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# UNIFORM IRRIGATION WITH A LOW-HEAD BUBBLER SYSTEM

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## ABSTRACT

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Existing closed-conduit irrigation systems are capable of saving water by increasing application uniformity. But, because most of them require pumping to pressurize water for distribution, the water is saved often at the expense of increased energy consumption. This paper describes a new irrigation system that reduces the energy requirement by using inexpensive, thin-walled, corrugated plastic pipe of sufficient diameter that the pressure head often available from a surface ditch is sufficient. A simple installation technique, giving extremely high application uniformity, is described for the system for permanent crops. Costs for the system can be less than for comparable sprinkler or drip irrigation systems.

## INTRODUCTION

Water-distribution systems that use closed conduits are potentially capable of higher irrigation uniformity than surface systems. A closed-conduit water distribution system makes it possible to apply water at a rate low enough that it does not pond on the soil surface. This transfers control of infiltration from the soil to the system. If during each irrigation, water is delivered uniformly in increments sufficiently small that soil storage capacity is not exceeded, variations in soil properties from place-to-place in a field no longer cause differences in the quantity of water stored for crop use. Each plant can effectively receive its water supply directly. For sparsely planted crops, like orchards or vineyards, uniform irrigation can be achieved with a system that fills small basins with equal quantities of water. This paper describes such a system that operates at low pressure by using large diameter lateral pipes. Use of thin-walled corrugated polyethylene helps keep the cost low.

## MATERIALS AND METHODS

Two test systems have been installed in citrus groves — one in Tacna, Ariz.,

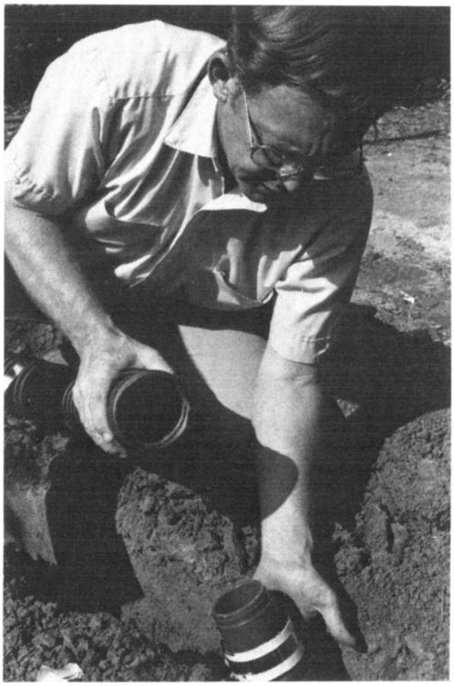

Fig.1. Connector for 76-mm (3-inch) ID corrugated polyethylene pipe. The 0-ring is shown inside the first full corrugation.

the other in Riverside, Calif. Both consist of corrugated polyethylene pipe laterals buried about 0.6 m (2 ft) deep midway between every other row of trees, with 9.5-mm (3/8-inch) inside diameter (ID) polyethylene delivery hose extending underground from the lateral both ways to the trunk of each tree. Flow is regulated by the elevation of outflow from the delivery hose at each tree. Both installations were designed for a nominal flow rate of 0.06 l/s (1 gallon/min) to each tree.

The corrugated polyethylene pipe is the same as that normally used for agricultural drainage, but without slots. Water-tight connectors had to be developed to use it as irrigation laterals. Fig.1 shows such a connector for 76-mm (3-inch) ID* pipe. The 0-ring, shown inside the corrugated polyethylene pipe, was made from 9.5-mm (3/8-inch) cross-section stock by using an 0-ring splicing kit.** 0-rings with this cross-section are satisfactory for use with most 76- and 102-mm ID pipe with circular corrugations manufactured in the United States. 0-rings for 76-mm (3-inch) ID corrugated pipe, had 73-mm (2 7/8-inch) ID; those for 102-mm (4-inch) ID had an ID of 98.5 mm

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*This is the minimum inside diameter for the corrugated pipe.

