Sequential NLEAP simulations to examine effect of early and late planted winter cover crops on nitrogen dynamics

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Interpretative summary

In different studies conducted during the last 10 years, underground well water NO_3–N concentrations have been found to exceed drinking water standards of 10 mg NO_3–N L^{-1} (10 ppm) for some areas of the San Luis Valley of south central Colorado. The new version 1.2 of the Nitrate Leaching and Economic Analysis Package (NLEAP) model simulated the effect of winter cover crop planting date on conservation of water quality for a lettuce–winter cover crop–potato rotation. The use of a winter cover crop increased N use efficiency in the system. Approximately 3.1 kg (6.8 lb) of every 4.5 kg (10 lb) of available N were used in the lettuce, early-planted winter cover crops and potato compared to 2.1 kg (4.7 lb) with the lettuce, late-planted winter cover crops, and potato or 1.9 kg (4.1 lb) for the lettuce and potato with no winter cover crop. The effect of early-planted winter cover crop on maintaining the NO_3–N in the plant biomass and rooting zone extended into the next growing season, increasing the system NUE and reducing NO_3–N leaching during the growing season of potato. This new version 1.2 of NLEAP can be used as a technology transfer tool to assess the effects of planting date of winter cover crops on nitrogen dynamics and conservation of water quality.

Key words: lettuce, nitrate leaching, nitrogen, nitrogen use efficiency, NLEAP, potato, rye, water quality, wheat, winter cover crops.

*ABSTRACT: In different studies conducted during the last 10 years, underground well water NO_3^--N concentrations have been found to exceed drinking water standards of 10 mg NO_3^--N L^{-1} (10 ppm) for some areas of the San Luis Valley of south central Colorado. Some of these studies reported that NO_3^--N leaching is a factor that can contribute to these high well water NO_3^--N concentrations. Computer models are technology transfer tools that can assess impacts of best irrigation and nutrient management practices. Sequential computer simulations of the effects of winter cover crop planting date on residual soil NO_3^--N concentrations have not been previously conducted. The new version 1.2 of the Nitrate Leaching and Economic Analysis Package (NLEAP) model was used to conduct an assessment of the effect of winter cover crop planting date on conservation of water quality. The NLEAP model simulated a lettuce (*Lactuca sativa* *L.) – winter cover wheat (*Triticum aestivum* *L.) and rye (*Secale cereale* *L.) (early- or late-planted) potato (*Solanum tuberosum* *L.) rotation, grown on a center-pivot irrigated Kerber loamy sand. Winter cover crops increased the system N use efficiency (NUE) ($P<0.05$). The effect of early-planted winter cover crops on conservation of water quality extended into the potato growing season, increasing NUE and reducing NO_3^--N leaching ($P<0.05$).*

Although the San Luis Valley (SLV) of south central Colorado has a variety of soils, most of them are of a coarse sandy texture over a coarse textured substratum (USDA-SCS 1973). Nitrate-N leaching can negatively affect water quality (Eddy-Miller 1993; AEI & CSU 1995; Stogner 1996). Austin (1993) tested 93 domestic wells in the SLV and found that 14% of them had NO_3^--N water concentrations that exceeded EPA drinking water standards of 10 mg NO_3^--N L^{-1} (10 ppm) (USEPA 1989). Stogner (1996) reported that on 16 sampling wells in the shallow unconfined aquifer in the central region of the SLV, water samples ranged from 0.1 to 72 mg NO_3^--N L^{-1} (0.1 to 72 ppm). He also found that for wells that were adjacent to the shallow wells and fully penetrated the unconfined aquifer, water samples contained a range of 4.3 to 46.5 mg NO_3^--N L^{-1}(4.3 to 46.5 ppm), with 50% of the samples containing greater than 15 mg NO_3^--N L^{-1} (15 ppm).

