NITROGEN AND WATER INPUTS FOR TRICKLE-IRRIGATED WINTER VEGETABLES

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Abstract

An experiment was conducted during 1992-93 at the University of Arizona Maricopa Agricultural Center to investigate the effects of nitrogen (N) and water management on yield, midrib nitrate-N, and N and water use efficiency of subsurface trickle-irrigated leaf lettuce, collard, and spinach. The experiment was a randomized complete block factorial with three water levels (deficient, optimum, excessive), four N fertilizer levels (deficient, suboptimal, supraoptimal, excessive) and four replications. Trickle tubing was placed in the center of the beds at 15 cm depth. Irrigation was applied daily as needed to maintain the appropriate target soil water tension and N fertilizer (urea ammonium nitrate solution) was applied in 4 to 5 split applications. Midrib samples were collected for nitrate-N analysis at 4 growth stages, and portions of the plots were harvested when plants were marketable size. The 1992-93 growing season was excessively wet, therefore optimum yields were achieved in the deficient irrigation treatment. The wet conditions apparently led to excessive N losses, therefore high rates of N fertilizer were needed for optimum yields. Nitrogen and water use efficiencies were maximized at low rates of water and fertilizer input. Midrib nitrate-N concentrations were responsive to N fertilizer treatments.

Introduction

The acreage planted to leafy winter vegetables in Arizona has been increasing in recent years (Arizona Agricultural Statistics, 1993). However, limited information is available for N and water management of these crops when grown under trickle irrigation. More information is also needed regarding tissue nitrate-N concentrations in response to N and water management.

Studies were initiated during fall 1990 to determine N and water response of trickle-irrigated leafy winter vegetables. The study reported here was the third and final year of these studies. The objectives were (1) to determine the response of lettuce, spinach, and collard to three levels of irrigation and four nitrogen (N) rates, (2) to determine irrigation water and N fertilizer use efficiency as affected by water and N management, and (3) to determine midrib nitrate-N concentrations as affected by N management.

Materials and Methods

Experiments were conducted during fall 1992 to spring 1993 at the University of Arizona Maricopa Agricultural Center on leaf lettuce (Waldmann's Green), spinach (Indian Summer), and collards (Vates). The experiments were randomized complete block factorial designs with four N levels ranging from deficient to excessive, three water levels (deficient, optimum, excessive), and four replications. A summary of the treatments is shown in Table 1.

Prior to planting, the experimental area was exhaustively cropped with sudangrass to remove residual N. The sudangrass was cut three times and all harvested material was removed from the field. Preplant N concentrations in the top 30 cm of soil were 6.9 mg NH_4-N/kg and 4.2 mg NO_3-N/kg. Following the final sudangrass harvest and subsequent tillage, the field was listed and bed-shaped (40 inch centers). A total of 200 kg P_2O_5/ha were applied as triple superphosphate prior to planting. Trickle tubing (Chapin Twinwall IV turbulent flow tubing) was injected into the center of the beds at a depth of 15 cm. Seeds were planted into dry soil and plots consisted of 4 beds 12.2 meters long. Water was applied through the trickle tubing to achieve germination. A total of 61.8 cm of water were used for stand establishment. Water treatments were initiated at the close of the establishment period (29 days after planting). Final plant populations were: collard, 238,000 plants per acre (ppa), spinach, 251,000 ppa, and leaf lettuce 32,400 ppa.

Nitrogen was applied in 4 or 5 split applications as urea ammonium nitrate solution (UAN) through the trickle tubing. The N application schedule is shown in Table 2. Tensiometers were installed in selected plots of all crops at depths of 30 and 60 cm near the trickle tubing. Irrigation treatments were three target soil moisture tension levels as shown in Table 1. Tensions were recorded five days per week prior to irrigation. Daily irrigation was scheduled based on these tensiometer readings. Table 1 shows the amounts of irrigation water applied and the actual mean seasonal soil moisture tensions at 30 cm. It was not possible to achieve sufficiently dry conditions in the deficient irrigation treatment due to the unusually wet conditions during 1992-93 (11.7 cm of rainfall following stand establishment).

