Selecting a Buried Gravity Irrigation System

Robert V. Worstell
MEMBER
ASAE

ABSTRACT

THE principal factors that affect the costs of installing a buried lateral multiset irrigation system are discussed. The financial and intangible benefits are also described.

INTRODUCTION

The need to improve the water application efficiency of gravity irrigation systems is increasing. Limitations in available energy or increasing energy costs will limit conversions of gravity systems to sprinkler systems with their lower labor requirements and, frequently, better water application efficiencies. Gravity systems can be designed and operated much more efficiently than most existing systems, but the new designs will cost more than basic systems and some will require surface pipe laterals which may not be compatible with modern high-speed, low-labor, farming operations.

An efficient graded surface irrigation system requires that the length-of-run be limited to prevent excessive percolation losses at the upper end of the field, while adequately irrigating the lower end. The stream size must be matched to the length-of-run and to the soil's intake rate to minimize runoff, but it must be large enough to reach and wet the lower end of the field. The duration of an irrigation must also be varied to adjust to changes in the soil's intake rate during the season. And finally, the stream size should always be limited to a flow rate that is nonerosive at all points along the furrow.

Multiset Low Pressure Gravity Systems

Rasmussen et al. (1973) developed and tested a "multiset" system that applied irrigation water by gravity to row crops at 80 percent efficiency. Addition of a return flow system would increase the efficiency above 90 percent. A multiset system divides a normal length-of-run of 300 to 400 m (985 to 1310 ft) into several short segments, each 60 to 90 m (200 to 300 ft) long. Small streams are then sequenced to the head end of each segment, and any runoff continues down the furrows into the next lower section where it usually infiltrates, except the runoff from the last segment. The inflow rate should be limited to prevent erosion, but large enough to permit a rapid rate of advance to minimize the difference in intake opportunity time between the upper and lower ends of each segment. Rasmussen's system used aluminum gated-pipe laterals at several midfield points. These pipes had to be moved manually before and after each cultural operation. This and the system's initial cost are probably the main reasons this design has not been adopted. Also, the system could not be automated to reduce irrigating labor since adequate controllers and valves were not commercially available.

A "buried lateral" automatic* multiset system has since been designed and tested on two small fields at the Snake River Conservation Research Center (Worstell, 1976), and a semi-automatic* buried single-lateral system has been installed on a cooperator's 5.3-ha (13-acre) field. These systems (Fig. 1) deliver water to the furrows from a pipe buried 38 cm (15 in.) below the soil surface, so that normal cultural operations can be performed unhindered by the irrigation system. The water flows up from the pipe into the furrows and downslope to and beyond the next buried lateral in the multiset system. This system can easily be automated to minimize irrigation labor. The system can be operated on a normal irrigation cycle of 7 to 14 days at about 80 percent application efficiency. With water available on demand, light, more frequent irrigations can be applied to achieve irrigation application efficiencies above 90 percent.

Snake River Research Center Buried Lateral System

The system was designed as a permanent installation for irrigating several different crops in a rotation. The design criteria as listed by Worstell (1976) were set to maximize water application efficiency and minimize labor requirements, energy requirements, and erosion.

Three systems are presently in use, one on a 1.6-ha (4 acre) field at the Snake River Conservation Research Center and two on cooperator fields within five miles of the Center — one a 5.3-ha (13 acre) field and the other an 8.0-ha (19.8-acre) field. The first half of the Research Center system was installed in 1975 and the second half in 1976. The cooperators' fields

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The author is: ROBERT V. WORSTELL, Agricultural Engineer, Snake River Conservation Research Center, Kimberly, ID.

*"Automatic" refers to a fully automatic system that will irrigate an area automatically during the entire season with only routine maintenance and inspection. A "semi-automatic" system requires that the irrigator start the system, and perhaps set the length of time of application, after which an electronic or mechanical controller cycles the water supply to the parts of the area to be irrigated. A "manual" system requires that the irrigator start the system and adjust valves to apply water to the various parts of the area to be irrigated. All these systems also require surveillance and maintenance by the irrigator throughout the season.

