Onion Irrigation and Nitrogen Leaching in the Arkansas Valley of Colorado 1990-1991

J.E. Ells¹,

A.E. McSay¹,

P.N. Soltanpour²,

F.C. Schweissing³,

M.E. Bartolo³, and E.G. Kruse⁴

Additional index words. *Allium cepa* L., nitrate

Summary. Water and nitrogen (N) are major inputs in the production of onions in the Arkansas Valley of Colorado. Because nitrates move with irrigation water, the effect of different rates of application of both N fertilizer and water on nitrate leaching were studied simultaneously. After a 2-year field study (1990-1991), it was concluded that >50 t·ha⁻¹ of onions could be obtained without any N fertilizer when >42 ppm of nitrate nitrogen (NO₃-N) were initially present in the top 33 cm of soil and up to 112 cm of irrigation water was applied. Total onion yield was not improved by applying more than the calculated irrigation requirement. The 2-m profile of soil under these experiments was found to contain >1400 kg·ha⁻¹ of residual NO₃-N prior to fertilizer treatments. When twice the estimated irrigation requirement was applied, >1000 kg·ha⁻¹ of NO₃-N was unaccounted for and presumed to have been mostly leached below the 2-m profile and partly denitrified. In both

¹Department of Horticulture, Colorado State University, Fort Collins, CO 80523.

²Department of Agronomy, Colorado State University, Fort Collins, CO 80523.

³Arkansas Valley Research Center, Rocky Ford, CO 81067.

⁴Agriculture Engineering Research Center, ARS/USDA, Colorado State University, Fort Collins, CO 80523.

Funding was provided by Colorado Agriculture Experiment Station (Project 756) and Cooperative Extension Service (Project 6101).

years, the onions were planted on land that had been fallowed the previous season, which does not help explain the presence of the high levels of nitrates found in the soil profile. It was concluded that sound water and N management practices in onion fields are crucial for preservation of water quality.

The objective of this study was to determine the effect of N fertilization and the amount of applied irrigation water on onion yield, water use efficiency, and residual soil $\text{NO}_3\text{-N}$.

Onions ('Colorado No. 6', Burrell Seed Co.) were planted in March of each year on a silty clay loam [Ustic torriorthents, fine-silty, mixed (calcareous, mesic)] at the Arkansas Valley Research Center in Rocky Ford, Colo. The top 33 cm of soil on this research center had a pH of 7.6 and an organic matter content of 2.75% in the areas where these studies were conducted. The only nutrient applied in this study was N. However, based on the N present in the soil, no N would have been recommended for a commercial onion crop.

Treatments were initiated in May when the onions were 20 cm tall, prior to bulbing. A split-plot, randomized complete-block design was used each year, consisting of 36 plots that included three levels of irrigation (main plot), three levels of N (sub-plot), and four replications. Each plot consisted of two 1-m beds, 6 m long, with two rows of onions planted on each bed. The plots were laid out so that there was a center bed with two half-beds on either side. A soil core was taken to a depth of 2 m, at increments of 33 cm between the rows on the bed. These samples were taken three times during the season: In May before treatments were applied, at mid-season, and again after harvest. Soil $\text{NO}_3\text{-N}$ was determined using a flow injection auto-analyzer (Workman et al., 1988). N treatments (0, 90 and 360 kg-ha^{-1} of N as ammonium nitrate) were applied to the bottom of the furrows on either side of the center bed. Furrows were dammed at both ends to impound irrigation water within the plots. Irrigation water, which contained between 1 and 8.2 ppm N, was taken from a ditch that received water from the Rocky Ford Canal, which, in turn,

Table 1. Irrigation and rainfall amount and number received by onions during irrigation scheduling periods, Rocky Ford, Colo., 1990 and 1991.

