Management Practices for Phosphorus and Sediment Reduction in the Salton Sea Watershed

Khaled M. Bali and Isabel Escabosa

Abstract—Nutrients, sediment and silt in drainage waters have been identified as the leading cause for water quality impairments in rivers and waterbodies in California. Approximately one-third of applied irrigation water leaves irrigated field as surface runoff and subsurface drainage.

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. 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. The loads of P in runoff waters were reduced by as much as 75% compared to normal irrigation and fertigation practices. Water-run application of P increased the concentration and load of P in runoff water by almost 100% compare to broadcast P applications. Avoiding water-run applications can reduce the load of P in runoff water by more than 50%.

Index Terms—Irrigation management, phosphorus, sediments, water quality.

I. 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 contaminants adsorbed on suspended sediment in waterways has multiple negative impacts on water quality and may cause environmental problems [1]. 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 [2].

Alfalfa is the principal crop in the Imperial Valley in southern California [3]. Approximately one billion cubic meter of water are used every year to irrigate 52,000 hectares of alfalfa. Approximately 10 million kg of phosphorus may be used annually to fertilize alfalfa in the Imperial Valley. 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 other regulated contaminants such as pesticides and phosphorus that are attached to eroded soil particles.

The Salton Sea continues to exist because of the drainage water from agriculture in Imperial and Coachella Valleys as well as flow of agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. As the largest inland body of water in California, the Salton Sea provides significant habitat for fish and wildlife. Rising salinity, sediment, nutrients, and other pollutions threaten these habitats. Excessive loads of nutrients (mainly phosphorus and nitrogen) in Imperial Valley drains and rivers have contributed to the eutrophic conditions in the Salton Sea that impair the designated beneficial uses of the Sea. 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.

II. MATERIALS AND METHODS

A. Phosphorous 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 approximately 6,000 cubic meter per hectare/year, this figure represents a net loss of approximately 2.25 ton of soil (in form of sediment) per hectare per year. The average sediment load to drains and rivers in the Valley is in excess of 450,000 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

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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 6-11 kg/ha per year, with an average annual load of approximately 1.14 million kg of *P* that end up in the Salton Sea every year.

Approximately 10 million kg of phosphorus (in the form of phosphate; P_2O_5) are used annually to fertilize the alfalfa crop [6], 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.

B. Field Experiments

A commercial alfalfa field in the Imperial Valley, California was selected to conduct the project. The field is approximately 32 hectares 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 61 m wide by approximately 366 m 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 91 and 274 m 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 (Table I) were determined.

TABLE I: ANALYTICAL INSTRUMENTS AND FLOW RATE MEASUREMENT METHODS AND QUALITY ASSURANCE OBJECTIVES.

Parameter	Method	Units	Detection limit	Sensitivity	Precision	Accuracy
Water delivered	Trapezoidal flume	Cfs	0 to 25	0.5 cfs	±4%	±10%
Runoff water	Long-throated flume	Cfs	0 to 9	0.2 cfs	±5%	±10%
PO ₄	US-EPA 365.2 (Acid Persulfate Digestion)	Mg/L	0-3.5	0.01	±5%	±5%
Salinity	EC (Tanji, 1990)	dS/m	0-3.0	0.05	±2%	±5%
NO ₃	Spectrum™ (Cadmium Reduction Method)	Mg/L	0-30.00	0.01	±5%	±10%
Turbidity/ standard method	US-EPA 180.1	NTU	0-1000	0.1	±2%	±5%
Turbidity/ OBS-3 Suspended solids and turbidity monitor	D & A Instrument Company	FTU Mg/L	0.02-2,000 0.1-5,000 (Mud, D ₅₀ =10µm)		2.0% (nonlinearity) 2.0% (nonlinearity)	

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 [4], [5], 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 112 kg/ha (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.

Water-run phosphorus or dry phosphorus was applied to selected lands according to the schedule (Fig. 1 - Fig. 3).

