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Beyond Drip Irrigation – Hyper-efficient Irrigation

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Abstract. *Plant establishment in arid lands and seasonally dry sites can be improved using hyper-efficient irrigation systems. These will work where drip, sprinkler, furrow or basin irrigation cannot. Deep pipe and porous tube irrigation systems enabled plants to survive for three years in extreme conditions with a total of less than 10 liters of irrigation water. Wick irrigation also shows some promise but needs additional development. Using the best of these systems trees could be established several kilometers from water sources even with only hand carried irrigation water.*

Keywords. Irrigation, arid lands, deserts, wick, porous tube, deep pipe, hyper-efficient, remote site, mesquite

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1. Introduction

One of the great challenges for agriculture, agroforestry, forestry and restoration is establishing plants on sites that are seasonally dry or dry all year (Kolarkar and Muthana, 1984; Bainbridge, 1991). This becomes even more difficult at remote sites where water must be carried in by hand, animal or truck. Traditional irrigation methods such as furrow or basin watering, sprinklers and even drip irrigation are ill-suited for this task. They demand too much water, water that is filtered and pressurized, or regular maintenance. In areas where the demand for plant establishment is greatest these are usually infeasible – too costly, too technical or too demanding of management time. Buried clay pot irrigation is well suited for this task (Shiek'h and Shah, 1983; Bainbridge, 2001), but clay pots are too costly for most remote sites. What can we do?

This is the question I have been exploring for the last 10 years, looking at systems that improve plant survival in these extreme environments (Bainbridge et al., 1995a; Bainbridge et al., 2001). My goal has been to develop hyper-efficient low cost irrigation systems that could keep plants alive until rains came, would work with low quality water, and could easily be installed and managed by unskilled or non-technical workers. The hope was to find systems that would use so little water that they could be kept supplied by hand carried water even several kilometers from water sources.

2. The nature of the challenge

Moisture stress is one of the critical factors in plant establishment in arid lands (Bainbridge and Virginia, 1990a). Moisture stress is related to the interrelationship of rainfall, evaporation and temperature. The low relative humidity and high wind speeds common in deserts can play an important role in water loss from soil and plants. In these severe environments establishing plants can be challenging even with supplemental irrigation. Little is known about natural establishment, but it is clearly related to relatively rare flow and flood events (Virginia and Bainbridge, 1988). If plants are grown in a nursery and then transplanted the task becomes delivering as much water as possible to the root zone to minimize evaporative losses and reduce watering cost while increasing survival and growth.

Plant shelters and plant protection can help reduce plant water demand and improve survival. Plants generally benefit from, and should receive a treeshelter, cage, thorn branch screen, or rock mulch (Bainbridge et al., 1995b). Treeshelters are particularly effective in reducing stress, but are too costly for many applications. Plants with roots in moist soil can often maintain water content in the treeshelter air at levels higher than open field air. The shelters also protect the plant from drying winds and sandblast and make it easier to control weeds. These factors enhance survival and growth in tree shelters (Bainbridge, 1991; Bainbridge and MacAller, 1996).

Water is heavy, awkward to handle, and quickly becomes expensive at remote sites. For example, an acre inch of rain weighs more than 100 tons and would represent 200-400 pickup truck loads. Over the years I have developed methods that use as little water as possible, but water is still needed when transplanting and usually must be transported to the site. In some cases a catchment can be built and used to collect precious rainwater. With a steep plastic/rubber catchment runoff occurred with just 3 mm of rain at our test installation in Anza-Borrego Desert State Park, figure 1.

Figure 1. Microcatchment system at restoration site, Anza Borrego Desert

When trucks or water catchments are used an on-site storage tank can be used. I have tested a variety of on-site storage tanks and polyethylene tanks worked best, although they will not be available in many parts of the world. They should be painted with latex paint to reduce algal growth and minimize sun damage to the plastic. Water tanks may be blown away by high winds, vandalized or stolen and should be fenced or wired in place. Once water is on site the choice of irrigation system becomes critical.

