SUBIRRIGATION

reduces water use, nitrogen loss, and moss growth in a container nursery

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ABSTRACT

With about half the amount of water, subirrigated *Metrosideros polymorpha* Gaud. (Myrtaceae) grown 9 mo in a greenhouse were similar to those irrigated with an existing fixed overhead irrigation system; moss growth was about 3X greater in the fixed overhead system after 3 mo. Moss growth was affected by the rate of preplant controlled release fertilizer added (more fertilizer, less moss) and moss maturity, quantified as presence or absence of sporangia, was slowed with subirrigation. About 5 g nitrogen (N) leached per m^2 (0.02 oz/ft^2) of greenhouse bench under the fixed irrigation system, whereas none was lost from subirrigation. Besides *Metrosideros macropus*, the USDA Forest Service and Purdue University are evaluating subirrigation for nursery production of other species. To date, the results indicate subirrigation may be a useful technique for growing native plants with large canopies where conventional irrigation systems are less effective, or where water use or other environmental concerns are paramount.

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KEY WORDS

irrigation, fertilization, *Metrosideros polymorpha*, *Quercus*, *Picea*, *Acacia*, *Echinacea*, electrical conductivity, Myrtaceae

NOMENCLATURE

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Overhead irrigation is the most common form of irrigation in forest and conservation nurseries (Landis and others 1989) and in greenhouse production overall (Leskovar 1998). Overhead irrigation systems are generally less expensive to install, and have the advantage of preventing the accumulation of fertilizer salts that can be detrimental to plant growth (Argo and Biernbaum 1995). A significant disadvantage, however, is that overhead irrigation can be fairly inefficient—in a reforestation nursery between 49% and 72% of the applied water was discharged from the nursery (Dumroese and others 1995). Because nursery and greenhouse production use higher rates of fertilization than do other agricultural crops (Molitor 1990), this discharge water can have significant amounts of unused fertilizer in it (Juntenen and others 2002; Dumroese and others 2005) and be a potential source of groundwater and surface water pollution. McAvoy and others (1992) found high amounts of nitrate in the soil below greenhouses. Several states now impose restrictions on the amount of wastewater that can be discharged from nurseries (Grey 1991), and some states are imposing restrictions on the amount of water that can be

One of the best ‘ōhi‘a seedlings after 6 mo of growth. This seedling was subirrigated and received 4 kg/m^3 (6.7 lb/yd^3) of controlled release fertilizer. Photo by Kas Dumroese, USDA Forest Service used during dry seasons (Oka 1993). Because of the increased public concern regarding water quality and conservation, many nursery growers are looking for new ways to address water issues (Todd and Reed 1998).

Subirrigation may be a way to reduce water use and fertilizer runoff from nurseries. Using a closed system, subirrigation water moves from a reservoir tank into an application tank. In the application tank, capillary action allows the irrigation water to move upward into the growing medium (Coggeshall and Van Sambeek 2002). When the irrigation is complete, unused water drains back to the reservoir for later recirculation through the system. Because the system is closed, a water use decrease of 86% was shown with subirrigation compared with overhead irrigation for food crops (Ahmed and others 2000), and fertilizer runoff is eliminated because leached water is recirculated. Some forbs showed improved and more uniform growth with subirrigation (Yeh and others 2004) because an equal amount of water is delivered to each seedling, which helps eliminate the common "edge effect" in overhead-irrigated crops (Neal 1989). By keeping foliage dry, subirrigation has reduced foliar diseases (Oh and Kim 1998). Three potential concerns with subirrigation are: 1) the possibility of disease, particularly root rots, spreading from plant to plant from the use of recirculated water; 2) accumulation of fertilizer salts in the upper portions of the root plug; and 3) higher installation costs.

Here we briefly describe a study comparing plant growth, water use, and nitrogen leaching with subirrigation and fixed overhead irrigation. We also provide some details on other subirrigation research work we have underway.

METHODS

The Nursery

On the Big Island of Hawai‘i, the US Fish and Wildlife Service has a remote native plant nursery that produces stock for restoration of the Hakalau Forest National Wildlife Refuge, a preserve for endangered endemic birds and plants. The only water source available for the nursery is water collected from the roofs of buildings in the compound and held in cisterns. This water is also used by staff for laundry, cooking, and sanitation. During recent drought events, insufficient water was available to keep plants in the nursery irrigated; water had to be trucked in at considerable expense. We thought that subirrigation may be a means to reduce water demands in the nursery and still produce quality plants. In addition, refuge personnel were concerned about the effects that nitrogen being leached from the nursery may have on the refuge environment. In August 2005 we installed a simple study to compare water use, nitrogen discharge, and growth of *Metrosideros polymorpha* Gaud. (Myrtaceae), commonly known as ‘ōhi‘a. ‘Ōhi‘a is Hawai‘i's most common native canopy tree and its striking red flower is known as ‘ōhi‘a lehua. ‘Ōhi‘a is an important source of nest sites and food resources, such as nectar and insects, for most of Hawai‘i's native and endangered birds.