Midrib samples from youngest fully expanded leaves were collected from plants within all plots at four growth stages (Table 3). Midribs were dried at 60° C, ground, and NO_3-N concentrations were measured using an ion-selective electrode. Collard plots were harvested on 1 March and spinach plots were harvested on 3 March from 3 m of row by severing the plants at ground level. Fresh weights were recorded. Leaf lettuce was harvested on 15 March from 2 m of row by severing the plants at ground level. Heads were then trimmed according to the specifications for "U.S. Fancy" grade leaf lettuce. The length and average fresh trimmed weight of heads from each plot were also determined. Subsamples of all harvested materials were dried and ground for analysis of percent dry matter, total N, and N recovery.

One plot each of collard, spinach, and leaf lettuce received optimum water but no N fertilizer application. These control plots were harvested for determination of uptake of soil N. These plants were extremely N-deficient and produced no marketable yield. Amounts of N taken up in these plots were 12 kg/ha for lettuce, 7 kg/ha for collard, and 7 kg/ha for spinach.

Nitrogen use efficiency (NUE) is defined as $NUE = (N_{plot} - N_{control})/FN$, where

N_{plot} = Nitrogen uptake by plants in a given plot (kg/ha);
$N_{control}$ = Nitrogen uptake by plants in control plot (kg/ha);
FN = Fertilizer N applied (kg/ha).

Applied water use efficiency (AWUE) is defined as AWUE (kg dry matter/mm water) = DM/W_{irr} ,where

DM = Total dry matter production (kg/ha);
W_{irr} = mm of irrigation water applied.

Results and Discussion

Fresh weight yields for collard and spinach are shown in Table 4. As expected, the crops responded positively and dramatically to N fertilizer. However, it is apparent from these data that excessive N rates were not achieved despite the high N rates applied (450 kg/ha). We believe that this was due to the excessive rainfall received during the growing season, which may have resulted in conditions that promoted losses of N through leaching and (or) denitrification. Collard and spinach did not respond appreciably to irrigation treatment. There was no significant yield increase beyond the deficient irrigation treatment, and there was a trend toward yield decreases at the excessive irrigation treatment. During the 1992-93 growing season, optimum yields of collard and spinach were achieved with only 7.4 cm of irrigation applied following stand establishment. This reflects the large amount of rainfall received. It is not expected that this reflects normal growing conditions in Central Arizona.

Fresh weights, marketable weights, numbers of heads, head weights, and head lengths for leaf lettuce are shown in Table 5. Leaf lettuce yields and head sizes were highly responsive to N up to the maximum N rate. Again, this probably reflects conditions conducive to N losses. Lettuce also was largely unresponsive to water inputs, probably due to wet conditions during the growing season.

Nitrogen use efficiency (NUE) represents the proportion of applied N that was taken up by the crops. Figs. 1 through 3 show response surfaces for NUE for leaf lettuce, spinach, and collard. NUE for all crops was highly dependent on N rate. For spinach and leaf lettuce, the highest efficiencies were achieved at the lowest N rates. For collard, the highest efficiencies were achieved at intermediate N rates. Irrigation treatment also influenced NUE. NUE for spinach and leaf lettuce was decreased markedly at the excessive irrigation treatment (less negative soil water potential), while NUE in collard was less affected by irrigation treatment. These results represent the influence of both fertilization and irrigation on recovery of N fertilizer. In general, they show that overirrigation and overfertilization will result in lower efficiencies. Nitrogen not recovered by the plant may have been lost to the atmosphere by denitrification, may have been leached as NO_3^- from the rooting zone, or may remain in the soil. Excessive N and water application can be expected to contribute to significant N losses by both nitrate leaching and denitrification. During 1992-93, optimum yields were achieved where NUE was lowest. Because of the high rainfall amounts, high N applications were needed to achieve optimum yields, and this resulted in low NUE. In normal years, it is expected that optimum yields could be achieved with lower N rates and higher resultant NUE.

