NITRATE LEACHING FOLLOWING POTATO FERTILIZATION

by
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Increasing attention is being directed toward possible environmental pollution arising from various activities of man. Agriculture received early attention through focus on animal waste disposal operations, and on contamination from various pesticides and pesticide residues. With the recent passage of greatly-expanded federal environmental legislation, however, the means have been established for imposing even tighter controls upon any agricultural operations having significant potential for pollution. The studies described below are a few of many which have been designed to assess the extent of actual and potential pollution accompanying typical agricultural operations, and to assist the agricultural community in the development of sound management practices having minimal pollution potential. The studies are based on the belief that control from within, rather than regulation from without, is the better means for correcting pollution problems from any segment of society.

Nitrate is a material common to agricultural crop production which can constitute a serious environmental hazard. Nitrogen is required for economic crop production, and most readily-available nitrogen in well-aerated soils is rapidly converted to the nitrate form during the growing season. Nitrate is not absorbed by soil particles, and thus moves readily through the soil whenever excess water is applied. It is one of the nutrients which can support the growth of algae and other aquatic plants in streams and lakes if it is returned to surface water supplies. In addition, current drinking water standards place an upper limit of 10 mg/liter (ppm) on the nitrate-nitrogen content of drinking waters, because of hazards to infants from higher nitrogen levels. Thus, leaching of soil solution from the plant root zone during the growing season can lead to potential nitrate pollution of local surface and ground-water supplies. Intensive crops such as potatoes, which have simultaneous requirements of both high nitrogen and high water levels, represent a particularly serious nitrate pollution hazard.

One method of monitoring nitrate levels in the soil solution involves placement of ceramic cups in the soil, connecting these cups with nylon tubing to a vacuum system at the soil surface, and applying a vacuum periodically to extract samples of the soil solution during the growing season. Typical results from such an approach are provided in Table 1, for an extremely sandy soil at a research and demonstration site [2/] in Block 21 of the Columbia Basin, south of Othello. Nitrogen fertilization for all plots represented in the table consisted of 500 # N/acre banded as ammonium nitrate. Extraction cups were placed at the depths indicated in the table, with the basalt underlay at the site occurring at a depth of 8 to 10 feet. Although results are reported as "dissolved nitrogen," extensive monitoring of nitrogen forms during these experiments established that the nitrogen moved through the soil profile almost exclusively as nitrate, so the results can be interpreted as nitrate-nitrogen values as well. Residual accumulations of nitrogen at concentrations of 50 to 90 mg/liter were not uncommon at the start of the growing season (April 20). Such levels of nitrogen are common for "fertile" soils, though the variations in dissolved nitrogen levels at different depths are not readily explained. Such variations may be related to the stratified nature of the soil at this site, with silt lenses found in a complex pattern throughout the soil profile. It should be noted that dissolved nitrogen values in many parts of the soil profile exceeded the drinking water standard of 10 mg/liter even before the irrigation season began.

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2/ Site maintained as a joint effort between Washington State University and the U. S. Bureau of Reclamation. Additional cooperators for the studies of table 1 included B. L. Carlile, J. E. Middleton, S. Roberts and T. Cline.

Table 1. Dissolved nitrogen (mg/liter) in samples of extracted soil solution from the sandy site throughout the 1970 growing season.

	High-rate furrow			High-rate sprinkler		
Depth	4-20	6-22	8-5	4-20	6-22	8-5
1'	89	--	3	904	1330	37
2'	7	48	0	65	--	--
4'	85	99	0	11	32	509
6'	9	328	0	55	44	495
basalt	12	0	0	7	3	6

	Low-rate sprinkler		
	4-20	6-22	8-5
1'	--	--	21
2'	79	20	884
4'	2	6	27
6'	8	0	18
basalt	133	13	9

By late June, the poor water control accompanying furrow irrigation had produced leaching of fertilizer nitrogen to the six foot depth at this site, whereas by early August there was essentially no nitrogen present throughout the entire profile of the furrow-irrigated treatment. Use of sprinkler irrigation resulted in considerably better water management and control of nitrogen leaching. Sprinkler irrigation at a high rate (1.5 times the rate required to replenish that moisture being used by the crop) leached nitrogen only to the one foot depth by June 22, and to the four and six foot depths by August 5. Sprinkler irrigation at a rate which essentially just replenished water used by the crop kept all fertilizer nitrogen in the top two feet of the profile even into August. Although some late-season leaching of nitrogen occurred for all treatments, these experiments showed that nitrogen could be maintained in the potato root zone (at depths more shallow than two to three feet) throughout most of the growing season even on extremely sandy soils, by using sprinkler irrigation and careful water management. Application of excess water during either sprinkler or furrow irrigation, however, produced substantial leaching of nitrogen below the root zone during the growing season.