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Implementation of appropriate irrigation and nutrient management practices are being conducted in the SLV to reduce the movement of NO_3^--N out of the root zone of planted crops and to protect soil and water quality (SLVWQDP 1994; Delgado et al. 1996a & b and 1998a & b). One of the promising best management practices is the incorporation of winter cover crops into current crop rotations (Delgado et al. 1998b). Winter cover crops can contribute significantly to the conservation of water quality by recovering NO_3^--N which remains in and below the root zone of previous crops and could be susceptible to leaching (Holderbaum et al. 1990; Brinsfield and Staver 1991; Meisinger et al. 1991; Decker et al. 1994; McCracken et al. 1994; Delgado et al. 1998b). Although a significant effort has been conducted in the simulation of these winter cover crop systems (Meisinger et al. 1991), no sequential simulation of the effect of planting date on water quality has been conducted.

The objectives of this study were to use the NLEAP sequential model to conduct an assessment of the effect of planting date on the potential of a winter cover crop to scavenge residual soil NO_3^--N; the effects of early-and late-planted winter cover crops on conservation of water quality; and the N use efficiency (NUE) of a lettuce–winter cover wheat and rye (early- or late-planted)–potato cropping system.

Materials and methods

Use of NLEAP to assess winter cover planting date effects on conservation of water quality. This manuscript presents results of a technology transfer effort conducted by USDA-ARS, USDA-NRCS, and USDA-NRCS San Luis Valley Water Quality Demonstration Project from 1992 to 1997. During this effort about 10,000 soil extracts were analyzed for NO_3^--N and NH_4^+–N concentrations, and about 3,500 plant samples were collected for C and N analyses at the USDA-ARS Soil Plant Nutrient Research Unit at Fort Collins, Colorado. These samples were collected from more than 70 multiple-year sites. A main objective of this technology transfer effort was the development of management information to test, simulate, and evaluate different management scenarios and their effects on residual soil NO_3^--N and conservation of water quality. This manuscript presents

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Table 1. Mean* monthly air temperature, precipitation, irrigation, and nitrogen fertilizer applied

	5/94	6/94	7/94	8/94	9/94	10/94	11/94	12/94	1/95	2/95	3/95	4/95	5/95	6/95	7/95	8/95	9/95
A_t (°C)	11.1	16.1	16.1	16.7	13.3	7.2	-2.8	-5.0	-4.4	1.7	2.2	3.9	8.9	13.9	15.6	17.8	12.8
P_t (mm)	45.7	25.4	7.6	40.6	88.9	15.2	12.7	0.0	2.5	0.0	58.4	0.0	0.0	10.2	68.6	58.4	25.4
I_r (mm)	50.8	33.0	147.3	71.1	25.4	25.4	0.0	0.0	0.0	0.0	0.0	0.0	12.7	17.8	71.1	127.0	12.7
N kg/ha	49†	13‡	91‡										90§	93¶	34‡	17‡	

* A_t air temperature (°C); Pt precipitation (mm); Ir Irrigation (mm); N nitrogen fertilizer applied (kg N ha^{-1})
† Ammonium polyphosphate
‡ Urea – ammonium nitrate (UAN)
§ Monoammonium phosphate 19 kg N ha^{-1}; ammonium sulfate 71 kg N ha^{-1}
¶ Monoammonium phosphate 28 kg N ha^{-1}; ammonium sulfate 40 kg N ha^{-1} and urea 25 kg N ha^{-1}

results of different management scenarios using NLEAP to simulate the effect of winter cover crop planting date on conservation of water quality.

Management information from a lettuce–early-planted winter cover rye–potato rotation grown on a loamy sand during the fall 1994 to spring 1995 season was used for this study. Data from late-planted winter rye, and from early- and late-planted winter wheat were collected from adjacent fields during the fall of 1995 to spring of 1996. Late-planted winter rye, and early- and late-planted winter wheat, were both grown as a cover crop on a loamy sand. At each site four replicate samples were collected at each sampling date.

