Using irrigation nitrate concentrations to simultaneously reduce costs of fertilizer and drinking water contamination

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1. Introduction

High nitrate concentrations in groundwater decrease water quality when the water is used for drinking water. However, they can actually be beneficial when the water is used for irrigation because the nitrate can serve as a source of crop fertilizer.

Recognizing irrigation water nitrate as a nitrogen fertilizer source can be a strategy to not only save producers money but also the local community. The strategy saves producers money by reducing their nitrogen fertilizer costs. Less nitrogen fertilizer needs to be purchased to reach target nitrogen inputs if we recognize that the irrigation water is delivering some of that nitrogen (Fig. 1). The strategy saves the local community money by reducing nitrate exports from crop soil. Nitrogen is an essential nutrient for plant growth, but there are limits to how much a plant needs (Zhang et al., 2021). Fertilizer applied beyond that limit leaches into aquifers and runs off to adjacent streams, which damages those ecosystems and increases treatment costs where the water is used for human consumption.

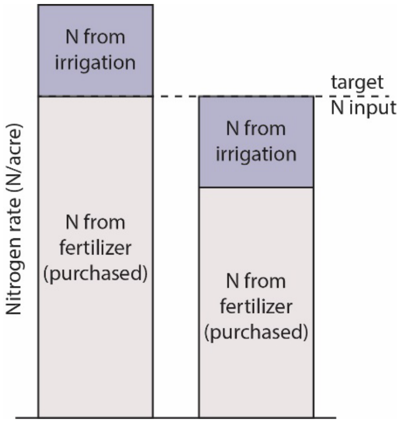

Figure 1. Schematic illustration of the N contribution of irrigation water. No scale.

The purposes of this guide are to (1) illustrate how to use irrigation water nitrate concentration to evaluate the nitrogen fertilizer contribution of irrigation water and (2) demonstrate the economic benefits of this strategy.

2. Calculating the amount of N supplied by irrigation

Data needed to determine the amount of nitrogen that will be delivered by irrigation water includes the irrigation water nitrate concentration (NO_3^-, mg/L as N) and the number of inches of irrigation water that will be applied per acre (irrigation inches). Irrigation water chemical analyses can be obtained by delivering a sample to a commercial or academic laboratory whereas irrigation estimates can be obtained by averaging past water use.

With these data, pounds of nitrogen (N) delivered per acre by irrigation water can be calculated as follows:

$$N\frac{lbs}{acre} = \left(NO_3^-\frac{mg}{L}as\ N\right)\left(\frac{1}{1000}\frac{g}{mg}\right)\left(\frac{1}{454}\frac{lbs}{g}\right)\left(102790.15\frac{L}{acre\ inch}\right)(irrigation\ inches) \quad (1)$$

which simplifies to

$$N\frac{lbs}{acre} = (0.22641)\left(NO_3^-\frac{mg}{L}as\ N\right)(irrigation\ inches) \quad (2)$$

Table 1 shows the amounts of N contributed by irrigation water with nitrate concentrations ranging from 5 to 50 mg/L as N calculated using equation 2.

Table 1. Irrigation nitrogen inputs as a function of irrigation water nitrate (NO_3^-) concentration (mg/L as N) and irrigation water usage (in/acre).*

in/acre	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NO_3^- (mg/L as N)	pounds of N per acre delivered by irrigation water																			
5	1	2	3	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	22	23
10	2	5	7	9	11	14	16	18	20	23	25	27	29	32	34	36	38	41	43	45
15	3	7	10	14	17	20	24	27	31	34	37	41	44	48	51	54	58	61	65	68
20	5	9	14	18	23	27	32	36	41	45	50	54	59	63	68	72	77	82	86	91
25	6	11	17	23	28	34	40	45	51	57	62	68	74	79	85	91	96	102	108	113
30	7	14	20	27	34	41	48	54	61	68	75	82	88	95	102	109	115	122	129	136
35	8	16	24	32	40	48	55	63	71	79	87	95	103	111	119	127	135	143	151	158
40	9	18	27	36	45	54	63	72	82	91	100	109	118	127	136	145	154	163	172	181
45	10	20	31	41	51	61	71	82	92	102	112	122	132	143	153	163	173	183	194	204
50	11	23	34	45	57	68	79	91	102	113	125	136	147	158	170	181	192	204	215	226

*Calculated according to equation 2.

The timing of irrigation N delivery and therefore its contribution to crop yield would depend on the annual rainfall pattern. N delivered during the period of rapid plant growth is as useful as N fertilizer application, but N delivered after the crop has satisfied most its N needs is of limited value to that year's crop (Powers et al., 2023). To accommodate this uncertainty, producers can reduce the estimated irrigation amount by 20% (Powers et al., 2023). For example, if a field has received on average 10 inches of irrigation per year over the past five years, use a value of 8 inches in equation 2 to determine the N contribution of the irrigation.

Additionally, the N delivery of irrigation water will be more prone to leaching than N supplied by ammonium-based fertilizer, given that nitrate has greater mobility than ammonium in soils (Ruiz Diaz and Knapp, 2019). This consideration would affect the efficiency of N delivery, particularly for soils with coarse texture.

It should be noted that the calculations described above are consistent with those in the Soil Test Interpretations and Fertilizer Recommendations in Kansas published by K-State Research and Extension (Ruiz Diaz et al., 2024), which provides guidance on a wider range of adjustments than considered here.

