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# Comparison of Water and Temperature Distribution Profiles Under Sand Tube Irrigation

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# Comparison of Water and Temperature Distribution Profiles under Sand Tube Irrigation

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**Abstract.** *Drip irrigation is one of the most efficient systems in delivering water to the plant root zone. Research has shown that the saturated, or nearly saturated, surface beneath the emitter may increase evaporation thereby reducing the irrigation efficiency. To increase the efficiency of surface applied drip irrigation on permanent tree crops a sand tube irrigation (STI) method was developed and tested. The sand tube method consists of removing a soil core beneath the emitter and filling the void with coarse sand. A weighing lysimeter was designed and instrumented to directly measure temporal evaporation during irrigation and for a period of three days after irrigation ceased. Thermocouples were used throughout the soil profile to detect the temperature variation and also to determine temporal movement of the wetting front. The results indicated that for the surface applied drip irrigation method, approximately 30% of the applied water evaporated during the four-day period after irrigation. The STI method resulted in approximately 4% of the applied water being evaporated. The STI method allowed more water to remain in the soil profile thereby increasing the irrigation efficiency.* ***Keywords.*** *Evaporation reduction, Drip irrigation, Microirrigation, Efficiency, Soil temperature.*

Historically, drip irrigation has been considered a highly efficient method of applying irrigation water while reducing evaporative losses, primarily due to the reduction of the wetted surface area, as compared to that of sprinkler or flood irrigation. Due to the high irrigation frequency of drip irrigation, an almost constant saturated soil surface or water puddle exists beneath each emitter. This wetted area, particularly in semiarid regions, is susceptible to high evaporation, not only due to solar radiation, but also due to the advective forces of hot dry air drifting across the surrounding soil which provides a steep vapor pressure gradient that promotes evaporation.

Surface drip irrigation systems contain point-source emitters that are located in/on tubing situated above the ground level to provide water to relatively small volumes of soil. The slow application of water typical with drip/trickle irrigation is helpful on low permeability soils. However, on soils that experience severe restrictions to water infiltration, surface drip systems may result in significant surface wetting and ponding (Grimes et al., 1990). Since the water content distributions within these wetted soil volumes may be non-uniform and variable over time, evaporation rates are anticipated to be spatially and temporally variable following irrigation (Jury and Eral, 1977).

Matthias et al. (1986) conducted studies on Gila sandy loam, to estimate bare soil evaporation for seven days following an application of surface trickle irrigation from a single emitter. Microlysimeter and infrared thermometer methods were used to estimate evaporation at several sites within both wetted and non-wetted areas surrounding the emitter. Based on data from both methods, evaporation accounted for about 33 to 40% of the applied water over the seven-day monitoring period.

Grimes et al. (1990) observed that water infiltration frequently becomes severely restricted as the growing season progresses for many eastern San Joaquin Valley soils, and plant water deficits develop during periods of moderate to high potential evaporation. They estimated that more than one million hectares are affected by restricted irrigation water infiltration in California. They conducted a study to determine if the plant-water relations of an established vineyard could be enhanced by subsurface water release in a soil having restricted surface infiltration. Water was released into a mulch of almond shells located 250 mm (1 in.) below the soil surface. Although their research focused on eliminating the effect of surface crust development beneath the emitter, they observed that the increased wetted surface area associated with surface application of drip irrigation resulted in higher evaporation compared to the other treatments investigated. Although applied water was constant for all treatments, more water was available to the crop for the subsurface water release treatments than for a surface application. They concluded that the distribution of root-zone soil water for grapevines was substantially improved by subsurface water release from a drip irrigation system in a soil that undergoes surface sealing. Grape production consistently reflected a 4 to 7% increase for subsurface water release treatments.

In this article, an irrigation method is proposed that utilizes a combination of a drip emitter and a sand column

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for the purpose of significantly reducing evaporation. In soils that exhibit surface ponding around the emitter, or areas where evaporation potential is high, a core of soil can be removed and replaced with an equal volume of sand. The core of sand transmits water into the profile through a combination of vertical flow from the base of the core and through horizontal flow around the core circumference. The sand tube irrigation method can be applied to currently existing systems, or incorporated into new surface trickle irrigation systems. Sand tube irrigation is only applicable to permanent tree/vine crops where harvesting and other field processes do not alter the soils yearly.

## MATERIALS AND METHODS

The objectives of the research were to investigate and quantify the evaporation occurring from a wetted area beneath an emitter in surface drip irrigation and to compare the evaporation to that measured in the STI method. A laboratory lysimeter (0.5-$m^3$ soil bin), which had a static weighing capability of 20 g (0.044 lb), was used to measure evaporation occurring from a soil surface with an accuracy of 0.025 mm (0.001 in.) (Meshkat, 1997).

