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677 South Segoe Rd., Madison, WI 53711 USA

A Buried Pipe System for Controlling Erosion and Sediment Loss on Irrigated Land[1]

D. L. CARTER AND R. D. BERG[2]

ABSTRACT

A new system comprised of a buried pipe, with riser inlets from the surface at intervals, along the lower end of furrow-irrigated fields was designed, installed, and evaluated on 21 fields to determine its effectiveness as an erosion and sediment loss control system for irrigated land. The system utilizes small sediment collection ponds with the riser inlets from the buried pipe serving as overflow outlets for the ponds. This system corrects convex-shaped field ends caused by erosion and solves an energy related erosion problem common on furrow-irrigated land. During the first season, these system removed from 80 to 95% of the sediment from runoff water and collected from 4.1 to 40.5 Mg ha^{-1} from 12 fields on irrigated land where detailed data were collected. All systems performed without problems and all convex end problems except one were corrected the first season. After the convex ends are corrected, the system continues to reduce sediment loss. This new system eliminates the tailwater ditch, puts more land into crop production, reduces weed problems, and prevents the usual problems associated with a wet tailwater ditch. The buried pipe erosion and sediment loss control system is a major advance in the control of erosion and sediment loss on irrigated land.

Additional Index Words: **furrow erosion, mini sediment ponds, tailwater control, surface irrigation.**

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FURROW EROSION has been recognized as a serious problem on irrigated land since the 1940s (7, 9, 11), and the problem continues today. Factors that influence furrow erosion, such as slope, furrow stream size, soil type, and type of crop, were recognized by scientists and engineers 40 or more years ago, but the application of available technology has been slow. Farmers continue to apply furrow streams that are larger than necessary and irrigated row crops down slopes that are too steep for satisfactory furrow irrigation. Recent research indicates that erosion and subsequent sediment and nutrient losses today are about the same as they were 35 years ago (2, 4, 5, 6). However, the scene is changing. Water quality legislation during the past decade has aroused public awareness of water quality problems. The initial interpretation of P.L. 92-500 (13), enacted in 1972, required that irrigators have a permit to discharge runoff water. The permit could be retained by meeting certain water quality standards. The legislative interpretation process has progressed from that point to the present approach of applying the best available technology to improve runoff water quality as much as possible before discharging it into a river or major stream. During this time available erosion and sediment control technology for irrigated land has been summarized and evaluated (2, 4) and new technology development has progressed significantly. Present research and development indicate that irrigation runoff water quality can be markedly improved.

Robbins and Carter (12) showed that an average of 1200 t of sediment were removed from 219 000 m^3 of surface runoff water by passing the water through a sediment retention pond. This represented a sediment removal efficiency of 85% during most of the irrigation season. A more detailed study has shown that sediment ponds efficiently remove both sediment and phosphorus from surface runoff water (3). Humpherys (8) developed an automatic furrow stream size control system that reduces the stream size when the water reaches the lower end of the furrow. Reducing the stream size in this manner reduces furrow erosion and sediment loss. Kemper et al. (10) recently introduced "Cablegation," which is an automated, furrow irrigation system that includes stream size reduction with time after the irrigation begins. Cablegation promises to be a highly efficient, low labor, low energy, and low erosion method of irrigating where it is applicable.

Cablegation and automatic cutback deal with the stream size factor relating to erosion and sediment loss control. Aarstad and Miller (1) reported that small amounts of straw in irrigation furrows provide excellent furrow erosion control. Their results are being used as a basis to place residue in furrows along critically erosive sections such as lengths of steeper slope along the furrow, upper ends, and lower ends of furrows.

Improved irrigation systems and practices that control stream size are needed for erosion and sediment loss control. Any practice that will reduce the energy of an eroding furrow stream will reduce erosion. However, the acceptance and implementation of new irrigation systems usually require several years. Therefore, significant impact of such new systems is in the future. During the interim, erosion and subsequent soil loss will continue unless abated by positive control and conservation practices. Hence, there is a need for simple erosion and sediment loss control practices to protect our soil resource now, and in the future. Our investigations over the past decade have shown that extensive erosion is occurring at the upper end portions of furrows, because of the larger stream size and attendant energy to erode, and that much of the sediment generated from that erosion generally is deposited before it reaches the lower end of the furrow.

