An Experimental Buried Multiset Irrigation System

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ABSTRACT

CRITERIA for the design, construction, and operation of an experimental buried lateral, gravity multiset irrigation system are presented. The system operating without automatic controls has a potential water application efficiency of 80 percent with very little runoff or erosion. With automatic controls and with water available on demand, light, frequent irrigations can be applied with 90 to 95 percent efficiencies. The energy required to operate the system is minimal and only periodic inspection and maintenance services are required of the operator. Estimated cost and benefits indicate that this system may be economically feasible, practical, and attractive with increasing energy costs and labor shortages.

INTRODUCTION

Improved efficiency of water application by surface or gravity methods is needed throughout the world. This need is becoming even more economically important in the U.S. as labor and energy costs increase. Also, environmental considerations may increase restrictions on allotted quantities and effluent quality of all water supplies.

Many soils can be irrigated very efficiently on level to gently sloping fields with surface systems if the length-of-run is greatly decreased below that normally used on most irrigated farms. The length-of-run is usually based on convenient farming operations rather than on the soil characteristics or hydraulics of the irrigation system. Most existing systems have application efficiencies ranging from 20 to 60 percent, and in many areas furrow irrigation causes moderate to severe erosion and sedimentation problems.

Rasmussen et al. (1973) attained surface irrigation application efficiencies exceeding 80 percent with a multiset design using surface gated pipe. With the multiset design, the overall length-of-run is divided into several subruns, but the system is operated as a unit. This design permits smaller nonerosive streams of water to be supplied at intermediate points along the furrows. The stream from each subset advances downslope to and beyond the next point of supply. Runoff from the upper sections infiltrates in the lower sections so that there is minimal runoff from the end of the field. With a reuse return system, water application efficiency can exceed 90 percent.

Despite these advantages, the multiset design has not been adopted. It requires considerable labor to move the gated pipe whenever other cultural and harvesting operations are required. A multiset system with buried laterals eliminates the labor required to move pipe and makes the system compatible with other farming operations. Varlev (1973) and Milligan (1974) have reported briefly on buried lateral systems used in Bulgaria and Texas, respectively. Their systems required pressurized lines equipped with emitters that were more intricate than the orifices used in this system.

Preliminary tests in 1973 with a buried lateral system on beans indicated that a system with simple orifices can be automated and operated at an application efficiency exceeding 80 percent. A multiset system with buried laterals must be designed to fit each specific field site since the discharges cannot be adjusted as with gated pipe or siphon tube systems. During 1974, the design procedures were developed and improved. This paper presents design criteria and operating experience with a buried lateral system during the 1975 season, together with economic estimates concerning its feasibility.

SYSTEM DESIGN AND INSTALLATION

Experimental Site

The site selected was an 0.8-ha field at the Snake River Conservation Research Center, Kimberly, Idaho. The Portneuf silt loam soil at the site has a lime-silica cemented "hard pan," beginning at a depth of 0.5 to 0.6 m (18 to 22 in.) except where erosion or land leveling has occurred. This layer restricts vertical drainage in the unsaturated state and limits all but the most persistent roots. The field is 155 m (510 ft) long and 50 m (165 ft) wide (Fig. 1), with about 1 percent slope in the direction of irrigation. The zero cross slope found at the upper end of the field gradually increases to more than 1 percent at the lower end. The lateral could not be placed on the contour because of the need to maintain rectangular plot shapes for replications in future experimental studies. Silage corn (Northrup King 497) was grown in 1975 in 76-cm (30-in.) rows. The crop was planted May 12—somewhat later than usual due to abnormally cold spring weather. The corn plants were set back by a freeze when they were 7 to 10 cm high. Rapid growth began early in July—about 1 month later than normal.

Design Criteria

The system designed was a permanent installation for irrigating a field on which several different crops would be grown in rotation. Design criteria were:

1 provide a uniform discharge along the lateral (each orifice within 10 percent of the average);

2 apply accurate water quantities to maximize water use efficiency and

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Article was submitted for publication in April 1976; reviewed and approved for publication by the Soil and Water Division of ASAE in September 1976. Presented as ASAE Paper No. 75-2540.

Contribution from the Western Region, ARS, USDA; University of Idaho College of Agriculture Research and Extension Center, Kimberly, cooperating.

