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Management Practices for Erosion and Sediment Control in Irrigated Agriculture

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Abstract: Irrigation erosion and subsequent sediment losses to rivers and streams continue to be serious problems confronting irrigated agriculture. The seriousness of these problems depends upon user concerns which in turn depend upon geographic area and populations. Erosion problems are less severe in California than in Idaho, but the concern for controlling water quality can be greater in parts of California because of subsequent water uses. Basin irrigating rice can reduce suspended sediment loads in water because the basins serve as sediment retention basins. Furrow erosion causes significant suspended sediment loads in return flows in California, but the problem is much more severe in Idaho. Topsoil redistribution by furrow erosion and sedimentation has reduced potential crop yields by approximately 25%. Several sediment loss control practices have been developed and evaluated, and are effective, but costs deter their application. Research is presently directed toward controlling erosion along irrigation furrows. Methods to increase soil cohesion and utilize residues in minimum tillage and no-till systems have high potential for controlling erosion and sediment loss during the next decade.

Introduction

Irrigation erosion causes a number of agricultural and environmental problems. The redistribution of topsoil caused by furrow erosion can severely reduce crop production (Carter, et al., 1985). Sediment losses from irrigated fields not only represent a natural resource loss, but also pollute waters and reduce their suitability for other uses. As water supplies have become limited, reuse has increased, and water pollution has received progressively more attention from all users. This increased attention has motivated legislative actions at the national, state, and local levels aimed toward preventing water pollution and removing various pollutants. Sediment in irrigation return flows has been identified as one of the most serious pollutants, and considerable research has been directed toward controlling irrigation erosion to reduce sediment concentrations in irrigation return flows. The seriousness of sediment in irrigation return flow depends upon potential subsequent uses of the water, which in turn depends upon the geographic area. Irrigation return flow water that will be used for subsequent surface irrigation in a low population density area may receive little attention even if sediment concentrations are several thousand mg/l. In contrast, a few hundred mg/l in irrigation return flow waters can present a serious problem attracting much attention if that water is a drinking water source or is used for water sport recreation in heavily populated areas such as parts of California.

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This paper reports results of research conducted in California where sediment production from irrigated lands may not be as severe as in some other states, but where the impact on receiving streams is of equal concern as in other states, and results of research in Idaho on highly erodible soils, where erosion has reduced crop yield potential by approximately 25%. Management practices for reducing sediment concentrations and loads in surface drainage waters from irrigation will be discussed.

Flooded Rice Fields in the Sacramento Valley.

Irrigation of rice fields in California consists of a series of basins surrounded by levees. Water is introduced into the uppermost basin controlled by an inlet gate and is discharged through levee boxes at the lowest elevation. Typically, water is maintained about 4 inches (100 mm) deep by flashboards in the levee boxes. Water from the uppermost basin passes through successively lower basins. The overflow water from the last basin is often discharged directly into a drain ditch through a "gooseneck" pipe to carry water under the access roadway and to minimize erosion of the drain ditch bank. Paddy rice culture requires a drainage system large enough to dispose of surface water runoff as well as cultural practices that require spill of water to a lower water level in the field quickly, e.g., during excessively windy conditions to prevent erosion of levees, or after application of herbicides and pesticides. More water is diverted for rice fields, because of continuous flooding and spilling, then for other crops, and rice irrigation is the largest contributor to irrigation return flows.

Extensive suspended sediment inflow and outflow studies showed that rice fields act as shallow sediment retention basins in series, with a sediment removal efficiency of about 84% (Tanji, et al., 1980). Approximately 20% of the inflow water becomes surface runoff and 16% of the sediment inflow exits in the drainage water. Therefore, rice irrigation reduces sediment concentrations about 4%, slightly improving water quality.

Furrow Irrigation Erosion Studies in California

Furrow irrigation erosion studies on tomato fields in the San Joaquin Valley showed that turbidity averaged 112 JTU in the inflow water and more than 2,000 JTU in the surface runoff, indicating significant erosion and sediment loss. Tailwater recovery systems are used for water conservation and to prevent sediments from entering streams (Tanji, et al., 1986). Similar studies were conducted in the Sacramento Valley (Tanji, et al., 1981). Furrow inflows from 3 to 15 gpm (0.19 to 0.95 l/sec) on land with a slope of only 0.001, produced initial sediment concentrations in the runoff water ranging from 4,500 to 10,300 mg/l. These concentrations dropped to 10 to 48 mg/l within a half hour indicating that erosion decreases quickly after the furrows are wetted. The unit mass emission of suspended sediments was 193 lbs/acre (216 kg/ha) for a field that had been periodically cultivated up to the time of the test. A second test, with no cultivations between the two tests yielded a mass sediment emission of only 60 lbs/acre (67 kg/ha) or about one third that of the first test. The difference represents the effect of recent cultivations on suspended sediment loss.

