Quality of Surface Irrigation Runoff Water

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IN recent years increased municipal, industrial, recreational, and agricultural use of water has intensified concern about quality. Irrigated agriculture, in particular, has been indicted for contaminating both surface and ground waters with surface and subsurface runoff from irrigated lands.

Agriculture uses water and nutrients to produce food or fiber for man, and most of what is produced enters the natural resource cycle again as waste. In irrigated agriculture, this cycle may be bypassed when fertilizers are leached through the soil or carried away by surface runoff. However, the actual loss of fertilizer from irrigated fields has been determined only in isolated cases.

The purpose of this study was to determine what differences, if any, existed between irrigation water applied to a field and surface runoff water from that field with respect to common fertilizer elements. Possible mechanisms by which water flowing over or through soil might acquire fertilizer ions are described.

Study of tile drain effluent from irrigated fields has shown that large amounts of nitrogen may be present in subsurface drainage water, but phosphorus concentrations are small (Johnson et al., 1965). In a Georgia study, the amount of phosphate in runoff from fertilized plots was proportional to the amount of soil eroded (Thomas et al., 1968). Phosphate ions become fixed to the soil particle and are not very soluble thereafter; consequently, most phosphate losses appear to be those associated with movement of soil particles.

The approximate contribution to the Yakima River from an irrigated area has been estimated to be about 33 lb of nitrate (NO_3^-) and about 1 lb soluble phosphate ($PO_4^{\equiv}$) per acre per year (Sylvester and Seabloom, 1963). The actual source of nitrate in the runoff water was not identified in either of the previously mentioned studies.

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Stromberg (1966) computed a nutrient balance for cultivated land in Fresno County, California, considering nutrients added by fertilizer application, irrigation water, soil amendments and rainfall, and removal of nutrients by marketed farm products. Fresno County gained approximately 14 lb of nitrogen per acre and lost potassium and phosphorus.

Ion Transfer Mechanism

Water flowing across the surface of land, as in an irrigation furrow, can pick up chemical constituents by mechanical incorporation of the soil particles or by diffusion of ions from the soil solution to the irrigation water. The diffusion of a given ion from the soil into water flowing over the soil can be countered by infiltration of water moving downward at a velocity equal to the ion transport velocity due to diffusion.

The necessary velocity can be estimated by Einstein's equation based on Brownian movement:

$$\Delta^2 = 2Dt \qquad [1]$$

where D is the diffusion coefficient, t is time and Δ is the average displacement produced by Brownian movement. Quoted diffusion coefficients for aqueous solutions of electrolytes at 25 C and one atmosphere of pressure are approximately 2 sq cm per day for sodium chloride, ammonium nitrate and potassium chloride (reference 1).

For example, the Einstein equation indicates that sodium chloride (D = 2.00 sq cm per day) would diffuse into water flowing over the soil surface at a velocity of 2 cm per day or 0.083 cm per hr. This velocity of ion movement is of the same magnitude as has been found for ion transfer in soils (Phillips and Brown, 1964). Infiltration velocities far exceed this on most soils, thus there would be very little or no diffusion of nutrients to water passing across the soil surface.

If the flow in the furrow is laminar and infiltration is occurring, ions would not be expected to enter surface flow. On the other hand, if the flow is turbulent, ions attached to soil particles will be in direct contact with the irrigation water in the furrow and the chance of their transfer to the water is much greater. However, the laminar sublayer in turbulent flow will normally extend above the roughness height so the example distance will probably exist as laminar flow in most cases.

When the soil is loose, such as after cultivation and at the beginning of the irrigation season, or when erosive streams are used, a greater concentration of nutrient ions, associated with soil particles, would be expected in the runoff water than in the applied surface water. Later in the season, the ion concentration in the runoff water should not be significantly different from that in the applied irrigation water.

The diffusion distance and flux concept also has application in leaching nutrients from the soil profile. At large intake rates, most of the flow occurs in the larger pore spaces and will pass through the soil profile with only sufficient contact time to acquire small concentrations of nutrients by diffusion. At smaller water flux rates, most of the flow takes place in thin films around the soil particles, increasing transit time, decreasing the diffusion distance and resulting in a larger concentration of ions in the percolating water.

METHODS

A study of water quality changes between applied irrigation water and runoff from the irrigated fields was conducted in the Paul, Idaho, area during the summers of 1966, 1967, and 1968. Water samples obtained periodically during the irrigation season were analyzed for: temperature, pH, electrical conductivity, carbonate, bicarbonate, chloride, sulfate, nitrate, nitrite, calcium, magnesium, sodium, potassium, phosphate, sediment, and color. APHA analysis methods were used (reference 2, 1965).

