# PHOSPHORUS RUNOFF MANAGEMENT FOR ALFALFA IN DESERT REGIONS

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## ABSTRACT

Alfalfa is the principal crop in the Imperial Valley. Approximately 1 million ac-ft of water are used every year to irrigate more than 150,000 acres of alfalfa. Approximately 20 million pounds of phosphorus (P) may be used annually to fertilize alfalfa in the Imperial Valley. In this project, we implemented seven standard and improved irrigation and fertigation management practices on a commercial alfalfa field to reduce the load and concentration of phosphorus and sediment in drainage waters. We evaluated the impact of each management measure on the load and concentration of phosphorus and sediment in drainage water. The most effective measures were irrigation management and runoff control. Reducing the amount of surface runoff after the application of P fertilizer is a key factor in reducing the load of P in drainage waters.

**Key Words: alfalfa, irrigation, runoff, phosphorus**

## INTRODUCTION

In California and elsewhere, how much of a pollutant a waterbody can tolerate on a daily basis is determined by setting a Total Maximum Daily Load (TMDL). A TMDL for agricultural drainage is defined as the load allocations for non-point source of pollution and natural background pollution, plus a margin of safety such that the capacity of the waterbody to assimilate pollutant loadings without violating water quality standards is not exceeded. A TMDL can be expressed in terms of either mass per time, toxicity, concentration, a specific chemical or other appropriate measures.

To comply with TMDLs and mitigate the impacts of agriculture drainage waters on other uses, irrigators and farm managers have to be more attentive to the quality of the water applied and the quality of drainage waters leaving their fields, as they must adjust their irrigation practices to ensure compliance with the regulatory standards. The presence of suspended sediment, phosphorus (P) and other constituents adsorbed on suspended sediment in waterways has multiple negative impacts on water quality and may cause environmental problems (Davies-Colley and Smith, 2001). The 1998 National Water Quality Inventory ranks suspended solids and sediment as the leading cause for water quality impairment of rivers and lakes in the United States.

Approximately 30% of applied drainage water in the Salton Sea watershed in southern California ends up as drainage water. Reducing the load and/or the concentration of suspended sediment in runoff has numerous benefits including reducing the amount of water applied and the load of

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other regulated contaminants such as pesticides and phosphorus that are attached to eroded soil particles. In this project, we summarize our experience in using irrigation and fertigation management practices to reduce the load of phosphorus in runoff water from irrigated fields in the Imperial Valley.

## PHSPOUROUS LOAD IN RUNOFF WATERS

Surface irrigation, by mainly of furrows or border checks, is the primary method for irrigation in the Imperial Valley, and is used on more than 90% of the cropped area. Drip irrigation is used on less than 5% of the cropped area and mostly on vegetable crops. Sprinkler irrigation is mostly used to germinate some crops, but growers switch to surface methods once the crop is established.

The average concentration of suspended sediment in Imperial Valley drains and rivers is approximately 350-400 mg/L. Based on the average agricultural drainage discharge of 2.0 ac-ft per acre/year, this figure represents a net loss of approximately 1 ton of soil (in form of sediment) per acre per year. The average sediment load to drains and rivers in the Valley is in excess of 500,000 tons per year. In addition to the loss of productive topsoil, sediment and eroded soil particles contain considerable amounts of P attached to soil particles that eventually end up in the Salton Sea. The average concentration of soluble P in drainage water is approximately 0.5-1.0 mg/L (eutrophication, a major problem in the Salton Sea, can occur at concentrations as low as 0.02 mg/L). The average load of P in drainage water in form of $P_2O_5$ is approximately 5-10 lbs/acre (6-11 kg/ha) per year, with an average annual load of approximately 2.5 million lb (1.14 million kg) of P that end up in the Salton Sea every year.

Approximately 22 million lb (10 million kg) of phosphorus (in the form of phosphate; $P_2O_5$) is used annually to fertilize the alfalfa crop (Meister et al., 2004), and this amount accounts for almost 50% of the total phosphorus applied to crops in the Valley. Phosphorus is applied once or twice per year as water-run phosphorus or broadcasted during the growing season with subsequent yearly applications in the springtime, or applied at a higher rate prior to planting to meet alfalfa demand for the entire growing season (approximately 3-4 years). The estimated phosphorus load in surface runoff waters is approximately 10-15% of total applied phosphorus. Phosphorus may move directly to surface waters via sediment carried in the surface runoff, and via cracks in the soil to subsurface drains.