Irrigation Districts Comparisons

In a previous publication (Tanji, et al., 1977), a comparison was made on 1975 seasonal supply and surface drainage water and their qualities for the Glenn-Colusa Irrigation District (GCID) in the Sacramento Valley and Panoche Drainage District (PDD) in the San Joaquin Valley.

The dominant crop in GCID is rice which is basin flooded and the major crops in PDD are tomato, cotton, and other row and field crops which are normally furrow irrigated. In the GCID, average seasonal irrigation was 6.31 ac/ft/ac (19,227 m^3/ha) and surface irrigation return flow, 1.84 ac/ft/ac (5,606 m^3/ha) or 29% of supply water. In contrast, PDD's average seasonal irrigation was 3.23 ac-ft/ac (9,842 m^3/ha) and surface drainage, 0.75 ac-ft/ac (2,285 m^3/ha) or 23% of supply water.

The flow-weighted average concentration of suspended sediment in GCID was 24 mg/l and return flow, 36 mg/l, while in PDD it was 90 and 348 mg/l, respectively. In terms of unit mass emission rate, GCID discharged less suspended sediment (0.09 vs. 0.21 tons/ac) (200 vs. 470 kg/ha) than the loading rate in supply water whereas PDD discharged more suspended sediment (0.39 vs. 0.33 tons/ac) (874 vs. 740 kg/ha) than applied by the irrigation water. Such concentration differences may be attributed to flooded rice culture acting as settling basins for suspended sediment in GCID while furrow irrigation produced sediments in PDD. But on a mass basis, only slightly more sediments were discharged by PDD than were brought in by the supply water.

The impacts of these return flows on receiving stream qualities were previously reported (Tanji, 1981).

Discussion of California Studies

The results presented on sediment production and discharge into receiving waters document some of the complex and interacting factors involved in soil erosion and sediment control. For instance, surface runoff from flooded rice fields contained only an average of 16% of the sediment brought in by supply water because the fields act as settling basins. On some soils like the Panoche clay loam in Panoche Drainage District, furrow irrigation produces a large sediment load, but it can be controlled if a tail water recovery system is installed. In a similar furrow irrigated tomato field in the Sacramento Valley, the first irrigation produced high concentrations of suspended sediment but a second irrigation produced less sediment mainly because tillage was not practiced before the second irrigation, indicating that reducing tillage will reduce sediment loss. Furthermore, in the Sacramento Valley, substantial amounts of sediments were picked up in the return flow ditch collecting tailwater from furrows because of increased current velocity and channel erosion in a freshly graded ditch.

At a larger spatial scale like in an irrigation district, sediments produced from fields or farms may be either deposited in drains when current flow velocities are small or transported through drains when velocities are large. In some instances, water in drains may pick up bed loads deposited from previous flood runoffs.

Based on these and other observations, it is clear that there are at least two levels of spatial scales that need to be addressed on sediment control, one at the on-farm level and the other at irrigation project and river basin level.

Erosion and Sediment Loss Studies in Idaho

Many erosion and sediment loss studies have been conducted on erosive silt loam soils in southern Idaho during the past 15 years. The first study measured sediment inflows and outflows for two large irrigated tracts. Sediment concentrations ranging from 20 to 15,000 mg/l were measured. The seasonal sediment loss from fields into drains on a 161,500 acre (65,350 ha) tract was 1.78 tons/acre (4,000 kg/ha). Most of this sediment deposited in drains requiring mechanized removal. The seasonal loss from an adjacent 203,000 acre (82,030 ha) tract was 0.63 tons/acre (1,420 kg/ha) (Brown, et al., 1974; Carter, 1976).

Individual irrigation and seasonal sediment losses have been measured on approximately 80 fields over the past 10 years in attempts to relate furrow slope, furrow stream size, run length, tillage management, crop and residue to sediment loss (Berg and Carter, 1980; Carter and Berg, 1983). Results from these studies have been used to develop tables of expected sediment losses for different slopes, crops, and run lengths, and depending upon the presence or absence of a convex end condition. The presence of a convex end, which is a progressive slope increase with distance over the last 20 to 60 ft (6 to 18 m) into the tailwater ditch (Carter and Berg, 1983), significantly increases sediment losses. General average values (Table 1) are useful for developing predictive models and mathematical relationships (Kemper, et al, 1985), but we must recognize that these data are highly variable. Therefore, predicted sediment losses may range widely from measured values on any particular field. Data in Table 1 represent the most common conditions. Sediment losses are greater where water application is with gated pipe or from an earthen ditch with cutouts. Run length also influences sediment loss.