Treatments

We used a 2 irrigation treatment x 3 fertilizer rate x 3 replication completely randomized design. The 2 irrigation treatments were: 1) the current fixed overhead system; and 2) subirrigation. The overhead system consisted of 6 Dramm Stix (Model SS36, 5.6 l/min [1.48 gal] at 50 psi; Dramm Corp, Manitowoc, Wisconsin) nozzles spaced equally over a 1.2 m x 3.7 m (4 ft x 12 ft) bench. On timers, this system ran once each day at about 14:00 for 2 min. Total water applied per bench was 15.5 l (4.1 gal). The water source was rain collected from roofs at the facility. The subirrigation trays were also 1.2 m x 3.7 m (4 ft x 12 ft) to fit on the existing benches. The trays (Ebb-Flo; Midwest GROmaster Inc, St Charles, Illinois) were 5 cm (2 in) deep. A pump was timed to run 3 times each day between 12:00 and 12:40. During each "on" cycle, the pump pushed water from a 285-l (75-gal) reservoir tank sitting beneath the bench into the subirrigation tray. Each "on" cycle lasted 2 min, which was sufficient to fill the tray, followed by a 12-min "off" cycle that allowed the water to drain back through the pump into the reservoir tank. Each treatment was replicated 3 times. We measured how much water was periodically added to the reservoir tanks.

The 3 fertilizer treatments were Nutricote® 13N:13P_2O_5:13K_2O (6 mo release at 25 °C [77 °F]; Sun Gro Horticulture, Bellevue, Washington) at a rate of 2, 4, and 6 kg/m^3 (3.4, 6.7, and 10.0 lb/yd^3) Pro-Mix® BX (Premier Horticulture, Quakertown, Pennsylvania). The highest rate approximated the amount of fertilizer applied incrementally as a top-dress during the same time period (the standard nursery procedure). The amended media were put into 10-cm (4-in) square pots. Each fertilizer (3)–irrigation (2)–replication (3) combination had 60 pots (1080 pots total). One month earlier, ‘ōhi‘a seeds were sown on Jiffy-7® (Jiffy Products of America Inc, Norwalk, Ohio) pellets that expand to 18 mm x 32 mm (0.7 in x 1.25 in). Those containers with a germinate were transplanted into the pots, and all transplants were immediately irrigated with a hose and gentle nozzle until the amended media were saturated.

Measurements

Leachate volume and nitrogen (N) concentration were measured under the overhead irrigation by installing identical subirrigation trays to collect the leachate, which then drained through a hose into a collection bucket under each replication. Each bucket had a tight-fitting lid to reduce evaporation. About every 2 wk during the 9-mo growth period, the volume of leachate was measured and a subsample collected for total N analysis. Similarly, a subsample of water from the reservoir tanks under the subirrigation benches was collected at the same interval and analyzed for total N. Nitrogen concentration in water samples was accomplished with a LECO-600 CHN analyzer (LECO Corporation, St Joseph, Michigan).

After 3 mo of growth, we used a scale of zero to 5 to quantify the percentage of the surface of the potting soil covered with moss and liverwort, with zero being 0% and 5 being 80% to 100%. We also noted presence or absence of sporangium (moss reproductive structures and an estimate of maturity). After 9 mo of growth, the moss and algae mats growing on the surfaces of the pots were removed from a randomly selected subset of 15 pots per irrigation–fertilization–replication combination; a high pressure stream of water was used to wash most of the medium from the mat. The plants from these same 15 pots were collected, roots were washed to remove the medium, and shoots and roots were separated for drying at 60 °C (140 °F) for 48 h to determine biomass. Because our data were not normally distributed, we used the nonparametric Wilcoxon Rank Sum Test and pairwise comparisons to compare irrigation treatments on moss growth and ʻōhiʻa heights. Similarly, to compare moss growth and ʻōhiʻa heights among fertilizer rates we used the Kruskal-Wallis test and pairwise comparisons. The presence or absence of sporangia in response to irrigation type and fertilizer rate was analyzed with logistic regression.

