



## CCA ADVANTAGE

Continuing Education  
Self-Study Course

# SEDIMENT AND TRANSPORT IN IRR

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Phosphorus is an essential nutrient for crop growth. Runoff from agricultural land is the main source of nutrients that impair stream water quality in the United States.

Forty-four percent of the irrigated land in the United States is surface irrigated and 51 percent (4.75 million hectares, or 11.7 million acres) of that is irrigated with furrows. Although farmers try to control runoff from rain or sprinkler irrigation, runoff is often necessary to achieve acceptable uniformity during furrow irrigation and in many cases, it is impractical to contain runoff on sloping fields (i.e., >1 percent).

The mechanics of erosion can be divided into three components: detachment, transport and deposition. Water flowing in irrigation furrows detaches and transports sediment. Deposition occurs when flowing water can no longer transport the sediment. Some particles may be deposited within a few meters, while others are transported off the field with runoff water. Most sediment detachment occurs on the inflow end of furrow irrigated fields with uniform slope because flow rate is the greatest and sediment load is the least when water enters a field.

Flowing water also transports P, either dissolved in water or sorbed to or part of sediment. Sediment-bound P is directly related to soil erosion. Typically, more than 90 percent of the P transported from furrow-irrigated row crop fields is associated with detached sediment. Runoff from fields of grass, hay or pasture contains minimal sediment so soluble P is a greater percentage of the total P loss. Phosphorus may also desorb as runoff water interacts with a thin layer of surface soil in the furrow. Soluble P concentration in runoff typically increases as the extractable P in surface soil increases. Suspended sediment may also be a sink for soluble P.

Irrigation furrows provide a unique opportunity to measure P transport changes with time and distance in a field without the interference of rain drops and sheet flow because P and sediment are detached and transported by only flowing water. We measured sediment and P transport during furrow irrigation to better understand the interactions between sediment detachment and deposition, and P sorption and desorption. Our objective was to identify factors affecting P transport during furrow irrigation.

## MATERIALS AND METHODS

We measured sediment and P transport during six irrigations conducted over five years using the same general procedures. All irrigations were performed on freshly tilled, fallow fields, 110 to 180 m (361 to 590 ft) long with 0.007 to 0.012 m m<sup>-1</sup> (0.7 to 1.2 percent) slopes, with Portneuf silt loam at the Northwest Irrigation and Soils Research Laboratory, near Kimberly, Idaho. Any surface residue remaining from the previous crop was tilled into the soil several months before any irrigation. Two to nine furrows were monitored during each irrigation. Each monitored furrow was wheel compacted when furrows were formed.

## FURROW FLOW SAMPLING AND ANALYSIS

The irrigation water source was the Snake River. Furrow inflow rate was controlled by spigot valves on gated pipe for all irrigations except Irrigation 2, which used siphon tubes from a concrete-lined ditch. Inflow rates were typical or slightly greater than normal for production fields to ensure that water advanced across the field in a reasonable time (1 to 3 h) without causing unrealistically high erosion rates. Inflow rates were measured by flumes or by the

time required to fill a known volume. Inflow rates were set the same for each furrow during an irrigation except during Irrigation 4, which had three different inflow rates to give a greater range of sediment and P transport.

Furrows were monitored at four equally spaced locations in each furrow. Water samples were collected from flume outflow to determine transported sediment and P concentrations.

## SOIL SAMPLING AND ANALYSIS

Surface soil (0–30 mm, or the upper 1 inch) samples from 10 to 12 points along the furrow bottom on each quarter segment were composited immediately before each irrigation (<1 h). Soil P should be relatively uniform in this surface layer because the field was tilled and furrows formed 1 or 2 d before irrigation, and P fertilizer had not been recently applied. The soil samples were analyzed for both bicarbonate-extractable P and calcium chloride-extractable P (0.01 M CaCl<sub>2</sub>) as an indication of water-soluble P. Soil samples were also collected from the furrow bottom after Irrigations 5 and 6, approximately 10 to 15 m (33 to 49 ft) from the inflow point and 10 to 15 m upstream from each flume location. Samples were collected from the surface seal layer (0–5 mm) and immediately below the surface seal (about 5–20 mm).

