Nitrogen Management in Drip Irrigated Leaf Lettuce, Spinach and Greens Crops

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Abstract

Preliminary nitrogen (N) management experiments with spinach, leaf lettuce,romaine, collard and mustard were conducted on a Casa Grande s.l. soil at the Maricopa Agricultural Center in the winter and spring of 1990-91. The purpose of this N rate experiment was to develop initial Best Management strategies for N fertilizer use for emerging, high value crops grown in Arizona using subsurface drip irrigation. Three rates of urea,ammonium nitrate were applied to each cultivar to provide deficient (N1), adequate (N2) and supraoptimal (N3) levels of N. All cultivars responded dramatically to the application of N. Fresh weight yields in the N1 and N2 treatments averaged 45 and 53% of the N3 treatment. The average N3 yields recorded in these trials were 23.1, 12.8 and 21.8 tons of marketable produce per acre for greens, spinach and leaf lettuce/romaine crops, respectively. Preliminary plant tissue test results indicated that for all five crops, whole plant total N (TN) levels and midrib + petiole NO_3-N and leaf blade TN concentrations in the youngest mature leaf were responsive to differences in soil N supply and show promise as diagnostic N tissue test procedures. The midrib + petiole NO_3-N test appeared to be the best indicator of plant N status throughout the growing season for all five crops studied.

Introduction

The research base needed to formulate nitrogen (N) fertilizer BMP's for most of the major acreage crops grown in Arizona is adequate. Tissue testing procedures for monitoring the in season nitrogen needs of cotton, small grains, melons, head lettuce and a number of other major vegetables are currently available. However, nitrogen management for virtually all emerging "new crops" is not well documented and needs further study. These are primarily high-value vegetable and specialty crops such as bok choy, greens, leaf lettuce, parsley, rapini, romaine, spinach and squash. The objective of this research was to develop initial Best Management strategies for nitrogen fertilizer usage in emerging high value crops grown in Arizona, specifically leaf lettuce, romaine, spinach, collard and mustard.

Materials and Methods

Field trials were initiated in the fall of 1990 at the Maricopa Agricultural Center (MAC) to develop nitrogen Best Management Practices (BMP's) for three high value vegetable crops. Leading commercial varieties of leaf lettuce (Waldmann's Green), romaine (Parris Island Cos), spinach (Crystal Savoy and Indian Summer), collard (Vates) and mustard (Southern Giant) were planted on 25 October. The experimental design for each of the five crops was a randomized complete block with four replications. Three rates of N were applied to provide deficient (N1), adequate (N2) and supraoptimum (N3) N as shown in Table 1. The soil type in the experimental area was a Casa Grande sandy loam with a preplant soil test NO_3-N level of 1.2 ppm. This is considered an extremely low value.

Seeding was accomplished using a Stanhay precision planter. Raw seed of the mustard, collard and spinach varieties were planted in the same configuration, using six seed lines per 40-inch bed. The final plant populations for these crops were mustard, 462,000 plants per acre (ppa); collard, 305,000 ppa; Indian Summer spinach, 523,000 ppa; and Crystal Savoy spinach, 173,000 ppa. Two seed lines of coated leaf lettuce and romaine seed were planted on each bed and then thinned to a plant population of 32,400 ppa at the 3- to 4-leaf stage on 29 November. This resulted in an interplant spacing of about 25 cm (10 inches) in both of the seed lines on each bed.

After seeding, solid set sprinkler irrigation was used for eight consecutive days to enhance seedling emergence and stand establishment. Approximately 26.7 cm of water was applied during this establishment period. Beginning on 31 October, subsurface drip irrigation was used to provide an adequate but not excessive amount of water for all of the crops. One line of Chapin Twin-wall IV® drip irrigation tubing was buried six to eight inches below the soil surface of each north-south oriented bed. The flow rating for this tubing is 6.2 L/minute per 100 meters and the outlet spacing is 22.9 cm. Irrigation was conducted once daily except when additional water was not needed due to recent rainfall or very cold temperatures. Cumulative amounts of irrigation water applied to the three experiments are shown in Figure 1.