No. irrigations (in parentheses) and rain events and amount of water applied (cm)						
Treatment	June	July	August	September	Total	Irrigation + rain
30 May–28 Sept. 1990						
0.75×	(3) 13	(1) 5	(3) 13	(1) 4	(8) 35	52
1×	(3) 17	(1) 7	(3) 17	(1) 6	(8) 47	64
2×	(3) 34	(1) 14	(3) 34	(1) 12	(8) 94	111
Rain ^z	(3) 1	(12) 12	(8) 3	(4) 1	(27) 17	
30 May–29 Aug. 1991						
0.75×	(3) 11	(3) 11	(3) 11	(0) 0	(9) 33	47
1×	(3) 15	(3) 15	(3) 15	(0) 0	(9) 45	59
2×	(3) 30	(3) 30	(3) 30	(0) 0	(9) 90	104
Rain	(7) 4	(10) 5	(9) 2	(5) 3	(31) 14	

^zRain received corresponding to the dates when the treatments became effective until harvest.

received its water from the Arkansas River. Water was lifted from the ditch, pressurized by a gasoline-powered pump, and forced into a network of tubing, from which the prescribed number of gallons were metered into the furrows of each plot.

An onion irrigation scheduling program that was developed by the ARS/USDA (Kincaid and Heermann, 1974) and modified for onions (Kruse et al., 1987) was used to determine when and how much water to apply. This program required inputs of wind-run, temperature, solar radiation, humidity, and precipitation, which were obtained from a battery-powered, portable weather station located near the plots. The program contained the onion growth curve, rooting depth, and water-holding capacity of the soil, which were used in conjunction with the weather data to determine the daily evapotranspiration losses. The program calculated the available soil water and predicted when half the available water would be depleted. It also gave the amount of water required to replace the deficit. The three irrigation treatments consisted of water applications equal to 0.75×, 1×, or 2× the estimated depletion. Irrigations were applied when the irrigation scheduling program estimated that half of the available water was depleted in the 1.0 irrigation treatment. At this time, all the plots were irrigated, applying 0.75×, 1×, or 2× the amount of water suggested by the program.

Irrigation scheduling began in May after the last unscheduled furrow irrigation, which was assumed to recharge the root zone. The water-holding capacity of the soil had been en-

tered into the irrigation scheduling program, and daily depletions were recorded by the program. Just before the first scheduled irrigation, the plots were laid out and fertilizer was applied to the furrows, being careful to keep it off the beds. The irrigation scheduling program remained in effect until the onions were harvested. Rain and irrigation water, used to establish the stand prior to initiating the irrigation scheduling program, were not measured.

When 80% of the tops were down, a 2.5-m section of both onion rows in the middle of the center bed of each plot was harvested, graded, and weighed.

The amount and number of irrigations and rain events that occurred during the irrigation scheduling period are shown in Table 1. The totals were used in calculating the water-use efficiency of each treatment.

Because we were only interested in the leaching effect of excessive irrigation on soil $\text{NO}_3\text{-N}$, and for budgetary reasons, only the 2× irrigation plots that received 0 and 360 kg-ha^{-1} N were sampled for $\text{NO}_3\text{-N}$ (Fig. 1). Treatments receiving lower amounts of water and N were assumed to have intermediate amounts of leaching. In the future, we intend to sample soils in the lesser-watered treatments to estimate denitrification losses. The level of $\text{NO}_3\text{-N}$ in the soil declined over the growing season, probably due to large water applications. Differences among soil depths were only apparent on 26 June 1990, but, by the end of the season, these differences had disappeared, probably as a result of continued leaching.

Fig. 1. Soil nitrate from onion plots receiving $2\times$ estimated water needs. (a) $\text{NO}_3\text{-N}$ from the first block of bars was not replicated or statistically analyzed. The remaining four bar blocks were statistically analyzed, but only the second block showed statistical differences ($P = 0.05$ by LSD mean separation). (b) $\text{NO}_3\text{-N}$ from the first block of bars was not replicated or statistically analyzed. The remaining four blocks were statistically analyzed, no differences were found ($P = 0.05$ by LSD mean separation).