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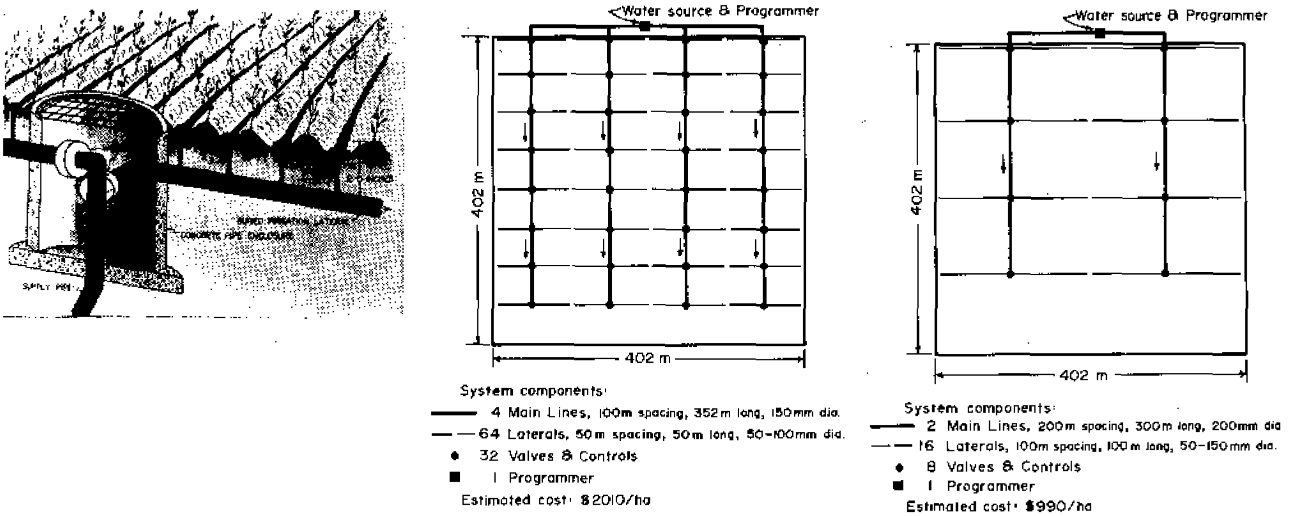

FIG. 1 Illustration of buried laterals. a) Illustration of buried lateral concept. b) Intensive buried lateral design for 16 ha (40 acre) field. c) Extended buried lateral design for 16 ha (40 acre) field.

were installed in 1976 and 1977. These systems have generally performed very well during the first 1 to 3 yr of testing. The life expectancy of these systems is undetermined, but is estimated to exceed 15 to 20 yr. The initial systems had more installation and operating labor requirements than will be needed after further refinements and testing are completed.

A computer program, written for a desk type computer, was used to calculate the pipe diameters and orifice sizes needed to deliver the design discharge (∓ 8 percent) to each furrow. the factors determining the costs of these systems and the benefits needed to justify these costs are summarized in this paper.

SYSTEM COSTS

The system was assembled from plastic pipe — smooth polyvinyl chloride (PVC) pipe on the first of the installations, with corrugated polyethylene and PVC for much of the later installations. The valves used to control the flow into the laterals were the Snake River pipeline valves described by Humpherys and Stacey (1975).

The systems costs were determined by the type of pipe, their diameters and lengths, and by the number and sizes of valves required to apply water to the irrigated area. These components were, in turn, determined by: (a) water flow rate available, (b) soil erodibility, (c) intake rate, (d) field slope and uniformity, (e) field shape and dimensions, and (f) development cost of a low-pressure water supply.

Costs were computed for alternative buried lateral systems to irrigate a square 16-ha (40-acre) field (Fig. 1-B, C). The soil type was assumed to be Portneuf silt loam on a 1 to 2 percent slope. The recommended furrow application rate for this soil with this slope range is 0.2 L/s per 100 m (1 gpm/100 ft) (USDA, 1970). The maximum nonerosive furrow stream size was 0.44 L/s (7 gpm) (USDA, 1970).

The mainline spacings were varied from 50 to 400 m (165 to 1312 ft), and the lateral spacings were varied from 25 to 400 m (83 to 1312 ft). An 81-cm (32-in.) furrow spacing was used. The system component costs are shown in Table 1. Fig. 2 shows the range of total system costs, and Fig. 3 shows the costs of the components of various systems. These figures show that a system's cost is highly dependent on a plentiful water supply rate.

The minimum water supply rate must be large enough to meet the maximum evapotranspiration (ET) needs of the crops. In southern Idaho, this is about 8 mm (0.3 in.)/day, or 0.93 L/s^{-1} ha^{-1} (5.6 gpm/acre).