3. Estimating the value of irrigation water as a source of N

To illustrate the value of the nitrogen supplied by irrigation water, we can take our calculations a step further. During 2025, anhydrous ammonia cost Kansas farmers $0.52/lb N (USDA, 2025). Factoring the N deliveries in Table 1 by that cost gives the value/acre estimates provided in Table 2. Scaling those results to a single quarter-section pivot (~127.5 acres) demonstrates that irrigation-water nitrate can have a significant value. For a quarter-section pivot that delivers 10 inches and has 10 mg/L as N nitrate, the value of the N contribution is about $1500.

Table 2. Estimated value of irrigation water nitrate as a function of irrigation water nitrate (NO_3^-) concentration (mg/L as N) and irrigation water usage (in/acre).

in/acre	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NO_3^- (mg/L as N)	Value per acre ($)*																			
5	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	11	11	12
10	1	2	4	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22	24
15	2	4	5	7	9	11	12	14	16	18	19	21	23	25	26	28	30	32	34	35
20	2	5	7	9	12	14	16	19	21	24	26	28	31	33	35	38	40	42	45	47
25	3	6	9	12	15	18	21	24	26	29	32	35	38	41	44	47	50	53	56	59
30	4	7	11	14	18	21	25	28	32	35	39	42	46	49	53	57	60	64	67	71
35	4	8	12	16	21	25	29	33	37	41	45	49	54	58	62	66	70	74	78	82
40	5	9	14	19	24	28	33	38	42	47	52	57	61	66	71	75	80	85	89	94
45	5	11	16	21	26	32	37	42	48	53	58	64	69	74	79	85	90	95	101	106
50	6	12	18	24	29	35	41	47	53	59	65	71	77	82	88	94	100	106	112	118

*Based on an anhydrous ammonia cost of $0.52/lb N.

In addition to saving fertilizer costs, accounting for nitrate in irrigation water may also decrease needs for liming. When nitrogen fertilizer is applied as an ammonium-based fertilizer, conversion of the ammonium (NH_4^+) to nitrate known as nitrification produces acid (H^+) as shown in the following reaction:

$$NH_4^+ + 2\ O_2(aq) \leftrightarrow NO_3^- + 2\ H^+ + H_2O \qquad (3)$$

Production of acid can lower soil pH, which can have a negative impact on crop growth. However, the nitrogen supplied by irrigation water is already in the form of nitrate and thus is not accompanied by acid production.

4. Benefits to groundwater quality

Drinking water with high levels of nitrate is well known to cause methemoglobinemia (i.e., blue-baby syndrome) in infants (Ward et al., 2018; Fossen Johnson, 2019). But the adverse health effects of high nitrate drinking water extend well beyond that condition and not only affect infants but potentially anyone. In addition to methemoglobinemia, high nitrate drinking water has been found to increase risks of pediatric brain cancer, non-Hodgkin lymphoma in children, miscarriages, preterm birth, fetal growth restrictions, central nervous system malformations, and bladder and ovarian cancer (Manassaram et al., 2010; Rhoades et al., 2013; Ward et al., 2018; Sherris et al., 2021; Lin et al., 2023; Jensen et al., 2023).

Because of these impacts, nitrate concentration of public water supplies is regulated by the US EPA, with a maximum contaminant level (MCL) of 10 mg/L as N. Public water supply wells that exceed this limit may be shut down or blended with water that has a low nitrate concentration, such that the mixture has a nitrate concentration below the MCL. However, where alternative water sources are unavailable, communities may be tasked with finding millions in funding to build a more advanced water treatment facility, which is an enormous burden for many small towns (Condos, 2022; Xu, 2022). Haviland, Kansas, as one example, has 677 people and needed to pay $2,435,000.00 to upgrade its facility, which comes out to $3,596.75 per person (Condos, 2022).

Unlike public water sources, water quality is unregulated for private wells. Ideally well owners have their water tested annually for nitrate and nitrite (collectively referred to as nitrates) to ensure that the nitrate levels fall below the maximum contaminant level applied to public water sources. Where high nitrate levels are found, the main option available is point-of-use reverse osmosis, which cost $5,000 to $12,000 to install initially and then $250 to $500 to maintain every year or two (MN Dept. Health, 2024). However, previous studies have found that most private well owners do not regularly have their water tested (Swistock et al., 2013; Malecki et al., 2017), creating an opportunity for health impacts from contaminated drinking water. The water may look fine, it may taste good, and it may have been high quality in the past, but none of that means the water remains safe to drink.

By reducing excess nitrogen inputs, the strategy outlined here offers one way to help decrease these water treatment costs over time and simultaneously benefit community health. If the nitrate content of irrigation water is not considered, then it adds to the excess nitrogen input to the soil and contributes to water quality degradation. But if it is considered, then the excess nitrate input will be reduced and eventually less nitrate will accumulate in our water resources.

5. Conclusions

We pay for excess nitrogen applications when the fertilizer is purchased and again when it is exported from crop soil to adjacent surface waters and groundwater. However, we can reduce fertilizer costs and water treatment costs at the same time by accounting for the nitrate in irrigation water. This summary illustrates how to calculate the nitrogen delivered by irrigation using irrigation water nitrate concentration and an estimate of the amount of irrigation.

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