At all sites, vegetable crops were grown under similar sprinkler irrigation practices. It was assumed that minimal differences due to site did not affect observed growth patterns of early- and late-planted winter cover crops. It was also assumed that differences due to year did not significantly affect the growth and N uptake patterns of the winter cover crop. Finally, it was assumed that information collected about the growth pattern of winter cover crops could be used to develop NLEAP input files that describe the uptake patterns on a loamy sand (Delgado et al. 1996a & b and 1998a & b).

Initially the management information of the lettuce–early-planted rye–potato rotation was simulated with NLEAP. The sequential simulations were conducted by replacing information for the early-planted rye with information on the late-planted rye. The same process was repeated for the early-and late-planted wheat.

Table 2. Growing season and mean root depth used for NLEAP sequential simulations

Crop	Planted	Harvest/spring kill	Root depth
Lettuce	5/18/94*	8/4/94*	0.39 (1.3)
Early planted winter cover crop	8/8/94	4/11/95*	0.90 (3.0)
Late planted winter cover crop	9/26/95	4/11/95*	0.60 (2.0)
Potato	5/4/95	9/13/95*	0.45 (1.5)

*Soil samples were collected

Table 3. Mean soil chemical and physical NLEAP input parameters for the 0 to 0.3 and 0.3 to 0.9 m depths of the Kerber loamy sand (coarse-loamy, mixed, frigid, Aquic Natrargids)

NLEAP INPUT	0 to 0.3 m	0.3 to 0.9 m
Soil organic matter (%)	1.7	N/N*
pH	7.9	N/N*
Cation exchange capacity (cmol kg^{-1})	10.0	N/N*
Coarse fragments by volume (%)	14.0	17.0
Plant available water holding capacity at 0.03 MPa (cc cc^{-1})	0.10	0.08
Soil water holding capacity at 1.5 MPa (cc cc^{-1})	0.08	0.07
Soil bulk density (g cc^{-3})	1.45	1.59

* N/N not needed

Table 4. Effect of winter cover crops and planting date on N use efficiency (NUE) of winter cover crops. Effect on residual soil NO_3^--N (RSN) at winter cover crop kill and NO_3^--N leaching from the 0 to 0.9 m (NLBL) during the growing season of the winter crop

Main effect*	Treatment	NUE (%)	RSN (0 to 0.3 m)	RSN (0.3 to 0.9 m)	NLBL
			kg NO_3^--N ha^{-1}		
Crop	Rye	51.9 a	17.8 b	56.3 a	26.0 a
	Wheat	49.6 a	30.0 a	54.5 a	21.4 a
Time	Early	81.1 a	5.9 b	31.4 b	24.2 a
	Late	20.4 b	41.8 a	79.5 a	23.3 a

* Within a main effect, treatments with different letters are significantly different at LSD $P < 0.001$

Field sites

The plant parameters for these simulations were collected from farmers' fields located around Center, Colorado. The management information for the lettuce–early-planted rye–potato rotation was collected from four plots, each measuring 20.9 m^2 (225 ft^2). Plots were established under a center-pivot irrigation sprinkler on a Kerber loamy sand (coarse-loamy, mixed, frigid Aquic Natrargids). Two transponders were placed permanently in plots to allow for plant and soil sampling during 1994 and 1995. The management information on the late-planted-rye, and early- and late-planted wheat was also collected from four plots established in adjacent fields during the fall of 1995 to spring of 1996.

Information about climate and management practices

Climatic data from the nearest weather station in Center, CO [10 km (6 mi) from our site] were used for these simulations. During the growing seasons, rain and snow precipitation were measured at the site. Potential evapotranspiration (Etp) was entered into the NLEAP model using the modified Jensen-Haise (JH) method (Follett et al. 1973; Jensen et al. 1990).