Since evaporation from a soil profile subjected to drip irrigation is inherently a three-dimensional problem, the soil bin within the weighing lysimeter was sized to contain the entire wetted bulb beneath the drip system to eliminate any potential sidewall leakage or interaction. A cylindrical bin 1 m (39.4 in.) in diameter and 0.7 m (27.5 in.) tall was selected for the weighing lysimeter. The soil bin volume was approximately 0.5 $m^3$ (35.3 $ft^3$). Previous studies by Angelakis et al. (1993), Omary and Ligon (1992), Lafolie et al. (1989), and Taghavi (1984) were used as a guide for the selection of these dimensions.

An artificial heat source was used to force evaporation from the weighing lysimeter by heating the soil surface to 50 to 60°C (122-140°F). This range was selected based on the Matthias et al. (1986) research, conducted in Arizona, where the mean soil temperature in the wetted region during the seven days after drip irrigation was 46 to 52°C (115-127°F). Twelve hours of heating in an on/off cycle were used to simulate diurnal fluctuations in evaporation. The soil surface was subjected to two days of evaporation prior to the application of irrigation water. The diurnal cycle of evaporation was continued for three days after irrigation while temperature changes of the soil profile, at selected points, were monitored. Throughout the experiment, a continuous recording of evaporation flux was monitored with the weighing lysimeter. At the termination of the test, soil samples were collected for water content determination. Two irrigation treatments, surface drip irrigation (here called, Normal Irrigation, NI) and sand tube irrigation, STI, with three replications were tested.

## SOIL

Intuitively, sand tube irrigation (STI) is more suitable for fine textured soils than for coarse textured soils. A fine textured Maury silt loam was pulverized (passed through a 2-mm sieve) and mixed to provide uniformity for interpreting and understanding observed results and in extending data through modeling. A mechanical pulverizer and sieve shaker were used to process the large amount of soil for the lysimeters. Dry soil was packed to an average density of 1.27 g/$cm^3$ (81.5 lb/$ft^3$) in each soil bin (table 1) for a total weight of approximately 700 kg (1543 lb) of soil per experimental unit.

**Table 1. Weight and density of soil used for Tests 1 through 6**

| Test | Weight (kg) | Density (g/$cm^3$) |
|---|---|---|
| 1 | 604.2 | 1.26 |
| 2 | 599.6 | 1.27 |
| 3 | 617.8 | 1.29 |
| 4 | 639.3 | 1.27 |
| 5 | 627.8 | 1.26 |
| 6 | 624.2 | 1.26 |

Soil texture was determined with the micro-pipette method on six samples taken from the pulverized silt loam (Miller and Miller, 1987). Micro-pipette analysis of the pulverized soil yielded an average 11% sand, 66% silt, and 23% clay.

The saturated hydraulic conductivity ($K_s$) of the reconstructed soil was tested in the laboratory using a constant head, rigid wall permeameter. The permeameters were 60 mm (2.4 in.) tall and 54 mm (2.1 in.) in diameter. After preparation, all cores were saturated in a vacuum chamber. The samples were then connected to constant head Mariotte tubes. Heads of 100, 300, and 600 mm (3.9 in., 11.8 in., and 23.6 in.) were applied across the sample. An average $K_s$ value of $5.5 \times 10^{-6}$ m/s (0.78 in./h) was determined.

## EXPERIMENTAL CONDITIONS

The soil was packed by hand in the soil bin and thermocouples were installed at designated locations (figs. 1 and 2). The individual soil bags were weighed to determine the mass of soil placed within the bin and the overall density (table 1). Insulation was placed around the soil bin, which was covered by a metal shield. A single soil bin was used for all experiments. After each treatment the