C. Phosphorus Application Rates and Methods

Dry *P* fertilizer (11-52-0) at a rate of approximately 112 kg/ha of P_2O_5 (or 215 kg/ha of actual fertilizer) per acre was applied to 12 lands in October 2004 prior to alfalfa planting. Three times the standard rate was applied to land 2. The first application practice (215 kg/ha of dry *P* fertilizer) mentioned above is the normal practice in the Imperial Valley. Some growers prefer to apply three times the yearly standard rate prior to planting instead of applying 215 kg/ha of actual fertilizer prior to planting then subsequent applications during the second and third years of the alfalfa growing period. A summary of the *P* application rates and methods prior to alfalfa planting is presented in Fig. 1. Phosphorus fertilizer was applied again in 2006 (approximately one year after the first hay harvest in 2005) and in spring of 2007. The

rates and methods of application in 2006 and 2007 are summarized in Fig. 2 and Fig. 3 respectively.

Date	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13 extra
March 2006	S RR	Zero	Zero	Zero	Zero	Zero	S	S RR	S RR	S	Zero	Zero	S
BMT	2						4	2	2	4			4
April 2006	Zero	Zero	WR 100%	WR 75%	WR 75%	WR 100%	Zero	Zero	Zero	Zero	WR 100%	WR 75%	Zero
BMT			5	6	6	5					5	6, 7 (FS)	7(FS)

S: Standard rate: 215 kg/ha of 11-52-0 (broadcast), approximately 112 kg/ha of P₂O₅

WR: Water run-P (phosphoric acid) approximately 112 kg/ha of P₂O₅

100%: Water run-P applied during the irrigation time

75%: Water run-P applied during the first 75% of irrigation time

RR: Reduced runoff

FS: Filter strip in 2006/2007

Fig. 1. Phosphorus application rates and methods in 2004 prior to planting.

Date	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13 extra
April 2007	S	Zero	Zero	Zero	Zero	Zero	S	S	S	S	Zero	Zero	S
BMT	4						4	4	4	4			4
April 2007	Zero	Zero	WR 100%	WR 75%	WR 75%	WR 100%	Zero	Zero	Zero	Zero	WR 100%	WR 75%	Zero
BMT			5	6	6	5					5	6, 7 (FS)	7 (FS)
October 2007	PA	PA	PA	PA	PA	PA	PA	PA	PA	PA	PA	PA	PA
BMT	3	3	3	3	3	3	3	3	3	3	3	3	3

S: Standard rate: 215 kg/ha of 11-52-0 (broadcast), approximately 112 kg/ha of P₂O₅

WR: Water run-P (phosphoric acid) approximately 112 kg/ha of P₂O₅

100%: Water run-P applied during the irrigation time

75%: Water run-P applied during the first 75% of irrigation time

FS: Filter strip in 2006/2007

PA: Precision application based on plant needs (soil testing and/or alfalfa uptake load, approx. 112 kg/ha of P₂O₅ per 8 tons of alfalfa).

Fig. 2. Phosphorus application rates and methods in 2006.

	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)

Fig. 3. Phosphorus application rates and methods in 2007.

III. RESULTS AND DISCUSSION

A. 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 [7]. 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 $NTU \geq 200$), 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

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

Threshold linear functions

$$C = 1.162T + 18.5 \quad NTU < 200 \quad (2a)$$

$$C = 0.898T + 12.1 \quad NTU \geq 200 \quad (2b)$$

Power function

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

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.

B. 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 II). 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 II: AVERAGE SEDIMENT CONCENTRATION IN RUNOFF WATER (MG/L) IN 2006

Irrigation number after P application	Irrigation date	P application type and irrigation practice			
		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
1 st irrigation	4/27/2006	59	44	39	79
2 nd irrigation	5/10/2006	46	43	44	43
3 rd irrigation	5/29/2006	69	52	47	44
5 th irrigation	6/26/2006	64	88	58	63
6 th irrigation	7/11/2006	25	32	39	39

TABLE III: AVERAGE PHOSPHORUS (PO_4) CONCENTRATION IN RUNOFF WATER (MG/L) IN 2006

Irrigation number after P application	Irrigation date	P application type and irrigation practice			
		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
1 st irrigation	4/27/2006	117.93	77.41	192.30	218.44
2 nd irrigation	5/10/2006	3.97	4.35	5.49	5.62
3 rd irrigation	5/29/2006	2.32	3.85	2.68	2.94
5 th irrigation	6/26/2006	1.32	4.49	2.79	3.22
6 th irrigation	7/11/2006	0.71	1.51	1.42	1.24
Average (1st-6 th)		25.25	18.32	40.94	46.29

The average concentrations of P for selected irrigation and fertigation practices in 2006 are shown in Table III. 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 III). 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.