Table 5. Residual effect of winter cover crop and planting date on N use efficiency (NUE) of potato, residual soil NO_3^--N (RSN) after potato harvest, and NO_3^--N leaching from the 0.0 to 0.9 m (NLBL) during the potato growing season

Treatment*	NUE (%)	RSN (0 to 0.3 m)	RSN (0.3 to 0.9 m)	NLBL
		kg NO_3^--N ha^{-1}		
Early rye	57.5 a	56.8 c	61.8 b	1.8 b
Early wheat	51.7 b	85.6 a	72.6 b	0.0 b
Late rye	49.1 bc	60.4 c	102.5 a	12.5 a
Late wheat	47.0 c	62.4 c	114.0 a	13.8 a
No cover crop	45.1 c	75.5 b	116.5 a	13.7 a

* Within a treatment, letters indicate significant differences at LSD $P < 0.05$

Table 6. Effect of cover crops on N use efficiency (NUE) of lettuce, winter cover crop, lettuce –winter cover crop and potato cropping systems

Treatment*	System			
	Lettuce	Cover crop	Lettuce + cover crop	Potato
	NUE (%)			
Early rye	35.7 c	77.2 a	76.6 . a	57.5 b
Early wheat	35.7 c	85.0 a	78.7 a	51.7 b
Late rye	35.7 b	26.6 c	49.3 a	49.01 a
Late wheat	35.7 b	14.2 c	42.7 ab	47.0 a

* Within a treatment, letters indicate significant differences at LSD $P < 0.05$

Monthly temperature, precipitation, rain, and fertilization practices are shown in Table 1. Center pivot sprinklers were calibrated for accuracy. Irrigation water samples were collected three times during the growing season and analyzed for NO_3^--N. Background NO_3^--N in the irrigation water applied to the plots was 26 kg NO_3^--N ha^{-1} y^{-1} (23.2 lb NO_3^--N a^{-1} y^{-1}). During the study period, 39 local precipitation events averaging 10.4 mm (0.41 in) were recorded. The most intense events occurred during the first two weeks of September 1994 when 25.4, 27.9 and 25.4 mm (1.0, 1.1 and 1.0 in) was reported on 9/1/94, 9/5/94, and 9/14/94. Lettuce received 153 kg N fertilizer ha^{-1} (137 lb N a^{-1}) and no fertilizer was applied to the winter cover crop. Potato received 234 kg N fertilizer ha^{-1} (209 lb N a^{-1}).

Plant and soil samples

The growing season for this research is outlined in Table 2. Prior to harvesting, plant parameters such as biomass yield of crops were collected. The mean bottom of the root depth for lettuce, early- and late-planted winter cover crop, and potato, is shown in Table 2.

At each sampling date, soils were sampled in 0.3 m (1.0 ft) intervals to 1.5 m (5.0 ft). Samples from each 0.3 m depth increment were air dried, and sieved through a 2 mm sieve (0.08 in). Soil measurements included: % coarse fragments by weight and by volume, % organic matter, pH, CEC, and water content at 1.5 and 0.033 MPa (15 and 0.33 bar) (Table 3). Bulk densities were estimated from texture as described by USDA-SCS (1988). Percentage weight of the coarse fragments was used to calculate the percentage coarse fragments by volume (Delgado et al. 1996). Sieved samples were extracted with 2N KCl and NO_3^--N and NH_4^+–N determined colorimetrically by automated flow injection analysis. Plant samples were dried at 55°C (131°F), ground, and analyzed for total C and total N content by using a Carlo Erba C/N automated combustion analyzer.

NLEAP 1.2 inputs. NLEAP uses a regional configuration file that contains crop N uptake indices, plant parameters, and soil parameters. We supplied the planting and harvesting dates, N- and water- management inputs and timing, soil and climate information, and measured yields. The model uses these values to simulate crop N uptake, soil N transformations, and water budgets. Development of the model was presented in more detail by Shafer et al. (1991). For detailed information about the observed growth and N uptake patterns of winter cover crop, see Delgado et al. 1996a & b, 1997, and 1998a & b.