The area studied was a small watershed covering approximately 700 acres. Six farms, totaling 536 irrigated acres, were included in a comprehensive water-use study where all inflow and surface runoff was measured. Runoff from the entire watershed was collected at a central collection pond and returned to the canal so that no surface water or sediment was lost from the study area.

Samples of runoff were collected from individual fields, the sediment pond, and the canal. Samples of canal water

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were collected upstream from the point where the runoff water was returned to the canal. All samples were taken from surface waters. No attempt was made to sample the soil water or the ground water (which is at a depth of approximately 200 ft in this area).

A detailed examination of water quality changes during an irrigation was made on one field at the Twin Falls Branch Experiment Station in 1965. This field had been fertilized with 100 lb of nitrogen and 130 lb of P_2O_5 per acre. It was then disked, planted to winter wheat, corrugated and irrigated. Duplicate areas of 10 corrugations each were selected. Corrugations were spaced 24 in. apart and were 470 ft long. Water inflow and runoff from each area were measured continuously during irrigation. Water samples for quality analysis were taken periodically during irrigation.

Results and Discussion

The nitrate (NO_3^-), phosphate ($PO_4^{\equiv}$), and sodium (Na) contents of applied and runoff water from the study area are summarized in Table 1 for 1966, 1967 and 1968. These data show that the concentrations of nitrate, phosphate and sodium appearing in the surface runoff are approximately the same as those in the applied water. All nitrate values were within the limits of accuracy of the analysis method.

Surface runoff from irrigation may add little to the nitrogen and phosphate content of the surface waters. Efficient irrigation stores water in the soil for use and also supplies small amounts of fertilizer for the crop. With runoff of only 16 to 20 percent of the water applied to the field, the ion concentration in the runoff water would have to be 5 to 6 times as high as that in the applied water to remove, by surface runoff, the same amount of ion constituents as are applied to the field.

Where nonerosive furrow streams are used, this is not probable. However, if the runoff water has an ion concentration higher than the applied water, the concentration in the receiving stream has been increased by an amount dependent upon the relative quantities and concentrations involved.

Both soluble ortho-phosphate and total phosphate content were measured. In 1968, the soluble/total phosphate ratio of the runoff as compared to that of the applied water increased through the first week in July. However, only in two of the five samples involved was the increase due to an increase in the concentration of soluble phosphate, indicating possible pickup of applied phosphate fertilizer during the irrigation process. Sediment content in both waters remained high through the second week in August. The last cultivations in this study area normally occur no later than July 20.

Water diverted from the Snake River during this study had a high phosphate content. About 20 lb of phosphate ($PO_4^{\equiv}$) per acre was added by a total irrigation of 3 acre-ft. Polyphosphates were approximately 50 percent of the total phosphate content of the water, indicating phosphorus contributions from other sources such as detergent and sewage additions upstream.

The potassium content of the applied and runoff water was also measured in 1967 and 1968. The runoff water had an 80 percent greater concentration than applied water in 1967, but only a 4.2 percent greater concentration in 1968. Potassium is readily leached from decaying organic matter, but data were insufficient to determine the source of the increase in these waters.

Other water quality characteristics measured were color, temperature, pH, electrical conductivity, and sediment content. The color of the incoming Snake River water at this point was consistently about 5 platinum-cobalt color units. The color of the runoff water varied over the season but averaged less than 10 color units for the three seasons. Current U. S. Public Health Service standards recommended an upper limit of 15 color units for drinking water. Both the Snake River water and the runoff water occasionally had a higher color value than allowable by this standard.

Idaho water quality standards for this portion of the Snake River limit pH to between 7.0 and 9.0. Any additions are to cause not more than a 0.5 pH unit shift in the receiving stream. The data obtained in this study show a three-season average of less than 0.1 pH unit difference between applied and runoff irrigation water.

Surface irrigation may or may not increase the water temperature in this area. An average seasonal temperature differential of 1 to 2 C was measured. Water traversing a furrow absorbs heat from the soil and the ambient air during most of the season and is cooled by evaporation. The temperature of a large stream like the Snake River, with large amounts of on-stream storage, does not change as fast as that of a small irrigation stream.