## TYPICAL FURROW FLOW, SEDIMENT, AND PHOSPHORUS TRENDS

Flow rate increased rapidly with time after water advanced past a monitoring station and then remained relatively constant. Flow also decreased between each monitoring station as water infiltrated. The dissolved reactive phosphorus (DRP) concentration at each station decreased rapidly with time until reaching a quasi-steady state concentration, a trend noted in

# PHOSPHORUS IRRIGATION FURROWS

previous runoff studies. The quasi-steady state concentrations were greater than the inflow DRP concentrations, which was typical for all irrigations.

Only 31 of the 805 furrow flow samples had DRP concentrations less than the inflow DRP concentration, indicating that DRP was not removed from flow in these furrows. At any given time during the irrigation, DRP concentration generally increased with distance down the furrow. However, the DRP concentration 1 min after water advanced past a flume (first sample) was similar among the four stations.

Sediment concentrations can be quite variable with time and distance during irrigation.

## WATER FLOW AND SEDIMENT TRANSPORT IN FURROWS

Although all irrigations were conducted on the same soil with similar surface conditions (fallow, recently tilled, no surface residue), soil and P losses were quite variable. Infiltration was much greater during Irrigation 1 than for all other irrigations, possibly because this field was moldboard plowed in the spring after being planted to grass for 8 years before this study. The high infiltration rate caused a slow advance rate, little runoff and small sediment and P losses. Erosion was minimal during Irrigation 1, with 36 percent of the samples having sediment concentrations below the lower detection limit for the Imhoff cone ( $<100 \text{ mg L}^{-1}$ , or 100 ppm). Irrigation 5 had the greatest soil loss even though runoff volume was less than Irrigations 2, 3, and 4.

The decreases in flow rate and flow volume with distance were approximately linear for all irrigations, which indicate uniform infiltration down the furrows. Flow-weighted sediment concentration always increased from inflow to Station 1 because inflow water contained little sediment and the furrow flow was most

erosive on the upper end of the field where flow rate was greatest. As water continued to flow down the furrow, sediment concentration increased, decreased, or remained unchanged depending on flow rate, soil erodibility, and possibly other undefined characteristics. Sediment load decreased between stations when sediment concentration was constant or decreased, because flow rate always decreased with distance. Sediment was deposited between Stations 3 and 4 for all irrigations but Irrigation 5. Suspended sediment usually deposits on the lower end of a field as furrow flow rate decreases when water infiltrates.

## TOTAL PHOSPHORUS IN FURROW FLOW

Changes in flow-weighted total P concentration with distance down a furrow during an irrigation were almost parallel to changes in sediment concentration, because total P was directly related to sediment concentration ( $r^2 = 0.75$ ). Thus, total P load increased as sediment was detached and decreased as sediment was deposited. This emphasizes the importance of controlling erosion to control total P loss. Furthermore, total P can be reduced in furrow irrigation runoff by removing sediment with settling ponds or similar practices.

Total P concentration was directly related to sediment concentration because the majority of the total P was associated with particulates, which is typical for clean-tilled irrigation furrows. Nearly 80 percent of the water samples collected during the six irrigations had greater than 95 percent particulate P; 92 percent of the samples had greater than 90 percent particulate P. More than 95 percent of the total P was particulate P when sediment concentration was  $>2500 \text{ mg L}^{-1}$ .

The linear relationship between total



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P and sediment concentrations did not change noticeably with time during irrigation or distance down the furrow. Sediment, total P, and DRP mass losses increased linearly with the three inflow rates used for Irrigation 4 because runoff volume increased with inflow rate. Sediment and total P concentrations also increased with inflow rate during Irrigation 4, but DRP concentrations were similar for all three inflow rates. There was not an overall trend between inflow rate and sediment and total P losses among irrigations. Irrigation 3, for example, had the highest inflow rate but Irrigation 5 and the high inflow rate on Irrigation 4 had greater sediment and total P losses. Field- and irrigation-specific characteristics are important factors affecting erosion and total P transport.