3. Hyper-efficient alternative irrigation systems

I have worked with and tested many alternative systems from traditional cultures and developed several methods that work well and use very little water. The water requirements for tree seedlings are in the range of 1-2 liters per month. Most of the irrigation systems we have tested are capable of keeping plants alive with this limited amount of water, but more water is desirable and will improve survival and growth. This report describes the results of a five way comparison of: deep pipe, porous tube, wick, injector, and surface irrigation. Other candidates that may be considered if more money or water is available include: clay pots, porous capsules, perforated pipe, and buried drip.

a. Deep pipe irrigation

Deep pipe irrigation is a very effective yet little known method for irrigation in arid areas. This method uses an open vertical or near vertical pipe, bamboo, or tube to deliver irrigation water to the deep root zone (Sawaf, 1980; Sahu, 1984; Kolarkar and Muthana, 1984; Mathew, 1987; Bainbridge and Virginia, 1990; Bainbridge, 1992). Deep pipe irrigation develops a much larger root volume than other forms of irrigation and helps develop a plant that is better adapted to survive after watering is terminated following establishment.

This is commonly done with 1-3 cm diameter plastic pipe placed vertically in the soil (with the bottom 30-50 cm deep) near the seedling or tree with a screen cover (1 mm screen) to keep out lizards and animals. Screen fabricators can make these at low cost and they can be glued on with silicone caulk. A series of 1-2 mm holes should be spaced about 5-7.5 cm apart down the side of the pipe nearest the plant to facilitate root growth in the early stages of development. If shallow rooted plants from containers are planted next to a deep pipe the roots may not make contact with the wetted soil unless these holes are drilled and the pipes are filled with water. If a drip just wets the soil in the bottom of the pipe the young seedling can be left high and dry.

Several pipes may be used for older trees. These may be filled from a water truck or hose, hand watering cans or fitted with a drip emitter (Sawaf, 1980: Bainbridge and Virginia, 1990). This has been a very effective system and can be combined easily with a drip emitter.

Deep pipe irrigation can be used with low quality water. It is possible to set up with simple materials and unskilled labor without extensive support systems (pressurized filtered water is not needed). The deep pipes provide better water use efficiency (due to reduced evaporation) and weed control. They also enable water to be applied quickly and efficiently with no runoff waste even on steep slopes.

b. Porous hose irrigation

This method uses a vertically placed section of porous hose to wet a vertical soil column. The porous hose can be installed before the plant is planted, using a drill to almost any depth desired (depending on soil conditions and rockiness). The porous hose can also be placed in the soil when the plant is planted. This can be connected to a water bottle or a tank and distributing system. Only the high volume leakers may work well at low pressure.

Porous hose water delivery should be fairly consistent through the soil column providing excellent conditions for deep root growth. A series of porous hoses could be used to develop wind firmness in very windy areas, placed in a tri-slotted planting hole to develop good root architecture. These could be left in place after the plants are established and the surface pipes are removed because the porous pipe breaks down fairly quickly.

c. Wick irrigation

Wick systems have been used in India in conjunction with buried clay pot irrigation (Mari Gowda, 1974). A hole or holes are punched in the buried clay pot and a porous wick made of cotton is inserted in the hole. The material wicks the water from the container into the soil and provides a slow steady source of water to encourage root development and plant growth.

Mesquite plants on capillary wicks in an early trial survived longer and grew faster than the control plants watered on the surface. Water consumption was not calculated precisely but appeared to be about 20 ml/day per plant. A test wick system set up in a hot dry greenhouse at U.C. Riverside using a Palo Verde (*Cercidium floridum*) seedling in a bucket of 16 grit silica sand used only 20-30 ml/day. Woven nylon rope is available in many diameters, but should be washed in hot water with detergent before use in wick irrigation systems. The flow rate with capillary wicks was perhaps to low, so a gravity fed wick system was used here.

d. Injectors on liter bottles

Different types of cone injector caps for liter bottles have been developed (Gardeners Supply). These look like a plastic carrot with small holes that is placed on a liter bottle inverted in the soil. The cost could be very low in high volumes, and liter bottles are increasingly available in remote parts of the world. Water delivery is relatively fast and not very deep (only 5-10 cm).

e. Basin irrigation -- the old standard

The control treatment for most of my irrigation system tests has been a basin about 10 cm deep and 50-75 cm square. Planting in these depressions provides some microclimate improvement for the plant and makes it less likely that irrigation water and rain will runoff and be wasted. These have always been watered at the same frequency as the other treatments. Survival has generally been very poor with basin irrigation at low water application rates (typically <2%).