A large flow rate to each lateral requires larger input pipes and valves, but each pipeline and valve would serve a greater area by simultaneously irrigating more or longer furrows. The furrow length should never be increased to a length that requires an erosive

TABLE 1. APPROXIMATE COSTS OF COMPONENTS NEEDED TO CONSTRUCT AN AUTOMATIC BURIED LATERAL SYSTEM

	Sizes mm (in.)							
Item and unit cost	25 (1)	50 (2)	75 (3)	100 (4)	150 (6)	200 (8)	250 (10)	300 (12)
Installed pipes (P.V.C.)								
Cost/m	$3.28	$4.10	$4.85	$5.25	$5.58	$6.40	$8.70	$11.15
(Cost/ft)	(1.00)	(1.25)	(1.48)	(1.60)	(1.70)	(1.95)	(2.65)	(3.40)
Snake River valves								
Cost (each)				135	150	175	200	225
Controller	3-station			10-station		22-station		
Cost	$200			$425		$595		
Wire cost	10¢/m (3¢/ft)			10¢/m (3¢/ft)		10¢/m (3¢/ft)		

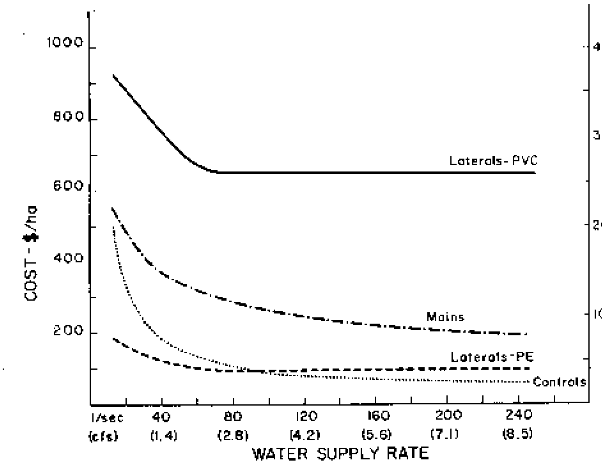

FIG. 2 Buried lateral total system costs related to water supply rate.

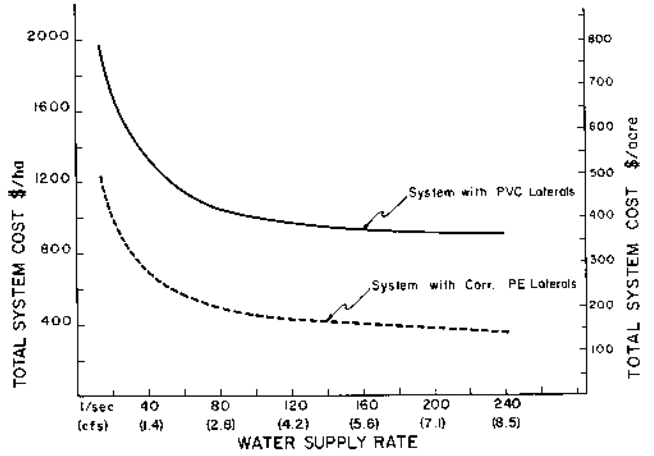

FIG. 3 Buried lateral system component costs related to water supply rate.

input flow. A system designed to apply the minimum flow to meet ET would cost about $1,850 to $2,000/ha ($750 to $810/acre) (Fig. 2). If the flow rate is increased by 4.5 to 5 times, the system cost would decrease about 50 percent. This can be accomplished by cycling the water supply and applying it to larger parts of the total area. With water supply rates above 80 L/s (2.8 cfs), there is little additional decrease in cost. A storage pond may be desirable to allow conversion from a low constant flow rate to a higher intermittent flow, which would often decrease the system's cost.

Soils with high intake rates require closer lateral spacings and larger pipe and valve sizes to achieve good application efficiency. This would increase the system's cost. Light, frequent irrigations (if water is available on demand) will maintain the furrows in a moist condition so that the initial intake rates are lower and more constant. This technique could allow for somewhat greater lateral spacings. With a design that takes advantage of this phenomenon, it would be difficult to uniformly irrigate the field after it is cultivated (unless furrow slickers are used), but repeated applications with 20- to 30-min pulses of waterflow, followed by equal length "drying" periods, would minimize the effects of this problem.

Fields that have not been surface irrigated previously will require leveling. Finish leveling may be required on a surface irrigated field that has eroded or had deposition or settling. Very nonuniform slopes will require a more intricate pipe system to achieve an acceptable high efficiency.

Fields with 3 to 5 percent slopes can be irrigated with smaller flow rates applied to each corrugate, or with wider spacings between laterals (until erosive rates are exceeded), and still achieve uniform applications since the rates of water advance and recession will increase. These smaller stream sizes will reduce the size of components in the system, but the number of components may increase.