Applied water use efficiency (AWUE) was affected by both water and N treatments (Table 6). Because of the high rainfall, high yields could be achieved with low water input. Therefore, the optimum and excessive irrigation treatments resulted in much lower AWUE than the deficient treatment. Nitrogen fertilization increased AWUE because of its positive effect on dry matter production. The irrigation treatments used in this study were determined by the experimental design, therefore the optimum treatment probably represents overirrigation. However, by using feedback from tensiometers a grower could have achieved high water use efficiencies under similar growing conditions. Figs. 1 through 3 show that, in addition to higher water use efficiencies, higher N use efficiencies may be achieved by preventing overirrigation.

Midrib nitrate-N concentrations for plants from the optimum water treatment are shown in Figs. 4 and 5. Nitrate-N concentrations were highly responsive to N fertilizer treatments in collard and spinach. However, nitrate concentrations were less responsive in lettuce until late in the growing season (9-12 leaf stage). These results show that the midrib nitrate tissue test should be an effective management tool for growers during essentially the entire growing season for spinach and collard, and during the latter part of the growing season for leaf lettuce. Results from 1992-93 will be combined with results from the two previous years to derive recommendations for deficient, optimum, and excessive concentration ranges for midrib nitrate-N for these crops.

Table 1. Water and Nitrogen treatments for 1992-93.

Crop	Irrigation Treatment	Soil Water Tension: Target	Soil Water Tension: Average†	Water Applied‡	N Rates§
		mbar	mbar	mm	kg/ha
Lettuce	Dry	120	85	93	80,110
	Optimum	70	62	329	180,300
	Wet	40	53	611	
Spinach	Dry	120	92	74	80,170
	Optimum	70	67	272	280,450
	Wet	40	49	450	
Collard	Dry	120	109	74	80,170
	Optimum	70	66	272	280,450
	Wet	40	51	450	

†Average daily soil water tension measured at 30 cm depth.
‡Plots also received 117 mm of rainfall.
§Experiment was factorial with 3 water rates and 4 N Rates for each crop.

Table 2. Application schedule for urea-ammonium nitrite solution for collards, spinach, and leaf lettuce crops grown at the Maricopa Agricultural Center, 1992-93.

Crop	Date	DAP†	Growth Stage	N Level			
				1	2	3	4
				kg N/ha			
Collard	12/11	31	1 leaf	0	20	40	60
	12/31	51	2- 3 leaf	20	30	60	90
	1/23	74	5- 6 leaf	40	60	80	150
	2/5	87	6- 7 leaf	20	40	70	100
	2/23	105	7- 9 leaf	0	20	30	50
			Total	80	170	280	450
Spinach	12/11	31	2 leaf	0	20	40	60
	12/31	51	4 leaf	20	30	60	90
	1/23	74	7- 9 leaf	40	60	80	150
	2/5	87	9-12 leaf	20	40	70	100
	2/23	105	12-14 leaf	0	20	30	50
			Total	80	170	280	450
Lettuce	12/15	35	1- 2 leaf	0	10	20	40
	1/12	63	4- 6 leaf	20	20	40	60
	2/110	92	8- 9 leaf	40	50	70	120
	2/25	107	Early Heading	20	30	50	80
			Total	80	110	180	300

† DAP = Days after planting

Table 3. Plant tissue sampling schedules for collards, spinach, and leaf lettuce crops grown at the Maricopa Agricultural Center, 1992-93.

Crop	Date	DAP†	Growth Stage	Midribs	Whole Plant
Collard	12/31	51	2- 3 leaf	X	
	1/25	76	5- 6 leaf	X	
	2/9	91	7- 8 leaf	X	
	2/26	108	8-10 leaf	X	
	3/1	111	Harvest		X
Spinach	12/31	51	4- 6 leaf	X	
	1/25	76	8-10 leaf	X	
	2/11	93	11-12 leaf	X	
	2/26	108	12-14 leaf	X	
	3/3	113	Harvest		X
Lettuce	1/12	63	4- 6 leaf	X	
	1/29	80	6- 7 leaf	X	
	2/15	97	9-12 leaf	X	
	2/25	107	Early Heading	X	
	3/15	125	Harvest		X

† Days after planting

Table 4. Marketable yields and dry matter yields of Vates collards and Indian Summer spinach as affected by water and nitrogen fertilization.