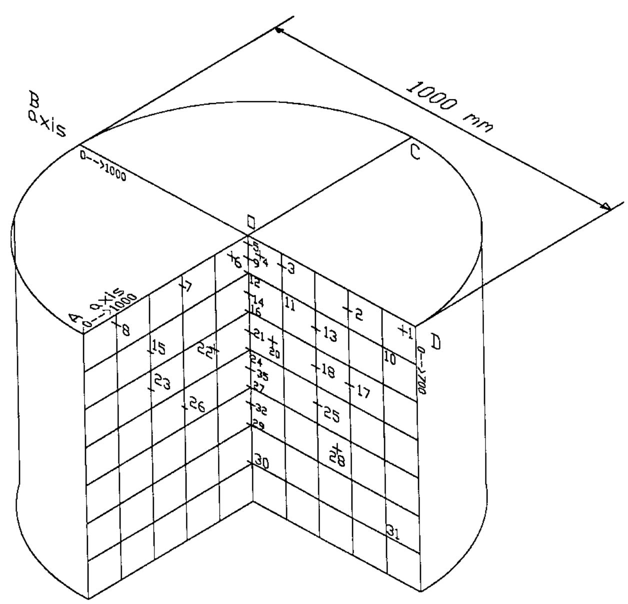


**Figure 1–Thermocouple location map for Tests 1, 2, and 3 of NI treatment. Grid is on 100-mm interval.**

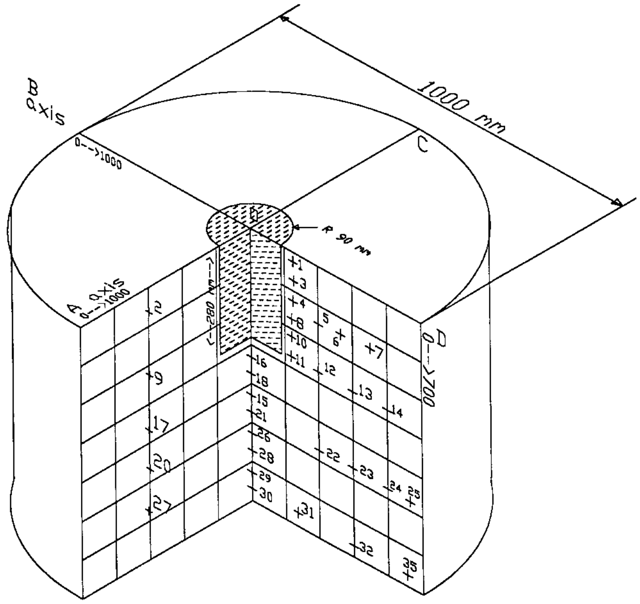


**Figure 2–Thermocouple location map for Tests 4, 5, and 6 of STI treatment. Grid is on 100-mm interval.**

soil was removed and was replaced with the soil of original initial moisture content.

Two days of heating prior to irrigation and three days of heating after irrigation were applied to all tests. Each heater element was placed on a timer to assist in turning the heater on and off. The data reading interval, prior to irrigation, was set at 10 min. Data were acquired at 4-s intervals during irrigation, which was the fastest rate that the data logger could scan all channels. A total of 34 channels were scanned during each acquisition interval including 30 thermocouples within the soil profile, one load cell, one humidity sensor, and two room temperature readings. Changes in temperature for each thermocouple were used to accurately locate the wetting front in time. After irrigation ceased, data acquisition continued at the fast rate for several hours to follow redistribution of water in the soil profile. The heating cycle continued for three days after irrigation ceased. On the fourth day, soil samples were collected from several locations along the AC and BD axes (refer to fig. 1). Since the method was destructive, the sampling was done only once at the end of the experiment.

Drip irrigation rates used in research have ranged from 1.5 to 12.3 L/h (0.4 to 3.25 gal/h) (Taghavi et al., 1984; Angelakis et al., 1993; Matthias et al., 1986; Lafolie, 1989). In practice, drip irrigation of trees considers parameters such as flow rate, number of operating hours, and frequency. These parameters are highly variable and must be adjusted based on the type of tree, soil physical properties, and meteorological conditions. A 4 L/h (1 gal/h) emitter was selected for all experiments. This selection was based on several factors. Preliminary tests with flow rates of 2 and 4 L/h (0.5 and 1 gal/h) preformed prior to the actual experiments produced a maximum wetted diameter of 500 and 700 mm (19.6 in. and 27.5 in.) on the soil surface and infiltration depth of 300 and 450 mm (11.8 in. and 17.7 in.), respectively. However due to the effect of pulverization on the soil and the shallower depth of infiltration for a 2 L/h (0.5 gal/h) flow rate, a higher evaporation rate of 32% in contrast to 30% for 4 L/h (1 gal/h) flow rate was measured. Also the 4 L/h (1 gal/h) flow rate would take better advantage of the lysimeter used. Irrigation application was set at 12 h. The irrigation-pumping rate was measured before and after each experiment to check for uniform application rates. Tests 1, 2, and 3 were performed as NI treatments.

The principle behind the sand tube irrigation method is that for evaporation reduction to be achieved, no surface wetting should occur. A set of parameters were selected that could readily be measured in an existing grove (ponded area beneath an emitter, $A_p$, and wetted area surrounding the ponded area, $A_w$) and applied to a set of simple formula to define the initial tube dimensions. The sand tube dimensions were determined with the following approximation method:

$$A_p = A_w + D \times H \quad \text{or} \quad D_p^2 = D^2 + 4 \times D \times H_1 \quad (1)$$

$$(D_w - D_p) / 2 = H_2 - H_1 \quad (2)$$

$$H_2 = 2 \times D \quad (3)$$

where $D_p$ and $D_w$ were the diameter of ponded area and wetted diameter surrounding a drip irrigation emitter in a normal surface drip irrigation system, D was the diameter of sand tube, $H_1$ was the depth of expected water rise inside the tube, and $H_2$ was the height of sand tube. The criterion was based on arbitrarily selecting the sand tube height to be twice its diameter (eq. 3). This selection could be changed relative to the coarseness or fineness of soil. The finer the soil the higher the ratio of H/D. Equation 1 states that the contact area of water inside the tube, that is the tube's bottom area plus the area of the cylindrical circumferential band to which the water rises inside the tube, should be equivalent to the ponded area of an emitter applying water on the soil surface. This assures that a similar infiltration surface area is achieved in the STI method and the surface drip irrigation. Equation 2 assumes that the capillary rise in the soil outside the sand tube will be as much as the difference between the ponded radius and the adjacent capillary wetted zone radius as observed for the surface drip irrigation. Thus eliminating the surfacing of water through the capillary fringe.