## DISSOLVED REACTIVE PHOSPHORUS IN FURROW FLOW

The DRP concentrations were greatest in the first samples collected from each station, when the advance front was about 1 to 5 m (3 to 16 ft) past the flumes. Since the infiltration rate is highest at the advancing water front, most water with the greatest DRP concentration infiltrates into the soil until the advance front reaches the end of the furrow.

Flow-weighted DRP concentration typically increased with distance down a furrow, indicating that P continued to desorb as water flowed down the furrow

even if sediment and total P concentrations decreased. Although DRP concentration increased with distance, DRP load often decreased on the fourth and sometimes on the third segment of the furrow because the mass of soluble P that infiltrated with irrigation water or re-sorbed to suspended sediment or furrow soil exceeded the mass of P desorbed. Most of the DRP load was supplied by inflow, with the exception of Irrigations 2 and 3, despite the fact that DRP concentration increased as water flowed down the field.

As discussed in the previous section, DRP concentration was a small proportion of the total P, except for a few samples during Irrigation 6 when sediment concentration was low (<2000 mg L<sup>-1</sup>) and during Irrigation 1, which had much lower sediment concentrations than the other five irrigations.

## SOIL PHOSPHORUS VERSUS DISSOLVED REACTIVE PHOSPHORUS RELATIONSHIPS

Correlations between extractable soil P and furrow flow DRP were not significant after the first sample at Station 1, with correlation coefficients varying from -0.02 to -0.30. These correlations indicate that soil P does affect DRP in furrow flow, but furrow flow hydraulics and interactions with transported sediment likely confound these relationships.

The poor correlation between soil P concentration and DRP concentration in furrow flow tends to contradict previous studies where soil P correlated with runoff DRP concentration.

The limited range of soil P concentrations among irrigations and field segments within each irrigation likely contributed to the lack of significant correlations between DRP concentration and furrow soil P concentration. The ratio of maximum to minimum soil P ranged from 1.6 to 2.9 for the six irrigations in this study, with the largest ratios occurring in Irrigations 4 (2.8) and 6 (2.9), which had significant correlations.

## SUSPENDED SEDIMENT AND SOIL PHOSPHORUS VERSUS DISSOLVED REACTIVE PHOSPHORUS RELATIONSHIPS

The DRP concentration in furrow flow correlated better with sediment concentration than furrow soil-extractable P (0.01 M CaCl<sub>2</sub>) concentration, especially on the first quarter segment of the field, at Station 1. Sediment concentration predicted 18 percent to 55 percent of the variability in DRP concentration at Station 1. Correlation coefficients between sediment and DRP concentrations ranged from 0.41 to 0.69 ( $P < 0.03$ ) for all sampling times at Stations 1 and 2.

Correlations were more erratic at Stations 3 and 4. The DRP concentrations down the furrow, especially at Stations 3 and 4, were affected by concentrations transported from upper furrow segments as well as sediment dynamics on these furrow segments.

In theory, any detached sediment is a source or sink for DRP. In general, DRP concentration tended to increase as sediment concentration increased as shown by the correlation between DRP and sediment concentration. However, increasing sediment concentration later in an irrigation often had little or no impact on DRP concentrations in furrows. A change in sediment concentration without affecting DRP concentration suggests that the time when sediment is first detached affects DRP concentrations in furrow irrigation flows.

## FURROW SOIL-EXTRACTABLE PHOSPHORUS CHANGES

The furrow surface seal soil samples (0–5 mm) had 5 percent to 40 percent lower extractable P (0.01 M CaCl<sub>2</sub>) concentrations than the soil before irrigation. Although sampling depths were different, the soil was thoroughly mixed to at least 80 mm by tillage before irrigation. Surface seals form as aggregates disintegrate and as fine sediment deposits on the furrow wetted perimeter when sediment laden

water infiltrates. Phosphorus probably desorbed from this soil as the aggregates broke apart during the initial wetting, as the sediment was transported with furrow flow before deposition, and as water infiltrated through the seal during irrigation. Phosphorus desorbed from the surface seal layer during infiltration may not contribute to DRP transport, but move downward with the infiltrating water. If soil in the surface seal layer is detached again and transported in furrow flow, less P would likely desorb from this sediment than when it was initially detached.

