Jan. 19, 2001

MEMORANDUM

To: Mr. Ron Cohen, Southwest Florida Water Management District

From: R. C. Beeson, Jr., MREC - Apopka

RE: Final Report

Agency No. P705 Project ID: 97CONOOO0 15

Subject: Improving Irrigation Management in Container-Grown Landscape Ornamentals.

INTRODUCTION

Nearly all landscape shrubs, and a large percentage of small trees, are produced in containers. Advantages of container production over field production have come at the cost of constricted root systems, resulting in increases in shoot:root volumes by severlal fold over field-grown plants. Since transpiration rates are similar between container and field-grown plants of the same size, container-grown plants must be irrigated much more frequently than field-grown material to account for the reduced root volume available to extract water.

To produce marketable plants, containers are spaced several inches apart to allow for canopy growth. Because of this spacing, a major portion of water applied through overhead irrigation falls between containers, and thus is unavailable to the plant (Beeson & Knox, 1990; Furuta, 1978; Weatherspoon, 1980). Spacing effects, combined with the additional volumes required to compensate for the deflection of overhead irrigation by plant canopies, requires that large volumes of water in excess of plant requirements be applied at each irrigation event. As a result, only 15 to 40% of the irrigation applied is typically retained in a container for plant use (Beeson & Knox, 1990; Furuta, 1978; Weatherspoon, 1980).

Despite its inefficiency, overhead irrigation is currently the only economically feasible method to supply water to landscape ornamental shrubs produced in small containers (less than 5 gallons). At this size, microirrigation is too expensive to be justified at current and projected plant market values due to material and labor costs (Haydu & Beeson, 1995). Furthermore, landscape shrubs do not respond to microirrigation with accelerated growth as trees do (Beeson & Haydu, 1995).

The objectives of this project were: 1) to evaluate container systems hypothesized to improve irrigation water use efficiency (IWUE) of existing overhead irrigation systems in production of landscape omamentals; and 2) to provide the industry with economically feasible water-conserving methods for container nursery irrigation. For this project, IWUE is defined as the percentage of water leaving the sprinklers which is gathered at the surface of a container's substrate. Systems evaluated in this project included products currently available and innovative items that theoretically should result in very high IWUE within a production bed. This information should enable the container nursery industry to choose among systems to increase IWUE over that of current overhead irrigation methods. Increasing IWUE of overhead irrigation systems can be an economically feasible way for the nursery industry to approach the water conservation levels desired by the water management districts.

MATERIALS AND METHODS

The experiment was repeated over three years (1997, 1998, and 1999) and consisted of four rates of irrigation: 0.16, 0.27, 0.60, and 1.0 inch, applied daily. The 0.6 inch rate was established as the base rate. This was derived from previous research which found this to be the average annual Actual Evapotranspiration (AET) of marketable-size plants of this species in 1 gal containers, based on the surface area at the top of the container. From this base rate, the 0.16 inch rate was established as the ratio of the surface area of a standard 6.25 inch diameter 1 gal container to that of the effective surface area of a funneled 1 gal container. The 1.0 inch rate was set as an excessive irrigation rate, with the 0.27 inch rate again derived from the ratio of surface areas of a standard container to that of a funneled container. These irrigation rates were amended based on rainfall quantity and timing. Effective daily rainfall was calculated as a linearly increasing function between 7 am and 9 pm. The later in the day the rain fell, the more the scheduled irrigation was reduced.

Each irrigation rate was replicated four times; thus, 16 independently controlled production beds were used. Within each production bed, six container systems were randomly placed. The six systems consisted of standard conventional blow-molded 1 gal containers ("Standard" model 0 10, Lerio Corp.), 8-inch diameter azalea pots ("Squat pots", Nursery Supplies), Lerio blow-molded 1 gal aquatic pots with drain holes elevated 1 inch above the bottom ("EDH pots"), Lerio injection-molded 1 gal containers placed in Water Collector Trays (Landmark Plastic, "Trays"), Lerio injection-molded 1 gal containers mounted with funnels ("Funnels"), and multi-pot boxes (Boxes).

For each container system except the Boxes, 24 rooted liners were transplanted into containers for each system within each production bed. These were placed in a rectangle arrangement of 4 containers per row and 6 rows long. The most uniform liners within each group of 24 were placed in the interior, from which canopy measurements were recorded. For the Boxes, one Multipot Box was placed in each production area. These were surrounded with 16 plants growing in 2 gal containers elevated on an inverted 2 gal container to match the height of the plants in the Box. These provided the border plants without the extra expense of producing extra Multpot Boxes to be used as borders.

Funnels were square in configuration, 11 inches on a side, and channeled overhead irrigation onto container substrate surfaces. Initially, Funnels were made from Water Collectors and attached to the containers with pop rivets. In 1998, a first generation prototype (Lerio) molded from black polypropylene was used. These Funnels were attached to the containers by fitting into a groove at the top of the container, and required that the containers be notched where each of the four corners of the Funnel met the container side to permit water to enter the pot. The third generation Funnels used in 1999 were a major improvement over previous designs, slipping up over the container from the bottom and held in place by friction against the side of the container. While these still need some modifications for ease of assembly, they were by far the closest manifestation of the concept developed.

Multipot Boxes consisted of a two-piece design: The bottom portion had 4 troughs in which water was held, separated by 3 raised shelves on which the containers were set. A wick material was draped over each shelf, extending into the trough on either side. This transferred the water held in the troughs to the containers. These containers had 4 extra holes, 3/8th inch in diameter, drilled in the bottom to facilitate absorption of water from the wick material. When assembled, the box completely enclosed 9 containers inside, with the plant shoots extending above the box top through holes slightly larger than the top diameter of the containers. The openings around each hole were concave and channeled water from the top of the box into the containers and/or the water reserve troughs in the bottom portion. Multipot Boxes were constructed of fiberglass and painted white to reduce the heat load on the containers.

All containers except those in Trays and Multipot Boxes were spaced on 1 l-inch centers when placed in the production beds. Trays were on 12-inch centers. The surface area of each section of the Multipot Boxes was 12 x 11 inches. The Trays, Multipot Boxes, and funneled containers formed a continuous surface over their respective allocated production areas. Based on the definition of irrigation water use efficiency (IWUE) used here, the IWUE of the Tray, Multipot Box and Funnel systems were 100% within a bed and would have been around 85% in a production area with 16-inch walkways every 6 rows, negating losses at the edges of areas. Both the EDH and Standard containers occupied 25% of their allocated production areas and thus had IWUE of 25% within a bed and 22% in a production area. Squat containers, with their low profiles, covered 42% of their bed area and had IWUE of 37% over the production area.

The experiments were conducted at the CFREC in Sanford in 1997 and 1998. In early 1999, the nursery research program was relocated to its new site in Apopka in anticipation of the completion of the new MREC facility, which was projected for late summer. Delays in ground preparation and installation of new infrastructure at the Apopka site resulted in potting being delayed by about 3 weeks in 1999 compared to previous years. Relative to the annual variations in climate during this research, this later potting date had insignificant effects on the results.

In 1997 and 1998, rooted liners of sweet viburnum were potted in early March. In 1999 the plants were potted in late March. The substrate each year was composed of 60% pine bark fines: 30% Florida sedge peat: 10% sand amended with dolomite and micronutrients (Florida Potting Soil, Apopka, Fla.). Each month after potting, canopy dimensions (height and two perpendicular width measurements) were recorded on interior plants in each container system within each of the 16 production beds. In 1997, four plants were measured per system per bed. This number was increased to six plants per treatment per bed for the last two years. Plants were fertilized with 12 g of Osmocote 18-6-12 shortly after potting and again in July, and pruned in a manner consistent with commercial nursery practice.

Based on the Florida Grades and Standards for Nursery Crops @PI, Tallahassee, Fla.), canopy dimensions for a sweet viburnum in 1 gal containers of 12 inches in average height and 9 inches in average width were established as the nominal size for a plant to be considered marketable. Using these criteria, the percentage of measured plants achieving marketability within each container system and irrigation rate was calculated each month after potting, as was the growth index (a measure of canopy size; (height x width, x $width_2$)/10^{-6} m) for each system. Data collection for each system was stopped when >92% of plants had reached marketable size (except for 1999; see below).

At the end of the experiment, regression analysis was performed for the monthly marketability data for each container system/irrigation rate combination. Plants growing in the Standard containers and irrigated with 0.60 inches of overhead irrigation daily were considered to be the Control, representing the normal situation in a nursery. To compare the container system/irrigation rate treatments to the Control, a single degree of freedom contrast comparison of regression line slopes was performed for each treatment against the Control. The number of weeks required for the Control to obtain >92% marketability (16 plants in 1997; 24 in 1998 and 1999) was used as the gauge by which the other container treatments at each irrigation rate were judged. Marketability at this point was extrapolated from regression equations for each system/irrigation rate combination. Growth index data was analyzed for each month using a t-test of least significant differences to compare system/irrigation rates.

RESULTS and DISCUSSION

CLIMATE AND IRRIGATION VOLUMES

During the course of the three-year project, weather conditions were influenced by the onset of El Nino in 1997 and La Nina in 1998. These phenomena influenced rainfall (Fig. 1) and temperature (Fig. 2), particularly during spring and summer. The 1997 growing season was marked by higher-than-normal rainfall, especially in July and August (Fig. 1.) Rain was recorded during each week from early June to October of 1997. In contrast, 1998 was very dry, especially during the spring. Less than 5 cm of rain was recorded from 4 March to 16 June 1998; this was followed by moderate rain levels in July, August, and September. Weekly mean temperatures reflected trends in rainfall (Fig. 2.) Weekly average temperatures were relatively low in the spring of 1997, peaking in late June and remaining in the upper 20°s C before dropping in October. In 1998, temperatures climbed rapidly in May and peaked in early June at near 30" C, then declined slightly in July and August.

The 1999 growing season was in contrast to the previous two years. Rainfall was higher in June than in either previous year, then dropped below previous years during July and early August. Rainfall was more seasonal in mid- to late August, with excessive rainfall recorded in September and October of 1999. Mean weekly temperatures were quite variable through the spring of 1999, and were lower than previous years from early May through the first of July. Mean temperatures then climbed steadily during July, reaching a high of near 30" C in late July (Fig. 2). The unusual rain and temperature patterns of 1999 had a significant effect on plant growth and data collection, discussed in detail later.