## METHODOLOGY

A commercial alfalfa field in the Imperial Valley, California was selected to conduct the project. The field is approximately 80 acres and it was planted with alfalfa in October 2004. Seven best management techniques (BMTs) for P load reduction were implemented during the second year and third year after of the project (first year normal practices, BMTs in 2nd and 3rd year). The field consisted of 13 standard borders approximately two hundred (200) feet wide by approximately one thousand two hundred (1,200) feet long. Flumes to measure water flow rates were installed at the head end and at the tail end of the field.

Hay samples were collected at 300 and 900 ft along each border prior to each cutting. Alfalfa yields were determined from sample cuttings and from bales. The numbers of hay bales on each border were recorded and the weight and moisture of selected bales were measured. Hay yields were determined from bale and hay samples data. Runoff water samples from each land were collected and the concentration of P and other water quality constituents were determined.

The following P agricultural BMTs were implemented on the field:

1. Irrigation water management- determining and controlling the rate, amount, and timing of irrigation water applied.
2. Runoff reduction- reducing the amount of surface runoff, using a runoff reduction method developed by UCCE, in just a single irrigation per year when broadcast P fertilizer is applied
3. Precision application rates/GIS utilization- applying precise amounts of P-fertilizer to the soil in specific parts of the fields according to the plant needs.
4. Proper fertilizer applications- selecting the proper time and method of fertilizer application (water-run P or broadcast-P applications) to reduce P losses through runoff and soil erosion.
5. Improved water-run P application practices- applying 100 pounds/acre (equivalent $P_2O_5$) of water-run phosphorous in a single irrigation.
6. Reduced water-run P application practices- applying 75 pounds/acre of water-run phosphorous fertilizer (in the form of $P_2O_5$) to the first 75% of the border.
7. Filter strip- establishing a section of land in permanent vegetation, down slope of agricultural operations.

A summary of the P application practices and BMTs implemented on each land is presented in Figure 1.

Figure 1. Summary of P application methods and rates and BMTs implementation. ↑ South

| | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 | L11 | L12 | L13 extra |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMT | 2,3,4 | 3 | 3,5 | 3,6 | 3,6 | 3,5 | 3,4 | 2,3,4 | 2,3,4 | 3,4 | 3,5 | 3,6,7 | 3,4,7 |
| P rate | M1 | M2 | M3 | M3 | M3 | M3 | M1 | M1 | M1 | M1 | M3 | M3 | M1 |
| Total P Applied 11-52-0 equivalent (lb/ac) | 600 | 600 | 600 | 500 | 500 | 600 | 600 | 600 | 600 | 600 | 600 | 500 | 600 |
| Total yield 2006 and 2007 | 20.92 | 20.81 | 20.88 | 22.15 | 20.34 | 23.32 | 22.52 | 21.90 | 23.40 | 22.80 | 23.23 | 22.89 | 19.90 |

Summary of total practices

M1: Standard practice (broadcast first, second, and third year)

M2: Standard practice (broadcast first year at 3 times the annual rate)

M3: Standard practice (broadcast first year, water run second and third year)

## SUSPENDED SOLIDS CONCENTRATION-TURBIDITY (C-T) RELATIONSHIP IN RUNOFF WATER

The concentrations of sediment (C) in runoff water were determined from turbidity (T) values using three C-T functions determined earlier in a previous study (Gao et al., 2005). Three possible C-T functions were tested by regression analysis (1) linear function, (2) threshold linear functions (i.e. two linear functions for data with NTU < 200 and NTU ≥ 200), and (3) power function. The regression results were compared with one another and the function with the best fit was selected.

For all turbidity measurements, the errors between the reading and the standard values were between 0.2% and 2.4% signifying that the turbidity values measured by the turbidity meter were reliable. The regression results based on the data and their corresponding relations are:

Linear function

$$C = 0.876T + 29.2 \qquad (1)$$

Threshold linear functions

$$C = 1.162T + 18.5 \qquad \text{NTU} < 200 \qquad (2a)$$

$$C = 0.898T + 12.1 \qquad \text{NTU} \geq 200 \qquad (2b)$$

Power function

$$C = 3.6T^{0.8} \qquad (3)$$

Although the linear function fitted the data well for high turbidity values, it over predicted *C* for *T* values less than 30 NTU. The two threshold linear functions agreed with the data well at high turbidity values but still over predicted *C* at low turbidity values. In addition, the two intercepts in the two types of linear functions indicated that as turbidity approached zero, *C* was 29.2 and 18.5 mg/L, respectively. This was contradicting to the value (i.e. zero) generated by pre-programmed formazin calibration. The power function fitted the data well at both low and high turbidity values. Validation of eq. (3) using the data collected in previous experiments indicated that the power function represented the best relationship between C and T. Therefore, we used eq. (3) to calculate the concentration of sediment in runoff water.