**The O-ring splicing kit (No. 112) was obtained from Loctite Corp., Newington, Conn. 06011. The citation of particular products or companies is for the convenience of the reader and does not imply any endorsement, guarantee, or preferential treatment by the Department of Agriculture or its agents.

(3 7/8 inches). The connection was made by slipping the 0-ring into the first full corrugation of the polyethylene pipe, and inserting a polyvinylchloride (PVC) pipe coupling into it. Tapering the ends of the pipe coupler with a lathe, as shown, and lubricating the 0-ring with soap help ease the coupler into position. Machining an 0-ring groove 1.6 mm (1/16 inches) deep by 6.3 mm (1/4 inches) wide kept the connection from slipping when pressure was applied to the pipe. The connection was completed by installing a 25-mm-(1-inch)wide hose clamp around the corrugation containing the 0-ring. (Because a hose clamp of this width was not available when the picture was taken, a fiberglass spacer is shown under the narrower hose clamps in Fig.1.) The PVC-pipe couplers were standard fittings. For 102-mm (4-inch) ID corrugated pipe, a schedule 40, 3-inch PVC-pipe coupler (or tee) has a satisfactory outside diameter (100 mm or 3 15/16 inches). For 76-mm (3-inch) ID corrugated pipe, schedule 80, 2-inch PVC-pipe connectors have the appropriate outside diameter (76 mm or 3 inches). Once the PVC coupler is installed, other standard PVC-pipe fittings can be used to join corrugated pipes of different diameters, or to connect the system to a water source.

The small hoses were connected to the corrugated lateral by cutting a small hole into the corrugated pipe and enlarging it by forcing the tapered shank of the tool shown in Fig.2 into it. This formed a short nipple protruding into

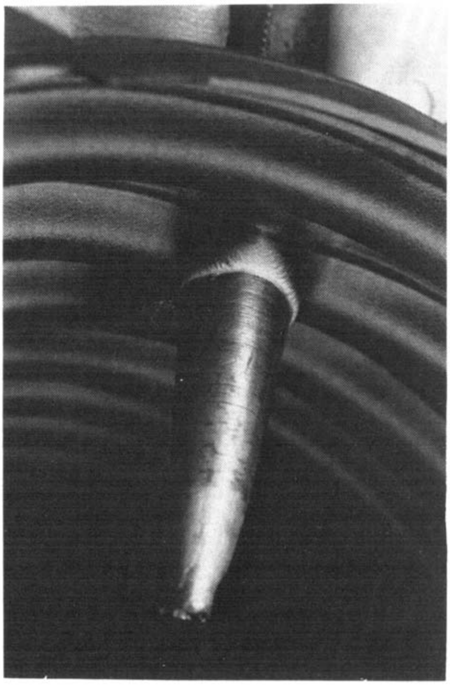

Fig.2. Procedure for connecting 9.5-mm (3/8-inch) ID polyethylene delivery hoses to corrugated polyethylene pipe. The hose can be inserted directly into the pipe immediately after the tool is withdrawn.

the pipe, which, in the Tacna, Ariz. site, was then threaded with the standard 3/8-inch pipe tap built into the tool. The nipple was sufficiently long for four or five full threads. The connection was completed by installing a gasket (made with room-temperature vulcanizing silicone rubber in a plaster of paris mold) and washer, and screwing a threaded tee-connector with barbed side arms into the threaded hole. Coating the rubber gasket with silicone caulking compound before it is installed helped form a water-tight seal. After 14 months of operation, only one leak (caused by a cracked silicone rubber washer) has developed in the Tacna, Ariz. system.