There are several recognized reasons for the variability in sediment losses from fields. One is that slope often varies over the run length. Another is that the previous crop has an impact on erosion and sediment loss, and usually was not considered in field selection for study. Tillage management influences erosion and sediment loss, and it is also a field to field variable. Irrigation management, including stream size and its adjustment during an irrigation, irrigation duration, and number

Table 1. Estimated sediment yields for different crops irrigated from cement lined ditches with siphon tubes. Run length was 660 feet (201 m)*.

	Average Field Slope, %											
	0.5-1			1-2			2-3			>3		
Convex end§	N	M	S	N	M	S	N	M	S	N	M	S
Crop												
Alfalfa	0.0	0.0	0.0	0.7	0.9	1.2	2.3	2.9	4.1	5.6	7.0	9.8
	0.0	0.0	0.0	1.6	2.0	2.7	5.2	6.5	9.2	12.6	15.7	22.0
Cereal grain	1.1	1.3	1.8	3.2	4.0	5.6	6.4	8.0	11.2	10.4	13.0	18.2
or peas	2.5	2.9	4.0	7.2	9.0	12.6	14.3	17.9	25.1	23.3	29.1	40.8
Dry beans	2.5	3.1	4.4	8.7	10.9	15.3	18.4	23.0	32.2	28.0	35.0	49.0
or corn	5.6	7.0	9.9	19.5	24.4	34.3	41.2	51.6	72.2	62.8	78.5	109.8
Sugarbeets	3.2	4.0	5.6	12.1	15.2	21.2	26.4	33.0	46.2	44.0	55.0	77.0
	7.2	9.0	12.6	27.1	34.1	47.5	59.2	74.0	103.6	98.6	123.3	172.6

[*] Top row of figures are English units of tons/acre
Bottom row of figures are metric units of thousands of kg/ha

[§] N = No convex end; M = moderate convex end; S = severe convex end.

of irrigations varies with the operator and influences erosion and sediment loss. There are also other, not completely understood, parameters that influence sediment loss.

Controlling Sediment Losses

During the past 15 years, several research projects have been conducted to develop and evaluate different management alternatives for reducing sediment loss from furrow irrigated land. The efficiencies of various "Best Management Practices" (BMP's) for reducing sediment losses have been established, and based on those efficiencies and cost considerations, BMP's can be applied by farmers. These BMP's have been applied in various combinations to two watersheds to determine potential reductions in sediment loss by applying best known technology. The BMP's will be discussed followed by a discussion of the two watershed projects.

Sediment Retention Basins

There are several types of sediment retention basins ranging from ponds of an acre (0.4 ha) or more located on a main drain to mini-basins receiving runoff from only 4 or 5 furrows. All are effective, and each has its best application. Large sediment basins on main drains are often formed by constructing an earthen dam across the drainage at a suitable site and installing a proper outlet. These large basins have sediment removal efficiencies of 65 to 90% depending upon the sediment concentration in the inflow water and the time required for water to pass through the pond (Brown, et al., 1981). Medium sized sediment retention basins are often excavations receiving runoff water from one or more fields. Their sediment removal efficiencies range from 75 to 95%. Mini-basins are formed by excavating a sequence of small basins along the lower end of a field or by placing earthen checks across the tailwater drainage ditch. If control outlets into a separate drainage ditch are placed in each minibasin, the efficiencies will range from 85 to 95%. If water is allowed to pass from one basin to the next, these basins become much less effective with efficiencies of only 40 to 70%, and often the flow volume destroys the checks and basins are washed out (Brown, et al., 1981; Carter and Berg, 1983).

Another type of mini-basin is the "I-slot" or "T-slot". These are slots excavated in the tailwater drainage ditch in the shape of an "I" or "T" as the names indicate. The efficiencies of these basins are about the same as for mini-basins where the tailwater flows sequentially through the entire series, or about 40 to 70%.

Buried Pipe Runoff and Sediment Control System

A runoff and sediment loss control system comprised of a buried drain pipe along the lower end of a field with vertical inlets at intervals was developed by Carter and Berg (1983). The first season these vertical inlets serve as outlets for mini-basins. As the mini-basins fill with sediment, a convex end problem can be corrected, and more land can be cropped because the tailwater ditch has been replaced by the buried pipe. This BMP has a sediment removal efficiency of 90 to 95% while mini-basins are filling with sediment and 75 to 90% after they have filled.

The initial cost of the buried pipe runoff and sediment control system is higher than for some other practices, but it has the potential of paying for itself in 4 to 8 years by correcting convex end and tailwater ditch problems, and adding productive area to fields where installed (Carter and Berg, 1983).

Vegetative Filter Strips

Strips of cereal, grass, or alfalfa seeded along the lower end of fields can reduce sediment losses by 40 to 60% depending upon the sediment load in the runoff water, the placement of the vegetative filter strip, and how far furrows are made into the strip. These vegetative filter strips can be harvested for some return from the land although yields per unit area are usually only 50 to 70% of field yields. Such vegetative filter strips can also be placed along the upper ends of fields to reduce erosion where furrow streams exceed the erosive size.