Potential evapotranspiration (PET) was calculated daily from temperature, radiation and wind data. Total weekly PET for all three years of this project was calculated using the modified Penman equation (Jones et. al., 1984; Table 3). In 1997, PET peaked in early May and then gradually declined through the rest of the season in response to weekly rainfall that continued through the summer and early fall (Fig. 3). PET for 1998 increased gradually from potting through mid-June, exceeding that of 1997 by the second week of May (Fig. 3). After mid-June, PET fluctuated wildly through the summer of 1998, but was consistently lower on a weekly basis than in 1997. In 1999, PET was lower than in previous years from late April through mid-July. However, from mid-July through mid-August, PET exceeded that of previous years, obtaining a 3 year high of 43 mm/week the last week of July. Thereafter, PET in 1999 ranged between that calculated for 1997 and 1998 until mid-November.

Average irrigation volumes per application rate, on a weekly basis, reflected both weekly rainfall and the occasional broken riser. All considered, weekly irrigation volumes were fairly consistent throughout each growing season (Figs. 4, 5 and 6). Weekly applied volumes varied slightly from year to year, especially for the higher irrigation rates. The dry conditions recorded in 1998 resulted in greater water consumption overall compared to 1997 and 1999, when rainfall was higher. In 1997, the 0.16-inch/day irrigation treatments used about 250 gal./week; the 0.27 inch/day treatments used about 600 gal./week; the 0.60 inch/day treatments used about 1200 gal./week; and the 1.0 inch/day treatments used about 2000 gal/week (Fig 4). In 1998, the 0.16-inch/day irrigation treatments used about 350 gal./week; the 0.27 inch/day treatments used about 600 gal./week; the 0.60 inch/day treatments used about 1250 gal/week; and the 1.0 inch/day treatments used about 2250 gal/week (Fig. 5). In 1999, the 0.16-inch/day irrigation treatments used about 250 gal./week; the 0.27 inch/day treatments used about 600 gal./week; the 0.60 inch/day treatments used about 900 gal/week; and the 1 .O inch/day treatments used about 1700 gal./week (Fig. 6).

PLANT GROWTH

1997. Figures 7-10 chart the growth index of each container system over time at the four different irrigation rates, in comparison to the Control. At the lowest irrigation rate (0.16 inch/day; Fig. 7), plants grown in the Multipot Box had a larger growth index than the Control treatment from week 11 to the end of the experiment. The growth index of Multipot Box plants was also considerably larger than that of the other container systems from week 15 to week 3 1, when plants in the Multipot Box were removed. Plants grown in Trays or Funnels tended to average similar size to the Control plants, whereas plants grown in EDH or Squat systems tended to be smaller.

The dash line in this figure and those afterwards indicates the Growth Index (GI) or canopy volume of a Florida Fancy sweet viburnum those minimum canopy dimensions must be an average width of 9 inches and height of 12 inches. Before plants in a system obtained 92% marketability, the mean GI greatly exceeded that required for an individual plant to be marketable. This difference reflects the relative degree of variability in plant growth, and to some extend is a result of the conditions set forth in this project. With the 12 inch spacing from the beginning, most plants were much wider than the 9 inch minimum width half way through the production period, but had not obtained the height requirement. Thus the large difference between the GI of a Florida Fancy and the mean GI when 92% of the plants became marketable is, to a large extent, the time required to achieve the minimum height. While plant canopies grew in stature, they also continued to grow wider. Since average width is squared in the calculation of GI, it contributes greater to the GI than height.

Among plants receiving 0.27 inch of irrigation per day (Fig. 8), the Multipot Box and EDH systems had larger growth indices compared to the Control. Again, the Multipot Box plants grew considerably faster than all other systems after week 15. Tray and Squat systems tended to produce larger GI than the Control by week 27 and thereafter. Growth indices of the Funnels were similar to the Controls until week 3 1.

At an irrigation rate of 0.60 inch per day (Fig. 9), the growth index of EDH pot and Squat pot plants surpassed that of the Control beginning at week 15, and the Multipot Box plants surpassed those of the Control from week 23 to week 3 1. Growth indices of Tray and Funnel system plants were similar to the Control plants until near the end.

All systems except for the Funnels exceeded the Control in growth index from week 19 to week 3 1 when irrigated with 1.0 inch per day (Fig. 10). The growth index data suggest that the Multipot Box, Tray, EDH, and Squat systems all accelerated the growth of l-gal plants to some extent over that of traditional l-gal containers, with the Multipot Box offering the most significant benefit. Growth of plants in the Funnel system appeared stunted, with abnormally small leaves associated with excessive stress at all irrigation rates. At the time, this was hypothesized to be due to high reflected radiation load on plant shoots due to the proximity of the highly reflective white plastic attached as makeshift Funnels. These symptoms declined after mid-summer when plant canopies began shading the Funnels and the climatic conditions tended to be cloudier as indicated by lower PET (Fig. 3).

Using the 0.60-inch plants in standard containers (>92% marketable at 32 weeks) as the Control for comparison, an irrigation rate of 0.27 inch/day produced >92% marketability in 32 weeks when plants were grown in Funnels, Multipot Boxes, EDH pots, or Squat pots (Fig. 11). Compared to the Control plants, these container systems produced plants of the same quality in the same time using less than half as much water. In addition, plants grown in the Multipot Box reached 100% marketability in 32 weeks at the lowest irrigation rate (0.16 inch/day; Fig. 11). Plants grown in Multipot Box systems and irrigated with 0.16 or 0.27 inch/day reached 92% marketability 8 weeks faster than the Control plants (24 weeks vs. 32 weeks). Funnel, Squat, and EDH systems that received 0.27 inch/day achieved 92% marketability at 28, 30, and 3 1 weeks, respectively. At the 0.60 inch/day irrigation rate, plants in the EDH system reached 92% marketability at 21 weeks, Squat pots at 22 weeks, Multipot Box at 25 weeks, and Funnels at 3 1 weeks. All of the container types reached 92% marketability more quickly with 1.0 inch/day irrigation compared to the Control, but the reduction time did not offset the cumulative application volumes over time.

1998. At the lowest irrigation rate (0.16 inch/day; Fig. 12), plants grown in the Multipot Box system had a larger growth index than Control plants from week 8 to the end of the experiment. Plants grown in both the Squat and Funnel systems were of comparable size to the Control plants irrigated with nearly 4-fold the irrigation rate. Growth indices of plants in the Tray and EDH systems were smaller throughout the period than Control plants.

Among plants receiving 0.27 inch of irrigation per day, those in the Multipot Box and Funnel systems had larger growth indices compared to the Control by 8 weeks after potting (Fig. 13). Growth indices of plants grown in Squat and EDH systems mirrored those of Control plants at twice the irrigation rate. By 17 weeks after potting, growth rates of plants in the Tray system were measurable slower that the Control plants or those of other systems at the 0.27 inch rate.

At an irrigation rate of 0.60 inch per day, the growth indices of all systems except for the Tray exceeded that of the Control beginning at week 12 (Fig. 14). Growth of plants in the Tray system was comparable to those of the Control.

Similarly, when plants received 1.0 inch per day, all systems except for the Tray exceeded the Control in growth index from week 8 to week 21, when plants in these systems were removed from further measurement (Fig. 15). Again, growth of plants in the Tray system mimicked that of the Controls.

Control plants reached 92% marketability in 25 weeks in 1998. Plants grown with Funnel or Squat systems that were irrigated with 0.16 inch/day reached 92% marketability one week faster than Control plants (24 weeks vs 25 weeks, Fig. 16). Multipot Boxes, Funnel, EDH, and Squat systems that received 0.27 inch/day achieved 92% marketability at 19, 21, 24 and 25 weeks, respectively. At the 0.60 inch/day irrigation rate, all systems except for the Tray reached 92% marketability 5 to 6 weeks earlier than the Control. Regardless of container system, improvement in crop time when the irrigation rate was increased from 0.60 to 1.0 inch per day was negligible at best.

In 1998 , plants in both Funnel and Squat systems produced similar size plants to the Control with one-fourth the irrigation rate. Funnels used in 1998 were of the same plastic material and color of the container, in contrast to the shiny white polyethylene funnels used in 1997. The first prototypes of the Funnels became available by the 1998 growing season. Unlike 1997, plants in Multipot Box systems at the 0.16 inch/day irrigation rate did not meet the 92% marketability level in a similar time frame to Control plants. However the mean growth index of these plants was significantly greater. In general, plant growth rates were accelerated over that recorded in 1997. PET was lower during the latter two-thirds of 1998 than 1997, and rainfall was more consistent during the summer.

1999. The extreme weather conditions which occurred in July-Aug set back most of the container systems, independent of irrigation rate. Despite abnormally high PET rates, plants were not given extra irrigation at night, nor were they cooled during mid-afternoon, as likely occurred in commercial nurseries. With the lower PET and higher rainfall rates in June through mid-July in 1999, plant shoot growth was quite rapid, and appeared to have been excessive, especially relative to irrigation volumes at the lower rates. None of the conventional container systems x irrigation rates obtained 92% marketability by the termination of the experiment (Week 43, Fig. 17). Thus there was no Control by which to compare treatments as in 1997 or 1998.

In addition to abnormal weather conditions, 1999 coincided with an explosion in the mouse and rat populations around the abandoned farmlands on the north shore of Lake Apopka. Beginning in January, the mouse population expanded rapidly north and east of Lake Apopka. The research nursery is situated about 1/4 miles east of the lake. The population multiplied until sufficient response was mounted by the County and State governments in September. By July, mice were chewing off roots in some containers for food and to make nests. Several plants on which measurements were being taken were affected and were removed from further consideration.

Plants grown in Multipot Box systems were unaffected by the drought, but in some cases made ideal homes for mice. All 24 measured plants per irrigation rate survived during the length of the experiment; however, 3 plants grown at the 0.27 inch irrigation rate were removed from the analysis due to mice burrows found in the root balls. While these plants were not killed, plant growth was noticeably stunted. Plants grown in Multipot Boxes at the 0.6 and 1 .O inch rates obtained >92% marketability 22 weeks after potting (Fig 17). Those grown at the two lower rates obtained >92% marketability by 26 weeks after potting.