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This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 19, No. 6, pp. 1122, 1123, 1124, 1125, 1126, 1127, 1128, 1976)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

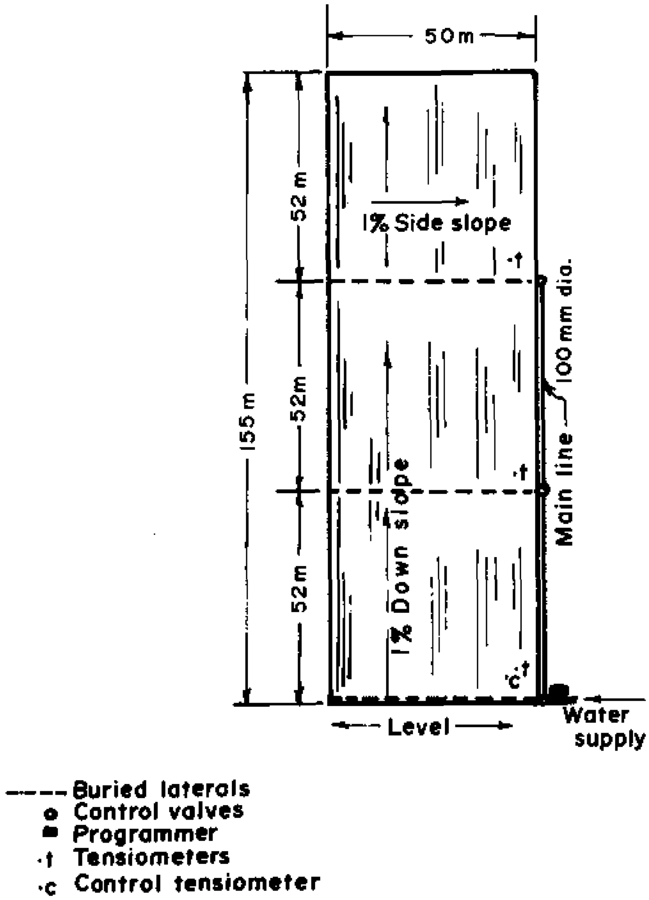

FIG. 1 Buried lateral field layout.

minimize runoff and erosion;

3 operate from a gravity or very low pressure water supply to minimize energy requirements;

4 be readily adaptable to different row spacings and water requirements of all the crops in the rotation;

5 have low operating labor requirements;

6 be adaptable to operation as a manual, semiautomatic, or fully automatic irrigation system;

7 be economically feasible;

8 be placed at a depth belowground that will permit regular cultural and harvesting operations to proceed without damage to the system; and yet

9 have laterals that are accessible for minor servicing, like occasional orifice cleaning, flushing, draining to prevent frost damage, and changing orifice intervals to fit different row spacings.

The 155-m field length was divided into three 52-m (170-ft) subruns, each served by a 50- to 100-mm (2- to 4-in.) diameter buried lateral supply pipe (Fig. 1).

The design orifice discharge rate selected for this field was 0.063 l/s per 30 m (1 gpm/100 ft) of furrow length, which was based on USDA, Soil Conservation Service Irrigation Guide (1970) recommendations for a silt loam soil on 1 percent slope. The discharge limits were set at ± 8 percent, which is the smallest limit that can be achieved when changing the orifice diameters in increments of 0.4 mm (1/64 in). Use of numbered or metric drills would permit using limits of about ± 5 percent. Either of these limits is well below the localized variations that are found in the intake rates of the Portneuf soil. The orifice spacing corresponds with the minimum row spacing expected in the crop rotation sequence. This permits applying water to both sides of every row. The orifice coefficient of discharge was based on laboratory tests and varied from 0.5 for holes drilled in the pipe, to 0.86 for the special "short tube" type nozzles. Tests to determine the approximate velocity required for a stream of water to jet reliably to the surface through 0.3 m (1 ft) of silt loam soil above the orifice indicated a required minimum orifice velocity of 4.6 m/s (15 ft/sec). We used a Hazen and Williams coefficient of 140 as the coefficient of roughness for plastic pipe. The pipe diameter at the end was limited to a minimum of 57 mm (2 in.) to minimize the number of increases in diameter and to maintain an adequate pipe wall thickness.

The length of the lateral was determined by the dimensions of the field plot. In some installations the lateral length may be limited by the available water supply and the orifice discharge rates. The distances and elevations above or below the input end were obtained from a survey of the ground surface profile on 7.6-m (25-ft) increments along the centerline of the intended lateral location.

A computer program, written in Basic language for use on a Hewlett-Packard 9830A calculator, was developed to determine the locations where the pipe and orifice diameters must be changed. The program is written in English units, but can be changed to metric units. The flow diagram for this program is shown in Fig. 2.