Observations and measurements on many irrigated fields made us aware that much of the sediment being lost from furrow-irrigated land was eroded from the last few meters of the furrows. The practice of keeping the tailwater ditch deep and well cleaned so that tailwater is removed rapidly has caused furrows to erode upstream from the tailwater ditch. Over the years the lower ends of fields have become convex shaped with slope increasing into the tailwater ditch. As water velocity increases along these increasing slopes, the energy available for erosion increases, and furrows erode into narrow channels to the plow depth or deeper. Lateral water movement to the roots of young row crop plants is limited and plants die from drought, leaving a barren strip along the lower field ends. We observed that the small furrow stream immediately upstream from the point where the slope began to increase often appeared to carry much less sediment than at the point where they entered the tailwater ditch.

[1] Contribution from USDA-ARS, Snake River Conservation Research Center, Route 1, Box 186, Kimberly, ID 83341. Received 25 Oct. 1982. Approved 14 Mar. 1983.

[2] Supervisory Soil Scientist and Agricultural Research Technician, respectively.

This paper reports the development and evaluation of a buried pipe system to control erosion and sediment loss from furrow-irrigated land by controlling the erosion that occurs near the ends of furrows.

MATERIALS AND METHODS

Nineteen fields exhibiting increasing slope along the lower few meters of furrows, thus having a convex-shaped end, were selected for installing experimental buried pipe runoff control systems. Ten of these sites were selected for detailed measurements of sediment removal efficiency, and another nine were selected where various applications of the system could be observed. An additional site selected for detailed study had a surface drain located between two fields (Sites 11 and 11A), both irrigated towards the drain, which served as a conveyance for surface drainage water from other fields. The total of 20 systems and 21 fields was studied. The field sizes were determined by measurement or from land use maps. Field slopes were measured with a survey level to the nearest 0.5%, or more exactly in some cases, from the upper to lower ends. The size of the irrigation supply stream was estimated based upon canal company diversion records or by questioning the farmer or irrigator. The pipe size was determined by calculating the hydraulic carrying capacity at the slope along the tailwater ditch and estimating that 50% of the applied water may run off (2).

Three types of pipe were used in the initial installations. These were solid PVC, corrugated PVC, and corrugated polyethylene pipe. Two sizes, 15.2 and 20.3 cm I.D., were used at all sites, except for the one that served two fields and is a drain for others, which was 30.5 cm I.D.

Trenches were dug along the tailwater ditch with a small trenching machine or with a backhoe. The slope along the trench bottom was determined with a survey level and adjustments made by shoveling to assure a continuous slope of 0.4% or more, except that less slope was allowed near the pipe outlet at one site in order for the pipe to pass through a road culvert. All systems discharged into a natural drain or a drain which was part of the canal system on the tract. The pipe was assembled using T-connectors at intervals to provide for a vertical inlet from the soil surface. Short pieces of pipe were placed vertically in the T-connectors. The spacing of the T-connectors varied from 6 to 24 m, depending on the slope along the pipe. The greater the slope, the closer was the spacing. The 24-m spacing was used where the slope was $< 1\%$. The pipe was placed in the trenches and covered. Depths varied among the sites, but in all cases, except a short distance along one pipe, the depth of cover was at least 45 cm.

Small earthen dams were formed immediately downslope from each riser inlet (Fig. 1 and 2), extended about 3 to 5 m perpendicular to the buried pipe, depending on the severity of the convex end. These dams and the usual obstruction along the lower end of the field formed small sediment ponds or "minibasins" along the lower end of the fields. At some sites, a dike had to be constructed parallel to the buried pipe to form the downslope side of the mini basins. The top of the riser inlet was cut off at an elevation approximately equal to the ground surface 3 to 5 m upslope along the furrows from the pipe. These riser inlets served as outlets for the minibasins.