After 9 mo of growth, electrical conductivity (EC) was measured using a Fieldscout (Spectrum Technologies Inc, Plainfield, Illinois). This device, once calibrated, provides direct measurements of EC in the medium, and the results are similar to those obtained with the saturated medium extract (SME) technique. EC readings were taken at depths of 1, 5, and 10 cm (0.4, 2, and 4 in) on a subsample of 5 pots per.

OBSERVATIONS AT 3 MONTHS

Water

Three months into the experiment, we realized that our initial assumption for water use in the subirrigation treatment was incorrect. Plants in the subirrigation treatment were being overwatered and the population of fungus gnats (*Bradysia* spp. [Diptera: Sciaridae]) was increasing rapidly. All plants in the experiment were treated with Gnatrol® (*Bacillus thuringiensis* sub. *israelensis*, Serotype H-14; Valent BioSciences Corporation, Libertyville, Illinois) to control the gnats. The pump timers were reset to operate only 3 times per week, at equal intervals (every 56 h), with the same 3-flood-cycle (2 min flood; 12 min drain, and so on) routine.

Moss and Liverwort

Moss and liverwort can grow quickly in container nurseries, choking out small seedlings or causing seedling stunting and (or) chlorosis by intercepting fertilizer and interfering with infiltration of fertigation solutions (Landis and Altland 2006). In general, about 3X more moss was growing under fixed overhead irrigation than with subirrigation (Table 1). Moreover, the moss growing under fixed overhead was more mature, with sporangium present at 4X the frequency (Table 1). The rate of fertilizer also affected moss—increasing amounts of fertilizer decreased moss coverage and maturity (Table 1) and the reduction was most evident with subirrigation (Figure 1). Liverworts were rarely encountered, but even so, significantly more ($P = 0.0003$) were growing in fixed overhead pots (16) than in subirrigated pots (1).

TABLE 1

The average coverage of moss in each pot with either fixed overhead or subirrigation (n = 540; 180 per replicate), percentage of those pots with sporangium present, and the effects of fertilizer rate on moss coverage and maturity.

Irrigation	Moss coverage (%)	Sporangium (%)
Fixed Overhead	50	86
Sub	15	23
P value	< 0.0001	< 0.0001
Fertilizer kg/m^3 (lb/yd^3)		
2 (3.4) Low (L)	36	67
4 (6.7) Medium (M)	30	54
6 (10) High (H)	27	46
Contrast *P* values		
L * M	< 0.0001	0.0007
L * H	< 0.0001	< 0.0001
M * H	0.0009	0.0334

Plant Survival and Size

At 3 mo, ʻōhiʻa survival in the fixed overhead irrigation was 95%, significantly higher ($P < 0.0001$) than the 85% rate in subirrigation—much of this difference was attributable to mortality caused by fungus gnats. Fertilizer rate had no effect on survival; the average of all treatments was 90% ($P = 0.3880$; data not shown).

After 90 d, the ʻōhiʻa were showing why their species name is *polymorpha*; plants were single-stemmed and multistemmed and ranged from a scant 4 mm (0.16 in) to a towering 122 mm (4.8 in). Irrigation had no effect on plant height ($P = 0.8500$); the mean (± standard deviation) for fixed overhead was 43.5 ± 19.6 mm (1.7 ± 0.8 in) while subirrigation was 44.3 ± 21.4 mm (1.7 ± 0.8 in). Fertilizer rate had no effect on height ($P = 0.1891$; data not shown).

OBSERVATIONS AT 9 MONTHS

Calamity—Moss and Plant Data Lost

At 9 mo, we sampled for ʻōhiʻa and moss biomass. Unfortunately, while processing the samples, they were destroyed in a freak oven fire. One replicate of the fixed overhead irrigation treatment escaped the fire—although no real conclusions should be made from a single replication, the data are interesting. In this replicate, more moss biomass (4.0 g/pot [0.14 oz]) was produced than ʻōhiʻa biomass (3.4 g/pot [0.12 oz]). Photos of the crop before sampling (Figure 2 *top*) and data from the surviving replicate (Figure 2 *right*) show a wide variety of plant sizes across irrigation and fertilizer treatments, indicating that neither irrigation type nor fertilizer rate affected plant growth. We also noted that survival was now similar between treatments—survival with subirrigation was similar to that observed after 3 mo, but additional mortality occurred under fixed overhead irrigation, particularly in corners where, apparently, the irrigation was less efficient and (or) the plants dried out faster.