A simpler technique, which eliminates the threaded fitting and molded gasket, was used to install the system in Riverside. The hole was cut and enlarged as is shown in Fig.2, except it was located on a ridge instead of in a valley of the corrugations. (Locating the hole on a ridge seems to distribute the stress, caused by stretching, more uniformly around the nipple wall.) With the nipple formed, the tool was withdrawn and the small diameter polyethylene delivery hose was immediately inserted, The stretched plastic shrinks around the hose forming a water-tight seal. After several days, the force required to dislodge delivery tubes from lateral pipes exceeded 5 kg (11 lb). Confined by the backfill in the trench and subjected to water pressure of no more than 30 kPa (5 psi), it is unlikely that the hose will pull out of the pipe. After more than 12 months of operation, no leaks have developed in the system at Riverside, Calif.

At the Tacna site, the small diameter delivery hoses were laid in trenches dug from each tree to the lateral trench. Making these trenches was time-consuming and considerable hand labor was required to clean them at their intersection with the lateral trench. This problem was eliminated at the Riverside site by using a water jet to force a small diameter pipe from the trunk of a tree to the lateral trench. By slipping the delivery hose onto the barbed fitting at the end of this pipe (Fig.3), when the pipe was withdrawn the hose was drawn into the hole. It was then a simple procedure to connect each delivery hose into the corrugated lateral by the procedure described above. Fig.4 shows hoses installed in a corrugated pipe, lying in a trench ready to be backfilled.

The procedure used to determine the proper elevation of the supply hose at each tree to provide equal flow rate was as follows. First, by standing water at a fixed static head in the lateral, a reference level was found and marked on each tree by lowering each supply hose until the water level stands at its opening. During the procedure, all other hoses were kept elevated above this level so that water did not flow from them, causing a pressure head gradient within the lateral. All subsequent elevation measurements were made relative to this reference elevation.

The second step was to estimate the head loss that would occur within the lateral between each pair of hose connections when the system is operating. This head loss in the lateral was then compensated for by lowering the point

Fig.3. Barbed fitting at the end of the pipe used for jetting a hole from the trunk of each tree to the trench containing the corrugated pipe. The delivery hose is slipped over this fitting and is thereby drawn into the hole when the jetting pipe is retracted.

Fig.4. Downward view of delivery hoses installed in a corrugated pipe lying in a trench ready to be backfilled.

of attachment of the supply hose from one tree to another a distance equal to it. Fig.5 gives the head loss gradient as a function of flow rate for several diameters of corrugated pipe. The flow rate within any section of the lateral pipe equals the flow rate to each tree, multiplied by the number of trees served beyond that section. For a given pipe diameter, the head loss for each section can be found from Fig.5 by determining the head loss gradient corresponding to the flow rate within it, and multiplying this by the length of the section. The total head loss for the lateral is the sum of the head losses for each section.

In designing the systems, it was necessary to choose a lateral diameter that kept the total head loss less than the head available at the water source. A convenient way of estimating the total head loss with uniformly spaced outlets along a lateral without calculating it separately for each section is: First, obtain from Fig.5 the head loss that would occur if the inlet flow ran the full length of the lateral. Then multiply this number by a reduction co-