The average load of P during the first six irrigations after P applications is about 1 kg/ha per irrigation in the standard broadcast-reduced runoff irrigation (Table IV). 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.

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

The average concentrations of *P* prior to the *P* application in April and in nine irrigation events after the application are shown in Table VI. 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.

The average load of *P* per irrigation during the first nine irrigations after *P* applications is less than 1.5 kg/ha per irrigation in the standard broadcast applications (Table VII). 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.

TABLE IV: AVERAGE PHOSPHORUS (PO₄) CONCENTRATION AND LOAD IN RUNOFF WATER DURING THE FIRST SIX IRRIGATION AFTER *P* APPLICATION IN 2006*

<i>P</i> application type and irrigation practice	Average <i>P</i> concentration (mg/L) per irrigation	Average <i>P</i> load per irrigation (kg/ha)
Standard <i>P</i> rate broadcast- standard irrigation (borders L7, L10, L13)	25.25	4.90
Standard <i>P</i> rate broadcast- reduced runoff (borders L1, L8, L9)	18.32	1.04
Standard <i>P</i> rate water-run- standard irrigation (borders L3, L6, L11)	40.94	7.95
75% of standard <i>P</i> rate- water-run- standard irrigation (borders L4, L5, L12)	46.29	8.98

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

TABLE V: AVERAGE SEDIMENT CONCENTRATION IN RUNOFF WATER (MG/L)

Irrigation number after <i>P</i> application	Irrigation date	<i>P</i> application type and irrigation practice			
		Standard <i>P</i> rate broadcast- standard irrigation (borders L7, L10, L13)	Standard <i>P</i> rate broadcast- reduced runoff in 2006 (borders L1, L8, L9)	Standard <i>P</i> rate water-run- standard irrigation (borders L3, L6, L11)	75% of standard <i>P</i> rate- water-run- standard irrigation (borders L4, L5, L12)
Pre-application irrigation	4/8/07	59	83	68	63
1 st irrigation	4/28/07	73	58	77	83
2 nd irrigation	5/10/07	51	41	56	65
3 rd irrigation	6/2/07	54	58	68	68
4 th irrigation	6/11/07	44	41	54	47
5 th irrigation	6/28/07	86	105	58	39
6 th irrigation	7/13/07	42	43	48	44
7 th irrigation	7/31/07	58	54	54	81
8 th irrigation	8/20/07	54	42	74	51
9 th irrigation	9/09/07	44	55	40	37

TABLE VI: AVERAGE PHOSPHORUS (PO₄) CONCENTRATION IN RUNOFF WATER (MG/L) IN 2007

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

TABLE VII: AVERAGE PHOSPHORUS (PO₄) 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 (kg/ha)
Standard P rate broadcast- standard irrigation (borders L7, L10, L13)	7.58	1.47
Standard P rate broadcast- reduced runoff in 2006 (borders L1, L8, L9)	6.99	0.40
Standard P rate water-run- standard irrigation (borders L3,L6, L11)	14.95	2.90
75% of standard P rate- water-run- standard irrigation (borders L4, L5, L12)	13.75	2.67

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

TABLE VIII: AVERAGE ALFALFA YIELD IN TON/AC BASED ON ALFALFA HAY SAMPLES COLLECTED AT 91 AND 274 M ALONG EACH LAND IN 2006 AND TOTAL YIELD PER CUTTING BASED ON BALES

Land No.	3/10/06	4/21/06	5/17/06	6/13/06	7/19/06	8/28/06	10/17/06	12/1/06	Total 2006
1	1.69	1.77	1.62	2.06	1.94	1.64	1.06	1.00	12.78
2	1.91	1.92	2.19	2.68	1.83	1.34	0.91	0.86	13.64
3	1.70	1.84	1.81	2.15	1.80	1.28	1.01	0.81	12.40
4	1.79	1.47	2.51	2.20	2.04	1.20	0.88	0.96	13.04
5	1.72	1.68	2.28	2.73	1.90	1.21	0.87	0.68	13.07
6	2.04	1.91	1.87	2.89	2.63	1.58	0.94	0.95	14.81
7	2.06	1.76	2.09	2.15	2.04	1.47	0.90	1.01	13.48
8	1.65	2.14	2.28	1.66	1.89	1.05	1.01	1.20	12.87
9	1.68	1.86	1.68	2.66	2.11	1.43	0.86	1.07	13.36
10	2.16	2.04	1.95	2.33	1.91	1.39	1.15	1.11	14.03
11	1.88	1.98	1.72	1.49	2.04	1.59	1.34	1.07	13.11
12	2.12	1.74	1.96	2.79	1.82	1.16	0.97	1.16	13.73
13	1.67	1.63	1.61	2.55	1.71	1.23	0.96	0.90	12.26
Average (hay samples)	1.85	1.83	1.97	2.33	1.97	1.35	0.99	0.98	13.28
Average (bales)	1.10	1.13	1.39	1.83	1.63	0.98	0.74	0.71	9.49