The input data for this program are:

1 Orifice discharge (gpm) (l/s)

2 Orifice discharge limits (± percent)

3 Orifice spacing (ft) (m)

4 Orifice coefficient of discharge

5 Minimum orifice velocity (ft/sec) (m/s)

6 Pipe coefficient of roughness (Hazen and Williams)

7 Pipe diameter at outer end (in.) (mm)

8 Length of lateral (ft) (m)

9 Distances from and elevations above or below the input end (ft) (m)

The computer program determines and prints the following output data in English units for each orifice location. (It can be changed to print (indicated) metric units):

1 Distance from the input end (ft) (m)

2 Flow rate in the lateral (gpm) (l/s)

3 Pressure head (ft of water) (m)

4 Velocity in the lateral (ft/sec) (m/s)

5 Velocity head (ft of water) (m)

6 Velocity head plus pressure head (ft of water) (m)

7 Required lateral diameter to maintain pipe velocity below 5 ft/sec (1.5 m/s) (in.) (mm)

8 The orifice diameter required to maintain the orifice discharge within the discharge limits (1/64th in.) (0.4 mm)

9 The computed orifice discharge rate (gpm) (l/s) for each of the selected orifices.

The program begins computing

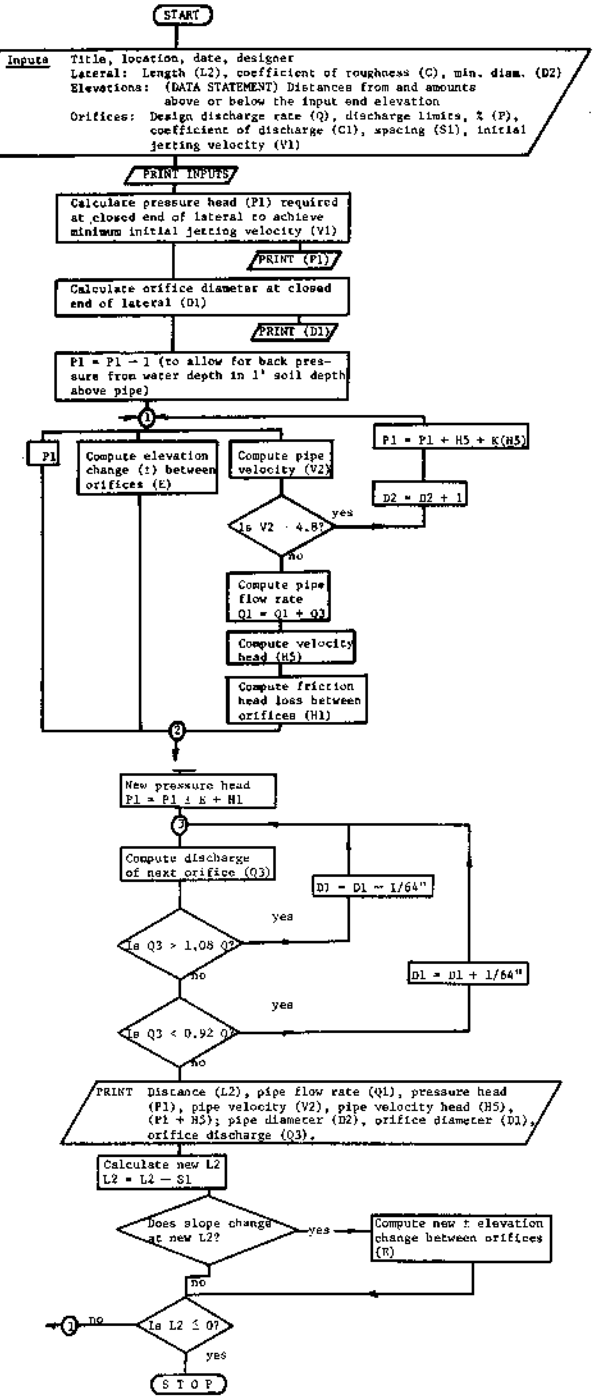

FIG. 2 Flow diagram of program that designs buried lateral systems.

these values at the terminal end of the lateral and continues stepwise upstream to the input end, taking into account any changes in elevation. Whenever the computed velocity in the lateral exceeds 1.5 m/s (4.8 ft/s), the pipe diameter is increased by a 25-mm (1-in.) increment, to decrease the head loss along the lateral and to keep the velocities below 1.5 m/s (5 ft/sec), the recommended maximum for plastic pipe. When the pressure head increases or decreases so that the orifice discharge is outside the prescribed limits, the orifice diameter is decreased or increased 0.4 mm (1/64th in.) to bring the discharge back within tolerance.

A 33.5-m (110-ft) long lateral with 60 orifices on 56-cm (22-in.) spacings designed by this program was tested for uniformity of discharge from the orifices by operating it above ground. The pipe was first operated on a 1.8 percent upslope. The nozzles were then changed for downslope operation, and the pipe tested on a 1.1 percent downslope. The discharge from every fifth orifice was measured in both tests. In the upslope location, the discharges ranged between + 7 percent and - 8 percent of the average discharge. The downslope test ranged between ± 5 percent of the average discharge. This range was considered satisfactory since individual furrows on the Portneuf soil have a greater variability of intake rates.