The initial experiment with the NI treatment was used to determine the dimensions of the sand column for the sand tube experiments. The maximum ponded area of 0.1258 $m^2$ (195 $in.^2$) and wetted area of 0.4480 $m^2$ (694 $in.^2$) were digitized from the photographic slides of Test 1. Applying Equations 1 through 3 resulted in a tube diameter of 177 mm (7 in.) and a height of 355 mm (14 in.). The tube height, due to limitation of the lysimeter depth, was reduced by 25% to 280 mm (11 in.). This is similar to reducing the arbitrarily selected factor of two in equation 3 to 1.6.

A thin-walled cylindrical ring was used to form the sand tube during placement of soil in the bin. After filling the bin with soil and placing thermocouples, the ring was filled with coarse sand and then removed. Thermocouple locations in the STI experiments were altered from the NI experiment to accommodate the sand tube placement (fig. 2). Coarse sand passed through a no. 8 sieve (2.36 mm), and collected on the no. 10 sieve (2.0 mm) was selected for the STI media which, compared to gravel, has the advantages of greater availability and a lower propensity for heat exchange. Although it has been shown (Modaihsh et al., 1985) that coarse sand is only slightly more effective than fine sand in evaporation reduction, coarse sand is suggested for the sand tube method because the capillary rise in the coarse sand is greatly reduced in contrast to fine sand. Another advantage of coarse sand is that the water will rapidly move toward the bottom of the sand tube.

The rise of water inside the sand column was monitored using a small wire inserted inside a glass tube with the tip of copper wire extending just beyond the edge of the glass. The glass-wire combination was then placed within a metal tube inserted in the sand column. Water rising in the sand also filled the metal tube. A conductivity meter was connected to the metal tube and the glass-wire combination to measure the resistance change. Increase in depth of water inside the sand tube is plotted versus time in figure 3.

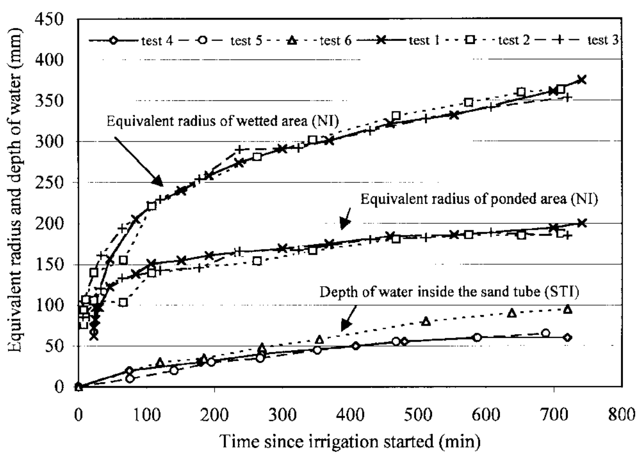


**Figure 3–Depth of water rise inside the sand tube during irrigation, STI treatment, and equivalent radius of the ponded surface and the wetted area, NI treatment, is plotted vs time since irrigation started. Depth of sand tube was 280 mm.**

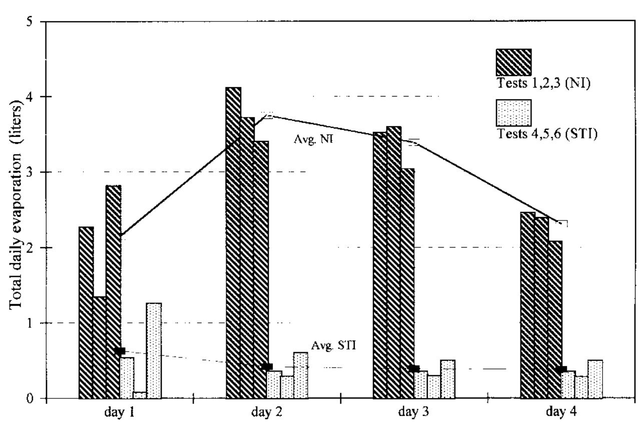


**Figure 4–Total daytime evaporation of the NI and STI treatments, since irrigation.**

# Results and Discussion

## Evaporation

Evaporation was measured by monitoring the weight change of the load cell. Figure 4 shows the distinct difference between total evaporation measured in the NI and STI methods. Prior to irrigation, during the periods while the heat was turned off, 0 to –12, and –24 to –36 h (table 2), there was a slight gain in the weight of the soil bin, which was presumed to be absorption from the humidity in the laboratory while the soil surface was cooling down. The negative evaporation trend continued throughout the sand tube experiments during the time that the heater was off but did not occur under the normal irrigation experiments.