Plants grown in the Funnel system had generally high survival rates (Table 1). Only those at the 0.16 inch rate had reduced survival (20 of 24), mainly from drought-induced death. Of the funneled containers, those grown at the 1 .O inch rate reached the target marketable percentage at 30 weeks, while those receiving the 0.6 inch rate required 35 weeks (Fig. 17). Two other container treatments also reached 92% marketable by the end of the experiment (43 weeks). These were the EDH and Squat containers at the 0.6 inch rate (Fig. 17). None of the other container treatments had obtained 92% marketability when the experiment was terminated due to frost (Fig. 19). However, plants in the Funnel system at the 0.27 inch rate almost obtained >92% marketable plants (87%) at termination.

Survival rates, despite problems such as shoot dieback and leaf' drop in July - Aug., were excellent at the common (0.6 inch) and high (1 .O inch) irrigation rates for all treatments except the Trays (Table 1). At the 0.27 inch rate, survival was still good for plants in the EDH system and fair for Control and Squat systems (Table 1). At the 0.16 inch rate, all container systems except the Funnels and Multipot Box had less than half of the initial plants alive at termination of the experiment (Table 1). For plants grown in the Trays, even the 1 .O inch daily rate was insufficient to keep more than 71% of the plants alive (Table 1). Of these, only one plant was of marketable size after 43 weeks (Fig. 19).

Growth rates of plants in the Multipot Box system were quite rapid at the 1 .O (Fig. 2 1) and 0.6 (Fig. 20) inch irrigation rates. Though slower, plants in the Multipot system at the 0.27 (Fig. 19) and 0.16 (Fig. 18) irrigation rates were still outstanding compared to the other treatments. Growth rates of plants in the other container system treatments generally increased with increasing irrigation rates from 0.16 to 0.6 inches, with the exception of plants grown in the Tray system. The growth rates of plants in the Tray system were very weak and independent of irrigation rate. Poor growth of plants in Trays was also observed in (1998). Growth rates were generally not increased by increasing the irrigation rate from 0.6 and 1 .O inch per day. After 22 weeks, growth indices tended to be higher for plants given the 0.6 inch rate compared to those under 1 .O inch irrigation. Seasonal rams began to return around 2 1 weeks after potting. The drought conditions occurred between weeks 12 to 21 after potting.

ECONOMIC ANALYSIS

Methods for Economic Analysis

Two factors of production critical for an economic analysis of the container systems examined in this study were irrigation cost and labor. Labor requirements to set up each container system were obtained by recording the time necessary to complete the various tasks from start-to-finish. These were recorded each year and averaged for this analysis. Labor used in the daily maintenance of the one-gallon plants was obtained from another research experiment conducted at a woody container nursery in Florida. This data was very comprehensive, as it was collected daily and spanned three consecutive years. Water consumption data was based on the 1998 data of this project. Cumulative consumption for each system over the experimental period was then converted from inches to gallons. All material inputs used in the production/maintenance process, such as containers, potting soil, fertilizers, and chemicals, were also obtained from this experiment, which used actual amounts and prices. Finally, data for the calculation of overhead and administrative costs were obtained from the University of Florida's Nursery Business Analysis Program. This program has been collecting detailed financial information from a wide range of nurseries, including woody container nurseries, for over 25 years. For comparative purposes and simplification of analyses, all data were converted from physical units to dollar units per container.

In the economic analysis, costs and returns were first calculated on a per container basis, and subsequently expanded to a 1,000 square meter area. In the calculation of profits, the expense (investment) for the Multipot Box and the Funnel were amortized for five and three years, respectively. For Funnels, the cost was based on the quantity of plastic and its equivalent cost as a container - in this case, an injection-molded C-650 (Lerio). For the Multipot Boxes, the price was assumed to be one-fourth that of the cost of the fiberglass prototypes, which were $80 each when manufactured. Since these were prototypes, no empirical data exists to quantify their expected life. Hence, conservative assumptions were made and applied. Finally, since plants in the Multipot Box attained marketable size four weeks earlier (21 vs. 25 weeks) than the other technologies, it was assumed that a second crop would be realized in the fourth year of production.

Results and Discussion

This analysis was based on the time required for 92% of the plants within a system to obtain commercially marketable size. A summary of this time requirement for each of the six systems is shown in Table 2. The Multipot Box required 21 weeks to reach marketable size. Analyses for the systems were based on the lowest irrigation rates which still achieved acceptable marketability in the same time period as the Control (25 weeks). Labor requirements are also presented for set-up time (time required to set up 100 containers) for each system. This data was then converted to a dollar expense. The Multipot Box and the Funnel system both required the most set-up time and represented substantially higher costs ($3.30) compared to the other designs which were roughly $1.00. Water consumption data is also shown in Table 2, both in terms of inches applied, and gallons per container. The Water Collector Tray required the most water at 2 1 gallons per container, followed by the Control which required 12.5 gallons per container over the production period. In contrast, the four other systems used between 3.2 and 5.3 gallons of water per container.

A comprehensive expense breakdown on a per container basis for the six container systems is presented in Table 3. By far the most prominent figure was the cost of building a prototype Multipot Box. Even with the cost calculated at 25 percent of original cost, at $2.20 per container, the expense far exceeds those of other systems. Other expense items include materials, labor (both set-up and maintenance), irrigation cost, and overhead costs, the latter calculated at 20 percent of total costs. Total costs vary markedly, from a high of $3.34 for the Multipot Box, to a **low** of $0.72 for the Control and EDH system. Note that, of all the expense items, the most insignificant is the cost of irrigation. Since nearly all Florida nurseries use groundwater for irrigation, figures were calculated using current pump costs (extraction costs) of $0.07/1,000 gallons.

To expand the analysis, revenues were generated by assuming a sale price of $2.00 for each 1 gallon sweet viburnum, regardless of the irrigation system used (i.e., the same quality is assumed across treatments). The publication *PlantFinder* ***was*** used to obtain typical prices for this plant at the wholesale level (Betrock Publications). With a standard price of $2.00, profits (revenues minus costs) per container in the first year varied from a low of – $1.34 per container for the Multipot Box to a high of $1.28 per container for both the Control and EDH (Table 4). These higher profits are reflective of the zero investment cost for enhanced irrigation efficiency. Conversely, the negative profits for the Multipot Box is due to the high ($2.20 per container) initial investment. Similar information is presented in Table 5, but for a 1,000 square meter production area. As is evident, start-up costs are very high for the Box, which is also reflected in the large negative profits.

The analysis presented up to this point considered four basic cost categories -- the installation costs associated with each system, production and maintenance costs of the material for the experimental period, the cost of irrigation, and overhead costs. As noted earlier, for three of the systems (Box, Funnel and Tray), the installation costs were an important component of total costs. However, based on its sturdy design the Box material was assumed to last for five years. The Funnel was assumed to last for three years, and the white Collector Trays were assumed to need replacement each year. This last assumption was based on the fact that the Trays had completely deteriorated after one production period (4-5 months). Consequently, in the calculation of profits, the Box was amortized over five years and the Funnel over three.

Costs and profits over a five year period for each irrigation systems and the Control are presented in Table 6. These figures include the depreciated values for the Multipot Box and the Funnel. Since costs and returns were assumed unchanged for four of the systems, profits were as well. The exception were the Multipot Box and the Funnel, due to the depreciation factor. In years 1, 2 and 3, the Box experienced negative gains, with positive profits in years 4 and 5. Unfortunately, the negative gains out weighed the positive ones over the five year period as cumulative profits were -- $8,881 for the Multipot Box. This loss was in spite of the depreciation factor and a second crop in the fourth year. The remaining four container systems were profitable each year, with the Tray being the least ($33,805) and the EDH being the most profitable.

FIELD DAY

In conjunction with the last year of data collection, a field day was planned and conducted by the investigators of the project. The objective of the field day was to demonstrate the technology and provide related information to the nursery industry and other interested parties. After a Welcome/Introduction address, attendees were divided into 7 groups and escorted through 7 stations set up at the research nursery. The stations consisted of Dr. Beeson at this project, Dr. Knox at a project investigating exterior capillary mat technology, Dr. Haydu providing an analysis of the economics of this project, Dr. Yeager discussing pallet flats and cardboard containers, Dr. Neal at an experiment comparing rectangular trays to standard round containers, Dr. Haman explaining the basis and research results from the Multipot Box, and a break. Dr. Smajstrala had planned to discuss rain shut-off devices, but was unable to attend. Registration began around 8:30 am, and a catered lunch was provided in the semi-complete auditorium beginning around 12: 15. Attendees were invited to then tour the lab/office complex under construction and/or return to the research nursery to discuss anything further. Several attendees returned to the nursery with discussions ending around 2:30 pm. There were around 110 non-IFAS personnel attending the Field Day. Geographically, the attendees were drawn from South Florida to Southern Georgia north of Tallahassee.

CONCLUSIONS

Plant growth and water conservation. In summary, the data collected in 1997, 1998, and 1999 suggest that existing and patent-pending container-systems offer advantages over conventional standard overhead irrigation systems, including improved irrigation water use efficiency (IWUE), reduced required irrigation application rates, and shorter crop production times when used with greater than the minimum irrigation rates. Multipot Boxes, Funnel attachments, 8-inch diameter azalea "Squat" pots, and pots with elevated drain holes (EDH pots) required half the volume of overhead irrigation required for standard l-gal containers irrigated to produced commercially acceptable growth rates (Control).

For the EDH system, this occurred even though the effective container surface areas were identical to those of the conventional standard 1 gal containers. Effective surface area is defined as the area from which water is collected for a container. The only difference between EDH and standard containers were the placement of drainage holes. Based on the average air porosity of the substrate used (20% by volume), elevating these drainage holes should have increased the amount of plant available water about 80 mL. This represents 20 to 25% of the average daily water use of marketable size 1 gal sweet viburnum (Beeson, SWFWMD Project S-l).

Multipot Box, Funnel and Squat systems increased the effective surface area of the substrate, thereby capturing more of the overhead-irrigated water than that of the standard conventional containers. In 1998, with a true Funnel prototype and more consistent mid- to late summer rainfall, both Funnel and Squat systems were found to produce market-quality plants with one-fourth the irrigation volume of the Control. While the increase in the percentage of the production bed area occupied by container surfaces was not as great with the Squat system compared to the effective surface area of the Funnel systems (42% vs 100%, respectively); the wider basal volume of Squat containers held more plant available water than conventional containers mounted with Funnels.