## SEDIMENT AND PHOSPHORUS CONCENTRATIONS AND LOADS IN RUNOFF WATERS

The average concentration of suspended sediment in runoff water for all irrigation and P application practices in 2006 was lower than 100 mg/L (Table 1). That is well below the TMDL threshold rate of 200 mg/L. This indicates that the irrigation or fertigation practices implemented here had little impact on water quality.

Table 1. Average sediment concentration in runoff water (mg/L) in 2006.

| | | P application type and irrigation practice | | | |
|---|---|---|---|---|---|
| Irrigation number after P application | Irrigation date | Standard P rate broadcast- standard irrigation (borders L7, L10, L13) | Standard P rate broadcast- reduced runoff (borders L1, L8, L9) | Standard P rate water- run- standard irrigation (borders L3,L6, L11) | 75% of standard P rate- water- run- standard irrigation (borders L4, L5, L12) |
| Pre- application irrigation | 3/21-23/2006 | 40 | 50 | 41 | 43 |
| 1st irrigation | 4/27/2006 | 59 | 44 | 39 | 79 |
| 2nd irrigation | 5/10/2006 | 46 | 43 | 44 | 43 |
| 3rd irrigation | 5/29/2006 | 69 | 52 | 47 | 44 |
| 5th irrigation | 6/26/2006 | 64 | 88 | 58 | 63 |
| 6th irrigation | 7/11/2006 | 25 | 32 | 39 | 39 |

The average concentrations of P for selected irrigation and fertigation practices in 2006 are shown in Table 2. The concentration of P in runoff water prior to P application practices was in the range of 1.63 to 3.99 mg/L. The concentration of P in runoff water increased dramatically after all P application practices.  The concentration of P in runoff water after dry P broadcast applications reached 118 mg/L (Table 4.2). However, the concentration of P in runoff water after the water-run applications was much higher than the concentration after the dry P broadcast applications (in excess of 218 mg/L). Applying P during the first 75% of irrigation time had no impact on P concentration in irrigation water. The average concentration of P in runoff water during the first six irrigations after P applications was the highest for the 75% water-run P application practice (46 mg/L). The standard broadcast-reduced runoff practice had the lowest average concentration of 18 mg/L. That is more than 50%lower than the concentration of P in the water-run P application practices.

Table 2. Average phosphorus ($PO_4$) concentration in runoff water (mg/L) in 2006.

| | | P application type and irrigation practice | | | |
|---|---|---|---|---|---|
| Irrigation number after P application | Irrigation date | Standard P rate broadcast- standard irrigation (borders L7, L10, L13) | Standard P rate broadcast- reduced runoff (borders L1, L8, L9) | Standard P rate water-run- standard irrigation (borders L3,L6, L11) | 75% of standard P rate- water- run- standard irrigation (borders L4, L5, L12) |
| Pre-application irrigation | 3/21-23/2006 | 3.99 | 3.76 | 1.77 | 1.63 |
| 1st irrigation | 4/27/2006 | 117.93 | 77.41 | 192.30 | 218.44 |
| 2nd irrigation | 5/10/2006 | 3.97 | 4.35 | 5.49 | 5.62 |
| 3rd irrigation | 5/29/2006 | 2.32 | 3.85 | 2.68 | 2.94 |
| 5th irrigation | 6/26/2006 | 1.32 | 4.49 | 2.79 | 3.22 |
| 6th irrigation | 7/11/2006 | 0.71 | 1.51 | 1.42 | 1.24 |
| Average (1st-6th) | | 25.25 | 18.32 | 40.94 | 46.29 |

The average load of P during the first six irrigations after P applications is less than 1 lb/acre per irrigation in the standard broadcast-reduced runoff irrigation (Table 3). The load of P in runoff water for this treatment was almost 75% lower than any other P application or fertigation practice. Controlling the rate and the amount of applied water is the most effective way to reduce the concentration and load of P in runoff waters.

Table 3. Average phosphorus ($PO_4$) concentration and load in runoff water during the first six irrigation after P application in 2006*

| P application type and irrigation practice | Average P concentration (mg/L) per irrigation | Average P load per irrigation (lb/acre) |
|---|---|---|
| Standard P rate broadcast- standard irrigation (borders L7, L10, L13) | 25.25 | 4.37 |
| Standard P rate broadcast- reduced runoff (borders L1, L8, L9) | 18.32 | 0.93 |
| Standard P rate water-run- standard irrigation (borders L3,L6, L11) | 40.94 | 7.09 |
| 75% of standard P rate- water-run- standard irrigation (borders L4, L5, L12) | 46.29 | 8.01 |
| *Based on average application depth of 4.5 inches (11.4 cm) and runoff rates of 17% and 5% for standard irrigation and reduced runoff practices, respectively. | | |

In 2007, the average concentration of suspended sediment in runoff water for all irrigation and P application practices was lower than 105 mg/L. This is well below the TMDL target of approximately 200 mg/L. This indicates that the irrigation or fretigation practices implemented here had little impact on sediment concentration in runoff water.