During irrigation, cumulative evaporation values for the STI method were 0.54, 0.08, and 1.26 L (0.14, 0.02, and 0.33 gal) (table 2). No clear explanation can be given as to the reason why Test 5 had only 0.08 L (0.02 gal) of evaporation during irrigation, since the evaporation after 12 h was similar to Tests 4 and 6 (see fig. 4). Test 6 produced the highest overall four-day cumulative evaporation as well as the highest rate of evaporation during irrigation in the STI treatment.

The evaporation results are summarized in table 2 indicating an obvious significant difference between evaporation in the NI and STI treatments. There were 48 L (12.68 gal) of water applied in each case. An average of 14.12 L (3.73 gal), or 29.4%, evaporated under the NI treatment and 1.81 L (0.48 gal) or 3.7%, evaporated under the STI method. As can be observed from the plot of average daily evaporation (fig. 4), the NI treatment produced the maximum evaporation during the second day of the experiment when the moist and darkened soil surface absorbed more energy resulting in a higher evaporation rate. The capillary moistened soil surrounding the ponded area contributed extensively to evaporation. On the third and fourth day irrigation had ceased, the surface had dried to a point that capillary flow was impeded, and the color of

**Table 2. Total evaporation (L) from the NI and STI treatments**

| 12 h Time Cycle | Heat Cycle | Normal Irrigation | | | Sand Tube Irrigation | | |
|---|---|---|---|---|---|---|---|
| | | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
| –48 - –36 | On | | 0.64 | 0.78 | 0.62 | 0.56 | 0.59 |
| –36 - –24 | Off | –0.17 | –0.13 | –0.11 | –0.13 | –0.15 | –0.15 |
| –24 - –12 | On | 0.35 | 0.43 | 0.39 | 0.38 | 0.34 | 0.40 |
| –12 - 0 | Off | –0.14 | –0.12 | –0.15 | –0.15 | –0.14 | –0.08 |
| 0 - 12* | On | 2.27 | 1.35 | 2.82 | 0.54 | 0.08 | 1.26 |
| 12 - 24 | Off | 0.78 | 0.79 | 0.70 | –0.11 | –0.12 | –0.17 |
| 24 - 36 | On | 4.12 | 3.73 | 3.41 | 0.36 | 0.29 | 0.60 |
| 36 - 48 | Off | 0.74 | 0.71 | 0.84 | –0.12 | –0.11 | –0.04 |
| 48 - 60 | On | 3.52 | 3.60 | 3.04 | 0.36 | 0.30 | 0.51 |
| 60 - 72 | Off | 0.63 | 0.32 | 0.64 | 0.10 | –0.09 | –0.03 |
| 72 - 84 | On | 2.46 | 2.39 | 2.08 | 0.36 | 0.28 | 0.50 |
| 84 - 96 | Off | 0.49 | 0.50 | 0.44 | –0.12 | –0.14 | –0.02 |
| Total evaporation† | | 15.05 | 14.21 | 14.87 | 1.89 | 1.10 | 3.37 |
| Avg | | | 14.71 | | | 2.12 | |
| Total evaporation after irrigation‡ | | 15.01 | 13.39 | 13.96 | 1.62 | 0.95 | 2.87 |
| Avg | | | 14.12 | | | 1.81 | |

* Irrigation occurred during 0 to 12 h.
† Algebraic sum of values.
‡ Sum of all positive values since irrigation.

the surface had become lighter, thus less radiation was absorbed. No drainage occurred during the experiment and the entire wetted bulb was contained within the soil bin.

## Temperature Profile and Determination of the Wetting Front

Surface drip irrigation on the pulverized soil with the normal irrigation treatment produced two distinct wetted areas; a ponded area beneath the emitter surrounded by a wetted circumferential ring. The latter was due to capillary action, exaggerated due to the pulverization effect in which the natural macropores were destroyed in the soil. Figure 3 summarizes the data for the spread of water over the pulverized soil surface for the NI tests. The ponded area was initially very small, and increased over time to a maximum equivalent radius of approximately 190 mm (7.5 in.). As described earlier, these data were used in equations 1 through 3 to determine the size of sand core in the sand tube experiments. The depth of water ponded in the sand tube is presented for each experiment on figure 3.