Crop	Irrigation Water	N Rate	Marketable Yield
	cm	kg N/ha	--------- kg/ha ----------
Collard	7.4	80	16940
		170	32680
		280	43790
		450	47930
	27.2	80	14280
		170	31040
		280	45160
		450	49770
	45.0	80	15930
		170	31730
		280	43270
		450	44960
		LSD 0.05	5940
Spinach	7.4	80	12840
		170	23440
		280	31880
		450	31820
	27.2	80	12520
		170	21360
		280	31680
		450	33700
	45.0	80	11910
		170	19800
		280	26840
		450	30540
	LSD 0.05		2660

Table 5 . Fresh weight, marketable yields, trimmed head length and weight and numbers of marketable heads of Waldmann's Green leaf lettuce in response to varying levels of irrigation and nitrogen fertilization.

Irrigation Water	N Treatment	Total Fresh Wt.	Total Marketable Head Wt.	Number of Marketable Heads	Average Length Trimmed Heads	Average Weight Trimmed Heads
cm	kg/ha	------------ kg/ha	-----------	/ha	cm	g
9.3	80	34350	25810	79970	21	340
	110	48810	38400	82430	24	466
	180	51240	41990	83660	25	511
	300	50700	41090	77510	25	548
32.9	80	31310	23670	78740	20	311
	110	46540	37540	78740	23	484
	180	49450	40300	79970	25	513
	300	59090	54020	81200	27	608
61.1	80	28880	19870	76280	20	283
	110	40750	32110	79970	23	430
	180	45300	35480	79970	24	465
	300	60490	49570	87350	25	577
LSD 0.05		6950	7120	9500	2.7	63

Table 6. Applied Water Use Efficiency (AWUE) for Trickle-Irrigated Collard, Spinach, and Lettuce.

Crop	Irrigation Water	N Rate	AWUE
	mm	Kg/ha	Kg dm / mm Water
Collard	74	80	31.9
		170	51.4
		280	58.4
		450	68.3
	272	80	8.0
		170	13.5
		280	16.3
		450	19.0
	450	80	5.2
		170	8.2
		280	10.1
		450	10.3
	LSD 0.05		7.2
Spinach	74	80	26.7
		170	40.9
		280	46.0
		450	48.6
	272	80	7.0
		170	9.8
		280	13.2
		450	13.8
	450	80	4.2
		170	5.8
		280	7.0
		450	7.7
	LSD 0.05		8.2
Lettuce			
	93	80	29.6
		110	41.3
		180	49.3
		300	46.2
	329	80	8.4
		110	12.3
		180	11.7
		300	14.7
	611	80	4.4
		110	6.0
		180	6.5
		300	7.4
	LSD 0.05		3.4