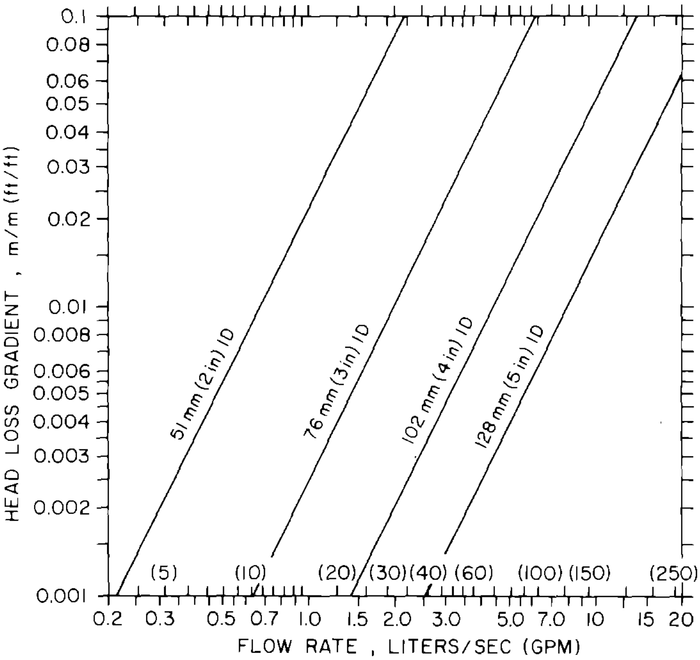

Fig. 5. Head loss gradient as a function of flow rate for four sizes of corrugated polyethylene pipe. The curves were calculated from the Manning's equation using a friction coefficient of 0.016 (Hermsmeier and Willardson, 1970).

efficient, *F*, to compensate for discharge along the line. Reduction coefficients for various numbers of equally spaced outlets are given in Table I.

Also, the head loss across each delivery hose was needed before the hose could be attached to each tree at the appropriate elevation. Fig.6 gives head loss gradients as functions of flow rate for various hose diameters. These were calculated from the equation

$$S = k\, q^{1.75}\, d^{-4.79},$$

where $S$ is the head loss gradient, $k$ is a constant, $q$ is the flow rate, and $d$ is the pipe diameter. For $q$ in l/s and $d$ in mm, $k = 8.86 \times 10^5$. For $q$ in gallons /min and $d$ in inches, $k = 1.30 \times 10^{-3}$. This equation is valid for smooth pipes only. Unlike most equations for head loss as a function of flow rate, it takes into account the decrease in the friction coefficient with increasing Reynolds Number, which is significant for smooth pipes. The diagonal line at which the curves terminate on the left represents a Reynolds Number of 4000. Systems should not be designed for flow below this rate, because the flow regime becomes unstable, and is, therefore, unpredictable. To find the head loss for the desired flow rate for a given diameter hose, the head loss gradient found in the figure is multiplied by the length of the hose.

TABLE I

Reduction coefficient, *F*, for various numbers of equally spaced outlets along a lateral line (from Karmeli and Keller, 1975, Table 5.1).

| Outlets | *F* | Outlets | *F* | Outlets | *F* |
|---|---|---|---|---|---|
| 1 | 1.000 | 8 | 0.415 | 20 | 0.376 |
| 2 | 0.639 | 10 | 0.402 | 25 | 0.371 |
| 3 | 0.535 | 12 | 0.394 | 30 | 0.368 |
| 4 | 0.486 | 14 | 0.387 | 40 | 0.364 |
| 5 | 0.457 | 16 | 0.382 | 50 | 0.361 |
| 6 | 0.435 | 18 | 0.379 | 100 | 0.356 |