Water and Nutrients

Water applied via subirrigation was just 44% of that applied with fixed overhead irrigation (Table 2). On a daily basis, we applied 36 ml of water per pot via fixed overhead irrigation compared with 16 ml per day with subirrigation. Nearly 70% of the irrigation water applied to ʻōhiʼa seedlings with the fixed overhead system was errant (not intercepted by the crop), and 13% of the applied water leached through the pots. Therefore, only 17% of the applied water was "used" by plants. Assuming this is the same amount "used" by the subirrigation plants, the subirrigated plants were also overwatered (Table 2).

In the experiment, we measured 554 l (146 gal) of leachate, and the average ppm N of that leachate was 43—that is, 24 g (0.8 oz) of N were lost per replicate, or only about 3% of the total applied. This is a somewhat surprisingly low value. With fertigation to ensure leachate, N losses were as high as 32% to 60% in a container reforestation nursery (Dumroese and others 1992, 1995). Some of the increased efficiency noted is probably due to the use of controlled release fertilizer (CRF), which by its nature limits the amount of N available for leaching over

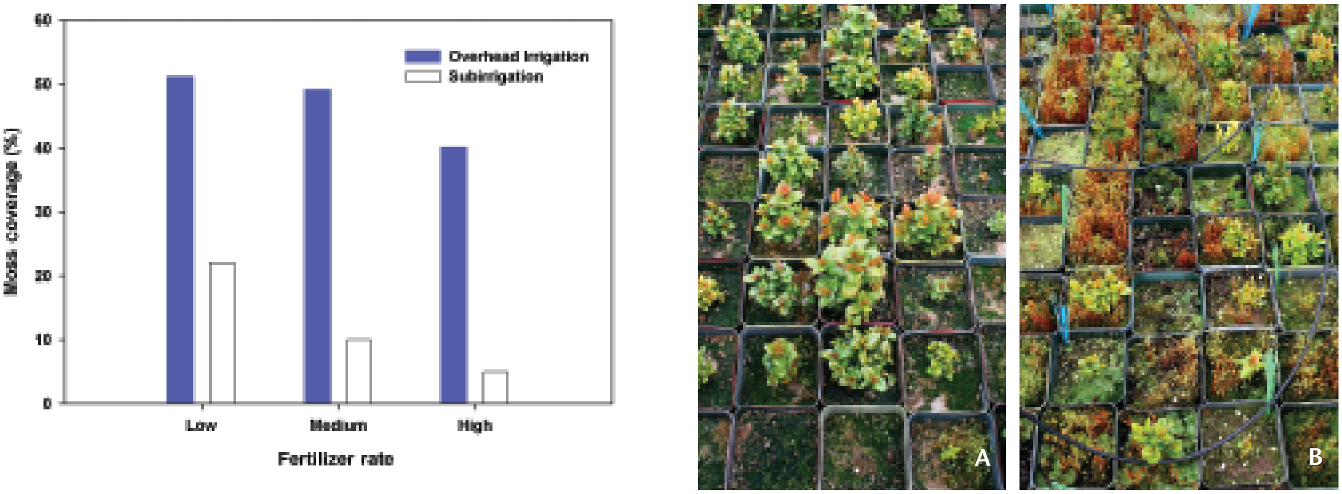


Figure 1. Left: The percentage of the surface of each pot covered with moss after 3 mo of growth with either subirrigation or fixed overhead irrigation with 3 rates of fertilizer. Low, medium, and high rates of fertilizer equaled 2, 4, and 6 kg/m³ (3.4, 6.7, and 10.0 lb/yd³) of Nutricote® 13N:13P_2O_5:13K_2O, respectively. Right: Notice the general lack of moss and liverwort growing on the surface of the medium of 6-mo-old subirrigated plants (A) versus that growing with fixed overhead irrigation (B). Photos by Kas Dumroese, USDA Forest Service

time. Even less N was lost using subirrigation—we measured a scant 5 ppm N in the reservoir tanks or about 0.7 g (0.02 oz) N per replicate tank. We presume these values were low because subirrigation encourages upward movement of nutrients rather than downward movement as is the case with fixed overhead, and any N leached from the pots was made available for uptake by plants during subsequent irrigations.