Fig. 2—Buried pipe erosion and sediment loss control system in operation.

We used two approaches to determine the quantity of sediment collected in the minibasins and the sediment removal efficiency of the systems. One approach was to use a survey level and determine the elevation of the minibasin bottom on a grid after they were formed, and then to determine the depth of deposited sediment on the same grid after the irrigation season. These measurements along with bulk densities of the sediment enabled calculating the amount of sediment deposited. This along with the known drainage area provided a measure of the sediment collected per unit of land area. The other approach was to measure water flow into the minibasins each irrigation and collect samples for determining sediment concentration entering and leaving the minibasins. Summarizing these data for the irrigation season gave a measure of the total amount of sediment eroded from the field, the amount deposited, and the sed-

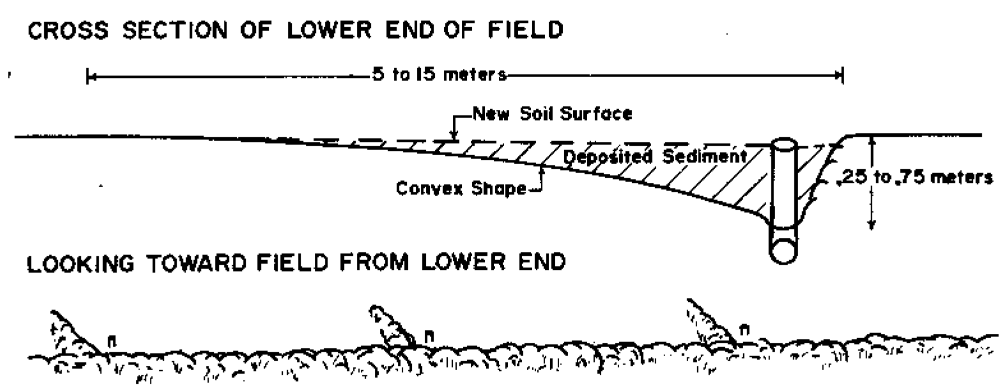

Fig. 1—Cross section of lower end of field illustrating sediment deposition and change in slope with buried pipe erosion and sediment loss control system. Looking toward the field from the lower end illustrates small sediment basins formed by small dams or burms.

Table 1—Sediment deposited and sediment and P removal efficiencies of buried pipe erosion and sediment loss control systems.

Site	Crop	Field size	Slope along furrows	Slope along pipe	Riser inlet spacing	Pipe size I.D.	Total sediment runoff	Sediment deposited	Sediment removal efficiency	Total P removal efficiency
		ha	%		m	cm	Mg/ha		%	
1	Beans	15.0	1.0	1.0–3.0	6–18	20	11.6	9.6	84	88
2	Beans	3.5	1.0	1.0	18	20	7.6	6.9	91	79
3	Beans	4.0	1.0	1–3	18	15	7.0	5.2	74	61
4	Beans	0.53	1.0	1–2	12	15	7.9	7.2	91	89
5	Corn	2.4	1.0	0.5–1.0	12–24	20	14.7	12.5	85	–¶
6§	Sugarbeets	8.8	1.0	1.5	18	20	26.9	22.8	85	63
7	Beans	8.8	1.0	1.5	18	20	45.0	40.5	90	–
8‡	Beans	2.2	1.5	1.5	12	15	23.9	22.5	94	–
9‡	Beans	5.8	1.0	1–2	12–18	15	5.1	4.1	81	–
10‡	Beans	7.9	1.5	1–4	6–18	15	15.4	12.8	83	–
11	Sugarbeets	6.0	1.0	0.6	18	30†	18.0	16.0	85	–
11A	Beans	6.7	1.0	0.6	18	30†	18.8	13.9	74	–

† Riser inlets were 20 cm I.D.
‡ Runoff at these sites indicated a need for 20-cm I.D. pipe. We had a supply of 15-cm I.D. pipe, and two lines were placed side by side with alternate riser inlets into each.
§ Minibasins were cleaned and data were collected another season.
¶ Where no total removal efficiency data are given, total P was not measured.