The concept of greater plant available water was taken to the extreme with the Multipot Box system. This was the most efficient system in terms of production of marketable plants with reduced overhead irrigation. Except in the very dry summer of 1998, plants in the Multipot Box system only required one-fourth the irrigation volume of standard containers. Even at the lowest irrigation rates, growth rates of plants in Multipot Boxes generally exceeded those of plants grown in all other systems.

At a typical daily application rate of 0.60 inch of water, all systems evaluated in the project, with the exception of the Water Collector Trays, generally reduced the time required to produce a marketable crop by a month or more compared to the conventional system. The Tray system is not a viable option for outdoor plant production. Trays deteriorated outdoors and became brittle and cracked by the end of the growing season. Furthermore, an unknown detriment associated with Trays, likely excessive reflected solar radiation, induced stress, frequently to the point of plant death, in the plants all 3 years.

Economic analysis. Several important conclusions can be drawn from the economic analysis. First, for the Water Collector Trays, Multipot Box and Funnel systems, the initial purchase price was a major cost impediment. The cost for Funnels and Multipot Boxes, especially the Multipot Boxes, may be conservatively high compared to actual market price should these become commercially available. However, both Multipot Box and Funnel systems are capable of multi-year use, and so costs after the initial year's investment drop considerably. Second, the cost of irrigation is not a limiting factor of production from an economic perspective. Using groundwater, the principal direct cost is for the energy to run the pumps. If reclaimed water was used as the water source, where the cost for water can be ten times the pumping cost of groundwater, the irrigation cost is still insignificant relative to other costs. Unless cost for irrigation rise substantially, or until water allotments are restricted prohibitively, thereby affecting both annual output and revenues, there will be little economic incentive for nursery owners to adopt these water-conserving technologies. Third, some of the data indicates a production advantage using the Multipot Box. For 1998, shrubs reached marketable size in 21 weeks compared to 25 weeks for the other systems. With the production period reduced by 15 percent, over a couple of years, an additional crop could conceivably be produced, thereby mitigating the high initial cost of the Box.

Based on economics, plant growth, and water conservation, switching to 1 gal containers with elevated drain holes would be the most profitable for the industry, while reaping 50% reductions in the volume of irrigation water applied. However, this assumes the cost of these containers is equivalent to standard, conventional containers. Commercially, 1 gal containers with elevated drain holes are not produced. However, larger containers are commercially available and are marketed as EFCs (Environmentally Friendly Containers). In general, EFC containers are more expensive than their conventional container counterparts. For a 3% reduction in projected profit, water conservation could be increased three-fold over conventional containers using Squat containers, These containers would required one-fourth the irrigation volume of conventional containers. However, with their larger diameters, shipping considerations may erode the profit a bit more. Production using funneled containers would also result in high water conservation, requiring only 25% of the normal irrigation volumes of conventional standard containers. However, their projected cost equivalence to that of a second container, and conservative 3-year life span, lowers projected profits by 14%. Further refinements in the prototype to reduce the labor component and inclusion of unquantified benefits, such as reduced heat loads on root balls, reduced wind-throw, and ability for mechanical precision fertilization may increase the profit margin and make the Funnel system a viable alternative to EDH and Squat systems. While Multipot Boxes are undeniably the best system in terms of water conservation and plant growth, in addition to probable benefits of improving runoff water quality, their cost must be decreased dramatically for this system to become economically viable.

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Acknowledgment: This project was accomplished by the support of the Hillsborough River Water Basin Board, the Southwest Florida Water Management District, the Tampa Bay Wholesale Growers and the Florida Nursery and Growers Association and some of its Chapters.

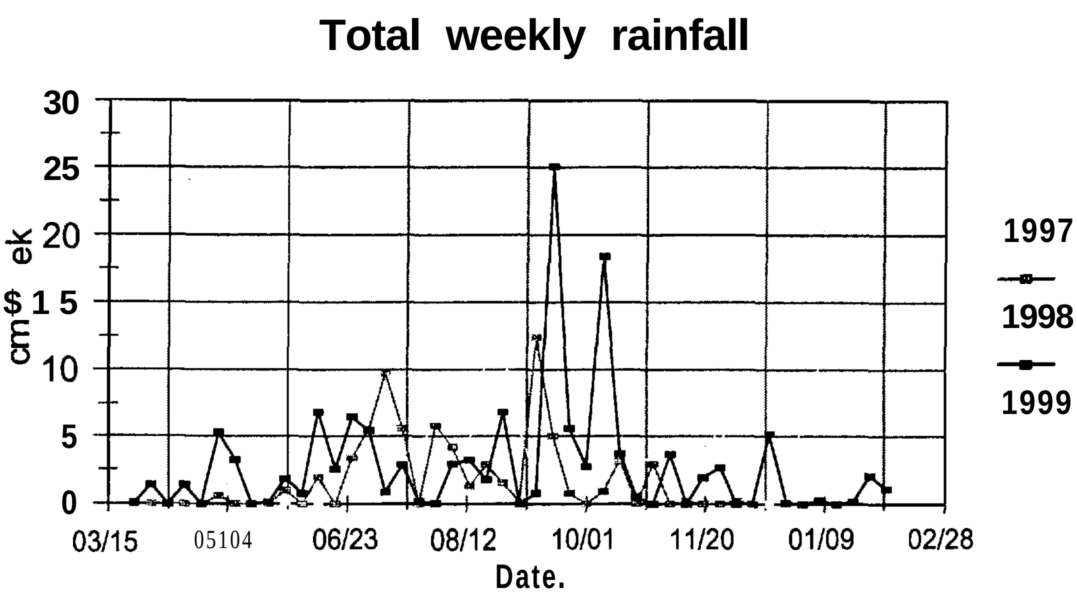

Figure 1. Total weekly rainfall (cm/week) during each growing season

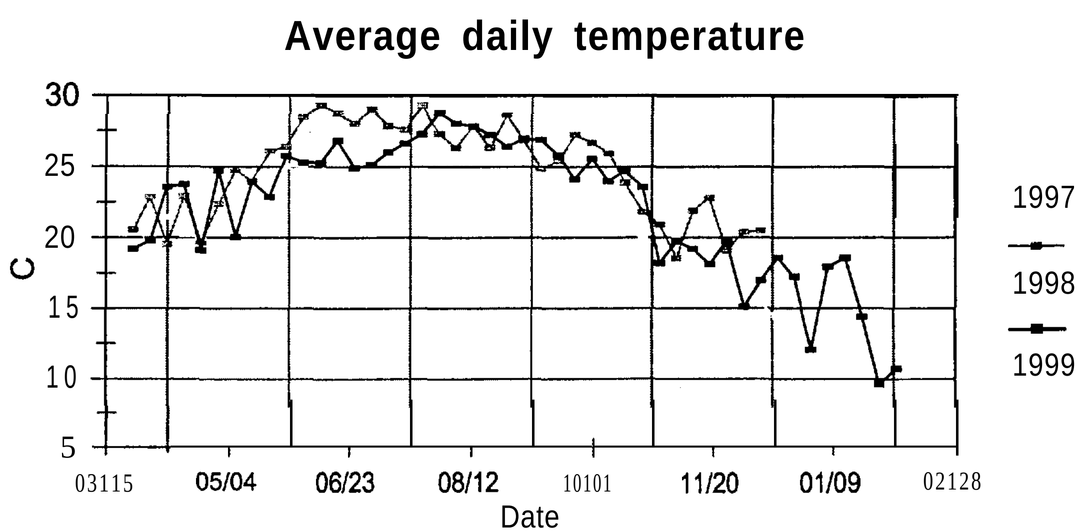

Figure 2. Average daily temperature (°C, averaged weekly) during each growing season.

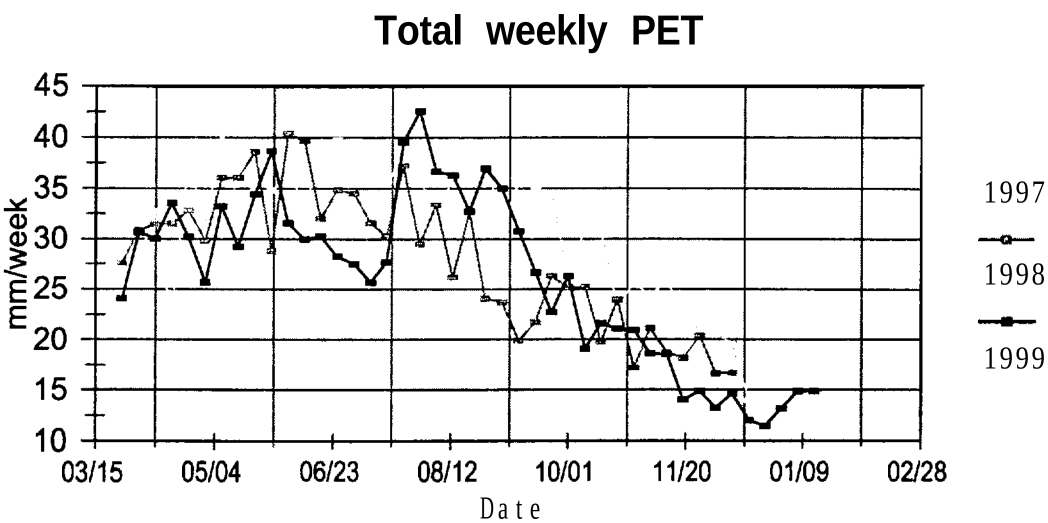

Figure 3. Total weekly potential evapotranspiration (PET; mm/week) during each growing season.

