Technologies to Minimize Water Quality Impacts of Irrigated Agriculture.

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Abstract

Irrigation transformed arid land in the Pacific Northwest into productive agricultural land. However, much of this land is prone to erosion during irrigation, which can cause problems on and off of the field. Management practices have been developed to control soil erosion on irrigated land and improve the quality of water returning to streams and rivers. Applying polyacrylamide (PAM) with irrigation water can reduce erosion from furrow irrigated fields more than 90%. Using PAM in combination with other practices, such as applying straw mulch in furrows and installing small sediment ponds on fields, can virtually eliminate sediment loss fromfields. Once soil runs off a field, it can be removed by settling in sediment ponds, although soluble nutrients remain in the water. Applying 20 mg/L alum to irrigation return flow water can remove about 50% of the soluble phosphorus that will not be removed as suspended sediment settlesin ponds. Using these management practices allows irrigation to continue with minimal impact on water quality.

Introduction

Irrigation improves crop yields and quality by controlling and reducing water stress. Controlling water stress is especially important for high value crops. Farms using irrigation on all harvested cropland comprises 9% of the total harvested cropland in the United States, but these farms produce 40% of the crop value, including nursery and greenhouse crops (NASS, 2004). Irrigated land, however, is often prone to soil erosion, especially with surface irrigation. Erosion rates as great as 145 Mg/ha in one hour (Israelson et al., 1946) and 40 Mg/ha in 30 minutes (Mech, 1949) were reported in some early furrow irrigation erosion studies. More recent studies have documented annual soil loss of 1 to 141 Mg/ha on 33 southern Idaho fields (Berg and Carter, 1980) and 0.2 to 50 Mg/ha in Washington (Koluvek et al., 1993). Not only does erosion reduce productivity on irrigated fields (Carter et al., 1985), but transported sediment and associated nutrients can negatively impact water quality of lakes, streams and rivers that receive return flow water from irrigation districts. Runoff from agricultural land is the main source of nutrients that impair stream water quality in the United States (USEPA, 2000).

For the past decade one focus of ARS research at Kimberly, Idaho, has been reducing potential negative water quality impacts from irrigation. On-field and off-farm practices have been developed and tested to reduce erosion and improve water quality. The objective of this paper is to summarize some of the benefits of these practices.

On-field Practices

Practices such as conservation tillage, filter strips and sediment ponds have been promoted for reducing soil loss from irrigated fields for decades (Carter, 1990). Carter and Berg (1991) showed that conservation tillage used with the appropriate crop sequence (e.g. small grain or corn following alfalfa) could reduce soil loss 47 to 100% compared to conventional tillage and crop sequences (e.g. dry bean following alfalfa) on furrow irrigated fields. Direct seeding and conservation tillage leave crop residue on or near the soil surface where it can protect the soil from erosion. Too much residue, however, can hinder water flow in furrows.

Filter strips or small sediment ponds on the end of a field remove sediment from runoff rather than control erosion on fields. These practices remove sediment by slowing the water flow rate, allowing sediment to settle. These practices do not interfere with tillage or irrigation on the field. However, without adequate on-field erosion control, sediment will fill ponds and cover filter strips, reducing the effectiveness of these practices.

The development of polyacrylamide (PAM) to control furrow irrigation erosion was a major breakthrough. Applying 10 ppm of anionic, water soluble PAM reduced erosion 94% on research plots compared to untreated furrows (Lentz and Sojka, 1994). Reducing soil erosion with PAM application also reduces runoff losses of nutrients associated with sediment (Lentz et al., 1998). Granular PAM costs $4 to $6 per kilogram, thus erosion can be controlled for less than $30/ha. PAM can be dissolved in irrigation water or applied directly to the top 1 to 2 m of furrowswhere it slowly dissolves during irrigation. PAM does not interfere with water flow in furrows as can happen with crop residue. In fact, PAM reduces detachment and redistribution of straw applied to furrows, allowing straw mulching and conservation tillage to be used with fewer complications. Applying both straw (485 kg/ha) and PAM (1 kg/ha for five irrigations) to furrows virtually eliminated erosion, reducing soil loss by more than 99% compared to untreated furrows (Lentz and Bjorneberg, 2003). The combination of these practices is more effective than either practice used individually.

Applying PAM with furrow irrigation reduces erosion on the field so less sediment reaches filter strips and sediment ponds. Less sediment was trapped in ponds receiving runoff from PAM-treated furrows, but the percent reduction in sediment was similar to ponds receiving runoff from untreated furrows (Bjorneberg and Lentz, 2005). Treating furrows with PAM and routing runoff through sediment ponds, with approximately 2 h detention time, reduced soil loss by 95 to 99% (Figure 1) and total phosphorus (P) loss by 86 to 98%. Soluble P loss reductions were not as large (Figure 1) because PAM and sediment ponds did not affect soluble P concentrations. Reduction in the mass of soluble P transported was directly related to infiltration on the field and in the ponds (Bjorneberg and Lentz, 2005).