* December 2006 cutting: insect damage

TABLE IX: AVERAGE ALFALFA YIELD IN TON/AC BASED ON ALFALFA HAY SAMPLES COLLECTED AT 91 AND 274 M ALONG EACH LAND IN 2007

Land No.	3/15/07	4/18/07	5/21/07	6/18/07	7/23/07	9/24/07	12/12/07	Total 2007
1	0.95	1.35	1.69	1.07	1.22	1.03	0.84	8.14
2	0.81	1.15	1.41	0.97	0.99	0.95	0.90	7.17
3	0.70	1.42	1.58	1.69	1.17	1.10	0.82	8.48
4	1.10	0.99	1.68	1.16	1.63	1.53	1.03	9.11
5	0.66	1.04	1.46	1.66	0.90	0.86	0.69	7.27
6	0.93	1.06	1.68	1.42	1.45	1.21	0.77	8.51
7	1.07	1.05	1.70	1.35	1.53	1.37	0.97	9.04
8	0.88	1.26	1.39	1.76	1.44	1.49	0.81	9.03
9	1.01	1.38	1.68	1.75	1.84	1.42	0.97	10.04
10	1.02	1.31	1.28	1.37	1.52	1.60	0.67	8.77
11	1.15	1.39	1.92	1.74	1.49	1.62	0.82	10.12
12	0.99	1.72	1.53	1.23	1.53	1.17	1.01	9.16
13	0.86	1.22	1.31	1.24	1.12	1.07	0.81	7.64
Average	0.93	1.26	1.56	1.42	1.37	1.26	0.85	8.65
Average (bales)	0.44	0.89	1.62	1.27	1.02	0.43	0.63	6.30

* March 2007 cutting: damage due to cold weather in January 2007.

* September 2007: cutting damage due to heat stress and insects.

TABLE X: AVERAGE ALFALFA YIELD (TONS/AC PER CUTTING) IN TWO CUTTINGS BEFORE AND IN THREE CUTTINGS AFTER THE *P* APPLICATION IN 2006

	<i>P</i> application type and irrigation practice			
	Standard <i>P</i> rate broadcast-standard irrigation (borders L7, L10, L13)	Standard <i>P</i> rate broadcast-reduced runoff (borders L1, L8, L9)	Standard <i>P</i> rate water-run-standard irrigation (borders L3, L6, L11)	75% of standard <i>P</i> rate- water-run-standard irrigation (borders L4, L5, L12)
Before <i>P</i> application	1.89	1.80	1.89	1.75
After <i>P</i> application	2.04	1.99	2.04	2.25
Amount of <i>P</i> applied 11-52-0 equivalent	200	200	200	150

TABLE XI: AVERAGE ALFALFA YIELD (TONS/AC PER CUTTING) IN TWO CUTTINGS BEFORE AND IN THREE CUTTINGS AFTER THE *P* APPLICATION IN 2007

	<i>P</i> application type and irrigation practice		
	Standard <i>P</i> rate broadcast-standard irrigation (borders L1, L7, L8, L19, 10, L13)	Standard <i>P</i> rate water-run-standard irrigation (borders L3, L6, L11)	75% of standard <i>P</i> rate- water-run-standard irrigation (borders L4, L5, L12)
Before <i>P</i> application	1.11	1.11	1.08
After <i>P</i> application	1.46	1.57	1.42
Amount of <i>P</i> applied 11-52-0 equivalent	200	200	150

C. Alfalfa Yield

Alfalfa yields based on hay samplers collected at 91 and 274 m along each border and the total number of bales are shown in Table VIII, Table IX, Table X, and Table XI.