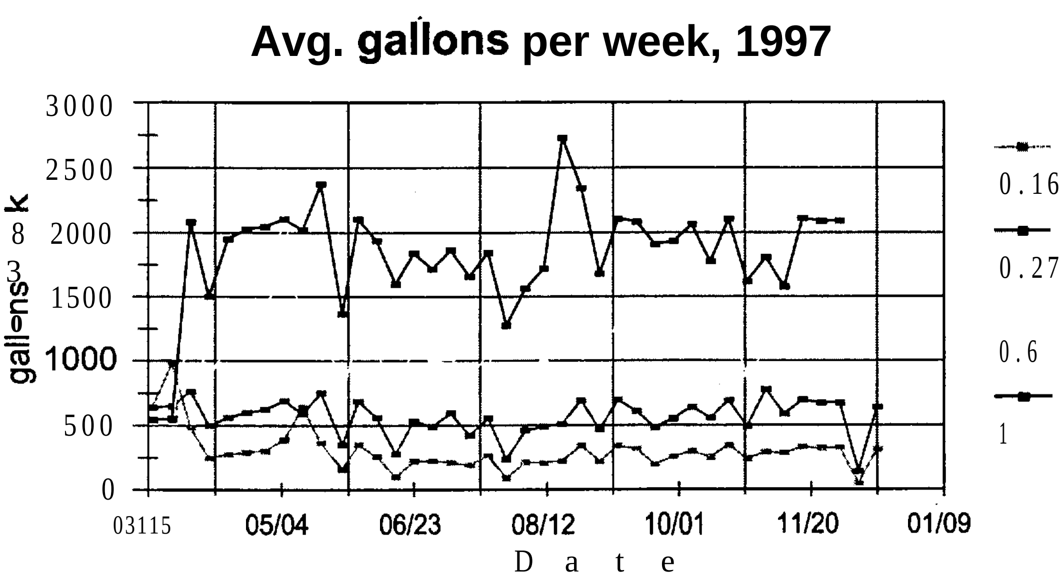

Figure 4. Average gallons used by each irrigation treatment each week during the 1997 growing season.

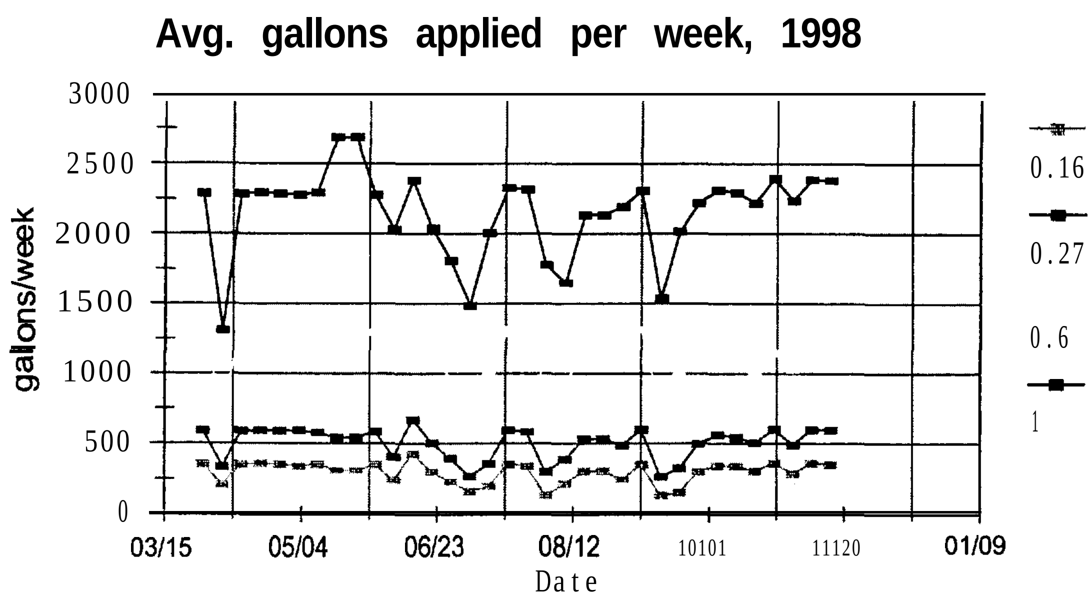

Figure 5. Average gallons used by each irrigation treatment each week during the 1998 growing season.

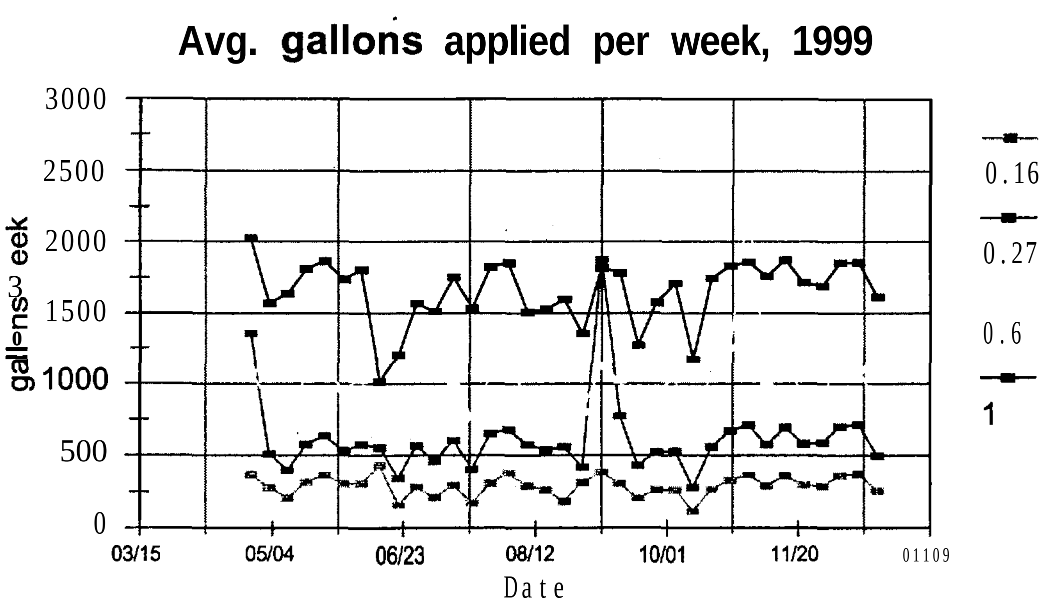

Figure 6. Average gallons used by each irrigation treatment each week during the 1999 growing season.

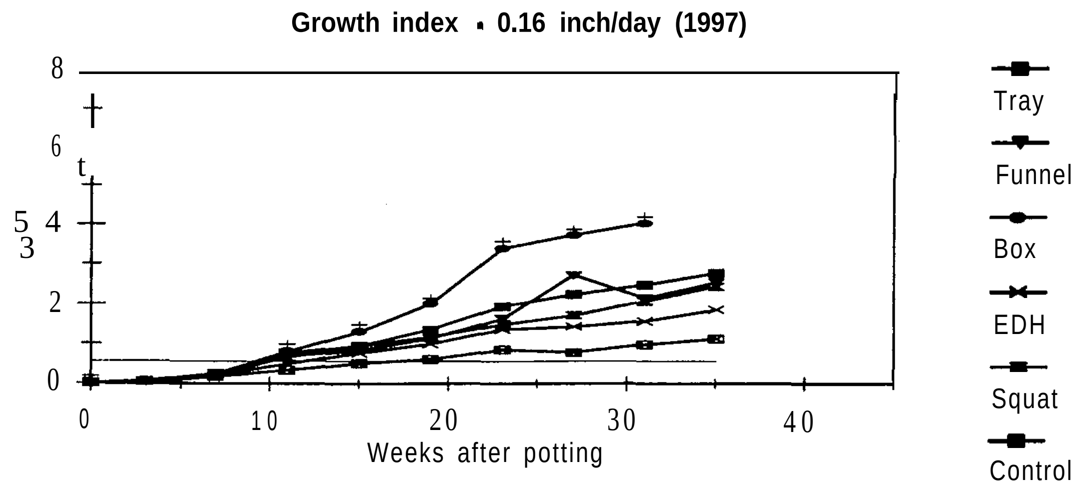

Figure 7. Growth index over time of plants grown in five different container types and receiving 0.16 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch/day; 1997 data). Data points marked with a + are significantly different from Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants

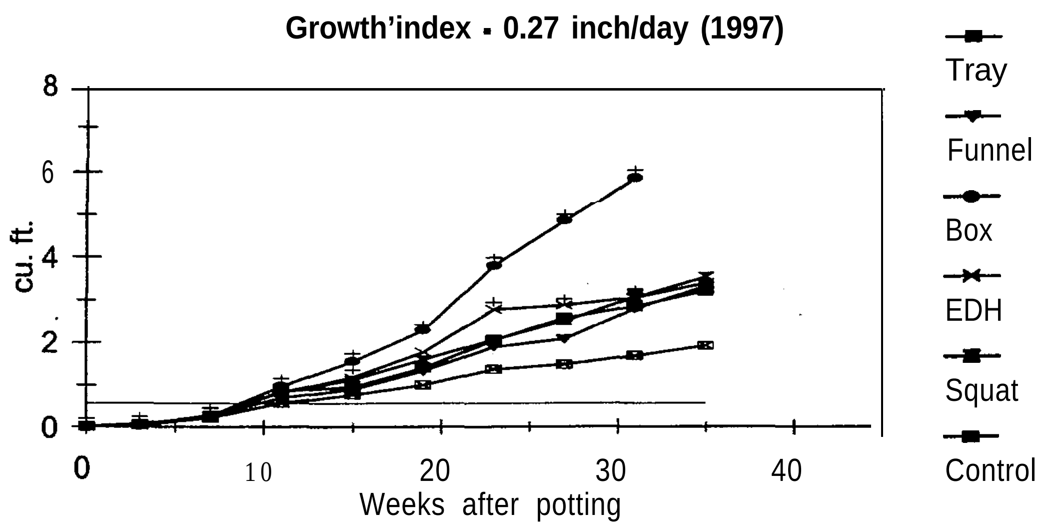

Figure 8. Growth index over time of plants grown in five different container types and receiving 0.27 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day;1997 data). Data points marked with a + are significantly different from Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants.