Table 2—Sediment removal efficiencies after small sediment basins have filled with sediment, and convex end problem has been corrected.

Site	Crop	Sediment removal efficiency, %
2	Beans	51
3	Beans	66
6	Beets	75
8	Beans	83

iment removal efficiency of the system. Of course, the sediment inflow onto the field in the irrigation water was measured and subtracted from the total sediment runoff to give net amounts.

A related study was conducted to determine the increase in erosion and sediment loss caused by convex field ends. This assessment was made by selecting fields with convex ends, measuring the sediment concentration in the furrow inflow water, in the furrow stream immediately above the point where the slope increase begins, and in the furrow stream at the point where the stream entered the tailwater ditch. Inflow and outflow furrow stream sizes were also measured with a small calibrated flume. Results from three or more furrows on each field were averaged. Some of these data are reported to demonstrate the effectiveness of the buried pipe systems for reducing erosion and sediment loss.

Sediment concentrations were determined by filtering, drying, and weighing the sediment in 1-L samples. These samples were obtained by catching the entire furrow stream or by means of a hand pump suction sampler.

Total phosphorus concentrations were determined using potassium persulfate digestion in an autoclave and the ascorbic acid procedure for determining PO_4^{-3} concentration (5).

RESULTS AND DISCUSSION

The quantity of sediment deposited in the minibasins at the 11 detailed data collection installations ranged from 4.1 to 40.5 Mg ha^{-1}, and the sediment removal efficiency from the runoff water ranged from 74 to 94% (Table 1). The sediment removal efficiency was > 80% at all sites except two. One was Site 3 where the minibasins filled early and the other was Site 11A where the field end had been shaped during installation so that the slope was < 1% near the furrow ends and the slope increased only slightly into the basins. Results indicate that the sediment removal efficiency of these systems will generally range from 80 to 95% the first season, until the minibasins are filled with sediment.

All 20 systems performed well with no clogging or operational problems. After one season the minibasins at all sites except Site 1 were filled with sediment, thus correcting the convex end problem, and eliminating the increase in slope near the furrow ends that previously allowed water velocity and erosive energy to increase. Three operators chose to clean the minibasins and used the sediment to fill low areas in fields. At those sites, the minibasins filled with sediment again the second season of operation. Actually, most of the minibasins were filled with sediment after four irrigations.

Sediment removal efficiencies were measured at some sites the season after the convex end problems were corrected by sediment deposition. The sediment removal efficiency of the systems decreased after the convex problems at lower ends of the fields were corrected (Table 2), but efficiencies remained favorable. The sediment removal efficiency after the convex field end has been corrected depends upon the overall field slope and the irrigation practice. These factors determine the quantity of soil eroded along the furrow, and the amount reaching the furrow ends. At sites where furrow stream sizes were small enough so that they carried little sediment a few meters from the furrow ends, there was very little sediment to be concerned about. At other sites where furrow streams were larger than necessary, more sediment was lost, but even at those sites the sediment removal efficiency remained fairly high and the quantity of sediment involved was much less than when convex problems were evident. Generally, the dead furrow left from plowing upslope is sufficient to trap most of the sediment running off in a season after the convex end is corrected.

Convex field ends can increase erosion and increase sediment loss two to three times where slope increases are most severe (Table 3). These data indicate that correcting the convex end problems would decrease sediment loss to one-half or one-third in subsequent seasons, by eliminating the erosion along the convex field ends. This reduction represents only part of the overall sediment loss reduction, because an additional 51 to 83% of the sediment was removed from runoff water after the minibasins had filled with sediment (Table 2). The effect of the buried pipe systems is twofold. The first is to stop the erosion along the last 5 to 30 m of furrows, and the second is to

Table 3—Sediment concentration increases associated with convex ends or increasing slope along the lower 5 to 30 m of fields.