NLEAP 1.2 outputs. The NLEAP model 1.2 version was used to simulate the effects of crop management on residual soil NO_3^--N, NO_3^-N leaching from the soil profile 0 to 0.9 m (0 to 3 ft) and N use efficiency of the system. We entered the initial soil NO_3^--N for spring 1994, as well as management practices and weather information, to permit model simulation of the residual soil NO_3^--N, NO_3^--N leaching, and NUE. For each cropping system the NUE was calculated as NUE = [(total N uptake by crop (aboveground + underground) / total N available in the 0 to 0.9 m (0 to 3 ft) soil profile) × 100]. Total N available included initial NO_3^--N in the soil profile, added fertilizer, added fertilizer in irrigation, background N in water, and simulated mineralized N in the soil and crop residue.

Statistical analyses

Statistical analyses were performed using the SAS analysis of variance GLM procedure, with the LSD main effect when used as the mean separation test (SAS Ins. 1988). Differences in residual NO_3^--N, NO_3^--N leaching, and NUE of winter cover crop were conducted for a factorial simulation of two crops (wheat and rye) and two planting dates (early- and late-planted)(Table 4). Early-and late-planted winter cover crop compared to the use of no winter cover crop was simulated to examine the residual effect of these practices on water quality during the growing season of the subsequent potato crop (Table 5). The effect of winter cover crop on the NUE of the lettuce, winter cover crop, lettuce + winter cover crop, and potato cropping systems was evaluated using the LSD procedure (Table 6).

Results and discussion

NLEAP 1.2 outputs. The early-planted winter cover crops limited nitrate leaching due to a greater NUE ($P < 0.05$) (Tables 4 & 5). This higher NUE was reflected in a lower residual soil NO_3^--N available to leach in the 0 to 0.3 (0 to 1 ft) and 0.3 to 0.9 m (1 to 3 ft) soil horizons ($P < 0.05$). The early-planted winter cover crops showed a potential to be an efficient scavenger crop and to reduce the residual soil NO_3^--N in the subsoil [0.3 to 0.9 m (1 to 3 ft)]. There were no significant differences in NO_3^--N leaching between early- and late-planted winter cover crops due to the 78.7 mm (3.1 in) of precipitation during a two week period early in the growing season (Table 4).

The effect of scavenging the subsoil residual soil NO_3^--N by the early-planted winter cover crops continued through the next cropping season. The sequential simulations for the potato following early-planted winter cover crops showed greater NUE and a lower subsoil residual soil NO_3^--N ($P < 0.05$)(Table 5). Greater NUE and lower subsoil residual soil NO_3^--N contributed to less NO_3^--N leached from the system during the potato growing season. The conservation of N in the plant-soil system was greater with the early-planted winter cover crops than with the late-planted (Tables 4 & 5) ($P \leq 0.05$).

Although the late-planted winter cover crops did not significantly contribute to a reduction of NO_3^--N leaching during the potato growing season, rye and wheat significantly increased the NUE of the combined lettuce and winter cover crop growing season ($P < 0.05$; Table 6). This significant increase in NUE in the system also contributes to conservation of water quality. Although the late-planted winter cover crop had a low NUE, it did increase the NUE of the lettuce crop from 35.7% to about 46%, a value similar to the potato system (Table 6). Delgado et al. (1997a) also reported that early-planted winter cover crop can help in the soil and water conservation by reducing wind erosion. These findings agree with results from other researchers who reported that NO_3^--N leaching losses through irrigated sandy soils below the root zone of crops can be kept very small with proper water and fertilizer N management practices (Smika et al. 1977; Hergert 1986; Westerman et al. 1988; Schepers et al. 1995; Thompson and Doerge 1996a & b).

Conclusions

NLEAP sequential simulations of effects of planting date on N dynamics of winter cover crops show that early-planted crops can significantly scavenge NO_3^--N from the subsoil (0.3 to 0.9). This reduction in residual soil NO_3^--N in the soil profile can reduce the NO_3^--N leaching potential and can protect water quality. The early- or late-planted winter cover crops are useful management options to enhance conservation of water quality. The benefits of late-or early-planted winter cover crops continue over the next growing season. The NLEAP 1.2 version has the potential to be a technology transfer tool capable of evaluating the trends in residual soil NO_3^--N for these irrigated systems of the San Luis Valley.

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