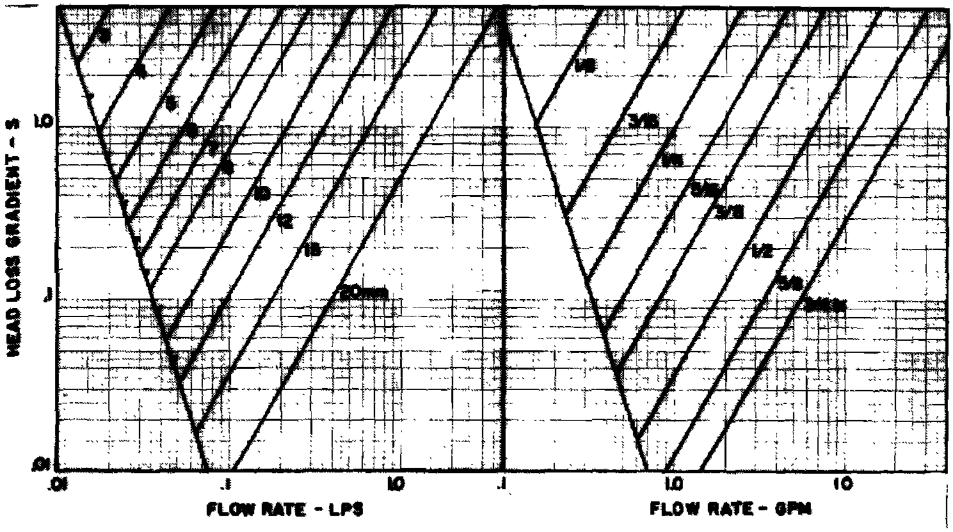

Fig.6. Head loss gradient ($S$) for polyethylene hoses of various inside diameters. The diagonal line at the left, at which the curves terminate, represents a Reynolds Number of 4000. Flow below this rate is unstable.

With the elevation of the water supply (measured relative to the reference level), and the head losses for each section of lateral pipe between hose outlets and across each delivery hose determined, the delivery hoses were ready to be attached to each tree. The goal was to eliminate head losses down the lateral by adjusting the outflow elevations so that each delivery hose has the same head loss across it. At the first pair of trees, the outlet of the delivery hose was attached at an elevation lower than that of the water source by a distance equal to the sum of (1) the head loss in the lateral from the water source to the first hose connection, and (2) the head loss in the delivery hose. At each subsequent pair of trees along the lateral, the outlet of the delivery hose is lowered an additional distance, equal to the additional head loss in the lateral.

Once the hoses were attached to the trees, a more precise, dynamic adjustment of the outflow elevations at each tree was made with the system operating. This was done by raising each hose, one at a time, to the point where water ceased to flow, and then measuring down from this point a distance equal to the desired head loss across the delivery hose. Relocating the delivery hose outlet at this elevation assured that each delivery hose had the same head loss across it, eliminating errors introduced by imprecise estimates of head loss in the lateral.

A convenient way to attach the delivery hose to each tree is shown in Fig.7. A plastic, barbed-tee fitting was stapled to the trunk with its horizontal side arm at the desired outflow elevation. The delivery hose was then connected to the bottom arm and an additional length of hose was attached to the side arm to conduct water away from the tree trunk. The upper arm of the tee draws air, breaking the siphon, which maintains the effective outflow elevation at the side arm of the tee, regardless of the actual elevation of outflow

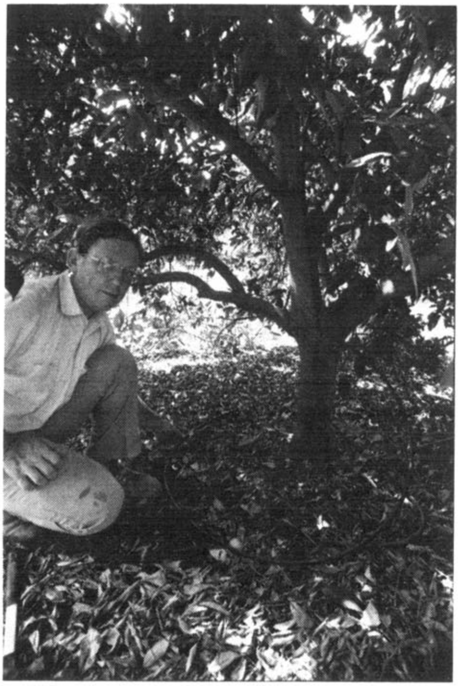

Fig.7. View of supply hose attached to the trunk of a citrus tree. The tee connector is stapled to the tree at the desired elevation of outflow.

from the hose attached to it. A length of hose attached to the upper arm of the tee allows a small head to build up momentarily when the system is turned on to flush any air blockages from the hose attached to the horizontal side arm.