Installation of System

The computer program was used to design the experimental buried lateral system. The laterals were assembled above ground from Class 125 PVC plastic pipe so that orifices could be spaced every 56 cm (22 in.) along their 50-m (165-ft) lengths. The 56-cm (22-in.) spacing was selected to allow every furrow to be irrigated when the crops with the smallest row spacing are grown. The two upslope laterals were then drilled and tapped so that short nozzles made from 10-mm (3/8-in.) pipe plugs could be threaded into the pipe walls. These nozzles were carefully drilled in the shop to the computed orifice sizes and the nozzle input ends were beveled to decrease head loss and shape the jet flow. The lower lateral was installed without these nozzles. Its orifices were carefully drilled through the pipe wall in the field. The orifice flow coefficients were smaller so the orifices had somewhat larger diameters than the nozzle inside diameters. All the outlet diameters ranged from 5 to 15 mm (3/16 to 9/32 in.) for this installation.

The assembled laterals were placed in a 15-cm wide trench and at a depth so that the top of the pipe would be at least 30 cm (12 in.) below the ground surface. The outer end of each lateral was brought to the surface at a 45-deg angle and closed with threaded pipe caps so that the lateral could be flushed or cleaned when needed. The trench was partially backfilled with soil and puddled. Three days later the soil was tamped around the pipe to prevent piping along the lateral. Mixing the backfill soil with sand and fine gravel could be used to prevent piping, but this could not be done in this experimental plot area. The trench was then backfilled to above ground level and again puddled.

Five small check structures were installed across the drain at the lower end of the field. This was done to aid in wetting the lower ends of the rows and to reduce runoff to a minimum.

SYSTEM OPERATION

The buried lateral system was op-

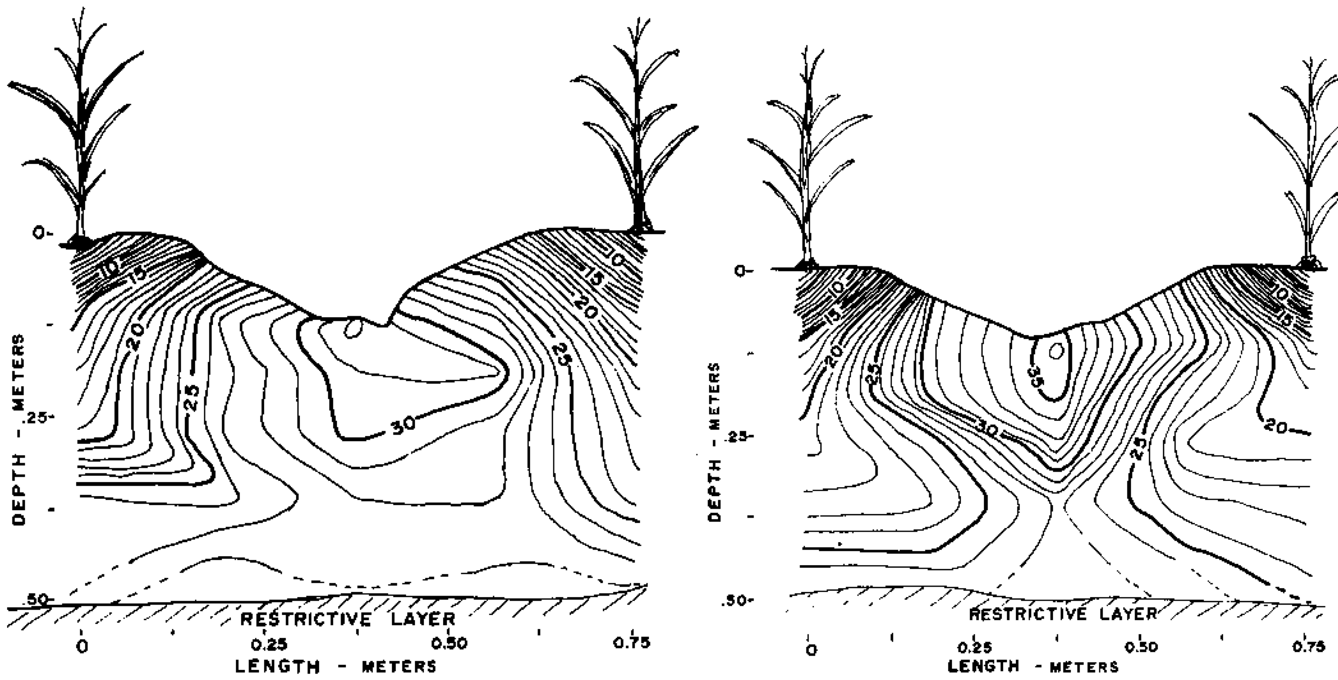

FIG. 3 Typical soil water distribution (percent volume) (A) prior to, and (B) 3 to 4 hr after daily application of 7.6 mm (0.3 in.). Contours indicate soil water contents (percent volume) as determined gravimetrically.

erated automatically from a gravity water supply. The pressure head at the inlet end was 17 to 18 kPa (5.5 to 6 ft) and was controlled with a float valve in the supply system. The pressure head decreased to 7 to 9 kPa (2.5 to 3 ft) at the outer end of the laterals. The flow in each lateral was controlled by automatic Snake River pipeline valves described by Humpherys and Stacey (1975). These valves, in turn, were sequenced by a commercial programmable turf irrigation controller. A tensiometer soil moisture sensor connected to the controller prevented the start of this sequencing if the soil moisture below the row at that location was below 50 centibars.