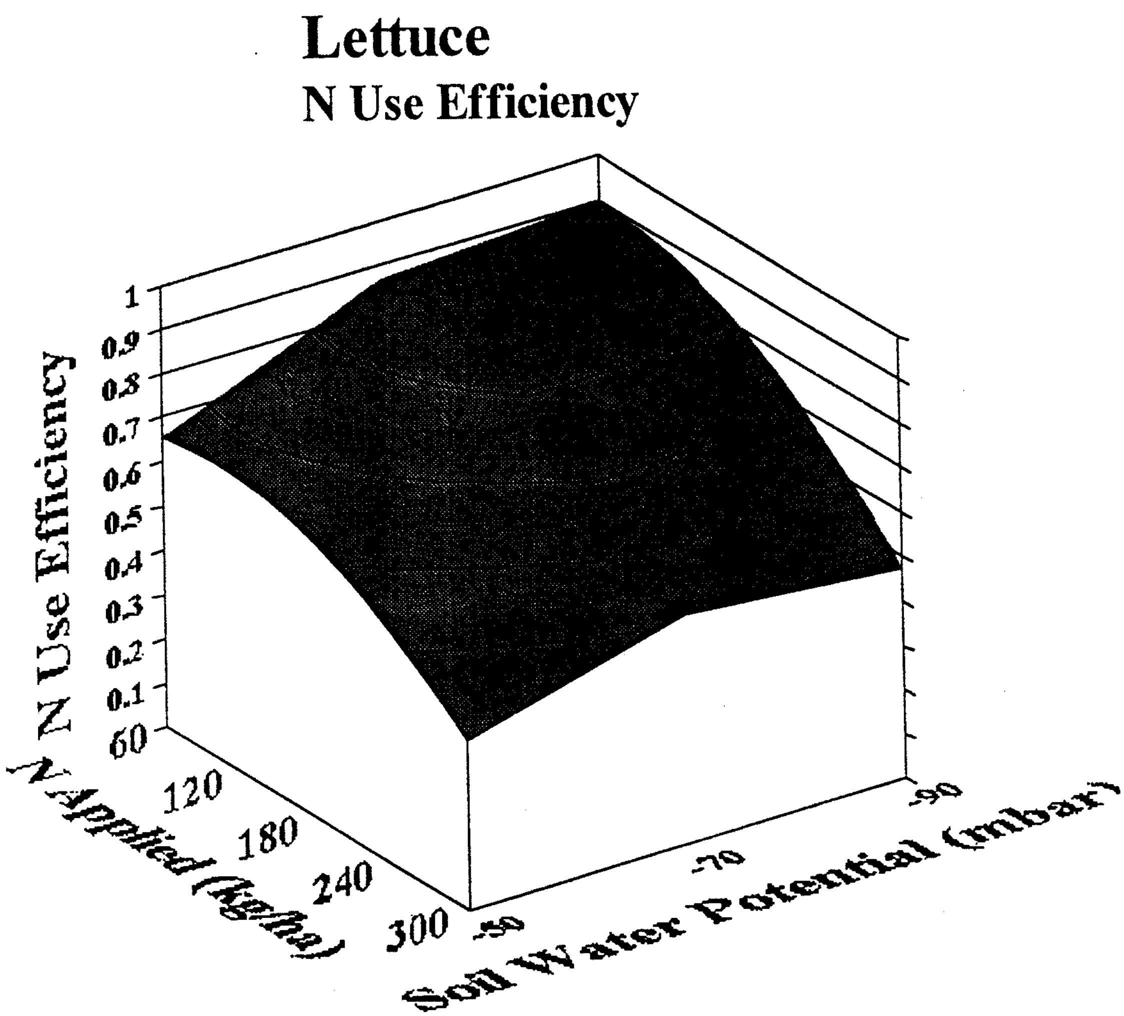


Figure 1. Nitrogen use efficiency for leaf lettuce.