Thermocouples were placed along the radial axis of quadrant AOD (refer to figs. 1 and 2) to track the movement of the wetting front by noting abrupt changes in temperature caused by the advancing water. This procedure provided a good assessment of the wetting front movement to depths of up to 350 mm (13.8 in.) at the center of the bin. In general, as the rate of advancement decreased, the accuracy of determining the wetting front diminished primarily due to the equilibrium state that was reached between the temperature of the water and the soil. Figure 5 illustrates the wetting front advancement as a function of time for Tests 1 and 4, respectively. In figure 5, the data to the centerline of the bin was duplicated from left to right, thus providing the symmetry. The nearly spherical shape of the wetted bulb in the STI method is contained within the soil profile in contrast to the NI method where the irrigated volume is contained in a half spherical shape beneath the emitter. The maximum depth of water penetration was 400 mm (15.7 in.) in the NI treatment and 650 mm (25.6 in.) in the STI treatment at the center of the bin. In Test 4 (STI treatment) the wetting front reached thermocouple 3, located 73 mm (2.9 in.) below the soil surface, adjacent to the sand tube wall, in 297 min. At the same time, the level of water inside the sand tube was 243 mm (9.6 in.) below the soil surface. The difference of 170 mm (6.7 in.) is due to capillary rise in the soil. In contrast the difference between $D_w$ and $D_p$ divided by two, used in equation 2, in sizing the sand tube was 177 mm (6.9 in.). The primary advantage of the STI method is evident in the profiles since the moisture advance is confined below the soil surface reducing potential evaporation and providing a greater opportunity for deep root development.

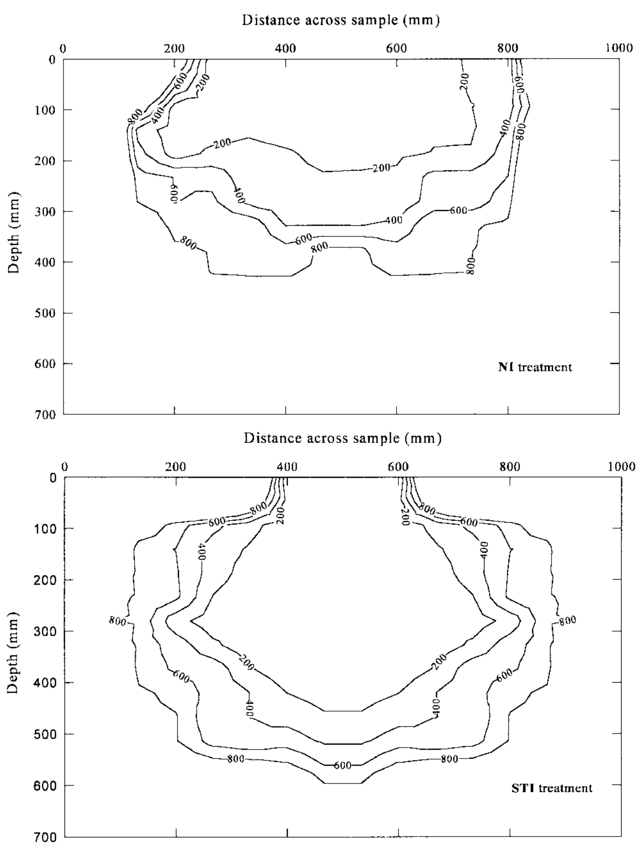


Figure 5–Wetting front position (isolines are time in min), during NI and STI treatment.

## Water Content and Wetted Profile Measurement at the Termination of the Test

After three days of post irrigation heating, approximately fifty soil samples throughout the wetted profile were collected from each lysimeter along the two axes, AC and BD (figs. 1 and 2). A split spoon core sampler was used to collect samples at 50-mm (2-in.) depth intervals down to the dry soil, for gravimetric water content determination. Location of sampling points depended on the extent of the observed surface wetness, however, one core was always taken at the center just beneath the emitter and two cores on each side of the center point of each axis, thus, nine cores were taken per experiment. The average water penetrating depth at the center of the bin under the NI treatment was 430 mm (16.7 in.) (fig. 6). In the case of the sand tube irrigation, water infiltration into the soil

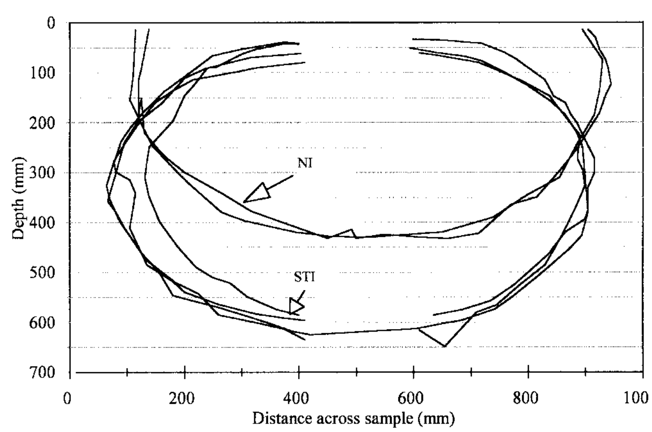


Figure 6–Water penetration depth versus distance across the sample along A and B axes for NI (test 3) and STI (tests 5 and 6) treatments.