When pressure was applied to the laterals, the water quickly jetted to the surface and flowed down the furrows. During the first irrigation, unneeded outlets were plugged by reaching into the hole washed by the jet and placing a small rubber stopper in the orifices or nozzles. A few furrow alignments also needed slight modification with a shovel to make them coincide with the lateral outlets. When outlets need to be reopened with narrow spaced furrows, the plugged outlets are located by measuring over from an operating outlet, digging down, and manually removing the stopper.

Minor Operational Problems

Turbulence at each outlet caused erosion and sloughing of the backfilled soil of the trench so that some adjacent scour holes enlarged until the flows from two or more orifices merged and tended to flow down a single furrow. This was remedied by manually placing a 40-mm (1.5-in.) diameter plastic tube over each jet to conduct the water to the surface without erosion. The scour holes were filled around these tubes with two or three shovels full of soil. These tubes were 20 cm (8 in.) long with the two ends cut parallel on 45-deg angles. This design permitted tilting the tube when necessary to deflect the flow laterally from the orifice to the furrow. We also found that a slightly longer tube was needed where the furrows crossed the midfield laterals. These laterals were on a slope of about 1 percent and without the longer tubes, runoff water from the upper reaches drained from the furrows on the high side of the field into the drained midfield laterals. This water emerged on the low side of the field resulting in a nonuniform distribution. This backflow also carried silt into the lateral. By placing longer plastic tubes over the lateral outlets, the discharge water emerged slightly above the flowing water surface in the furrows and prevented "tailwater" from upper sections from entering the lateral when it was empty. Installing downfield laterals on the contour would overcome this problem.

Using curved tubes or tubes with elbows at the top is an alternate solution. Such a tube could be placed in the plant rows out of the way of cultivators and yet direct the flow from the orifice to the proper corrugate.

About one-half hour of hand work was required to install the 66 tubes on each lateral. This would amount to an annual cost of \$4.60/ha (\$1.85/ac) if labor is valued at \$2.50/hr. They were left in place until harvest since no cultivations were needed. They may not be required at the upper end of the field in future seasons after the trench backfill has settled and stabilized. Other methods of controlling the size of these scour holes are being considered.

There was minimal problem with orifice plugging. Out of the 198 outlets, 5 became noticeably plugged during the season, but were easily reopened with a short wire. The water supply was Snake River canal water that had passed through a small holding pond with a 30-mesh screen over the outlet to the irrigation system. The laterals were flushed for 1 to 2 min weekly, at which time we noted an accumulation of silt.

Field Testing and Results

Between July 7 and September 4, the crop was irrigated with light, frequent irrigations that closely approximated evapotranspiration. This was achieved by daily irrigations during most of this period. The 48 irrigations applied 491 mm (16.5 in.) of water. The profile held 63 mm (2.5 in.) of water at the start of the season and precipitation was 20 mm (0.8 in.) dur-

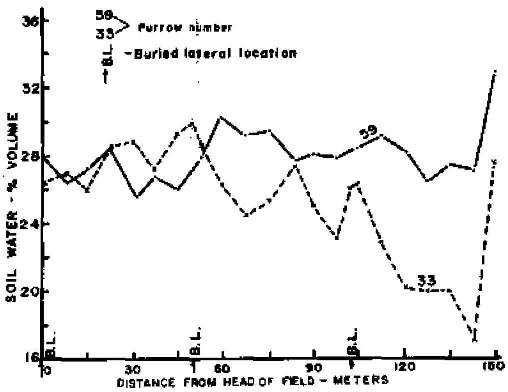

FIG. 4 Soil water distribution along the length of 2 furrows at midseason.

ing the season. The frequent irrigations kept the interrow spaces damp, but the plant rows remained rather dry, as illustrated by Figs. 3A and 3B. The light, frequent irrigation procedure helps achieve high water use efficiency. Water use efficiency, E_u, is defined as:

$$E_u = \frac{\text{crop water requirement}}{\text{water application}} (100)$$

Measured runoff amounted to 2.6 percent of the water applied during the season. Deep percolation was estimated to be less than 2.5 percent of the water applied. This estimate of flow under unity gradient was made using the unsaturated hydraulic conductivity value of 0.008 mm/hr that occurs when the volumetric moisture content is about 27 percent, a condition that was found throughout the season just above the restrictive layer (see Fig. 3). These calculations indicate that the seasonal water use efficiency was approximately 95 percent. This high efficiency did not cause a salt accumulation problem under the local soil, water, and climate conditions. If the soil eventually requires leaching over and above that achieved by winter rainfall, excess irrigation could be applied by the system early in the season or after harvest.