## RESULTS

The field emission uniformity (Karmeli and Keller, 1975) calculated from measurements of the flow rate from each delivery hose for the Tacna, Ariz. system, was 89.2% before the dynamic calibration was made. (No measurements were made after the calibration.) The field emission uniformity for the Riverside, Calif. system, measured after the dynamic calibration, was 97.3%. This is extremely high as compared with commercial irrigation systems. This is a consequence of the fact that the outlets are simply and individually adjustable. The fact that flow was controlled by height of the outlet rather than by an orifice should insure that it remains constant.

## DISCUSSION

Because the system operates at low pressure, the existing elevation of ditches or pipes used for furrow or flood irrigation should often be sufficient to provide it. There is, of course, a minimum elevation required, either to keep the lateral pipe size within economic limits, or, in some cases to maintain flow velocities high enough either to prevent siltation or to allow for periodic flushing. The kinds of questions that need to be considered can be illustrated by a specific example.

Assume water is available at 1-m (3.30-ft) elevation above one end of the field 200 m (660 ft) long. The slope down the rows is 1%, and each row has 40 trees. Assume that each tree is to be supplied with 0.063 l/s (1 gallon/min). If one lateral serves two rows, the inlet flow rate is 5.0 l/s (80 gallon/min). If this flow rate ran the full length of the lateral, the head loss would be 13 m (43 ft) for 76-mm (3-inch) ID pipe, or 2.6 m (8.5 ft) for 102-mm (4-inch) ID pipe. Multiplying each by a reduction coefficient of 0.364 to account for flow from the 40 outlets (Table I), the actual head loss would be 4.7 m (16 ft) for 76-mm (3-inch) ID pipe, or 0.95 m (3.1 ft) for 102-mm (4-inch) ID pipe. As a consequence of the 1% slope, the elevation change along the row (2 m or 6.6 ft) would more than compensate (by a factor of 2) for the head loss for 102-mm (4-inch) ID pipe, but would be only half enough to compensate for the head loss along a 76-mm (3-inch) ID lateral. A tapered lateral, half 102-mm (4-inch) ID and half 76-mm (3-inch) ID would have a total head loss of 1.1 m (3.6 ft), which would still be more than compensated for by the slope of the field. If a 5-m (16-ft) length of 9.5-mm (3/8-inch) ID hose were used to deliver water to each tree, the head required to supply a flow rate of 0.063 l/s (1 gallon/min) to each tree would be (from Fig.6) about 0.72 m (2.3 ft).

Fig.8 shows elevation for the ground, the hydraulic head in the lateral, and the required elevations for the delivery hose outlets, relative to the reference level, for the tapered lateral described above. The reference level is arbitrarily chosen to be 0.3 m above the ground level at the water source. The hydraulic head level in the lateral was found by calculating the head loss for each section using Fig.5. The break in the hydraulic head curve at 100 m (330 ft) is the result of decreasing the lateral pipe diameter from 102 to 76 mm (4 to 3 inch). The delivery hose outlet level is shown a constant distance of 0.72 m (2.3 ft) below the hydraulic head level. This provides the required constant head across each delivery tube. The minimum elevation of a delivery hose outlet above the ground occurs at tree 6, 0.51 m (1.6 ft). The maximum occurs at tree 40, 1.13 m (3.7 ft).

Of course, the lateral could be tapered more by using smaller diameter pipe at the end, but presently, the price reduction is negligible for diameters less than 76 mm (3 inch). Using smaller pipe would also decrease the maximum flow velocity that could be attained within the lateral for flushing.