Furrow inflow	Stream outflow	Crop	Sediment concentration			Erosion increase factor†
			Inflow	Above‡	Below§	
— L/min —				mg/L		
43.5	22.2	Sugarbeets	97	2 460	5 180	2.0
38.2	16.9	Sugarbeets	142	4 940	10 600	2.1
21.2	10.4	Sugarbeets	272	2 410	6 920	2.9
18.3	10.1	Beans	62	2 570	5 820	2.3
17.1	12.8	Beans	123	5 440	13 300	2.4
20.8	2.28	Beans	66	6 310	13 900	2.2

† The sediment concentration increase factor from "above" to "below," or the increase along the short convex-shaped furrow end section.
‡ The upslope end of the increasing slope or convex-shaped end portion of the furrows.
§ The downslope end of the increasing slope or convex-shaped end portion of the furrows.

remove much of the sediment arising from erosion further up the furrow. The latter effect results from hydraulic leveling the lower end of the field causing flow velocities to decrease so that sediments settle out before water enters the pipe inlets. Every season, the hydraulic leveling extends a little further upslope. Tailwater along the lower ends of fields does not accumulate because of the numerous pipe inlets, each handling the flow from a few furrows.

Several sites had field roads along the lower ends of the fields separated from the field by the drain ditch that was too deep for equipment to cross. This required turning equipment around on the crop side of the tailwater ditch. Installing the buried pipe system made possible the use of the field road as an equipment turn-around area, because the ditch no longer existed after the first year. This added productive area to the field, increasing the net income.

The productive area was also increased on many fields because furrows no longer eroded so deep that lack of lateral water movement prevented growth of young plants. This factor combined with the elimination of the drainage ditch added from 3 to 7% to the productive area of fields studied. Although we did not do a detailed economic evaluation, we estimated that increased profits would pay for installing a buried pipe erosion and sediment loss control system in 4 to 8 years on most fields.

There are also other benefits to be derived from installing buried pipe erosion and sediment loss control systems. One is that farmers can more readily cultivate part of a field while another part is being irrigated, because the conventional, wet, tailwater ditch no longer exists. This is a distinct advantage on tracts where irrigation water is delivered on a continuous small stream basis, or where water is pumped from wells. Irrigating an 8-ha field often requires several days under these circumstances. With the buried pipe systems, cultivating can be done at the most beneficial water content or just ahead of the irrigation set if that is desired, without concern for a muddy ditch.

Another benefit is improved access for weed control and fewer weeds to control. Once the lower ends of fields have been hydraulically leveled and drain ditches eliminated, more of the area is covered with crop plants and fewer weeds grow because of crop plant competition. Also, because the tailwater ditch and its associated almost continually wet environment have been eliminated, fewer weeds grow, particularly those preferring a wet environment, and the lower end of the field is accessible to weed control equipment most of the time.

The buried pipe erosion and sediment control system takes advantage of the sediment transported by furrow streams to change the shape of the field end and eliminate or greatly reduce the energy of furrow streams to erode the lower ends of fields. The small furrow streams, which have already lost their energy to erode because of the decreased slope, gently flow into a riser inlet and carry little sediment with them.

Buried pipe erosion and sediment loss control systems should be very durable. We do not have longevity data, but information from manufacturers indicates that polyethylene pipe materials should last indefinitely. We are projecting a life of at least 30 years. The greatest hazard to these systems is mechanical damage from farm implements. Running over risers comprised of flexible pipe causes no damage, but sharp cultivating tools can cut the risers, requiring repair by adding a collar connection and a new portion of the riser. To date, no risers have required repair in our experimental systems.

These systems are easy to install. Our experience indicates that black polyethylene pipe is least expensive and easiest to handle when T-connectors are included. It is light weight for easy handling, and yet resistant to collapse under heavy loads, and connectors are easy to attach. These systems do not need to be water tight. Any kind of pipe can be used in these systems, but low cost, durable, easy-to-handle materials make these systems most practical.

The new buried pipe erosion and sediment loss control system is a major advance in the control of erosion and sediment loss on furrow-irrigated land, and in improving the quality of irrigation runoff water.

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