Uniformity of application is more difficult to analyze when using this system than with a sprinkler system. It would require taking very many soil samples several times during the season to adequately determine the coefficient of uniformity when irrigating with light, frequent furrow irrigations. The crop did not show any evidence of nonuniform irrigation. The uniformity of application along the length of a furrow is greatly improved when water is applied frequently and the furrow remains damp so that water moves quickly through it. In our system, the water advanced from one lateral to the next in 20 to 30 min. The recession time was 8 to 10 min. An application period of 40 min permitted an opportunity time at the upper end of the set that was about twice that at the lower end, but the curvilinear change from the "initial" intake rate of this damp soil to its "final" rate tends toward a uniform application along the length of a furrow. There were some intake rate variations between rows due to tractor wheel compaction effects.

Fig. 4 shows the moisture variations along the length of the center of furrow No. 59, a typical furrow at mid-season. Volumetric soil water content (0 to 50 cm depth) varied between 25 and 31 percent along most of its length. At the same time, furrow No. 33 with a higher intake rate did not get sufficient water near the lower end, but the corn showed no visible stress symptoms. Adjacent furrows seemed to be somewhat wetter and could have supplied much of the water used by these plants. Despite the slow start, the corn grew to a height of 2.5 to 3.5 m and produced 74 metric tons/ha (33 tons/ac) with 71 percent moisture content when it was mature and sampled on September 5. The yield was about the same on an adjacent carefully irrigated check plot with 155-m furrow length. The higher flow rates required for this length of run caused erosion of the furrows in the adjacent plot that exceeded 45 metric tons/ha (20 tons/ac) at the upper ends which resulted in silt depositions near the lower ends of the furrows and decreased their flow capacities. The total seasonal water application on the check plot was 803 mm (31.6 in.) with 35 percent runoff. This total application was 1.6 times that of the multiset plot and the runoff from the check plot was 22 times greater than the runoff from the multiset system. There was no visible erosion or deposition in the multiset plot.

SYSTEM ECONOMICS

Costs of Buried Systems

The initial cost of a buried multiset system is about the same as a solid-set sprinkler system. Many variables affect the cost, but to determine a relative cost, we evaluated the following two buried multiset designs.

A square 16-ha (40-ac) field was used in both designs. The first design (Fig. 5a) could enable achieving about 95 percent water use efficiency with no erosion, while the second design (Fig. 5b) could enable achieving about 80 percent water use efficiency with minimal erosion. Both designs were based on Class 125 PVC plastic pipe with drilled orifices. The estimated cost of the valves was $100 each, and the valve control units about $50 each. Estimated installed costs for the 150-mm (6-in.) mainline used in design 1 were about $6.50/m ($2/ft) and $5.75/m ($1.75/ft) for the laterals. The master control unit was estimated to cost about $500. Using these figures, the total cost of the system shown in Fig. 5a would be $32,500, or $2,010/ha ($813/ac) for a fully automatic system. A manually operated system would cost about $1,880/ha ($760/ac).

Using the same estimated unit costs for the system shown in Fig. 5b, but with a master controller cost of $400, the less intensive system with longer subruns and lateral lengths as shown would cost $16,000, or $990/ha ($400/ac). A manually operated system could be installed for about $925/ha ($375/ac) on this design.

Jensen and Humphreys (personal communications) suggested designs where the distance between laterals would be nonuniform with longer runs on the upper part of the field and shorter runs below. One design (Fig. 6) would have one 3-way control valve that would divert the water sequentially over three separate sections of an area. The length-of-run in Sections I and II would be twice as long as the length-of-run in Section III. The total flow would be directed first to Section I, then to Section II, and then downfield where it would be distributed over Section III to

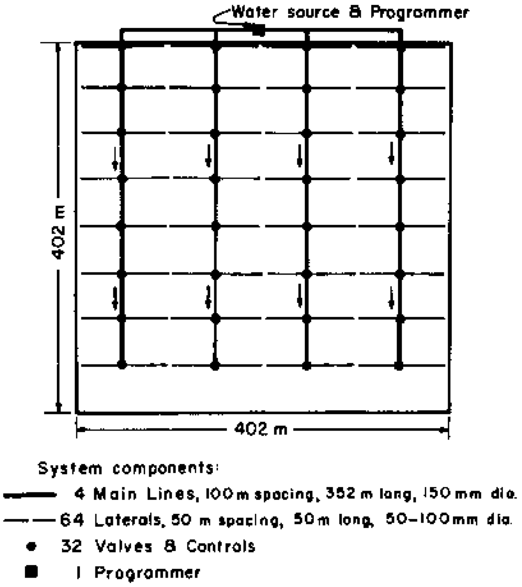

FIG. 5a Very high efficiency, zero erosion design for buried lateral system installed on a square 16-ha (40-acre) field with a uniform slope. The estimated cost of this system is $2,010/ha.