4. Materials and Methods

This comparison trial was conducted in the Imperial Valley of California, west of the Salton Sea in an abandoned borrow pit. The soil is an alluvial flood deposit of lenses of sand/clay that is quite dense and compact. The site is 3-4 m above but adjacent to San Felipe Creek and the water table is at creek level. The average annual rainfall is about 7.5 cm with average ETo about 165 cm. Temperatures may reach 40°C any month of the year and high winds with very low humidity are common.

The plants selected for the trial were mesquite (*Prosopis glandulosa*) seedlings from Imperial Valley and Coachella Valley seed sources. Mesquite is a locally important wildlife resource, and was once a critical food resource for the local native Americans (Bainbridge et al., 1990; Bainbridge and Virginia, 1990b).

a. Experimental design

The mesquite seedlings were grown in 5x5x15 cm plant bands. Side branches were pruned to make it easier to place treeshelters over seedlings. Seedlings were planted in ten sets of four matched seedlings in groups in a degraded borrow pit. The four control plants in basins were placed in the most favorable section of flat ground (all seedlings comparable vigor and health).

b. The irrigation systems *(see figure 2)*

Aqua cones (plastic watering cones, 17 cm long, 3 cm wide at top, 5 mm at tip) mounted on a 1 liter bottle with the bottom cut off. One hole at loam level, 6.5 cm, punched out on side adjacent to the seedling. Aqua cones™, Gardener's Supply company #32-116, $12.50 per 6 in 2002, but could be produced for a few cents in large quantities. The Aqua cones were the easiest to install.

Nylon wicks mounted on a 1 liter bottle with the bottom cut off, using 35 cm wicks made with Lehigh 1.1 cm braided nylon rope, washed with detergent to remove oils. A knot was tied inside the bottle. The transition to the sport bottle head with valve removed was sealed with heat shrink tubing. The wicks were easy to install as the rope could be pushed into the soft sand at hole bottom with a rebar pin.

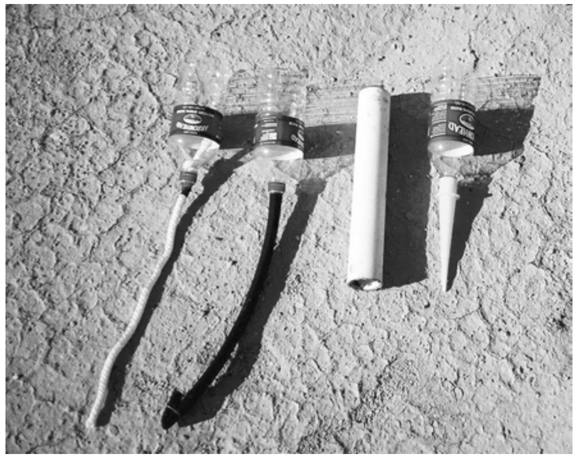

Figure 2. The irrigation systems: wick, porous tube, deep pipe, and cone

Fast rate porous tube mounted on a 1 liter bottle with the bottom cut off attached to 35 cm (not counting folded and wired end) fast rate porous hose #XC122, 1.6 cm inside diameter. Leak rate 120 liters per 15 m per hour at typical hose pressure. The tubing fit the sport bottle head with valve removed, and was secured with duct tape. Price $13.50 per 15 m in 2001 from Lee Valley Garden Supply. The larger porous hose was harder to push into the sand at the bottom of the hole and required a cleaner hole.

Deep pipe 30 cm, 5 cm diameter PVC pipe with 3 mm screen top secured with silicone caulk and two 3 mm weep holes spaced on side adjacent to plant. Recycled from a previous project.

Basins for controls were approximately 5 cm deep and 30 cm x 30 cm.