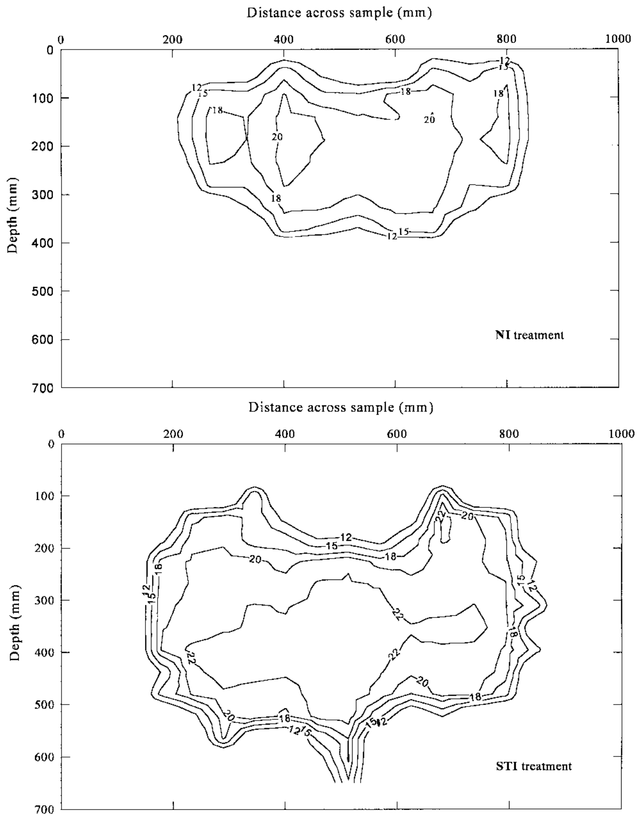


**Figure 7–Contour plot of moisture content (%) distribution for NI and STI treatments.**

occurred from the bottom of the sand tube at the 280-mm (11.0-in.) depth, and reached an average depth of 650 mm (25.6 in.).

Further insight into the water distribution pattern under the two treatments can be learned from plotting the moisture distribution measured at the termination of each test. Contour plots of the water distribution profile of Test 3 and Test 5 were chosen as representative of the NI and STI treatments, respectively, and are shown in figure 7. It must be realized that developing any sort of contour plot based on unevenly spaced data points in a domain must be carefully performed and only general observations rather than specific conclusions can be drawn. The first noticeable difference between the two plots in figure 7 is the relative overall larger size of moisture distribution at the 12% contour interval, due to the overall increase of water in the soil (less loss). The next sizable difference is the presence of the 22% contour interval in the STI treatment that is nonexistent in the NI treatment. Contour intervals 18% and 20% are remarkably expanded over a larger portion of the domain in Test 5 in contrast to Test 3. These plots reflect the potential water conservation capabilities of the sand tube irrigation method.

## Sand Tube Effect on Temperature Gradient

Temperature profiles are provided to contrast the effect of the STI and NI treatments. Temperatures measured by the 12 thermocouples located between thermocouples 5