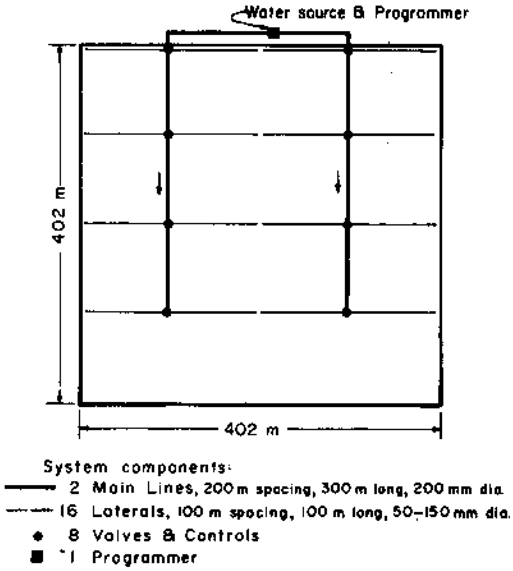

FIG. 5b High efficiency, low erosion design for buried lateral system installed on a square 16-ha (40-acre) field with a uniform slope. The estimated cost of this system is $990/ha.

apply water to each of these shorter furrows at half the flow rate used for furrows in the upper sections. This design would not enable as high an application efficiency or the degree of erosion control as the first two designs, but it would be a great improvement over many existing gravity systems and would result in the same savings in energy or labor costs as the first two designs. The system would be made up of "modules" (Fig. 6), and the size of the module would be determined by the water supply rate and the intake characteristics of the soil. System module 1 installed on a loam soil could require a flow of 28 l/s (1 cfs); system 2, 57 l/s (2 cfs); and system 3, 85 l/s (3 cfs). Table 1 shows that as water supplies and module sizes increase, installation costs per unit area decrease because a large proportion of the costs of the smaller modules is in the "downfield" line. We have not determined the optimum cost design of the many possible variations.

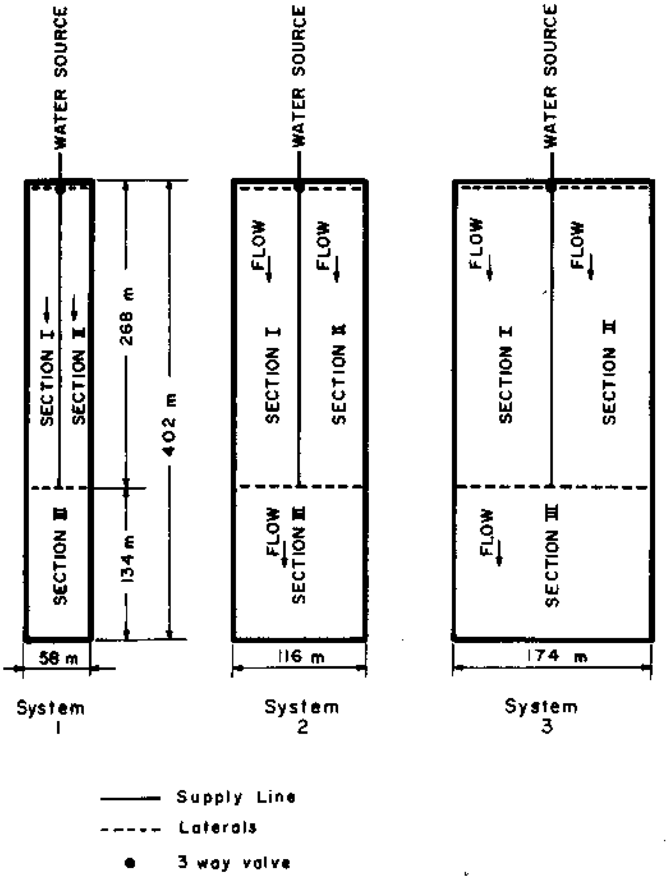

FIG. 6 Illustration of modular concept for design of buried lateral systems.

Operational Savings

The high initial cost of a buried multiset system can often be partially offset by reduced or zero power costs when compared with sprinkler systems, or by lower labor costs when compared with present types of gravity systems. Farmers in southern Idaho are presently paying between $12 and $37/ha ($5 and $15/ac) per year for

TABLE 1. COMPARISON OF COSTS OF 3 MODULE SIZES OF BURIED LATERAL IRRIGATION SYSTEMS.

	System					
	1		2		3	
Flow required						
l/s	28		57		85	
(ft³/s)	(1)		(2)		(3)	
Area						
ha	2.3		4.7		7.0	
ac	(5.8)		(11.5)		(17.3)	
Costs per module:						
Laterals	$ 428	18%	$1,235	32%	$2,137	40%
Midfield line	1,760	75%	2,420	63%	3,080	57%
Controls	175	7%	175	5%	200	3%
Total	$2,363		$3,830		$5,417	
Cost/ha	$1,027		$ 815		$ 774	
Cost/ac	(410)		(332)		(314)	

TABLE 2. ANNUAL REPAYMENT COSTS/HA OF 2 BURIED LATERAL MULTISET SYSTEMS.

