black willow irrigated with effluent grew slightly taller in the field (Figure 4). Eucalyptus appears to have the best growth in the containers, after the effluent-irrigated willow, and seems equal to the effluent-irrigation black willow (Figure 4). These results indicate the potential for the use of effluent for growing selected tree crops for wood production, aesthetics, and environmental benefits.

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