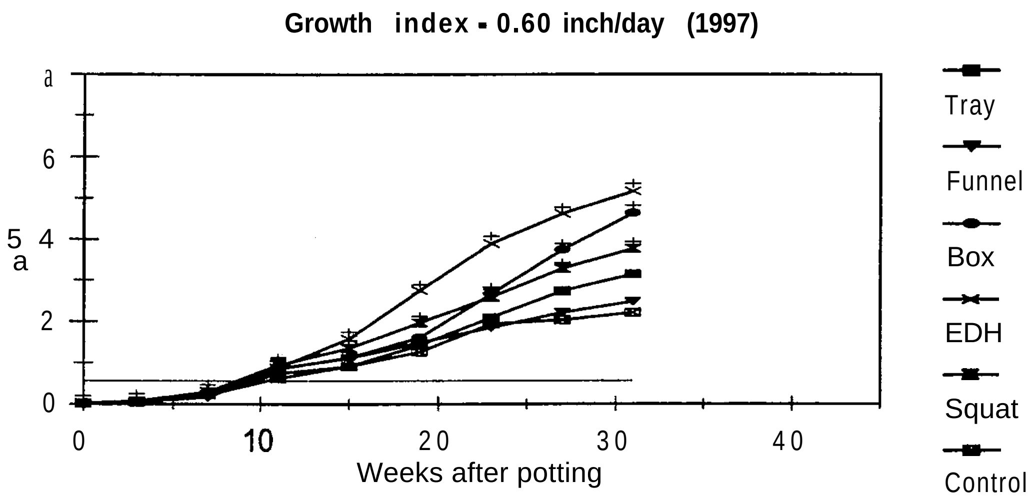

Figure 9. Growth index over time of plants grown in five different container types receiving 0.60 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1997 data). Data points marked with a + are significantly different from Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants

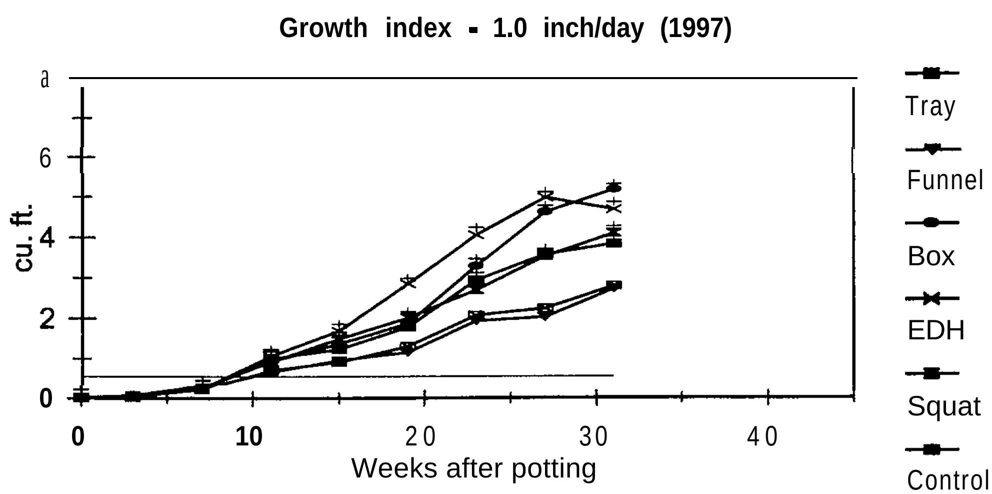

Figure 10. Growth index over time of plants grown in five different container types receiving 1 .O inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1997 data). Data points marked with a + are significantly different from Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants

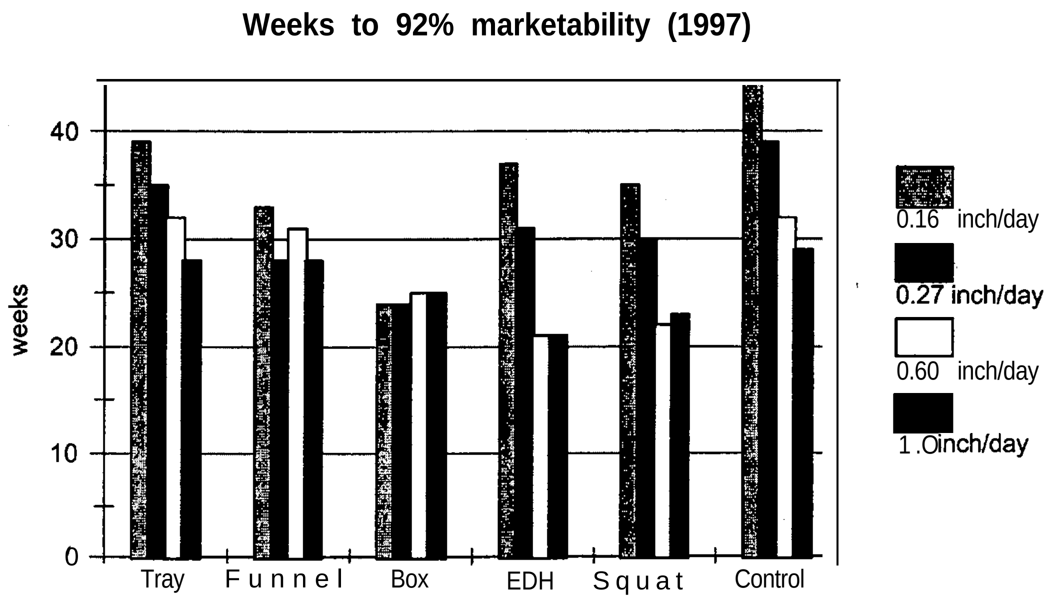

Figure 11. Number of weeks required for each container/irrigation rate combination to achieve 92% marketability, extrapolated from regression equations for each combination (1997 data).

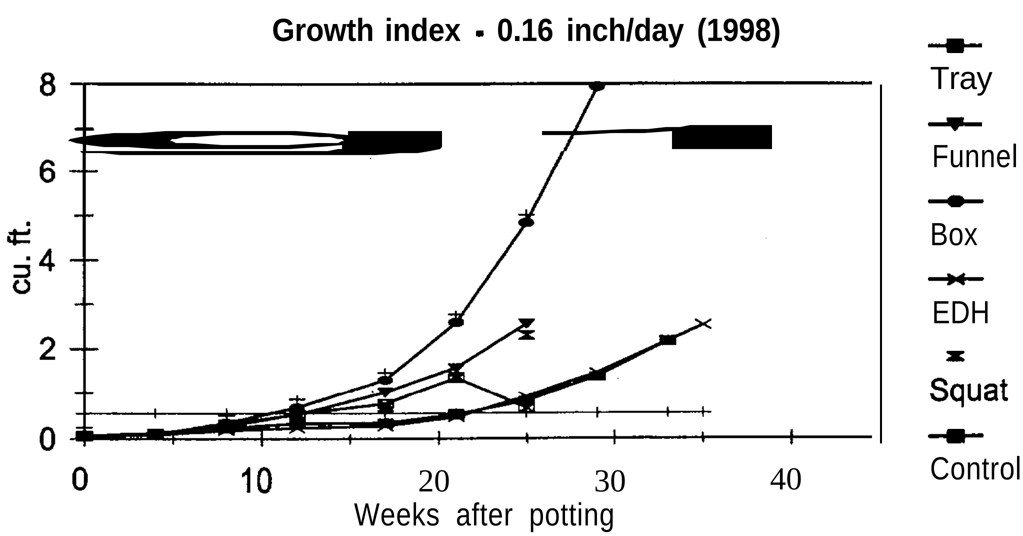

Figure 12. Growth index over time of plants grown in five different container types and receiving 0.16 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1998 data). Data points marked with a + are significantly different from the Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants.

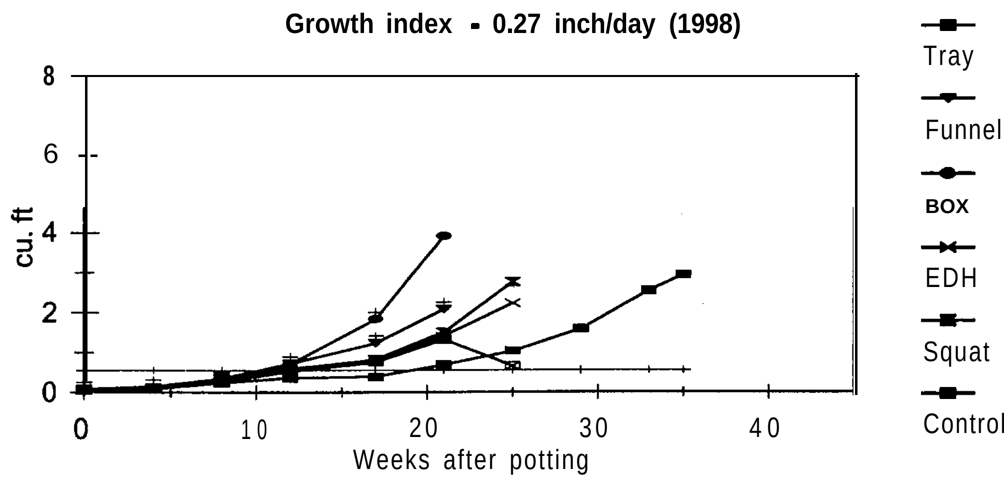

Figure 13. Growth index over time of plants grow-n in five different container types and receiving 0.27 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1998 data). Data points marked with a + are significantly different from the Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants.

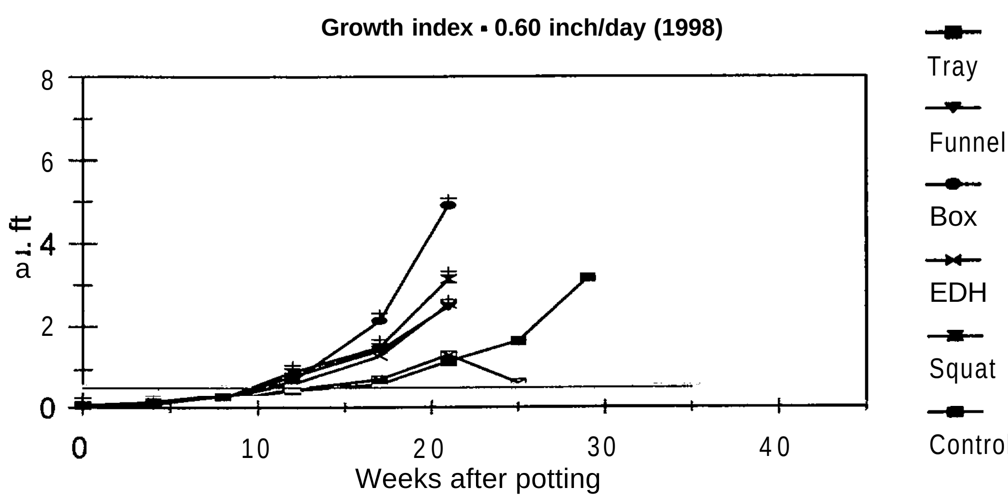

Figure 14. Growth index over time of plants grown in five different container types and receiving 0.60 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1998 data). Data points marked with a + are significantly different from the Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants.