The remaining data in this report were obtained from soil samples collected on the WSU research station east of Othello, for a finer-textured soil. All results are expressed as mg/liter of dissolved nitrogen in the soil solution, because it is the soil solution which is displaced during the leaching process, and which constitutes the major pollution hazard. Results were verified in several cases by comparing them to dissolved nitrogen values for samples of the soil solution extracted with ceramic cups similar to those used at the Block 21 site. In table 2, values are presented for the average dissolved nitrogen concentrations in soil solutions from long-time fertilizer rate experiments. All plots received 450 # N/acre in 1972, but the N_1, P_1 and K_1 treatments received essentially no added nitrogen, phosphorus or potassium from 1965 through 1971, whereas the N_4, P_4 and K_4 treatments received approximately 400#/acre of the respective nutrients from 1965 through 1968, and in 1971. No fertilizer was added to any of the plots in 1969 and 1970, when wheat was grown to "mine" residual nitrogen from the soil profile. Average dissolved nitrogen values for the soil solutions of the top two feet of the soil profile at the end of the 1972 growing season were in the range of 40 to 60 mg/liter nitrogen. This was true regardless of plot fertilization history, and appears to be typical of the range of dissolved nitrogen values in the soil solutions of soils for which adequate nutrition has been maintained throughout the growing season. This re-emphasizes the importance of careful water management if excessive losses of nitrogen to the ground water are to be prevented during the growing season for high-demand crops like potatoes.

Table 2. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken in the fall of 1972 from a long-time fertilizer factorial experiment at the silt loam site.

Depth	N_1	N_4	P_1	P_4
0-2 ft	63	44	44	62
2+ ft	49	147	102	105

	K_1	K_4
0-2 ft	44	63
2+ ft	108	99

Average values for dissolved nitrogen in soil solutions below the plant root zone (at depths greater than two feet) fell in the same general range (40 to 60 mg/liter) for the lowest nitrogen fertilization rate, demonstrating that concentrations of this magnitude commonly are leached even when low levels of commercial fertilizer are being applied. However, average nitrogen concentrations approximately three-fold higher were observed for soil solutions below the root zone in plots which had received approximately 400# N/acre annually since 1965. Thus, although prevention of nitrogen leaching losses from soil solutions containing 40 to 60 mg/liter of dissolved nitrogen is dependent primarily upon proper water management, prevention of even higher nitrogen concentrations in leaching waters may be possible by modifying the timing and rates of annual nitrogen applications. Varying the phosphorus or potassium fertilization rates had no apparent effect on the concentrations of nitrogen being leached.

Table 3. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken from the 1972 suspension fertilizer experiment at the silt loam site.

Treatment	Depth	June 22	Aug. 3	Sept. 1	Nov. 1
600#	0-2 ft	138	48	54	89
Broadcast	2+ ft	190	29	127	43
600#	0-2 ft	475	245	40	54
Banded	2+ ft	118	115	54	42

Values in table 3 demonstrate the levels of dissolved nitrogen present in samples of the soil solution taken throughout the growing season from a series of experiments designed to test various rates and methods of application of suspension fertilizers. Nitrogen concentrations generally decreased throughout the growing season, as the crop utilized the nitrogen for growth processes. By the end of the season, average dissolved nitrogen levels generally were in the 40 to 60 mg/liter range indicating typical nitrogen levels for good potato production. Lower nitrogen fertilization rates could have lowered these soil solution values somewhat, but preliminary observations suggest that soil solution nitrogen values would be lowered less rapidly than would crop yield and quality. A killing frost occurred in mid-September, so the apparent re-distribution of dissolved nitrogen between September 1 and November 1 may reflect gradual movement of soil solution back into the surface layers to replenish solution evaporated during the dry and windy autumn months of the Columbia Basin.