Flushing lateral lines periodically will often be necessary to remove accumulated sediment. In the example illustrated in Fig.8, removing the end plug would allow a 3-m (9.8-ft) head to be dissipated. This would permit 3.4 l/s (54 gallons/min) to flow through the lateral. The velocity would be 0.8 m/s (2.6 ft/s) through the 76-mm (3-inch) ID lateral section, but only 0.4 m/s (1.4 ft/s) through the 102-mm (4-inch) section. Whether this velocity is sufficient to resuspend sediment will depend on the particle size distribution within it. Making the lateral entirely with 102-mm diameter pipe would permit a flushing velocity of 0.7 m/s (2.2 ft/s). Experience with silt-laden irri-

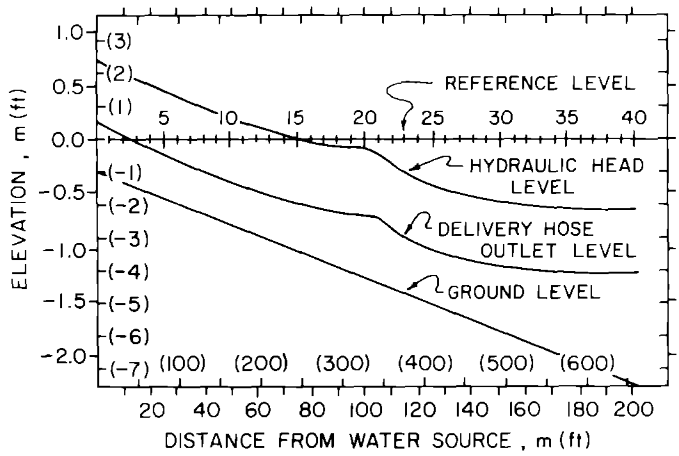

Fig.8. Hydraulic head, delivery hose outlet, and ground levels as functions of distance from the water source. The lateral pipe ID changes from 102 mm (4 inches) to 76 mm (3 inches) at 100 m (330 ft).

gation water from the Snake River near Twin Falls, Idaho, in an irrigation system (Worstell, 1975) with flow velocities less than these, indicates flushing the lateral lines weekly by removing the end cap prevents sediment accumulation (R.V. Worstell, personal communication, 1976).

If the available head and/or the slope were less than that in the previous example, either the flow rate to each tree would have to be reduced, or pipe sizes would have to be increased. Halving the flow rate decreases the head loss through the tapered lateral from 1.1 to 0.26 m (3.6 to 0.8 ft). Likewise, the head loss through the delivery hoses is reduced from 0.72 to 0.21 m (2.3 to 0.68 ft). The minimum head at the water source required for a level field would, therefore, be about 0.5 m (1.5 ft). Heads of this magnitude are often available or can be made available by enclosing a surface water supply in a pipeline to a sufficiently high elevation.

A system with one hose to each tree could only be operated at this low flow rate if the infiltrability of the soil were low enough to permit some surface distribution of the water. Also, it may be necessary to use a portable pump to provide sufficient pressure to flush the system.

## CONCLUSIONS

This low-head bubbler system appears to have the potential for efficient irrigation of tree crops. Cost for materials for the system will, of course, vary with distance from manufacturing plants. The cost at Riverside, Calif., for corrugated tubing, connectors, and drip hose was approximately US $620/ha (US $250/acre) for a system using 76-mm (3-inch) ID corrugated pipe and US $740/ha (US $300/acre) for 102-mm (4-inch) ID pipe. Installation costs on a commercial scale are difficult to estimate from my experimental systems. Costs of trenching and backfilling at Tacna, Ariz., are estimated at US $0.72/m ($0.22/ft)(Soil Conservation Service, personal communication, 1976). With row spacing of 6.1 m (20 ft) and a lateral between every two rows of trees, this would amount to US $590/ha (US $240/acre). I estimate that installing the system by the procedure used at the Riverside site would require less than 10 man days/ha (4 man days/acre). At a wage of US $30/man day, this would add US $300/ha (US $120/acre), for a total of US $1510/ha (US $610/acre) for a 76-mm (3-inch) system and US $1630/ha (US $660/acre) for a 102-mm (4-inch) system.

These costs are comparable with or lower than many complete drip irrigation systems including pumps and filters. The advantage of the longer life of a completely buried system, and the lower energy requirements may make this closed-conduit, gravity system an attractive alternative, particularly for relatively level fields that can be converted from surface irrigation methods.

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