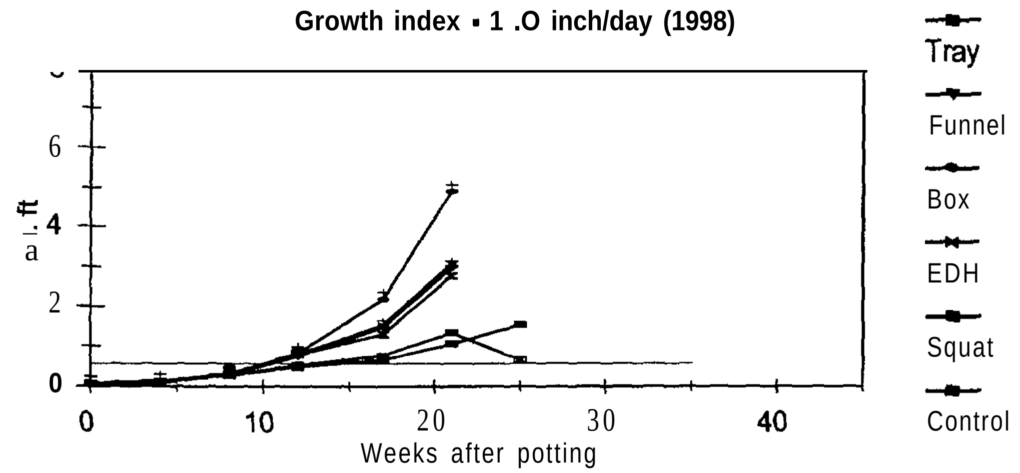

Figure 15. Growth index over time of plants grown in five different container types and receiving 1 .O inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch per day; 1998 data). Data points marked with a + are significantly different from the Control at the same time point (5% confidence level). Dashed line indicates volume of marketable plants.

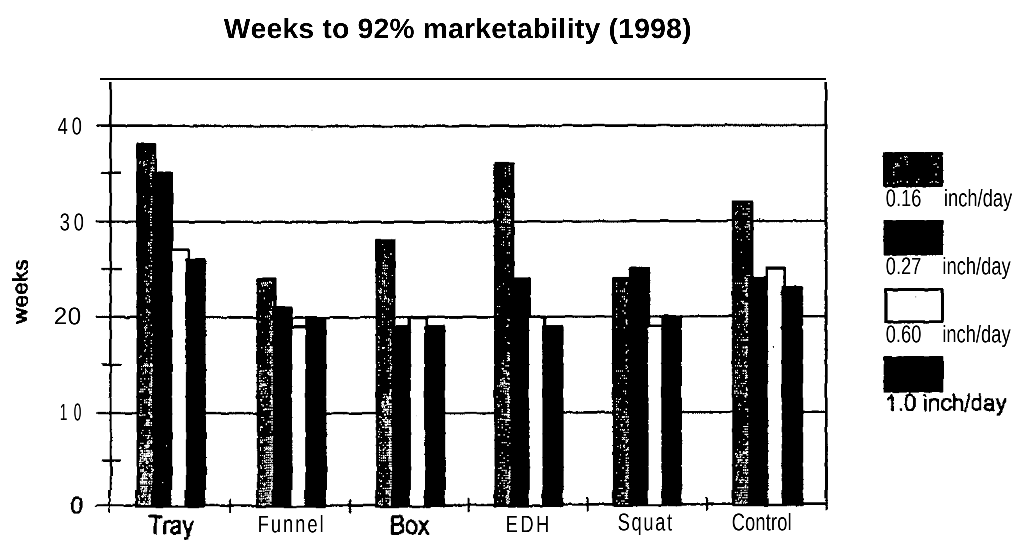

Figure 16. Number of weeks required for each container/irrigation rate combination to achieve 92% marketability, extrapolated from regression equations for each combination (1998 data).

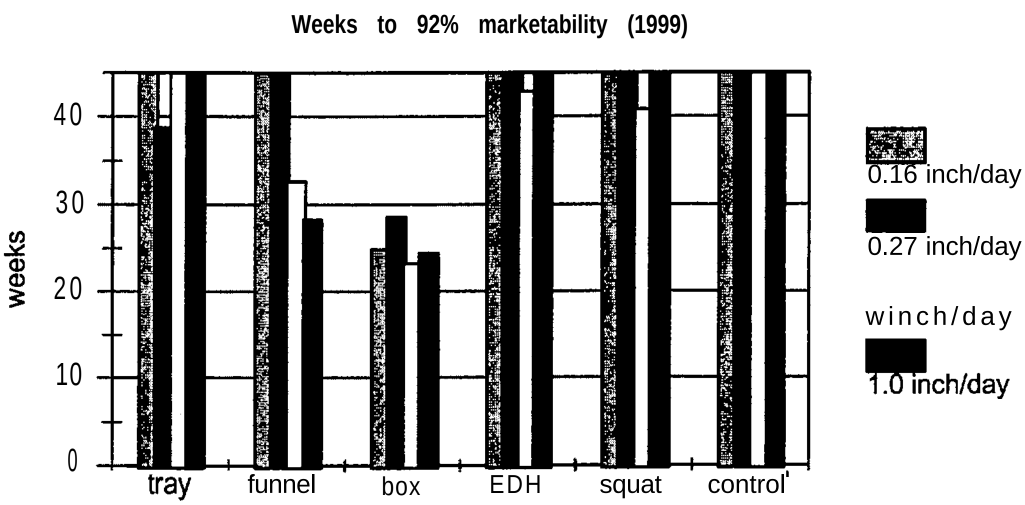

Figure 17. Number of weeks required for each container/irrigation rate combination to reach 92% marketability, extrapolated from regression equations for each combination (1999 data) where possible. The experiment was terminated at week 43.

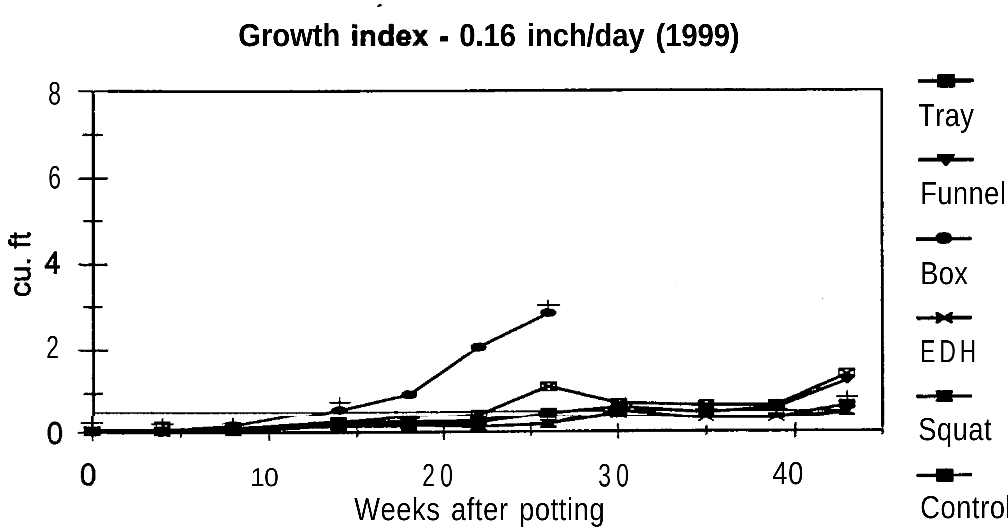

Figure 18. Growth index over time of plants grown in five different container types and receiving 0.16 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch/day; 1999 data). Means were initially based on 24 plants per container treatment. However the number of replications of some treatments declined to those given in Table 1. Dashed line indicates volume of marketable plants.

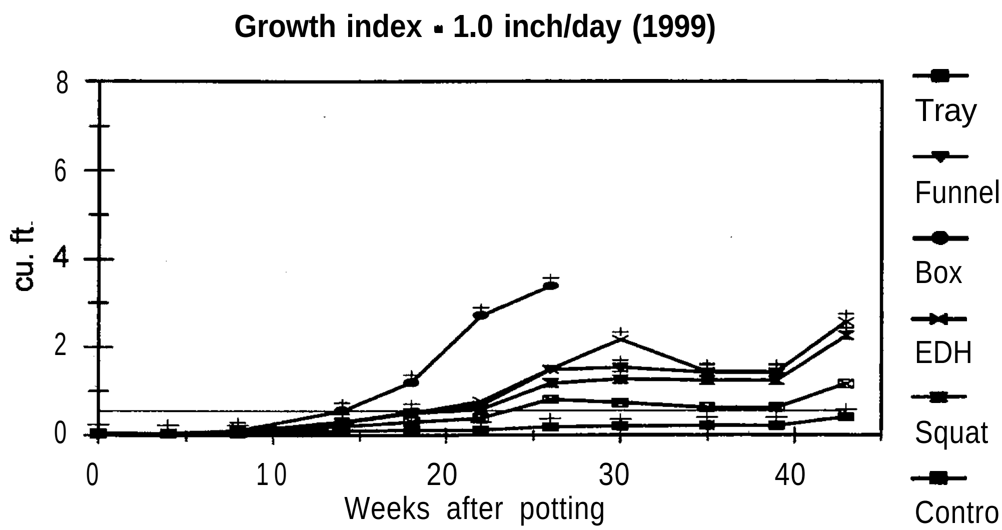

Figure 2 1. Growth index over time of plants grown in five different container types and receiving 1 .O inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 irrigation per day; 1999 data). Means were initially based on 24 plants per container treatment. However the number of replications of some treatments declined to those given in Table 1. Dashed line indicates volume of marketable plants.

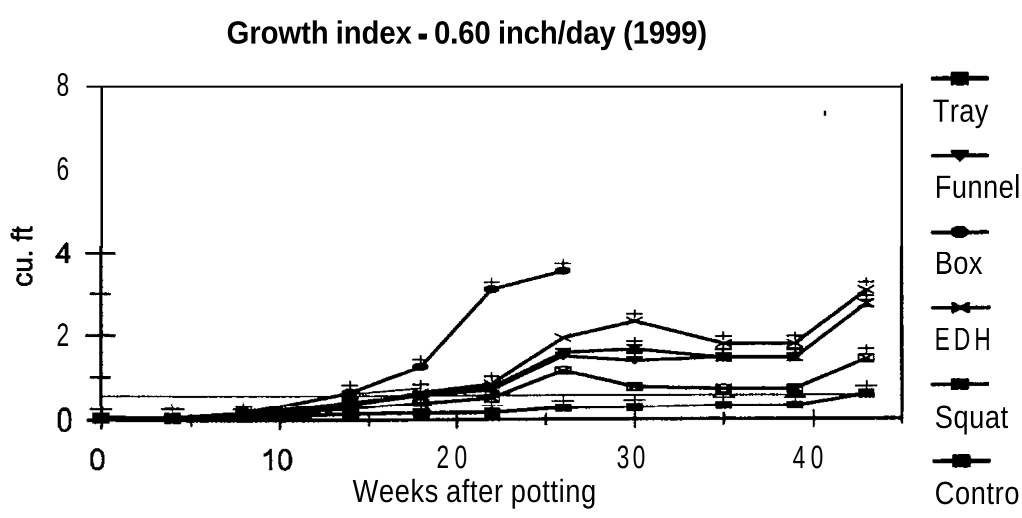

Figure 20. Growth index over time of plants grown in five different container types and receiving 0.60 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch/day; 1999 data.) Means were initially based on 24 plants per container treatment. However the number of replications of some treatments declined to those given in Table 1. Dashed line indicates volume of marketable plants.