Vegetative filters must be properly installed and managed if they are to be an effective BMP. They are a relatively low cost alternative, but their effectiveness is less than that of some other BMP's.

LQ Drain Evaluation

A 3,300 acre (1,336 ha) watershed tributary to the Snake River in southern Idaho was studied as a Section 208, P.L. 92-500, project. Earlier measurements of sediment loss had been made in 1972 and the study period was 1977 through 1980. All drainage water entered the Snake River at one point where water and sediment outflows were measured. The watershed was comprised of 25 farming units. Water and sediment inflows and outflows were measured for the 4-year period. 1977 was considered the baseline year. The BMP's discussed earlier were applied on fields, farms, and on the main drain. The BMP's applied to each particular farm or field were selected through discussions with farmers and an evaluation of which BMP's appeared most promising. In addition to the BMP's discussed earlier in this paper there were some tillage treatments, one tailwater recovery system, improved water conveyance and control structures, some improved water management practices initiated such as using gated pipe to shorten run lengths, and some improved irrigation systems installed. Vegetative filter strips and sediment retention basins comprised most BMP's applied.

The application of these BMP's as best available technology did significantly reduce sediment loss from the watershed (Table 2). Two large sediment ponds on the main drain accounted for much of the loss reduction. The slight increase in sediment loss in 1980 over 1979 resulted from greater water outflow at a lower sediment concentration in 1980 compared to 1979. Therefore, the effectiveness of the control BMP's improved each year.

Table 2 - LQ Drain flow and sediment discharge to the Snake River

Season	Cum. flow cubic meters, thousands	Cum. sediment kg, thousands	Sediment loss (% of 1972)	Sediment loss (% of 1977)
1972	10,855	11,385	100	-
1977	10,084	8,709	76	100
1978	12,304	3,447	30	40
1979	11,595	1,769	16	20
1980	13,969	2,086	18	24

Rock Creek Rural Clean Water Project Watershed

A Rural Clean Water Act Project has been underway for the past five years. This watershed is comprised of about 45,000 acres (18,225 ha). BMP's are being applied to more fields and farms each year, and the project is not complete. Preliminary results are similar to those obtained on the LQ project for subunits of this project. One additional BMP being applied beginning in 1986 is conservation tillage practices. Impacts of this new BMP are not yet known, but preliminary results are promising.

Erosion and Sediment Loss

Most of the research and technology application to date has been directed toward reducing sediment losses into rivers and streams. Hence, much of the information available concerns trapping sediments to prevent them from polluting waters. There are costs associated with the initial installation and maintenance of sediment trapping BMP's, and many farmers cannot afford these extra costs or they are not willing to spend resources for such practices, without some cost sharing from outside sources. Therefore, present research efforts are aimed at preventing the erosion that suspends sediment, at little or no cost to the farmer.

Only a portion of the damage caused by erosion and sedimentation is represented by the sediment loss from furrow irrigated land. Tragic yield potential losses have resulted from the dynamic erosion and sedimentation processes along irrigation furrows. Brown (1985) has shown that severe erosion occurs along upper length segments of furrows and sedimentation occurs along length segments further down the furrows. The process varies with each irrigation. Carter, et al. (1985) concluded that the redistribution of topsoil from upper to lower ends of fields by this erosion and sedimentation process has reduced potential crop yields approximately 25%. In other words, present yields are only 75% of what they could have been had there been no erosion. Our efforts should be directed at stopping erosion, which will also reduce sediment concentrations in return flows.

Erosion Control Technology

Effective furrow erosion control depends upon methods to increase soil cohesion and to use plant residues to dissipate stream flow energy and to bind soils together. Applying small amounts of residues to furrows can almost eliminate soil erosion and sediment loss (Miller and Aarstad, 1983; Berg, 1984; Brown, 1985). A better approach, however, is to leave residues from the previous crop on the soil, with the right amount in the furrow. Presently, several conservation tillage regimes are being evaluated for this purpose. Limited results indicate that sediment losses can be reduced 50 to 90% by applying minimum tillage practices. Results from one field study indicated that no-till farming can be applied to at least part of the crop rotation on furrow irrigated land, almost eliminating furrow erosion, and without reducing crop yields (Carter, unpublished data).

Conclusions

Irrigation erosion is a serious environmental problem needing continued research aimed toward prevention. For many years, the problem was unnoticed, while each year an additional increment of damage and loss resulted. Research during the past 15 years has led us to the threshold of major advances in erosion control and the near prevention of sediment loss into rivers and streams. The potential is good for controlling furrow erosion, but continued extensive and intensive research will be required for at least the next decade to develop and apply the needed technology to accomplish these major advancements.

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