Table 4. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken in the fall of 1972 from the 1972 suspension fertilizer experiment at the silt loam site.

Treatment	Depth	100#/A	400#/A	600#/A
Broadcast	0-2 ft	37	49	89
	2+ ft	21	31	43
Banded	0-2 ft	38	45	54
	2+ ft	23	17	42

Data in table 4 demonstrate the effects of nitrogen fertilization rate on the levels of dissolved nitrogen remaining in the soil solution at the conclusion of the 1972 suspension fertilizer experiments. As would be anticipated, increasing the nitrogen fertilization rate increased the levels of dissolved nitrogen remaining in the soil solution at the end of the season. Even the 100# N/acre fertilization rate produced dissolved nitrogen values of approximately 40 mg/liter in the soil solution of the plant root zone, however. There was only a small increase (ca 10 mg/liter) in residual dissolved nitrogen levels in the root zone at the 400# N/acre fertilization rate, but a larger increase (ca 25 mg/liter) was produced by the 600# N/acre fertilization rate. Although increasing the nitrogen fertilization rate increased the residual dissolved nitrogen concentrations below the root zone (2 + feet) as well, the latter values were consistently lower than the averages for the 0 to 2 foot depth increments. This may result from some denitrification (loss of gaseous forms of nitrogen) whenever water accumulates momentarily at the shallow layer of dense soil which commonly is observed at this site. The data could also be explained by the mixing of low-nitrogen soil solutions which existed previously in this field with solutions from the root zone which were higher in nitrogen, so the information is inconclusive with respect to possible denitrification losses.

Table 5. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken in 1972 from the 1971 suspension fertilizer experiment at the silt loam site.

		Spring of 72		Fall of 72	
Treatment	Depth	100#/A	600#/A	100#/A	600#/A
Broadcast	0-2 ft	78	199	12	17
	2+ ft	24	83	31	47
Banded	0-2 ft	81	148	17	31
	2+ ft	39	127	47	87

Data in table 5 indicate the rate of change for soil solution dissolved-nitrogen values from 1971 suspension fertilizer experiments, after an over-winter period (data for the spring of 1972), a fallow summer period, and three months of ryegrass growth prior to sampling in the fall of 1972. Dissolved-nitrogen levels increased with increasing plot fertilization rates in all cases, and were substantially higher in the spring of 1972 than would have been predicted from the fall 1972 sampling of the 1972 suspension fertilizer experiments. Further sampling of the 1972 experiment is being continued to establish whether this is a reproducible phenomenon, and, if so, whether it is related to movement of soil solution to the soil surface during the over-winter period, or to a rapid "flush" of nitrogen mineralization from plant residues during the succeeding spring.

By the fall of 1972, residual dissolved nitrogen values in the surface two feet of each plot had decreased to low levels, with three of the four values almost meeting EPA drinking water standards. Values for dissolved nitrogen below the plant root zone remained high, however, with essentially no change at the 100# N/acre fertilization rate, and with a decrease of only 40 mg/liter at the 600# N/acre fertilization rate. The observed decreases in dissolved nitrogen levels were probably brought about by a combination of nitrogen assimilation into organic matter, and nitrogen uptake by the ryegrass crop. Some gaseous losses of nitrogen compounds due to denitrification during irrigation of the ryegrass was also possible. In any event, the data demonstrate that crop rotations can be effective in reducing dissolved nitrogen levels in the soil solution following intensive crops such as potatoes.

Table 6. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken from the 1972 experiment on slow-release nitrogen sources at the silt loam site.

	NH_4NO_3		$(NH_4)_2SO_4$	
Treatment	Aug. 10	Aug. 29	Aug. 10	Aug. 29
450#	470	76	106	49
300# + 150#A*	136	24	74	14
300# + 150#B	404	59	40	36
300#.+ 150#C	139	33	160	36