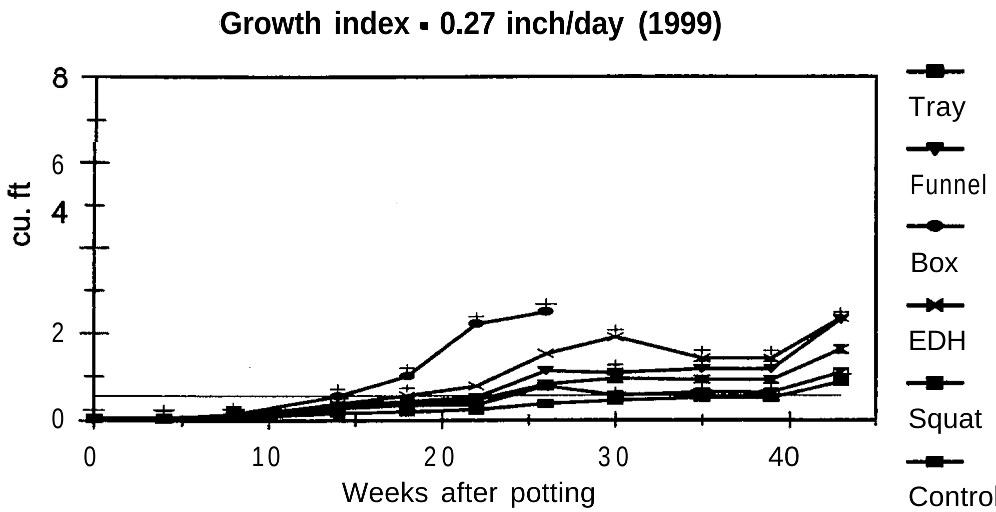

Figure 19. Growth index over time of plants grown in five different container types and receiving 0.27 inch of irrigation per day, in comparison to Control plants (standard containers receiving 0.60 inch/day; 1999 data). Means were initially based on 24 plants per container treatment. However the number of replications of some treatments declined to those given in Table 1. Dashed line indicates volume of marketable plants.

Table 1. Number of measured 1 -gal. viburnum remaining alive at the end of the 1999 production period by container systems and irrigation rates. Initially 24 plants were measured for each container system at each irrigation rate.

Irrigation rate	Number of viable plants					
Inch/day	Tray	Funnel	Box	EDH	Control	Squat
0.16	7	20	24	11	6	13
0.27	13	23	24	23	20	20
0.60	14	24	24	24	23	24
1.0	17	24	24	23	23	24

Table 2. Summary of production time, labor requirements and irrigation volumes per container for the Control and most water-conserving irrigation rates that produced acceptable plant quality for each container system.

Irrigation Technology	**Weeks Marketable** 1998	**Labor – 1998**		**Water Use – 1998**	
		Set-up Time'	**Dollar Rate[b]**	**Inches [c]**	**Gallons/Container[d]**
Multipot Box	21	28.26	$3.30	0.23	4.474
Control	25	7.81	$0.91	0.60	12.464
EDH	25	7.87	$0.92	0.27	5.326
Funnel	25	28.10	$3.28	0.16	3.205
Squat	25	8.20	$0.96	0.16	3.205
Water Collector Tray	25	16.93	$1.98	1.00	21.278

a Set-up times are man-minutes required to organize 100 containers.
b Calculated as follows: 28.26/60 minutes = 0.47 1 * $7/hour = $3.30.
c Minimum acceptable irrigation rates applied to produce plants equivalent to the Control.
d Cumulative inches of water converted to gallons applied per container.

Table 3. Summary of total costs on a per container basis for the most Control and at the most water-conserving, commercially acceptable irrigation rates for each container system.

Irrigation Technology	Cost Breakdown per Container in Dollars						Overhead[e]	Total Cost per Container
	Container System		Materials [a]	Labor		Water[d]		
	Pot	Tray		Set-up[b]	Maintenance[c]			
Multipot Box	0.157	2.20 [f]	0.152	0.0330	0.24	0.000313	0.556	$3.34
Control	0.104	—	0.19	0.0091	0.30	0.000872	0.12	$0.72
EDH	0.104	—	0.19	0.0092	0.30	0.000372	0.12	$0.72
Funnel	0.104	0.16[g]	0.19	0.0328	0.30	0.000224	0.16	$0.94
Squat	0.136	—	0.19	0.0096	0.30	0.000224	0.13	$0.76
Collector Tray	0.104	0.31 [h]	0.19	0.0198	0.30	0.001489	0.19	$1.11

[a] Includes potting substrate, fertilizers, and herbicides for potting one gallon containers in addition to materials for one year's production maintenance.

[b] Data taken from Table 1 where labor "set-up" costs were for 100 containers. Therefore, labor time for "Box" was $3.30/100 containers, or $0.033/container.

[c] Includes labor activities for potting and maintenance. Labor expense calculated at $7.00 per hour wage rate.

[d] Gallons from Table 1 converted to dollars, at pump cost rate of $0.07 per1000 gallons.

[e] Overhead cost assumed to be 20% of total costs.

[f] Original cost of Box prototype was $80. Assumes final sale price at 25% original cost. Nine containers per Box ($20 / 9 = $2.20).

[g] Cost based on price of a container of equivalent volume of plastic, model C-650 Lerio Corp.

[h] Water Collector cost is $62.50 for 100 trays, each holding two containers.

Table 4. First year costs and profits on a per container basis for the Control and most water-conserving irrigation rates that produced acceptable plant quality for each container system.

Irrigation Technology	Container System[a]	Materials	Labor[b]	Water"	Overhead[d]	Total Cost	Revenue[e]	Profit
	-------------Dollars—							
Multipot Box	2.357	0.152	0.2730	0.0003 132	0.556	3.34	2.00	- $1.34
Control	0.104	0.190	0.309 1	0.000872	0.121	0.72	2.00	$1.28
EDH	0.104	0.190	0.3092	0.000372	0.121	0.72	2.00	$1.28
Funnel	0.264	0.190	0.3328	0.000224	0.157	0.94	2.00	$1.06
Squat	0.136	0.190	0.3096	0.000224	0.127	0.76	2.00	$1.24
Tray	0.414	0.190	0.3198	0.001489	0.185	1.11	2.00	$0.89

a Combines cost of container and any container system apparatus from Table 3.

b Set-up time and maintenance combined from Table 2.

c Water is groundwater with pump-cost calculated at $0.07 per 1,000 gallons.

d Assumes overhead at 20% of total cost, less overhead.

e Assumes $2.00 wholesale price for each 1 gal. sweet viburnum.

Table 5. First year cost and returns for container systems expanded to 1,000 square meter production area.' for the Control and most water-conserving irrigation rates that produced acceptable plant quality for each container system.

Irrigation Technology	Container System [b]	Materials	Labor'	Water [d]	Overhead [e]	Total Cost	Revenue [f]	Profit
	Dollars							
Multipot Box	$17,913	$1,155	$2,075	$2.38	$4,229	$25,375	$15,200	-$10,175
Control	$790	$1,444	$2,349	$6.63	$918	$5,508	$15,200	$9,692
EDH	$790	$1,444	$2,350	$2.83	$917	$5,505	$15,200	$9,695
Funnel	$2,006	$1,444	$2,529	$1.70	$1,196	$7,178	$15,200	$8,022
Squat	$1,034	$1,444	$2.353	$1.70	$966	$5,799	$15,200	$9,401
Trav	$3,146	$1,444	$2,430	$11.32	$1,406	$8,439	$15,200	$6,761

a Assumes 7,600 one-gallon containers per 1,000 square meters.
b Combines cost of container and any container system apparatus from Table 3.
c Set-up time and maintenance combined from Table 3.
d Water is groundwater with pump-cost calculated at $0.07 per 1,000 gallons.
e Assumes overhead at 20% of total cost, less overhead.
f Assumes $2.00 for each 1 gallon sweet viburnum.

Table 6. Total costs and profits of container systems for 1,000 square meter area, over five years, with "Box" and "Funnel" amortized over five and three years, respectively".

Irrigation Technology	Year 1	Year 2	Year 3	Year 4	Year 5	Five Year Total
1. Box						
* cost	$25,375	$21,362	$17,349	$26,772 [a]	$9,323	$86,745
* Profit	– $10,175	$6,162	– $2,149	$3,728 [a]	$5,877	– $8,882
2. Control						
* cost	$5,508	$5,508	$5,508	$5,508	$5,508	$27,541
* Profit	$9,692	$9,692	$9,692	$9,692	$9,692	$48,459
3. EDH						
* cost	$5,505	$5,505	$5,505	$5,505	$5,505	$27,523
* Profit	$9,695	$9,695	$9,695	$9,695	$9,695	$48,477
4. Funnel						
* cost	$7,178	$6,691	$6,205	$7,178	$6,691	$33,943
* Profit	$8,022	$8,509	$8,895	$8,022	$8,509	$42,057
5. Squat						
* cost	$5,799	$5,799	$5,799	$5,799	$5,799	$28,994
* Profit	$9,401	$9,401	$9,401	$9,401	$9,401	$47,006
6. Tray						
* cost	$8,439	$8,439	$8,439	$8,439	$8,439	$42,193
* Profit	$6,761	$6,761	$6,761	$6,761	$6,761	$33,807

[a] Assumes one gallon sweet viburnum sold for $2.00. For "Box" technology, assumes two crops obtained in fourth year due to shorter production period.