Cost of system	Repayment period 10 years	15 years	20 years
per ha		@ 8%	
$ 2,010	$ 300/yr	$ 235/yr	$ 205/yr
990	148/yr	116/yr	101/yr

electric power for pumping from a surface water source to operate sprinkler systems. This cost is increasing and is expected to triple within the next 10 years.

Surface irrigation labor costs are more difficult to estimate since they are subject to many variables. Assuming it requires 1.85-hr/ha (0.75-hr/ac) for each irrigation of row crops like beans, beets, corn, or potatoes in a rotation, and if the pay rate for irrigators is $2.50/hr, the estimated annual irrigation labor costs for the above crops would average about $50/ha ($20/ac). Ditch cleaning, depreciation of siphon tubes or gated pipe, and structure repair would be additional expenses and may offset the annual unknown depreciation and maintenance expenses of the buried lateral system. There would be other less tangible benefits, such as erosion control, less water use, and more convenient farming. If energy and labor costs increase as expected, or if labor becomes less available, a buried or other automated gravity system may be necessary in some areas.

Table 2 shows an amortization approach to this cost analysis. The annual repayment values (dollars/ha) in Table 2 would be partially offset by $50/yr for labor savings as compared with present surface irrigation systems, or by $25/yr for power savings as compared with sprinkler systems. If these expenses on present systems increase as expected, the $990/ha system will soon become feasible on this basis alone. The $2,010/ha system needs even higher power or labor costs, or other less tangible benefits of convenience, erosion control, and greater water use efficiency to make it feasible.

SUMMARY AND CONCLUSIONS

An experimental automatic, buried lateral, multiset, gravity irrigation system has been designed, installed, and tested for one season with irrigated corn on a 0.8-ha field. A computer program has been developed to readily compute pipe diameter and orifice size for any specific site.

The silage corn irrigated by this system produced an excellent crop in spite of late planting, frost damage, and very cool early season weather. The amount of water applied was about 2/3 of the adjacent check plot and with no erosion or sediment loss from the field. The check plot had 22 times more runoff and substantial erosion and deposition in the furrows. The system was operated automatically during July and August to apply light daily irrigations to replace the estimated daily evapotranspiration. The overall seasonal water use efficiency is estimated at 95 percent with no yield reduction. This routine maintained a damp inter-row space with dry surface soil in the plant rows. The moist furrows tended to equalize water intake amounts throughout the furrow lengths, thus providing quite uniform water application along the length of most of the furrows. The intake rates of alternate furrows varied widely with some furrows infiltrating the water as much as 2.5 times faster than others. This was mostly because of wheel compaction. Using furrow slickers or other compaction techniques could reduce this variation in many soils.

The system performed very well with very little maintenance. The laterals were flushed briefly each week, and only 2.5 percent of the orifices required cleaning throughout the season.

The initial cost of this system installed on fields that have been surface-irrigated is about the same as a solid-set sprinkler system. Buried lateral systems installed on new lands would require additional expense of some land leveling to achieve consistent downslopes to accomplish uniform intake rates. Slopes up to 10 percent could be irrigated by a buried multiset system, but the small diameter laterals would be very closely spaced to apply small, nonerosive streams. Fields with rolling, irregular topography would also require many more laterals and controls. Under these conditions, sprinkler irrigation systems probably would be advisable for most crops. Additional guidelines are needed to assist in deciding between a buried lateral or a sprinkler system for specific fields.

We estimate that furrows with up to 4 percent or more side slope could be irrigated with a buried multiset system without breakover between rows because the smaller, nonerosive streams do not deposit sediment in furrows. In spite of high initial costs, the savings on power compared with sprinkler irrigation and low labor costs of automated systems may make the buried system an attractive option to irrigators.

References

1 Humpherys, A. S., and R. L. Stacey. 1975. Automated valves for surface irrigation pipeline systems. Proc. Am. Soc. Civil Eng., J. Irrig. & Drain. Div. 101(IR2):95-109.

2 Milligan, T. 1974. Buried automatic furrow irrigation in Texas. Irrig. Age, Mar. 1974, p. 16.

3 Rasmussen, W. W., J. A. Bondurant, and R. D. Berg. 1973. Multiset irrigation systems. ICID Bull., Jan. 1973, p. 48-52.

4 USDA, Soil Conservation Service. 1970. Irrigation guide for southern and southeastern Idaho. USDA, SCS, Boise, ID.

5 Varlev, I. 1973. Surface irrigation underground pipelines with movable risers. TRANSACTIONS of the ASAE 16(4):787-789.