* A, B and C = different forms of slow-release nitrogen

Another means of minimizing the leaching of fertilizer nitrogen from soils is the use of fertilizer sources which release the nitrogen over a substantial period of time, instead of all at once. In table 6, data are presented on the average dissolved-nitrogen concentrations in the soil solution of potatoes fertilized at a rate of 450# N/acre with either ammonium nitrate or ammonium sulfate, or with the same rate of a formulation consisting of 2/3 of the ammonium fertilizer source, and 1/3 of a slow-release form of nitrogen such as sulfur-coated urea or urea-formaldehyde. As the data are preliminary, and must be coupled with crop yield and crop quality data before any recommendations are formulated, the three sources of slow-release nitrogen are designated only by the code letters A, B, and C. Use of some slow-release nitrogen in place of the readily-soluble ammonium nitrogen generally led to lower nitrogen levels in the soil solution during the growing season, and to lower residual nitrogen levels near the end of the growing season (on August 29). One source (source "A") was particularly effective in lowering the dissolved nitrogen concentrations of the soil solution. Source "C" appeared to be the next most effective source of slow-release nitrogen when used in conjunction with ammonium nitrate, whereas source "B" appeared to be superior to source "C" when used in conjunction with ammonium sulfate. Analysis of a more extensive sampling of these plots in the fall of 1972 should shed additional light on the question of the most effective source of slow-release nitrogen.

Table 7. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken from the 1972 irrigation rate experiment at the silt loam site.

Location	Depth	High Water	Low Water	High N	Low N
Head of field	0-2 ft	30	38	47	21
	2+ ft	6	13	10	9
Tail of field	0-2 ft	49	104	88	64
	2+ ft	31	93	88	36

A final question in the appraisal of nitrogen leaching from potato fields is the extent to which variations in leaching occur throughout the fields. Data on this aspect of the problem are presented in tables 7 and 8. In table 7, results are presented from a combined fertility-irrigation rate experiment which was carried out on the Othello station in 1972. As is evident from the data, residual dissolved nitrogen values were higher whenever lower quantities or water had been passed through the soil profile during the growing season, as at the tail of the field at a given water or nitrogen application rate, or at the lower of two water application rates. As reported previously, residual dissolved-nitrogen levels were consistently higher at higher nitrogen fertilization rates, and were at levels comparable to the EPA drinking water standards only in soil solutions below the plant root zone at the head of the field, where the greatest amount of leaching should have occurred in these furrow-irrigated plots. Finally, as is evident in table 8, it must be recognized that dissolved nitrogen levels vary across the row-furrow sequence in furrow-irrigated fields, due to variations in prior wetting history, and due to the tendency of dissolved nitrogen to move with the wetting front. This type of variation also must be taken into account when devising a sampling scheme to determine rates of nitrogen leaching in furrow-irrigated fields.

Table 8. Average values for dissolved nitrogen (mg/liter) in the soil solution for soil samples taken from some 600# broadcast plots on June 22 for the 1972 suspension fertilizer experiments at the silt loam site.

Depth	Wetted Ridge	Next Furrow	Next Ridge
0-2 ft	353	15	44
2+ ft	248	190	131

CONCLUSIONS

Results are reported from experiments at two sites, involving different approaches to fertilizer and water management in potato production. The studies have indicated that a) dissolved nitrogen levels of 40 to 80 mg/liter are common for the soil solution in the root zone of an actively growing potato crop; b) proper water management, and especially practices involving sprinkler irrigation, can minimize leaching during potato production even for sandy sites, and permit use of residual soil nitrogen by subsequent crops; c) furrow irrigation of potatoes, particularly on sandy soils, can lead to considerable leaching of fertilizer nitrogen; d) use of high rates of nitrogen fertilization for several years can lead to substantial accumulations of dissolved nitrogen in the soil solution below the plant root zone; e) levels of residual dissolved-nitrogen in the soil solution following the growing season are related to the nitrogen fertilization rates used during that season, with the largest increases in residual nitrogen occurring at the highest rates of nitrogen fertilization; f) levels of dissolved soil nitrogen can be reduced markedly when potatoes are followed in rotation by a non-fertilized crop; g) use of slow-release forms of nitrogen (and, by analogy, application of nitrogen with the irrigation water throughout the growing season) show promise as a means of lowering nitrogen levels in the soil solution while still providing adequate nitrogen for near-optimum plant growth; and h) values for levels of dissolved nitrogen in the soil solution vary markedly from point to point in the field, and across paired sets of rows and furrows, so that adequate sampling procedures must be used to obtain valid estimates of nitrate leaching over an entire field during a given water and fertilizer management regime.