The incoming Snake River water was about 20 C for approximately 2½ months in 1966 and for 2 months in 1967. Idaho standards limit adding water that would cause a stream temperature increase of more than 2 F or any in-

TABLE 1. QUALITY OF APPLIED AND RUNOFF WATER FROM SURFACE IRRIGATION OF A 536-ACRE STUDY AREA NEAR PAUL, IDAHO*

	1966			1967			1968		
	On	Off	Off/on, percent	On	Off	Off/on, percent	On	Off	Off/on, percent
Nitrate, NO_3^-, ppm, avg.	0.1	0.1	100.0	0.1	0.1	100.0	0.2	0.2	100.0
Phosphate, $PO_4^{\equiv}$, lb per acre	22.42	3.78	16.8	7.54	1.15	15.3	5.07	1.02	20.1
Phosphate, $PO_4^{\equiv}$, ppm, avg.	2.60	2.72	104.6	2.03	2.01	99.0	1.42	1.52	107.0
Sodium, lb per acre	124.63	20.79	16.7	85.09	14.31	16.8	100.78	17.52	17.4
Sodium, ppm, avg.	14.09	14.52	103.2	23.77	27.47	115.6	26.89	23.96	89.0
Potassium, ppm				4.30	6.90		4.08	4.85	
Color, units	5.4	8.8		6.0	9.0		4.5	9.6	
Temperature, deg C	19.3	21.5		20.6	19.6				
pH	8.3	8.3		8.3	8.3		7.6	7.7	
Conductivity, ec x 10^{-6}	525.0	525.0		384.0	389.0		405.0	358.0	
Sediment, ppm	48.5	30.3		26.2	42.3		100.4	242.3	
Water, acre-ft	1749.0	283.0	16.2	735.0	114.0	15.5	1010.0	187.0	18.5
Water, percent of seasonal total	96.4	97.5		45.5	52.5		71.2	76.2	
Period of record	6 May - 12 Oct.			27 July - 10 Oct.			10 June - 9 Sept.		

* All values weighed for flow volume.

crease when stream temperatures are above 68 F (20 C).

The Snake River from this point on downstream to Bliss, Idaho, receives water from underground sources discharging as springs and seeps into the river. These discharges reduce water temperatures of the main Snake River, and it is unlikely that the temperature of the river is significantly affected by surface runoff from the study area. The average temperature of the Snake River at King Hill, Idaho, for the period 1951-1968 was: June - 64 F (17.8 C), July - 68 F (20 C), August - 66 F (18.9 C), September - 63 F (17.2 C).

The temperature readings (Table 1) were taken at various times of the day and may not represent an accurate sample. Temperature data taken during the runoff study at the Twin Falls Branch Experiment Station showed that the temperature of runoff water was higher than the incoming stream part of the day and lower than the incoming stream during part of the day.

Data from the runoff study at the Twin Falls Experiment Station showed that nitrate (NO_3^-) and phosphate ($PO_4^{\equiv}$) concentrations vary during an irrigation. Both nitrate (NO_3^-) and phosphate ($PO_4^{\equiv}$) concentrations in the runoff water were higher during initial runoff, but followed a pattern similar to that of the concentration in the applied water during the remainder of the irrigation. There was a net input to the soil of both NO_3^- and $PO_4^{\equiv}$ during irrigation.

The initially higher concentration of nitrate and phosphate in runoff waters from these plots was also accompanied by high rate of sediment production. However, high rates of sediment production later in the irrigation did not produce ion concentration increases in the runoff. These data also emphasize the necessity of sampling from a pooled sample or taking continuous samples of runoff in smaller streams to obtain representative sampling. Spot sampling from isolated streams, particularly during early runoff, may give values which are not as representative of the average condition as a pooled sample.

Conclusions

Chemical constituent concentrations increase in runoff waters during surface irrigation because of incorporation of undissolved fertilizer particles in the irrigation stream or by erosion of soil particles having attached fertilizer ions. Diffusion due to ion concentration differences in the soil water at the soil surface and the irrigation water is negligible.

The Einstein equation for Brownian movement shows that the diffusion process is not likely to cause an increase in ion concentration in water running over the surface of the land because the mean velocity of diffusing ions is less than the velocity of water infiltrating into the soil. An infiltration rate of 0.1 cm per hr would be adequate to overcome extreme diffusion fluxes.

Analysis of water applied to and runoff from a surface irrigation area near Paul, Idaho, shows only small changes in ion concentrations in runoff water as compared to applied water. More nutrient elements were applied to the field in the irrigation water than left in the runoff water. Losses of nitrate, phosphate and sodium as a percent of that applied were approximately the same magnitude as the loss of water as runoff.

Improving the overall efficiency of surface irrigation would further reduce nutrient and sediment losses. This improvement can be obtained by using return systems to prevent loss of runoff water and by using the largest non-erosive stream size to promote uniform distribution and minimize deep percolation. Even without reusing the runoff water, a grassed filter strip or a silt settling pond or both would reduce the loss of sediment and improve the quality of runoff water.

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