The amount, duration and timing of transported sediment are critical components affecting DRP concentration in furrow flow, as well as the mass of DRP being transported. Initial extractable soil P concentration also affects the DRP concentration but is masked by furrow flow hydraulics, suspended sediment loads, and nonequilibrium conditions.

## CONCLUSIONS

Sediment and P transport in shallow ephemeral channels like irrigation furrows involve many interacting processes. Total P concentration was strongly correlated with sediment concentration on these tilled fallow fields with typically more than 90 percent of the total P associated with particulates. Thus, soil erosion must be controlled to reduce total P loss. The DRP concentration in furrow flow was also affected by sediment concentration along with the time that the water was in contact with soil and suspended sediment, furrow soil P concentration, and furrow hydraulic conditions. Results from this field study indicate that suspended sediment concentration has a greater influence on DRP concentration in-furrow flow for whole fields than furrow soil P concentration. Sediment detachment, transport, and deposition in furrows must be understood to accurately predict both soluble and particulate P transport. **AG**



# Sediment and phosphorus transport in irrigation furrows

## July Self-Study Examination

- 1. Irrigation water runoff in furrow irrigated fields is often necessary to**
- a. achieve uniformity of water coverage.
  - b. push water across fields with undulating topography.
  - c. lessen residue redistribution.
  - d. minimize the effects of salinity in irrigation water.
- 2. The percentage of P transported off-site due to detached sediment in furrow irrigated row crop fields is typically**
- a. 60%.
  - b. 70%.
  - c. 80%.
  - d. 90%.
- 3. An objective of this research was to**
- a. quantify how various forms of P fertilizer react in irrigation water.
  - b. determine how furrow irrigation influences ground water quality.
  - c. identify factors affecting P transport during furrow irrigation.
  - d. assess the effect of crop residue on nutrient transport.
- 4. A characteristic of this research was that the experiment was conducted on**
- a. irrigated as well as rainfed fields.
  - b. fields with slopes exceeding 5% where erosion had been a problem.
  - c. clay loam soils.
  - d. freshly-tilled, fallow fields.
- 5. A finding in this study related to dissolved reactive phosphorus (DRP) concentrations was that they**
- a. were highest in irrigation water inflow.
  - b. generally increased with distance down the furrow.
  - c. tended to be removed as water flowed across the field.
  - d. precipitated out of the water as irrigation flow decreased.
- 6. A reason why flow-weighted sediment concentration always increased between inflow and Station 1 is**
- a. water inflow was rich in sediment.
  - b. more erosion occurred in the upper end of the field where flow rate was greatest.
  - c. sediment concentration increased as flow decreased.
  - d. sediment deposition was greatest at the upper end of the field.
- 7. Total P concentration was directly related to sediment concentration because**
- a. most of the total P was associated with particulates.
  - b. phosphorus in water is quickly absorbed into solids.
  - c. recent fertilizer applications were surface-applied.
  - d. soil organic matter separates from sediments during irrigation.
- 8. A lack of correlation between dissolved reactive phosphorus and soil phosphorus is likely due to**
- a. a limited range of soil P concentrations among field segments.
  - b. antagonism of phosphorus in high pH environments.
  - c. the lack of precision of current soil testing methods.
  - d. the clay soil of the field acting as a nutrient buffer.
- 9. A reason why the furrow surface seal samples had less extractable P concentration than the soil before irrigation is due to**
- a. water-soluble compounds concentrating in the surface seal.
  - b. phosphorus desorbing from the soil as the aggregates broke apart.
  - c. high levels of carbon occupying exchange sites following irrigation.
  - d. soil testing methods that detect less phosphorus in the highly alkaline surface seal.
- 10. Strategies for reducing phosphorus loss from fields when Total P concentration is strongly correlated with sediment concentration might include all of the following EXCEPT**
- a. controlling soil erosion.
  - b. using settling ponds for irrigation water runoff.
  - c. more carefully controlling water flow to minimize runoff.
  - d. using gypsum on fields to encourage soil aggregation.

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**Rating Scale: 1=Poor 5=Excellent**

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