Although CRF released nutrients over time so that plant uptake could be more efficient, we observed a high loss of N through leaching early in the growth cycle (Figure 3). From early December through early February N losses through leaching were much less, perhaps a reflection of cold temperatures experienced at this nursery. Because nutrient release from CRF prills is mainly temperature dependent, the low temperatures (some around freezing) no doubt reduced nutrient release, preventing leaching. This concurs with our fertilizer weight loss measurements, too. Generally, about 33% of CRF weight is residual polymer material (Jacobs and others 2003); therefore, most of the fertilizer in our experiment was released by about March regardless of irrigation treatment (Figure 3).

The EC values were as we expected: subirrigation had higher EC values toward the top of the pots whereas fixed overhead irrigation had higher values toward the bottom (Figure 4). Increasing rates of fertilizer yielded increasing levels of EC (Figure 4). The highest values (nearly 2.5 ds/m² in the subirrigation treatment with the highest rate of fertilizer) were not sufficiently high to cause concern (Fisher and Argo 2005; Jacobs and Timmer 2005). The higher overall EC values in the subirrigation treatments, however, indicate more residual fertilizer salts remained in the media after 9 mo when compared with the fixed overhead system, indicating some fertilizer could still be used by plants (Figure 4).

OBSERVATIONS WITH OTHER SPECIES IN OTHER STUDIES

Plant Growth

We are currently analyzing data from several of our studies, but we are encouraged by what we see. In *Acacia koa* Gray (Fabaceae), subirrigated and overhead irrigated plants had similar survival, heights, and root-collar diameters across a range of fertilizer rates and container types during nursery production. Similar results were also seen with *Quercus rubra* L. (Fagaceae) and *Picea pungens* Engelm. (Pinaceae). In a variety of container sizes, subirrigated *Echinacea pallida* (Nutt.) Nutt. (Asteraceae) accumulated more biomass than those grown with overhead irrigation and mortality was greater with fixed overhead irrigation.

What about Salts?

To date, we have noted that EC readings are higher toward the surface of subirrigated pots than those being irrigated from above. If the plants are being subirrigated in an outdoor nursery exposed to natural precipitation, we noted EC values at the surface can be quite low as the precipitation leaches salts downward in the profile. When grown indoors, EC values can be much higher—the highest EC values we have measured were still, however, within acceptable ranges (Fisher and Argo 2005; Jacobs and Timmer 2005) and could be lowered immediately and drastically with an application of clear water. This indicates that careful monitoring of the growth medium can alert growers to a potential danger that can easily be ameliorated with an overhead application of water.

Figure 2. Top: The typical spread of ʻōhiʻa growth in every irrigation and fertilizer treatment. The seedlings on the left are about 20 cm (8 in) tall whereas those on the right are only about 2 cm (0.8 in) in height. Right: For each fertilizer treatment, ʻōhiʻa seedlings responded by accumulating a wide variety of biomass. Each dot represents a single ʻōhiʻa plant.

Photo by Kas Dumroese, USDA Forest Service

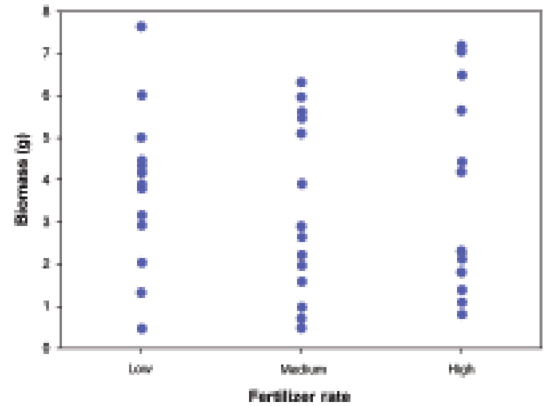


TABLE 2

Water applied by irrigation treatment and subsequent amounts of errant (not applied to crop) and leached water during the 277 d of the experiment (29 Aug 2005 through 2 May 2006). We assumed that the applied amount less the excess applied (the sum of errant and leached) was the amount used by plants. We also assumed that plants grown with fixed overhead irrigation and subirrigation used the same amount of water.