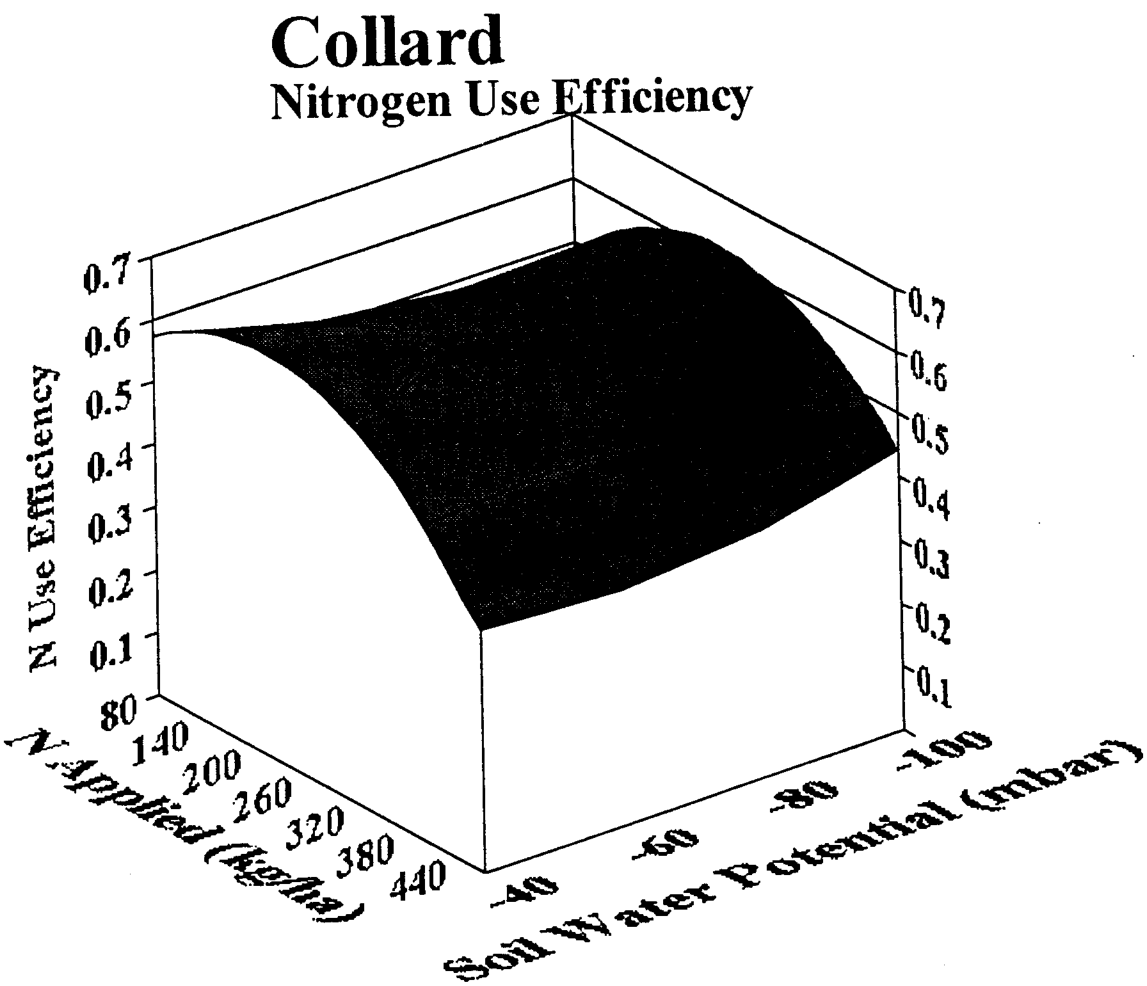


Figure 2. Nitrogen use efficiency for collard.