Tensiometers were installed at 30 and 60 cm depths in the N2 plots of collard, leaf lettuce and Crystal Savory spinach to help guide the irrigation scheduling. In general, irrigation water was applied in amounts necessary to maintain soil moisture tensions measured just prior to the daily irrigation between -60 and -100 mbars. This represents total soil water depletions of about 45 to 60%, respectively. The actual soil moisture tensions observed in the greens, lettuce and spinach experiments are shown in Figure 2.

A total of 280 kg of P_2O_5 per hectare supplied from phosphoric acid (0-26-0) was uniformly injected into irrigation water applied to all plots between 1 November and 8 November at the one-true leaf stage. On 13 November 1.1 kg of Zn per hectare as Zn EDTA was also uniformly injected into irrigation water applied to all plots. No other nutrient solutions were applied throughout the growing season. No pesticides were applied and weed control was accomplished by hand hoeing. The amount of NO_3-N + NH_4-N in the irrigation water ranged from 5.2 to 6.9 kg N per hectare not including N contained in the sprinkler applied water.

Plant tissue samples were obtained from all plots at about two-week intervals beginning at the 3- to 4-leaf stage of growth. Samples included petiole + midrib tissue from the youngest fully expanded leaf and the leaf blade tissue from that same leaf. The samples were dried at 60°C and ground to pass a 40 mesh screen. The petiole + midrib samples were analyzed for NO_3-N content using an ion specific electrode and the leaf blade samples were analyzed for total N concentration using a CNS automated analyzer.

On each sampling date, whole plant samples were collected from one square meter of row. The entire above-ground portions of the plants plus crown tissue was collected. These samples were dried and ground as described above, weighed and analyzed for total N concentration using the same CNS automated analyzer. Total N content in crop biomass was calculated as the product of the plant dry weight and the total N concentration in all plant parts. The actual plant sampling schedules for the three experiments are shown in Table 2.

Plots were harvested for fresh weight yields according to the size of plants and prevailing marketing practices. Spinach was harvested on 31 January and 13 February as leaves only and as whole plants (leaves + crowns). On these two dates, the largest leaves in the N3 plots were 13 cm and 15 cm long, respectively. This represents a normal harvesting interval for spinach. Secondary harvest of spinach following clipping and regrowth was not possible due to onset of curly top virus symptoms (chlorosis progressing to death of plants).

Mustard plots were harvested initially on 17 January by clipping the plants from 2 m of row at a height of 2 to 4 cm above the ground level. Fresh weight of the leaves was measured followed by clipping of the remainder of the plot area to allow for regrowth. All clippings were immediately removed. Mustard leaves were regrown and harvested again on 28 February from 1 m of row length.

Collard was harvested on 31 January and on 13 February when the average diameters of the largest-sized leaves were 18 and 23 cm, respectively. Plants were harvested from a 1 m length of row at a height of 3 to 5 cm above the ground level. Collard plants were not clipped and allowed to regrow due to insufficient time available for the regrowth period.

Lettuce plants from 1 m of row (8 plants) were harvested by horizontally severing the main tap root at the soil surface. Heads were then trimmed according to the specifications for "U.S. Fancy" grade Leaf Lettuce and Romaine. The vertical dimension (length) and average fresh trimmed weights of the eight heads from each subplot were determined within 1 to 2 hours after harvest. Leaf lettuce and romaine plots were harvested on 28 February with one additional romaine harvest on 12 March. The marketability of lettuce "heads" were determined based on visual characteristics and head length (> 23 cm for romaine only).

Results and Discussion

Yield and Quality

The fresh weight yields of spinach, leaf lettuce, romaine, mustard and collard cultivars are listed in Tables 3-6. In addition, head characteristics and percent marketable heads for leaf lettuce cultivars are listed in Tables 5 and 6.