In 2007, the average concentrations of P prior to the P application in April and in nine irrigation events after the P applications are shown in Table 4. The concentration of P in runoff water prior to P application practices was in the range of 1.34 to 2.24 mg/L. The concentration of P in runoff water increased dramatically after all P application practices. The concentration of P in runoff water after dry P broadcast applications reached 54 mg/L. The concentration of P in runoff water after the water-run applications was higher than the concentration after the dry P broadcast applications (in excess of 110 mg/L). Applying P during the first 75% of irrigation time had little impact on P concentration in irrigation water. The average concentration of P in runoff water during the first six irrigations after P applications was the highest for both the 100% and 75% water-run P application practices. The standard broadcast application practices had average concentrations in the range of 7-8 mg/L. That is almost 50%lower than the water-run P application practices. These levels of reductions are similar to the levels obtained in 2006.

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**Table 4. Average phosphorus ($PO_4$) concentration in runoff water (mg/L) in 2007**

| | | P application type and irrigation practice | | | |
|---|---|---|---|---|---|
| Irrigation number after P application | Irrigation date | Standard P rate broadcast- standard irrigation (borders L7, L10, L13) | Standard P rate broadcast- reduced runoff in 2006 (borders L1, L8, L9) | Standard P rate water-run- standard irrigation (borders L3,L6, L11) | 75% of standard P rate- water-run- standard irrigation (borders L4, L5, L12) |
| Pre-application irrigation | 4/8/07 | 1.34 | 2.24 | 1.73 | 1.76 |
| 1st irrigation | 4/28/07 | 54.22 | 47.35 | 113.25 | 109.5 |
| 2nd irrigation | 5/10/07 | 3.42 | 4.99 | 6.43 | 3.54 |
| 3rd irrigation | 6/2/07 | 2.30 | 2.14 | 4.63 | 2.81 |
| 4th irrigation | 6/11/07 | 1.70 | 1.83 | 2.22 | 1.57 |
| 5th irrigation | 6/28/07 | 1.69 | 2.52 | 2.19 | 1.09 |
| 6th irrigation | 7/13/07 | 0.98 | 1.11 | 1.46 | 1.09 |
| 7th irrigation | 7/31/07 | 1.63 | 1.19 | 1.24 | 1.55 |
| 8th irrigation | 8/20/07 | 1.54 | 0.75 | 2.11 | 1.73 |
| 9th irrigation | 9/09/07 | 0.76 | 1.05 | 1.00 | 0.83 |
| Average (1st -9th) | | 7.58 | 6.99 | 14.95 | 13.75 |

Table 5 Average phosphorus ($PO_4$) concentration and load in runoff water during the first nine irrigations after P application in 2007*

| P application type and irrigation practice | Average P concentration (mg/L) per irrigation | Average P load per irrigation (lb/acre) |
|---|---|---|
| Standard P rate broadcast-standard irrigation (borders L7, L10, L13) | 7.58 | 1.31 |
| Standard P rate broadcast-reduced runoff in 2006 (borders L1, L8, L9) | 6.99 | 0.36 |
| Standard P rate water-run-standard irrigation (borders L3,L6, L11) | 14.95 | 2.59 |
| 75% of standard P rate- water-run- standard irrigation (borders L4, L5, L12) | 13.75 | 2.38 |

*Based on average application depth of 4.5 inches (11.4 cm) and runoff rates of 17% and 5% for standard irrigation and reduced runoff practices, respectively.

The average load of P per irrigation during the first nine irrigations after P applications is less than 1.5 lb/acre per irrigation in the standard broadcast applications (Table 5). The load of P in runoff water for these treatments was almost 50% lower than any other water-run P application or fertigation practices. Controlling the rate and the amount of applied water is the most effective way to reduce the concentration and load of P in runoff waters.

## CONCLUSIONS

Irrigation management is a key factor in controlling the concentration and the load of P discharged from irrigation fields in the Imperial Valley. Reducing the rate of surface runoff during and after P application practices could reduce P load into surface waters by as much as 75% as compared to standard irrigation practices. Water-run application of P increased the concentration and load of P in runoff water by almost double the load generated from dry P application practices.

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NOTE
None of the runoff water generated from this field during any of the P application practices was discharged to drains. All the runoff water was captured by a tailwater recovery system and was reused to irrigate nearby fields.