Other factors that can affect a system's cost are:

1 The field's shape influences system cost by limiting the maximum length of laterals that can be used with the available water supply. A system with long laterals requires fewer mainlines and valves. Thus, a field whose longer dimension is perpendicular to the irrigation direction will often have the lowest cost design for a given flow rate.

2 An erosive soil requires more closely spaced laterals and smaller streams, which will require more valves and a larger control module for each field.

3 Systems designed for maximum water application efficiency with minimum runoff and erosion will require more closely spaced laterals and will be more expensive.

4 A low pressure water supply to operate these systems can be developed at low cost from a high gradient surface supply system. A very low gradient supply system may require a pump installation.

The system also requires screening the surface water supply, which is similar to that needed for a sprinkler system. A small settling basin may be needed in some supply systems to remove sand and most of the silt from the water.

Modified designs or practices may be required before the buried multiset concept can be used on some soils or crops. For example, if the grower must deep chisel or deep plow, he must operate such implements parallel to the buried laterals, carefully avoiding them; or, if he must work perpendicular to the laterals, he will have to briefly raise the implements enough to cross over them; or he can install the laterals below the maximum chiseling depth and equip them with risers that are easily removed and replaced or are expendable if struck or cut by these tools. The latter design would require further research to develop slightly different methods of cleaning plugged orifices.

New materials and improved installation techniques should reduce these system costs. For example, the corrugated polyethylene tubing used in part of the installations has been very satisfactory during the first two seasons of use (Fig. 2).

BENEFITS OF A BURIED AUTOMATED SYSTEM

The cost of a buried automated gravity irrigation system must be justified by its benefits to the grower. These benefits will vary with the grower's needs and the design of the system.

Energy Savings

In energy-deficient areas, and in those where energy costs are increasing, some farmers may change from

TABLE 2. ESTIMATE OF ANNUAL OPERATIONAL LABOR COSTS FOR A 16-ha (40-acre) BURIED MULTISET SYSTEM

Operation	Required annual time		Pay rate	Annual cost
	h	h/ha (h/ac)	$/h	$/ha ($/ac)
Mainline maintenance	2.5	0.16 (0.06)	10	1.48 (0.60)
Changing orifice spacings (annually)	20	1.23 (0.50)	3	3.70 (1.50)
Monitoring discharges and flushing lines (bi-weekly)	30	1.85 (0.75)	3	5.55 (2.25)
Servicing moisture sensors (weekly)	10	0.62 (0.25)	3	1.85 (0.75)
Electronic servicing (annually)	10	0.62 (0.25)	10	6.17 (2.50)
Totals				$18.75 (7.60)

a sprinkler system to a low-pressure automatic gravity system. If sufficient gradient is available in the surface supply system, the pressure required to operate this system may be available by connecting the supply pipe to the surface water supply at a distance of 100 to 200 m (330 to 660 ft) upslope from the high point of the field or farm to be irrigated. For example, the additional initial investment needed for a 100 m (330 ft) supply line would range between $38 and $75/ha ($15 and $30/acre), depending on the field size and flow rate.

If the water supply must be pumped to provide the needed head, the cost of adding 3 m (10 ft) of total dynamic head is about 6 percent of the cost of pressurizing a sprinkler line to 520 kPa (75 psi). Similar savings could be expected on the investment and maintenance of the pump and motor.

Labor Savings

Savings in labor costs will depend on the following variables:

1 Type of system that is being replaced.

2 Crop rotation.

3 Number of irrigations per season with the existing system.

4 Labor costs and the availability and dependability of skilled irrigating labor.

5 Degree of sophistication of the new system.

6 Reliability of the new system.

We have estimated an average labor cost of $50/ha ($20/acre) per year for irrigating row crops in southern Idaho with present systems. Table 2 shows estimated operational costs for a 16-ha (40-acre) buried lateral system. These values are based on the following assumptions:

1 Mainline maintenance work will be needed every fourth year (10 h work estimated every fourth year).

2 Orifice spacings will be changed at the beginning of each season to adjust to row spacings of crops grown that year. This would require opening or closing from 10 to 18 outlets in each 100 ft of lateral. At present, this is done by inserting or removing rubber stoppers in the orifices while water is flowing from the pipe. This takes an average amount of time similar to one setting and adjustment of siphon tubes, or 1.25 h/ha (0.5 h/acre).

3 The discharge monitoring and flushing needs will depend on the solids carried by the water supply. The figures used here were estimated from experience with a screened (12-mesh/cm (30-mesh/in.)) water supply from a canal that carried a small amount of suspended silt and clay.