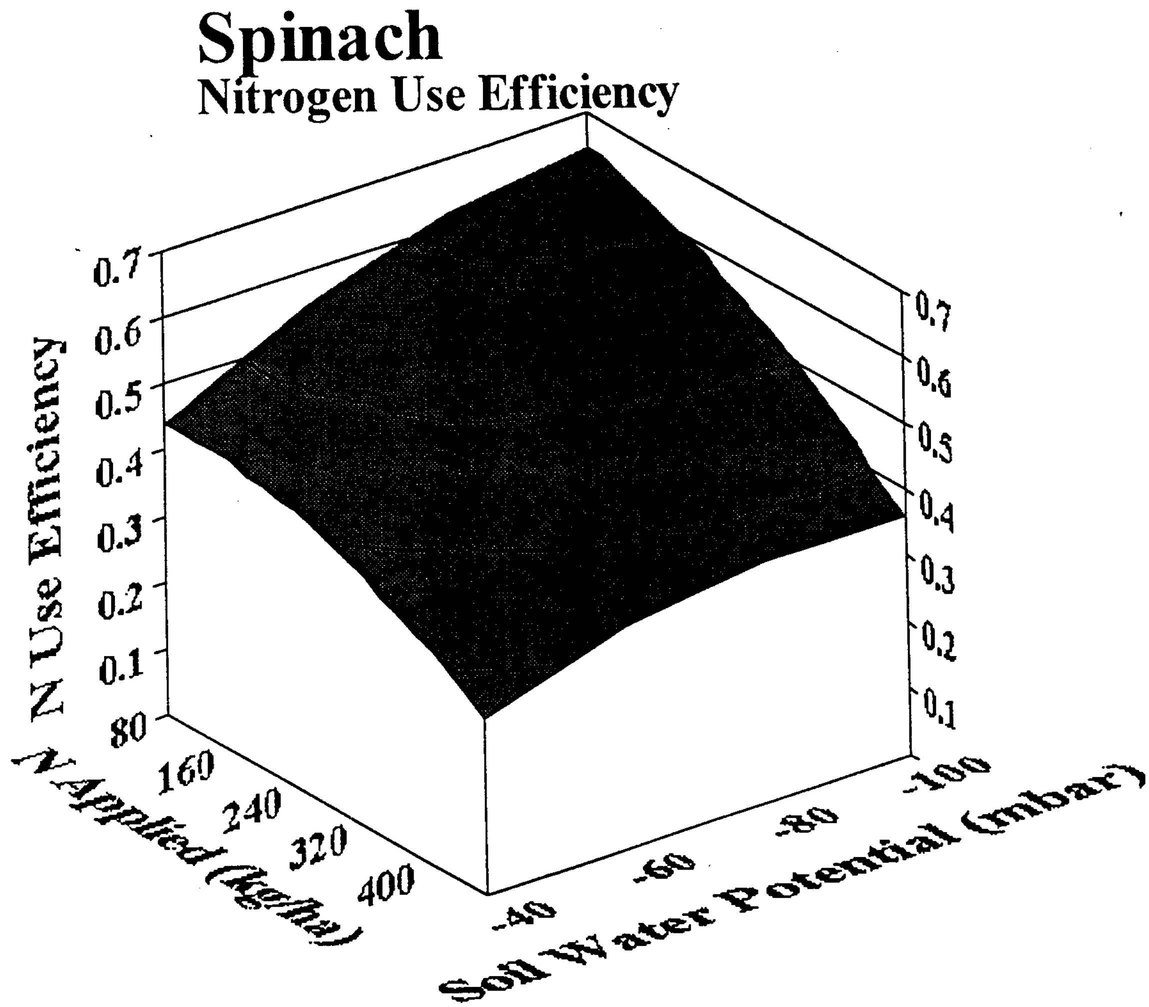
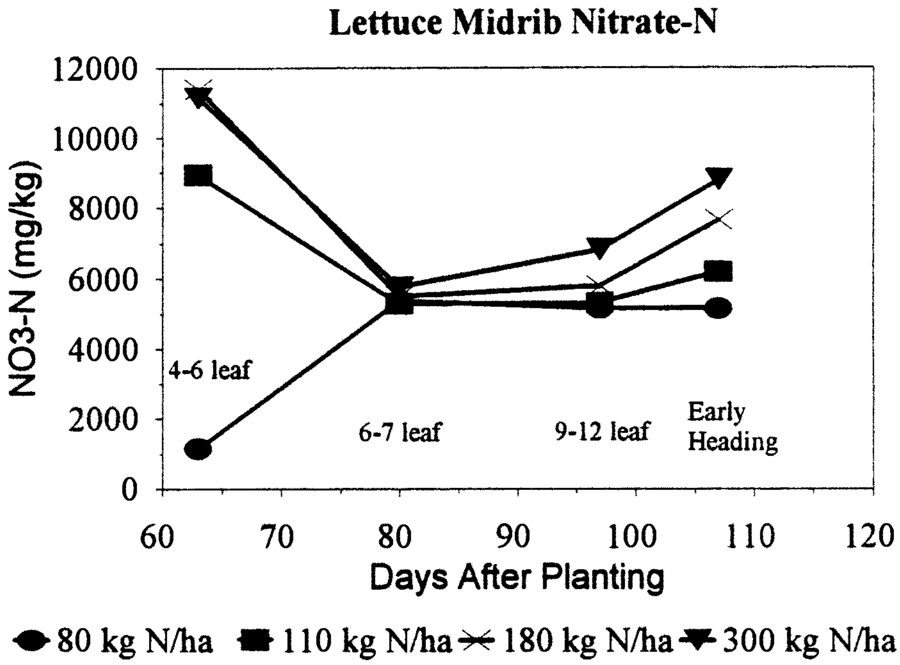


Figure 3. Nitrogen use efficiency for spinach.