Planting holes for seedlings and irrigation installation were dug with an AMS hand auger with 7.5 cm bit, all dug to ~36 cm. The soil was very dry throughout the soil profile. Seedlings were spaced 1-1.5 m apart in groups. Holes were backfilled during installation and planting. The planting hole was watered for the basin planted seedlings, but the soil was not wetted during planting the seedlings on the other systems. Each seedling was protected with a Tubex™ treeshelter. Each treeshelter was nylon quick tied to a 3 mm rebar pin. Duct tape was used to secure the 1 liter bottles to tree shelter and pin. Each seedling then received 2.5 liters of water, 2 liters in the irrigation system and then a half liter added to each treeshelter. Installation rate was approximately 10 plants per person hour, most of the work was hand drilling holes in hard ground. With a power auger planting rate would double or triple - perhaps 150-200 seedlings per person day.

The rainfall in the subsequent years was below normal, figure 3. No heavy rains occurred on the site from 2002 until the fall of 2005, when a heavy downpour thoroughly wetted the borrow pit for the first time. Total precipitation over 33 months was 19 cm with total ETo of 530 cm (CIMIS, 2006).

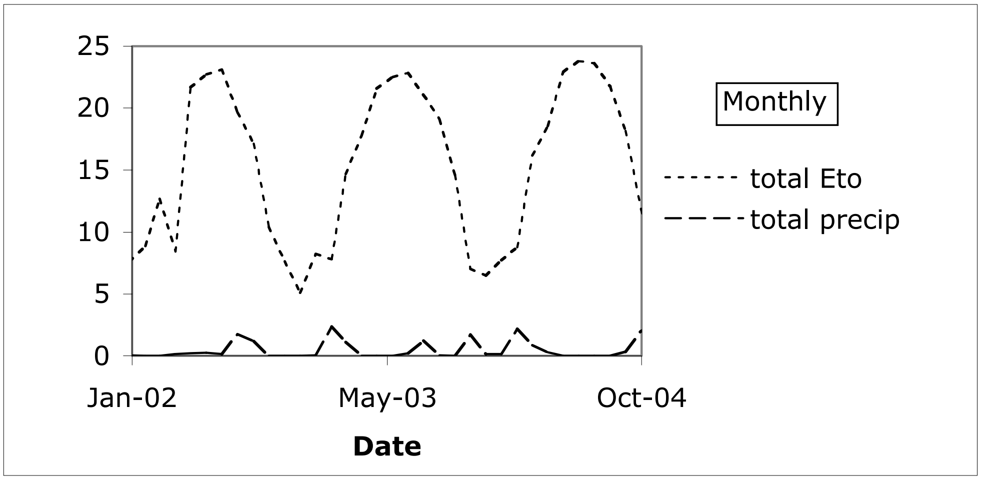

Figure 3. Precipitation and Evapotranspiration

5. Results

The overall survival of plants over three years was low as would be expected with minimal water application, less than 10 liters total, and limited rainfall. The rate of decline shows the differences in system effectiveness quite well, figure 4. The basin irrigated seedlings were all dead within five months. Some cone and wick irrigated plants were surviving at 180 days, but just barely. The porous tube and deep pipe systems were effective, with 60-80% of plants alive at 180 days and 30-40% of plants still alive in the fall of 2005 when a significant rainfall finally occurred.