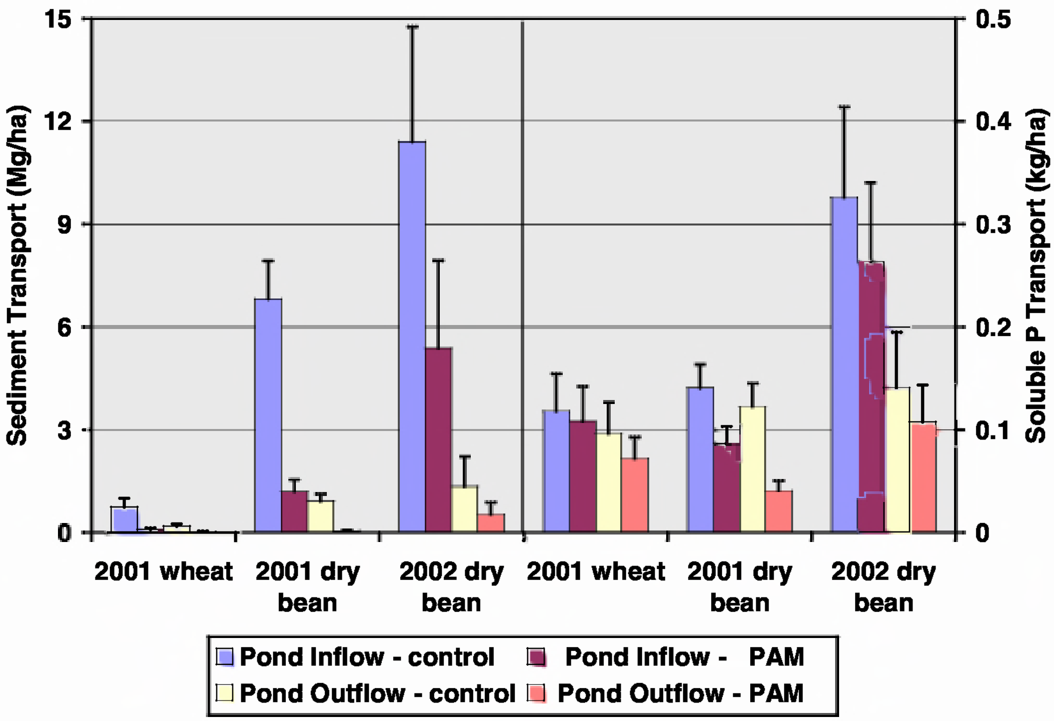

Figure 1. Sediment and soluble phosphorus mass transported into and out of sediment ponds for three field years. Data from Bjorneberg et al. (2005). Error bars are one standard deviation.

Runoff from sprinkler irrigated fields is much less of a problem than from surface irrigated fields. Proper sprinkler system design and management should match water application with soil infiltration. Tillage management, such as conservation tillage and reservoir tillage, can improve the opportunity for water to infiltrate rather than runoff. In situations where tillage, management and system design do not adequately control sprinkler irrigation runoff, PAM can be used to improve infiltration. Laboratory tests showed that applying 2 to 4 kg/ha PAM with 20 mm irrigation on 1.9 m^2 soil boxes, reduced runoff by 70% and soil loss by 75% compared to untreated soil (Aase et al., 1998). Applying PAM with multiple irrigations was more effective than applying the same total mass of PAM with a single irrigation in both laboratory (Bjorneberg and Aase, 2000) and field tests (Bjorneberg et al., 2003). Applying PAM with four irrigations (3 kg/ha total) reduced runoff 77% (7 mm) compared to untreated plots even though 22% (49 mm) more water was applied to PAM plots (Bjorneberg et al., 2003).

Off-farm

Off-farm practices, such as sediment ponds and wetlands, remove sediment from water, but have little effect on soluble nutrient concentrations. Water samples were collected in 2002 from inflow and outflow of two large ponds (1 to 2 ha) located about 400 m apart on an irrigation drain in the Twin Falls Irrigation District near Filer, Idaho. Results from the three sampling dates (six samples collected on each date) showed that sediment concentration decreased 85 to 98% between pond 1 inflow and pond 2 outflow, but soluble P concentration was only reduced by 15 to 45% (Figure 2). A small amount of water flowed into the drain and some water was diverted out of the drain between the two ponds, but the majority of the flow (about 250 L/s) continued from pond 1 to pond 2.