4 The estimate of time needed for servicing moisture sensors is based on the use of one tensiometer control unit for each 4-ha (10-acre) area—serviced each week.

5 The estimate of electronic servicing needs are based on use of basically well designed control units, but with allowance for some maintenance and modification, especially while operating personnel are gaining experience with the system.

The time needed for maintenance will probably decrease in the future. For example, orifice spacings may not change every year; cleaner water (as from wells) would need less flushing and monitoring; moisture sensors may not always be used, or new design may require very little attention; and controllers will be perfected to operate for many years with little attention. The benefits realized from labor savings would depend on other uses that can be made of the time saved.

Water Savings

The buried automatic gravity system is based on Rasmussen's et al (1973) multiset concept, where small flows are applied and the tailwater from the upper parts of a field flow over and are largely infiltrated into the lower sections. Worstell (1976) found that by using such a system with light, frequent applications, the water use efficiency could be maintained above 90 percent without a return flow system. Seasonal water application on silage corn was less than 430 mm (17 in.)—less than two-thirds of the normal net application.

If the total volume of available water is limited, the high efficiency and precise control of a buried automated system would permit applying water at the most beneficial time for the crop and over the largest area deemed practical. Research is still needed to determine the minimum irrigation needs for most crops and the most effective time to apply water from a limited source.

Most surface irrigation systems operate with water application efficiencies that range between 25 and 65 percent. A buried automated system could irrigate the same fields with 28 to 72 percent of the water presently applied. The actual value of these savings would again depend on how the saved water would be used and the cost of the energy required to supply it to the field.

Erosion Control

Few measurements have been made of erosion soil losses on furrow-irrigated land, but the silt loam soils of southern Idaho are highly erosive, as evidenced by deep rills cut into the soil at the upper end of irrigation furrows, and depositions at the ends of fields and in drains. This erosion was visually estimated to exceed 110 L/ha (50 tons/acre) each year at the upper ends of the rows in many fields. This soil moves downslope and is largely deposited in the furrows as the flow rate is decreased by water infiltration. When the slope gradients are nonuniform, and there is cross-slope, this deposition causes the streams to flood to damage the crop and to flow together, which causes poor uniformity of water application and further erosion and pollution problems. The small flows applied at several points along a furrow length maintain the soil in place, give uniform applications in all furrows, reduce drain ditch maintenance, and improve runoff water quality.

Crop Production

Crop production is enhanced by maintaining high moisture levels when irrigating saline soils or irrigating with saline water, as was determined from studies with drip irrigation. An automated, buried multiset system can achieve much the same soil moisture condition if the water supply is available on demand or constantly, so that light, frequent applications can be made. This system is not as expensive as installing a drip irrigation system on row crops, and it does not require the degree of filtration and water treatment needed for drip systems.

When salinity is a problem, special cultural techniques may be required to allow for salt build-up in the ridges or beds. For example, in the Imperial Valley, melons must be planted on the sides of furrow-irrigated beds to avoid the salt concentrations that develop in the bed center. Precise water applications may help reduce these salt build-ups by partially controlling upward salt movement by capillary forces from deep in the soil profile.

Off-season leaching techniques would relocate the furrow to the center of the former bed and small amounts of water would be applied frequently to maintain a downward gradient for a short period of time. This would carry the salts back down into the profile and then to the drain.

Convenience

A permanent buried irrigation system eliminates all pipe moving and pipe storage operations, and provides a clear field surface for maximum efficiency in performing all mechanized cultural operations. The daily demands of present surface irrigation systems limit the amount of attention the irrigator can devote to other activities. This is a greater problem when skilled irrigating labor is not readily available. Most sprinkler systems also require considerable attention, maintenance, and labor.

Although further development and improvement are needed, the automatic buried multiset gravity systems have the potential of being operated fully automatically and unattended for extended periods at low cost and high water application efficiency.

SUMMARY

An automatic buried lateral gravity irrigation system is being developed and tested by the Snake River Conservation Research Center.

The initial cost of this system is presently in the \$750 to \$2250/ha (\$300 to \$900/acre) range. The actual cost will depend on water supply rate, field size and shape, soil intake rate, soil erosivity, and water application efficiency needs.

The potential benefits from this system include eliminating or greatly reducing energy requirements (as compared with sprinkler systems), labor savings (as compared with present gravity systems), increased water application efficiency, erosion control, increased crop production under saline conditions, and much convenience.

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