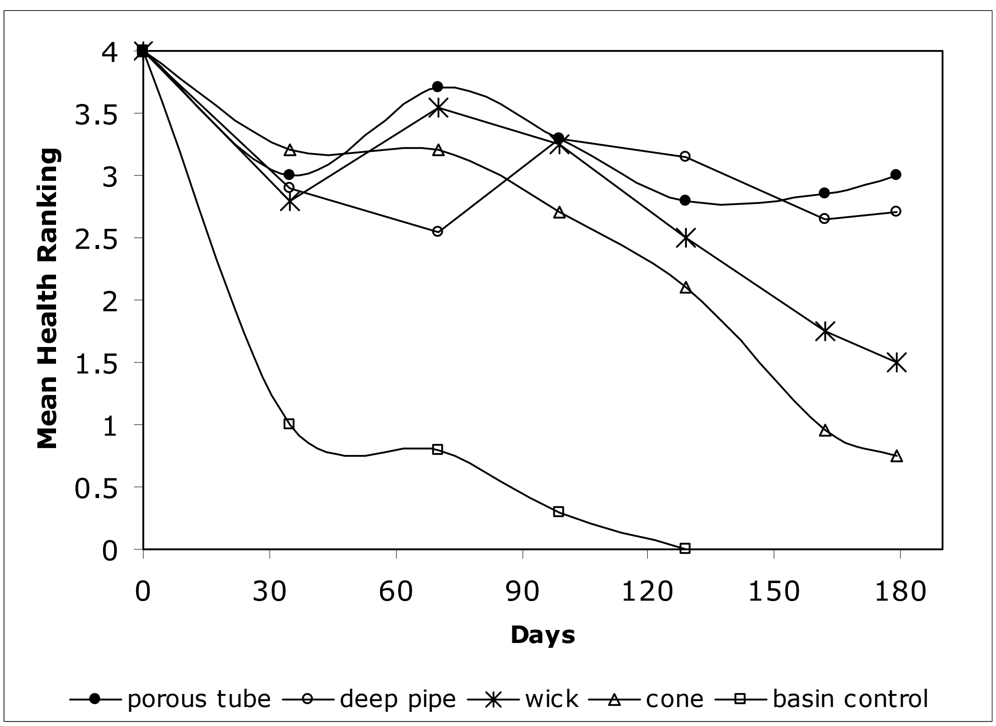

Figure 4. Mean health rating of plants (4=good, 1=Very poor)

This may not look very good, but considering the plants had received a total irrigation delivery of only 7 liters and very limited rainfall after planting it is quite impressive. The small numbers of plants limit the power of analysis, but the message is clear – we can do better in growing trees, shrubs and other plants on severe sites and locations with these hyper-efficient systems.

Conclusion

Successfully planting seedlings on remote arid sites is critical to support the billion people who live in dry lands. The lessons learned here can also be helpful on seasonally dry sites in more humid areas. These hyper-efficient systems can play an important role in plant establishment. The plants will not grow much with this limited water supply, but the goal is simply to keep them alive until the rains return. Surface shaping with microcatchments can improve moisture delivery to seedlings for continued growth (Shanan and Tadmor, 1979; Edwards et al., 2001).

The cost of all of these systems is low compared to the total cost of planting at remote sites. Deep irrigation can improve survival and growth and the deep pipe systems will typically be the first choice. The deep pipe with treeshelter systems are durable and after plant establishment the pipes or treeshelters can be pulled and reused. The efficient water delivery of deep pipes multiplies the value of expensive water compared to the much less efficient surface irrigation systems commonly used. Where the materials and technology for drip systems are available deep pipes with drip emitters can be monitored and repaired much more readily than a buried drip system.

The porous tube systems are also very promising for remote sites. Additional development may well make them the least-cost option per survivor. Porous tubing is typically made of recycled rubber and could presumably be produced in many countries at a low cost.

Wicks will need further development to slow water delivery, perhaps using a hose clamp to compress the wick at the bottle-wick junction. The ease of installation makes this an interesting option for future development. I will be exploring deep wick systems with a controllable flow rate in the future.

The most appropriate system for a given site should be chosen after reviewing survival and growth goals, water availability (and cost), plant species water demand, labor skill and availability and budget. With the best of these systems a person carrying water in a pack or jugs could irrigate many trees several kilometers from a water source. If walking conditions are good the delivery at 5 km could be 250 liters a week. If each plant received one liter a month, a single person could support more than 1000 trees. This could be the start of a new forest. Growth would be minimal, but the goal in these systems is to have an established plant in the ground for the rain event that will eventually come. If planting is combined with microcatchment basins a forest could be re-established at very low cost, with very limited technology.

The best of these alternative and little known irrigation systems can dramatically increase survival and improve plant growth even in severe desert conditions. Supplemental irrigation should be provided for as long as possible, perhaps one liter every two weeks the first two months and then a liter a month for two summers. These effective and efficient irrigation systems should also be considered for much wider use in agroforestry, forestry, restoration, landscaping and revegetation because they work well and save water. They could benefit from additional testing and research on root development. Work on rapid deep root development is also desirable for sites like this one, where the groundwater is only 3-4 meters deep. These are excellent projects for students – please consider them for future courses!

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Supplies and materials.

Screen disks for deep pipes TWP Inc.	www.twpinc.com/index.html
High rate soaker tube from Lee Valley Garden Supply	www.leevalley.com
Cones from Gardeners Supply	www.gardeners.com