	Applied	**Errant**	**Leached**	**Used by plants**	**Excess applied**	**Excess applied**
	liters per day (total)					(%)
Fixed overhead	15.5 (4300)	10.9 (3020)	2.0 (554)	2.6 (720)	12.9 (3575)	83
Subirrigation	6.8 (1890)	NA	NA	2.6 (720)	4.2 (1163)	62

Conversion: l = 0.26 gal

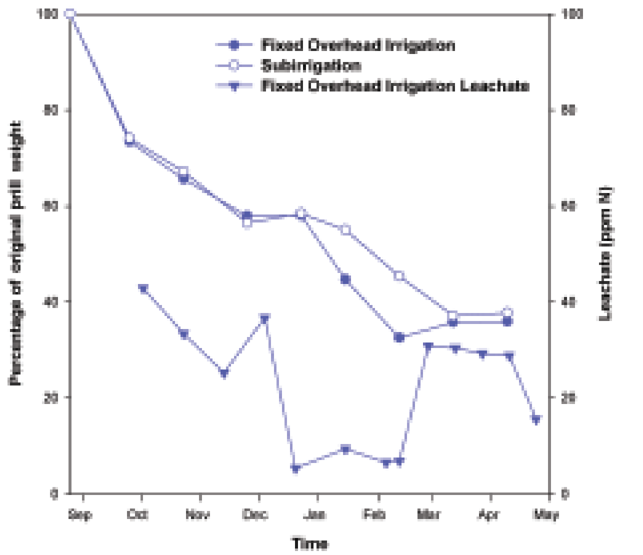
On-going Work

Currently we are following the growth of outplanted *Acacia koa* seedlings and soon will be outplanting *Quercus rubra* seedlings as well. Because of the similarities in seedling morphology, we do not expect to see many differences in outplanting survival and growth between subirrigated and overhead irrigated plants. We do plan, however, a more extensive physiological examination of subirrigated and overhead irrigated plants and hope to include a greater variety of native plant types.

We are working with the USDA Forest Service Missoula Technology and Development Center to automate the subirrigation pumps—our hope is to better match plant need with subirrigation so that we avoid overwatering. Some growers we have been telling about our work are concerned with waterborne pathogens such as *Phytophthora* spreading through the irrigation water. Therefore, we plan to investigate in-line UV radiation treatments—like those used in bottled water lines—to destroy any potential pathogens.

SUMMARY

Subirrigation is an effective way to produce ʻōhiʻa plants because less water is applied, less N is leached, and moss growth is reduced. For ʻōhiʻa, neither irrigation treatment nor fertilizer rate appeared to affect plant growth of this polymorphic species. Given that, it may be possible to grow ʻōhiʻa at this nursery with less fertilizer than what is currently being used, although more research is needed. Subirrigation caused EC values to be higher at the surface of the medium, but after 9 mo these values were within



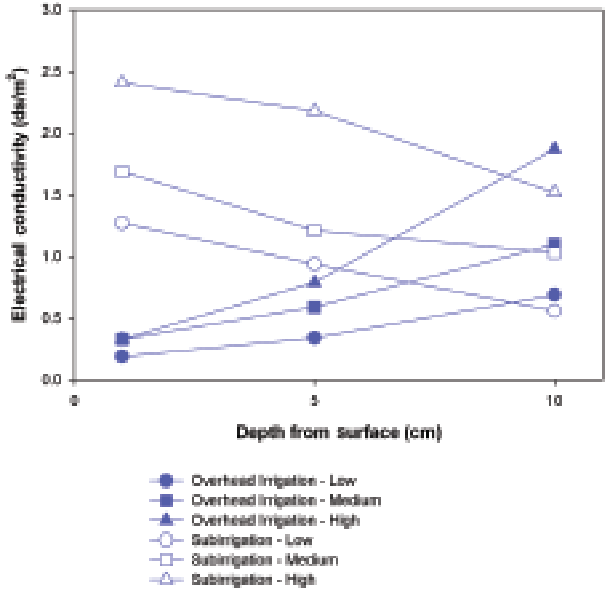


Figure 3. Changes in the weight of controlled release fertilizer prills over time under subirrigated or fixed overhead irrigation and the average ppm N in the leachate collected from pots under fixed overhead irrigation.

Figure 4. Electrical conductivity (EC) values for subirrigated and fixed overhead irrigated media initially amended with low, medium, and high (2, 4, and 6 kg/m^3 [3.4, 6.7, and 10.0 lb/yd^3], respectively) rates of controlled release fertilizer. Note that at every depth, the highest rate of fertilizer had the highest residual EC values and that EC values were consistently higher in the subirrigated treatments, indicating more fertilizer was available for plant use than was available in the fixed overhead irrigation treatment.

acceptable ranges. We are investigating the growth of many species of plants with subirrigation. To date, our results indicate this may be an easy and effective way to produce a variety of native plants, especially those with large canopies that tend to shed conventionally applied overhead irrigation, or where water conservation is paramount.

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