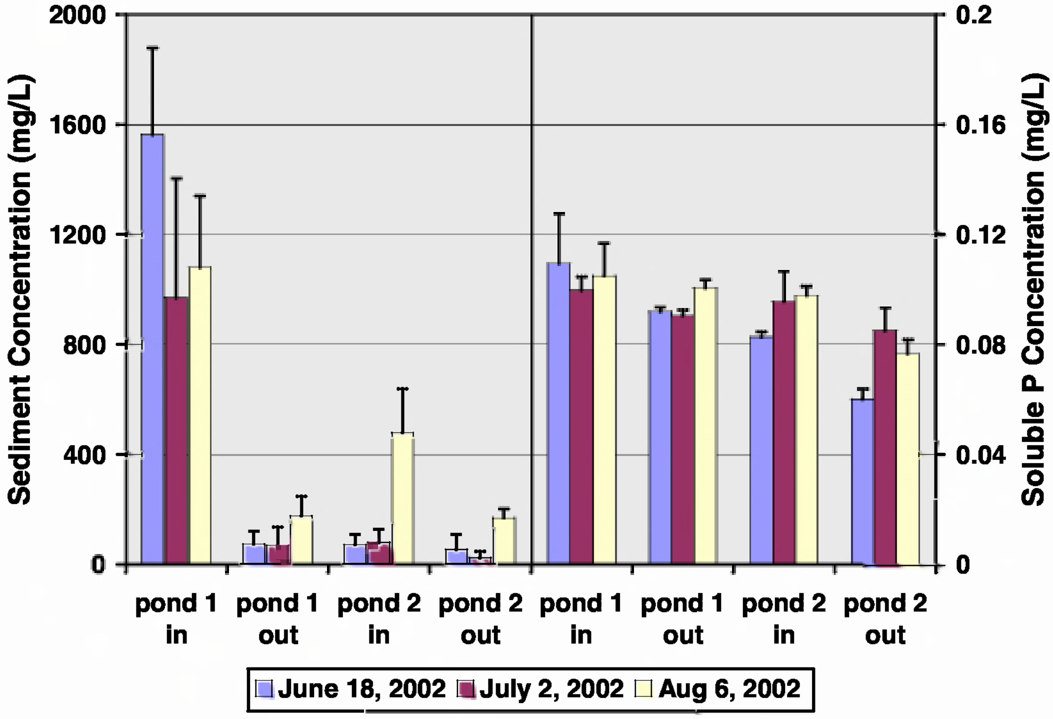

Figure 2. Sediment and soluble phosphorus concentrations in irrigation return flow. Error bars are one standard deviation.

For the June and July samples, sediment concentrations decreased in pond 1, remained almost constant between ponds 1 and 2, and decreased slightly in pond 2 (Figure 2). During the August sampling, sediment concentration increased between ponds 1 and 2 due to irrigation runoff (about 30 L/s) from one sugar beet field that did not use any management practices to reduce soil loss. Runoff from this one field increased average sediment concentration in the drain from 180 to 480 mg/L. Soluble P concentrations did not decrease as dramatically as sediment concentrations when water flowed through the ponds (Figure 2). Soluble P concentrations in pond 2 outflow were near the TMDL (total maximum daily load) target concentration of 0.075 mg/L for *total P* for the Snake River in this area. Total P concentrations followed a similar trend as sediment concentrations in pond 1 because 90% of the total P flowing into pond 1 was associated with particulates (data not shown). Since the relative decrease in sediment concentration was greater than the decrease in soluble P concentration, almost 50% of the total P in outflow from pond 2 was soluble P.

In an attempt to reduce soluble P concentrations, alum was added to irrigation water in laboratory and field tests. Applying 20 mg/L of $Al_2(SO_4)_3$ in a laboratory test reduced soluble P concentrations by about 50% when the initial soluble P concentration was about 0.1 mg/L (Leytem and Bjorneberg, 2005). Similar reductions occurred in field tests where initial soluble P concentrations varied from 0.1 to 0.2 mg/L and sediment concentrations varied from 20 to 500 mg/L. Alum application (45 mg/L) had dramatic visual effect in one field test where 45 mg/L alum was applied to water flowing into a sediment pond (Figure 3). This treatment reduced soluble P from 0.15 to 0.01 mg/L. At the current alum cost of \$0.33/kg, achieving 50% reduction in soluble P would cost about \$0.007 per cubic meter of water (\$8.25 per acre-ft), which probably is not cost effective for routine use on irrigation districts at this time.

Figure 3. Untreated (left) and alum treated irrigation return flow. Alum was applied at approximately 45 mg/L before water flowed through two sediment ponds.

Conclusions
Sediment and nutrients in runoff from irrigated land can negatively impact water quality in streams, lakes and rivers. Management practices have been developed to control erosion on fields and remove sediment and phosphorus from water returning from irrigation districts. The adoption of these practices depends on how well they fit a producer's or irrigation district's operation and the cost of not controlling erosion or improving water quality.

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