The average alfalfa yield in 2006 for the entire field (9.5 tons based on bale weight) is within the normal expected yields in the Imperial Valley. None of the implemented *P* application practices had any negative impact on yield. The average yield in 2007 was relatively lower compare to normal years due to unusual freeze damage to the entire field and many alfalfa fields in the Valley. The night time temperatures were below freezing for more than one week in January of 2007. The temperature damage reduced alfalfa yield by 0.65 tons as compared to the same period in 2006. None of the *P* implementation practices in 2007 had any negative impact on alfalfa yield.

D. A Precision Application of *P*-Fertilizer to the Soil in Specific Parts of the Fields According to the Plant Needs

Phosphorus is the most important nutrient needed for alfalfa production. Potassium (*K*) and sulfur are also important but in many soils in the low desert areas of California, the amount of *K* in the soil and irrigation water is sufficient for alfalfa growth. Most nutrients for alfalfa production come from the soil and some from irrigation water. The most effective way to evaluate the nutrient requirements for *P* in alfalfa is to measure the concentration of *P* in the plant tissues and the soil (Table XII). But

sometimes, such as prior to planting, it is not possible to use plant tissue analysis to evaluate the status of *P* in the alfalfa. Soil testing could also be helpful prior to planting to evaluate the amount of *P* needed for alfalfa growth.

Soil testing and plat tissue analysis are needed to determine the amount of *P* required for the proper application of *P* and other fertilizers. Soil testing is usually conducted prior to planting and approximately two to three years after planting. Plant tissue analysis could be done every year or more frequently if needed. Soil samples should be taken from the first foot or so of the soil profile if broadcast *P* was used applied to the field. Deeper samples may be needed if water-run *P* was applied to the field. However, most of water uptake and nutrient uptake in alfalfa in the low desert region occurs from the top two to three feet of the soil profile. In heavy cracking clay soils, some of water-run *P* may move to depths below three feet and may not be available to the alfalfa roots. It is better to avoid applying water-run *P* when the soil profile is dry and deep cracks are present. Therefore, fertilizer application practices must be taken into account when soil testing is needed. Most top dressed *P* is in the top six inches of the soil profile.

Phosphorus analysis should be conducted using the Olsen method (for soils in southern California). The method is applicable for the conditions in the desert region (high pH and calcium soils and low organic matter). The phosphorus concentration should be reported in ppm (parts per million) *P*. If other units are used (such as PO_4 or P_2O_5), the values should be converted to ppm *P* using one the following equations:

$$\text{PO}_4 = 3.07 \times P$$

$$\text{P}_2\text{O}_5 = 2.29 \times P$$

For alfalfa, the following guidelines have been developed for *P* soil tests:

P concentrations between 0 and 6 ppm of *P*, the amount of *P* in the soil is: LOW

P concentrations between 7 and 10 ppm of *P*, the amount of *P* in the soil is: MARGINAL

P concentrations higher than 10 ppm of *P*, the amount of *P* in the soil is: ADEQUATE

TABLE XII: THE AMOUNT OF *P* FERTILIZER NEEDED PER YEAR BASED ON SOIL *P* TESTS

Soil test level (ppm)	Amount of P_2O_5 needed per ac per year (based on 8-10 tons of alfalfa per year)
0-3	200
3-6	150
6-10	100
10-15	50
Above 15	0

Most irrigated soils in the Imperial Valley have soil *P* in excess of 5-10 ppm, therefore, applications of *P* in excess of 112-168 kg/ha of P_2O_5 may not be needed. The removal rate of *P* by alfalfa is about 7 kg of P_2O_5 per ton of hay. In general, dry forms of *P* fertilizers for alfalfa such as 11-52-0 or 0-45-0 are as effective as liquid forms (10-34-0, phosphoric acid).

In this project, soil samples were collected in September 2007 from depths varying from surface to 60 cm below the surface from two locations along each land (91 m and 274). Four soil samples were collected from each location (surface

to 15 cm, 15-30 cm, 30-45 cm, and 45-60 cm). The samples at depths of 6 and 12 inches were analysed for available *P* using the standard sodium bicarbonate-extractable phosphate

method. The average concentration of *P* and *K* in soil samples and plant samples are presented in Table XIII and Table XIV, respectively.