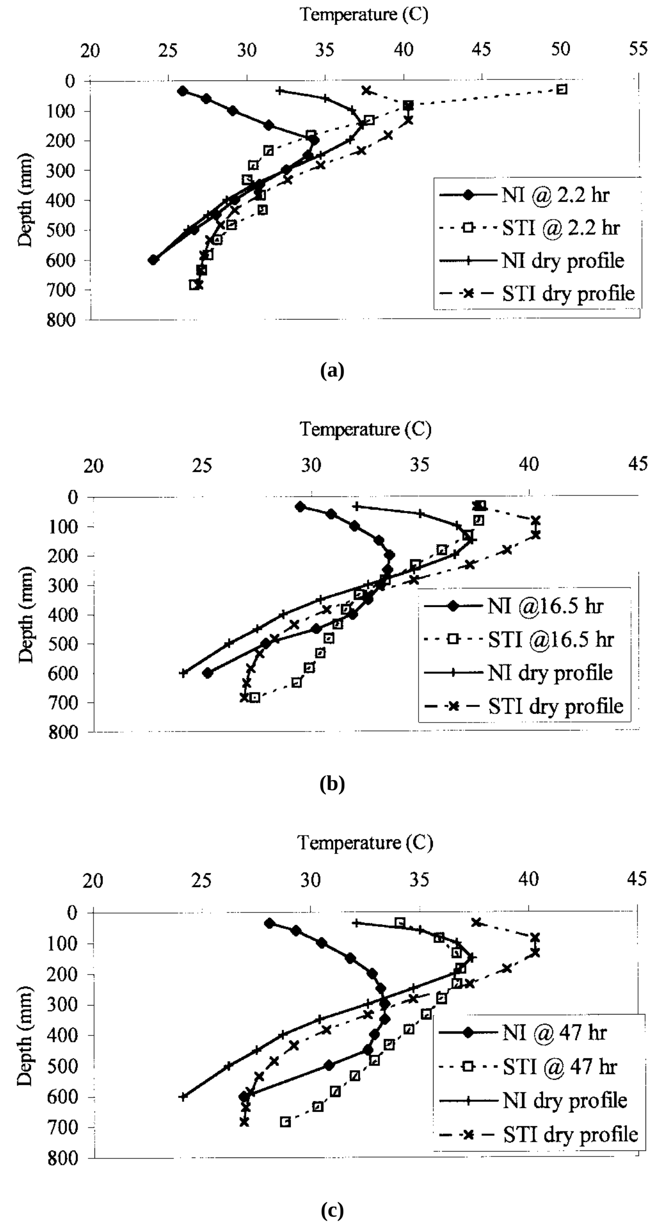


**Figure 8–Temperature profile since irrigation along the center line of the soil bin in the NI treatment and along thermocouples 1, 3, 4, 8, 10, 11, 16, 18, 15, 21, 28, 29, and 30 in the STI treatment (refer to fig. 2).**

and 30 (along the center line of the bin) in Test 1 (refer to fig. 1) are plotted in a series of graphs, shown in figure 8. Also plotted in figure 8 are the temperatures at thermocouples 1, 3, 4, 8, 10, and 11 located along the edge of the sand tube and thermocouples 16, 18, 15, 21, 28, 29, and 30 positioned at the center of the soil bin beneath the sand tube in Test 4 (refer to fig. 2). These graphs are plotted since irrigation commenced at time zero. Prior to irrigation, the temperature distribution closely followed the same pattern in both treatments, with the sand tube treatment having slightly higher temperatures throughout the profile. At 2.2 h the difference is clearly evident [fig. 8(a)]; the NI treatment has cooled on the surface while the STI treatment has substantially increased in surface temperature and cooled down at the 280 mm (11.0 in.) depth below the surface, the bottom of the sand tube.

Figure 8b shows a positive downward gradient for the entire soil profile for the STI method. In contrast the NI treatment indicates a change in heat gradient at the 200- to 300-mm (7.9- to 11.8-in.) depth range. The negative gradient would cause the moisture migration to occur from the lower depths toward the surface. Through the end of the experiments, the downward positive heat gradient existed in the soil profile in the STI treatments. Only after 10 h of cooling (heater being off) the first 200-mm (7.9-in.) depth of the soil profile in the STI method showed a negative gradient, i.e., 47 h. However the negative gradient is much shallower and occurs for a shallower depth in the STI method in contrast to the NI treatment (fig. 8c). The established thermal gradient is viewed as one of the main advantages of the sand tube irrigation method. The warmer surface and cooler depths in the STI method sets up a downward heat gradient as a deterrent to upward moisture migration.

## Conclusion

Pulverized, reconstructed, soil was used in experiments to measure and compare evaporation from surface applied drip irrigation (NI treatment) and a sand tube irrigation (STI) method. The laboratory analysis of the STI versus the NI method has been performed and shown to achieve an average 3.7% versus 30% evaporation from the pulverized soil. The surface applied drip irrigation treatment on the pulverized soil may have exaggerated the evaporation, due to the extensive spread of water over the surface. It was shown that the second day evaporation provided the most significant difference between the two irrigation methods. Since, most drip irrigation systems apply water at a frequency of two to three days or much higher, the relatively moist surface beneath surface applied drip irrigation may result in excessive evaporation. The STI method eliminates this condition. Employment of thermocouples to detect the wetting front in the dry pulverized soil was essential; tensiometers would not have functioned properly in such an environment.

Advantages of the STI method, in contrast to the NI method can be summarized as follow:

1. In the STI method the nearly spherical wetted bulb is confined below the soil surface, thus reducing evaporation and providing a greater opportunity for water extraction by the roots.
2. The thermal gradient induced by the STI method is seen as one of the main advantages of this method. The dryer, warmer surface and cooler depths set up a downward heat gradient as a deterrent to upward moisture migration.
3. Since water is applied at a lower depth in the STI method, the surface gradually becomes drier. This reduces the hydraulic conductivity thereby inhibiting the movement of water upward.
4. A potential problem with any type of subsurface irrigation is the migration and accumulation of salts close to the soil surface, which poses the danger of leaching into the root zone with rainfall. With STI a lesser chance for addition of salt accumulation in the root zone exists since the STI method applies less water, equivalent to less evaporation.

Initially, the STI method does not seem feasible in large-scale operations, similar to the advent days of the drip irrigation itself, when the general feelings were that you could not irrigate trees individually. Drip irrigation is being practiced more in the third world countries and smaller farmers are using the system. A hand auger may be used to construct different tube sizes beneath emitters. The appropriateness of the tube size that matches the maximum irrigation intensity can be easily established by observation. A tractor-mounted auger can accomplish further construction of the sand tubes at larger field scales. The potential water saving capability of the STI method may justify the cost associated with the construction of sand tubes.

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