On 30 May 1990, $360 \text{ kg}\cdot\text{ha}^{-1}$ of N were applied as NH_4NO_3 . On 26 June 1990, an assay of the soil profile indicated 34 ppm of $\text{NO}_3\text{-N}$ and 0.15 ppm of $\text{NH}_4\text{-N}$, indicating that nearly all of the $\text{NH}_4\text{-N}$ had been converted to $\text{NO}_3\text{-N}$ and that there was no need to continue the $\text{NH}_4\text{-N}$ assays.

The $\text{NO}_3\text{-N}$ means (in $\text{kg}\cdot\text{ha}^{-1}$) from Fig. 1 were multiplied by 26.6 ($10,000 \text{ m}^2 \times 2 \text{ m} \times 1330 \text{ kg}\cdot\text{m}^{-3} \times 10^{-6} = 26.6$) and used in Table 2 as a basis for further calculations. To these values were added 360 kg of N applied as NH_4NO_3 to half the plots, and either 77 (1990) or 9 (1991) $\text{kg}\cdot\text{ha}^{-1}$

of N that was estimated to have been supplied by the irrigation water based on 8.2 ppm of $\text{NO}_3\text{-N}$ found in the irrigation water in 1990 and 1.0 ppm of $\text{NO}_3\text{-N}$ found in the irrigation water in 1991, and the amount of water used. The N removed by the onion crop was calculated from published values (Hamilton and Bernier, 1975), and estimated to be $70 \text{ kg}\cdot\text{ha}^{-1}$ of N by the bulbs and tops in 1990 and $108 \text{ kg}\cdot\text{ha}^{-1}$ of N in 1991. Next, the soil samples that were taken after harvest indicated the residual N remaining in the soil. Finally, the bottom line of Table 2 lists the net unused $\text{NO}_3\text{-N}$

that is presumed to have been mostly leached below the 2-m level, with lesser amounts possibly lost through denitrification.

Because the potential for denitrification in the subsoil is low due to the very low organic matter levels and absence of root activity and root exudates, we assume that the majority of N loss from the profile was due to leaching.

Because each value on the bottom line of Table 2 is more than $1000 \text{ kg}\cdot\text{ha}^{-1}$ of $\text{NO}_3\text{-N}$, the implication is that these treatments have contributed $>1000 \text{ kg}\cdot\text{ha}^{-1}$ of $\text{NO}_3\text{-N}$ to the groundwater, assuming negligible denitrification. If these soils had been irrigated excessively in the past, the residual $\text{NO}_3\text{-N}$ probably would not have been as high as it was at the beginning of each experiment. Furthermore, we could not have leached another $1000 \text{ kg}\cdot\text{ha}^{-1}$ of $\text{NO}_3\text{-N}$ from these same plots the following year because the N was not there to leach. However, this does draw attention to the potential for these soils to contribute nitrates to the groundwater, and it does underscore the need for serious N/water management in the Arkansas Valley of Colorado through an extensive extension education program.

Yields were not enhanced by N application in either 1990 or 1991, nor did N have any influence on water-use efficiency (Table 3). It can, therefore, be said that, under the conditions of this study ($>41 \text{ ppm}$ of $\text{NO}_3\text{-N}$ in the soil and $>1 \text{ ppm}$ of $\text{NO}_3\text{-N}$ in the water), that additional N fertilizer did not benefit onion yields.

In 1990, yields were not improved by applying more than $0.75\times$ the estimated irrigation requirement, while more than $0.75\times$ the water requirement was detrimental to water-use efficiency. Therefore, on the basis of the 1990 data, one would be advised to apply only 75% of the estimated irrigation requirement. However, we had a severe hail storm on 20 June 1990 that damaged the onions badly; this storm undoubtedly contributed to the lower yield of the 1990 onion crop as compared to the 1991 crop. Under these circumstances the onions did not require as much water after the storm, because they did not have the tops to use it.