TABLE XIII: THE AVERAGE CONCENTRATION OF PHOSPHORUS (*P* IN PPM) AND POTASSIUM (*K* IN PPM) IN SOIL SAMPLES COLLECTED IN SEPTEMBER 2007

Land No.	<i>P</i> ppm Average of 4 samples (0-30 cm) Two depths at two locations	<i>P</i> ppm Average of 2 samples (0-15 cm) One depth at two locations	<i>P</i> ppm Average of 2 samples (15-30 cm) One depth at two locations	<i>K</i> ppm Average of 4 samples (0-30 cm) Two depths at two locations	<i>K</i> ppm Average of 2 samples (0-15 cm) One depth at two locations	<i>K</i> ppm Average of 2 samples (15-30 cm) One depth at two locations
1	5.5	5.8	5.1	148.0	145.5	150.5
2	5.5	5.6	5.5	151.8	155.0	148.5
3	6.5	7.0	5.9	163.8	172.0	155.5
4	5.8	6.2	5.5	150.0	156.5	143.5
5	9.0	8.2	9.8	142.5	148.5	136.5
6	9.8	10.1	9.5	158.8	162.5	155.0
7	11.7	11.1	12.3	174.0	172.5	175.5
8	10.7	10.9	10.5	181.0	184.0	178.0
9	6.2	6.4	6.1	173.8	175.5	172.0
10	8.4	7.9	8.9	179.3	178.0	180.5
11	7.9	7.4	8.4	150.3	152.0	148.5
12	10.0	10.2	9.9	174.8	178.5	171.0
13	13.4	13.6	13.1	166.8	169.0	164.5
Average	8.5	8.5	8.5	162.7	165.3	160.0

TABLE XIV: THE AVERAGE CONCENTRATION OF PHOSPHORUS (PO_4 -*P* IN PPM) AND POTASSIUM (*K* IN %) IN PLANT SAMPLES COLLECTED IN NOVEMBER 2007

Land No.	PO_4 - <i>P</i> ppm Average of 2 samples (91 m and 274 m)	PO_4 - <i>P</i> ppm at 91 m	PO_4 - <i>P</i> ppm at 274 m	<i>K</i> % Average of 2 samples (91 m and 274 m)	<i>K</i> % at 91 m	<i>K</i> % at 274 m
1	1285	1290	1280	1.29	0.93	1.64
2	1255	1360	1150	1.26	0.83	1.69
3	1150	1160	1140	1.52	1.13	1.90
4	1055	1180	930	1.87	1.65	2.09
5	1395	1160	1630	1.00	1.01	0.98
6	1165	960	1370	1.55	1.57	1.53
7	1240	1120	1360	1.50	1.40	1.59
8	1280	1270	1290	1.84	1.94	1.73
9	1105	1160	1050	1.72	2.00	1.43
10	1230	1140	1320	1.91	1.79	2.02
11	1185	1250	1120	1.56	1.55	1.56
12	1315	1440	1190	2.11	2.34	1.87
13	1235	1400	1070	1.48	1.28	1.68
AVERAGE	1223	1222	1223	1.58	1.49	1.67

TABLE XV: INTERPRETATION OF TEST RESULTS FOR ALFALFA PLANT TISSUE SAMPLES TAKEN AT ONE-TENTH BLOOM [7]

Nutrient	Plant part	Unit	Plant tissue value			
			Deficient	Marginal	Adequate	High
Phosphorus (PO_4 - <i>P</i>)	Middle third, stems	ppm	300-500	500-800	800-1,500	Over 1,500
Potassium	Middle third, stems	%	0.40-0.65	0.65-0.80	0.80-1.50	Over 1.50

The average concentration of *K* in the soil profile is about 163 ppm that is above the threshold limit of about 150 ppm of *K*. Therefore, *K* fertilization is not needed. The average concentration of *P* in all locations was about 8.5 ppm; therefore, additional *P* application may be needed next spring in areas where *P* concentration is below 10 ppm. However, alfalfa tissue testing is needed to determine the exact application rates and to determine the *P* status in the plant.

Using soil *P* test for determining the amount of *P* needed for alfalfa is usually recommended prior to planting. However, for established stands, tissue testing is the most accurate method of determining the nutrient needs of alfalfa. Alfalfa samples were collected from at least 30 plants near the soil sampling locations. The samples were tested for *P* and *K* using the methods recommended by [8].

Table XV shows the recommendations of [7] for interpreting alfalfa tissues, based on this table; none of the 13 lands need any *P* or *K*. The average concentration of *P* in all lands and at all location was in excess 1,200 ppm. The average concentration of *K* was 1.58 % and that is in the high range according to Tables IV-XIV.

IV. 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 application practices.

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