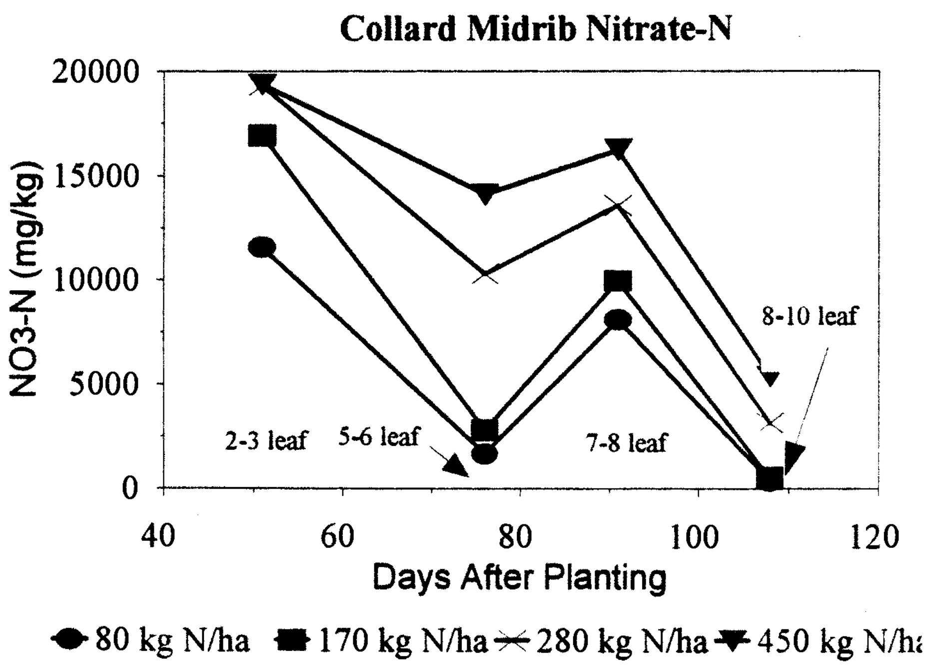


Figure 4. Midrib nitrate-N concentrations for leaf lettuce and collard from the optimum irrigation treatments.

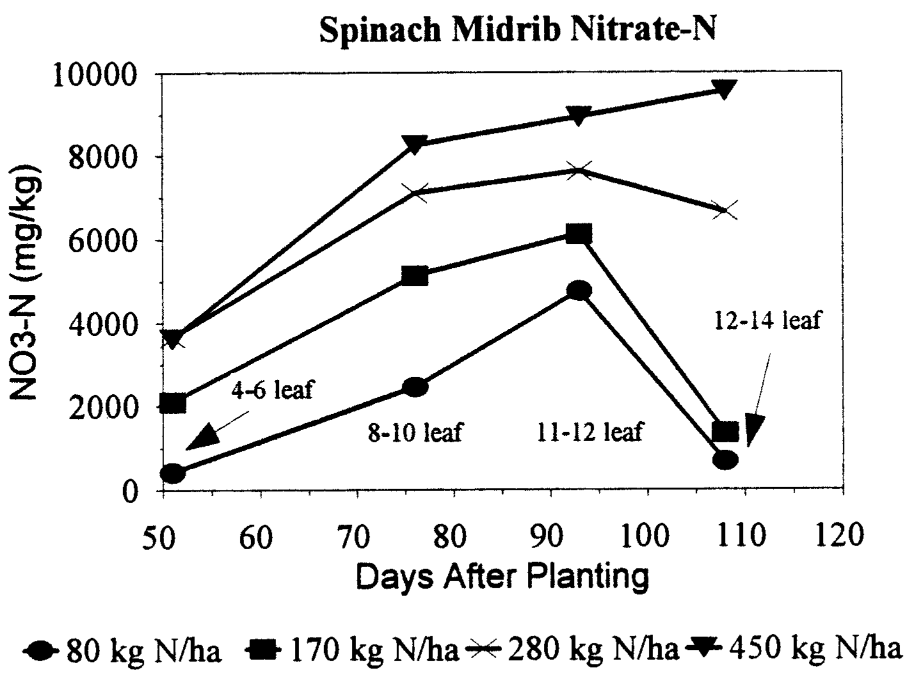


Figure 5. Midrib nitrate-N concentrations for spinach from the optimum irrigation treatment.