The 1991 study, which escaped hail, produced 50% more onions than the 1990 test. Perhaps because of more

Table 2. *Accounting of NO₃-N in the top 2m of soil under research plots of onions that received 2× the irrigation requirement and either 0 or 360 kg·ha⁻¹ of N, Rocky Ford, Colo., 1990 and 1991.*

Contributing factor	Year			
	1990		1991	
	<i>NO₃-N in the top 2 m of soil (kg•ha⁻¹)</i>			
Soil, initial ^z	1516	1516	1436	1436
Fertilizer	0	360	0	360
Water ^y	77	77	9	9
Estimated crop removal ^x	(70)	(70)	(108)	(108)
Net total	1523	1883	1337	1697
Remaining at harvest	(213)	(106)	(160)	(186)
Net unused	1310	1777	1177	1511

²Values from Table 2.

³1990: 0.94 m of irrigation water × 10,000 m² × 1000 kg·m³ × 10⁻⁶ × 8.2 ppm N = 77 kg NO₃-N/ha; 1991: 0.90 m of irrigation water × 10,000 m² × 1000 kg·m³ × 10⁻⁶ × 1.0 ppm N = 9 kg NO₃-N/ha.

⁴Estimated N removal by onion bulbs and tops (Hamilton and Bernier, 1975).

Table 3. *Onion yields and water-use efficiency as influenced by N and irrigation.*

Treatment	Yield (t•ha ⁻¹) ^c			Total	Water-use efficiency (t•ha ⁻¹ •cm ⁻¹)
	Jumbo (>7.5–10 cm)	Medium (>5.5–7.4 cm)	Prepack (>4.5–5.4 cm)		
1990					
N (kg•ha ⁻¹)					
0	21 a	14 a	1 a	36 a	0.44 a
90	19 a	13 a	2 a	34 a	0.47 a
360	20 a	15 a	1 a	36 a	0.47 a
Depletion applied					
0.75	19 a	15 a	2 a	36 a	0.68 a
1	20 a	14 a	1 a	35 a	0.54 b
2	21 a	13 a	1 a	35 a	0.31 c
1991					
N (kg•ha ⁻¹)					
0	28 a	25 a	3 a	56 a	0.80 a
90	30 a	21 a	2 a	53 a	0.75 a
360	27 a	26 a	3 a	56 a	0.80 a
Depletion applied					
0.75	23 b	24 a	3 a	50 b	1.04 a
1	29 a	25 a	3 a	57 a	0.97 a
2	33 a	23 a	3 a	59 a	0.57 b

²Values in each section of a column followed by different letters are different at P = 0.05 by LSD separation of means.

tops, as well as a greater yield, the 1991 onion crop benefited from the full 1× estimated irrigation requirement. Again, applying 2× the estimated wa-

ter requirement did not benefit yields, and proved detrimental to water-use efficiency (Table 3).

This study has highlighted the

potential that these soils have for contributing nitrates to the groundwater. This has been observed for other shallow-rooted crops (Moore, 1970). It is now incumbent upon us to survey the irrigation and N management practices to determine the educational needs of farmers. The onion irrigation scheduling program used in this study, as well as irrigation scheduling programs for other vegetables, are available on floppy disk to anyone who would like to use them. Details of the programs available and how to acquire them may be found in the Resources Available section of this issue of *HortTechnology*.

Literature Cited

Hamilton, H.A. and R. Bernier. 1975. N-P-K (nitrogen-phosphorus-potassium) fertilizer effects on yield, composition and residue of lettuce, celery, carrot and onion grown on an organic soil in Quebec. Can. J. Plant Sci. 55(2):453-461.

Kincaid, D.C. and D.F. Heermann. 1974. Scheduling irrigations using a programmable calculator. USDA Bul. ARS-NC-12.

Kruse, G.E., J.E. Ells, and A.E. McSay. 1987. Comparison of two onion irrigation scheduling programs. J. Amer. Soc. Hort. Sci. 112(5):738-742.

Moore, F.D. 1970. Furrow irrigation of lettuce resulting in water and nitrogen loss. J. Amer. Soc. Hort. Sci. 95(4):471-474.

Workman, S.M., P.N. Soltanpour, and R.N. Follett. 1988. Soil testing methods used at Colorado State Univ. for the evaluation of fertility, salinity, and trace element toxicity. Colo. Agr. Expt. Sta. Bul. LTB 88-2:11-14.