As expected, all cultivars responded very dramatically to the application of N. Fresh weight yields in the N1 and N2 treatments averaged 45 and 83% of the N3 treatment yields. The N3 yields were assumed to represent the maximum biomass accumulation with N supply not limiting plant growth. Climatic and cultural conditions were excellent for growth of the leafy green crops. The late planting date eliminated stand establishment problems associated with high soil temperatures and while fly pressure. Beneficial insect activity was high and no insecticide treatments were required to protect crop quality and appearance. The average N3 yields recorded in these trials were 23.1, 12.8 and 21.8 tons of marketable produce per acre for greens, spinach and leaf lettuce, romaine, respectively. In comparison the 1989 Arizona state averages for the same crops were 10.2, 5.1 and 10.1 tons per acre. In short, growth conditions were excellent and yields were at least comparable to typical commercial operations.

Plant Tissue Testing

The nitrogen plant tissue test used in head lettuce and most other annual vegetables is determination of the NO_3-N concentration in petioles or midribs from the youngest fully expanded leaves. Guidelines for total N (TN) concentrations in the youngest fully expanded leaf blade have also been used in a smaller number of vegetable crops. In addition, total N concentration in the entire above ground plant tissue could also be used to characterize the N status of these crops. These three approaches to plant tissue testing were evaluated as potential indicators of the N status of the five leafy green vegetables grown in this trial.

The seasonal patterns of midrib NO_3-N, leaf blade TN and whole plant TN concentrations for the collard mustard, leaf lettuce, romaine and spinach varieties grown in this experiment are shown in Figure 3 - 8. Approximate critical levels" of NO_3-N and TN were determined on each sampling date by evaluating the statistical differences in dry matter yield on that same date. The minimum NO_3-N or TN level which was associated with maximum dry matter yield on a particular sampling date was thus defined as the critical level. These critical levels will need to be further refined in more detailed experimental work.

In general, the NO_3-N levels in midrib tissue were much more sensitive to differences in soil N supply than either of the two TN methods. This was true for all cultivars. Collard and mustard midrib NO_3-N levels were the most responsive to differences in soil N supply (Figures 3 and 4). Nitrate-N levels in leaf lettuce and romaine midribs were the least sensitive to soil N supply, especially early in the season, prior to the 12- to 15-leaf stage (Figures 5 and 6). Nitrate-N levels in spinach midribs were very similar in the two varieties grown, despite differences in plant morphology and stand density (Figures 7 and 8). This suggests that one set of diagnostic guidelines may be appropriate for each crop type with reasonable accuracy. It also appears that separate NO_3-N and TN interpretation guidelines will be required for each particular species.

The responsiveness of leaf blade and whole plant TN levels to differences in soil N supply were very similar for each of the five crop species that were grown. The TN values in whole plant samples (i.e. all above ground leaves) tended to be somewhat lower than leaf blade TN, particularly after the plants had reached the 6 true leaf stage.

These preliminary results suggest that the plant tissue test which holds the most promise for all of the test crops is determination of midrib NO_3-N concentration. This is especially true for spinach, mustard and collard crops. One very positive finding is that midrib NO_3-N levels in spinach, mustard and collard were most responsive to differences in soil N supply during the middle half of the season. This generally corresponds to the portion of the growing season when the greatest quantities of N fertilizers are applied.

The use of TN concentrations in spinach, mustard and collard leaf blade or whole plant samples may also be useful, but to a lesser extent. Total N analysis of leaf lettuce and romaine leaf blades or whole plant samples showed very little promise as a tool for diagnosing N status.

Dry Matter and Nitrogen Accumulation

Cumulative and daily accumulation patterns of dry matter and nitrogen are shown for spinach, collard, mustard, leaf lettuce and romaine in Figure 9 - 20. In addition, total and maximum daily dry matter and N accumulations measured in the high N treatment (N3) are listed in Table 7. These represent the maximum values that would be reasonably expected to occur under commercial production conditions.

In general, the daily dry matter and the daily N accumulation (flux) patterns for each of the five individual crops were very similar. This is because N concentrations in the biomass of each species remained relatively constant over the entire growing season and differences in biomass N concentrations between plants in deficient N (N1) and excessive N (N3) treatments were not extreme.

Accumulation rates of dry matter and N by spinach cultivars showed a gradual, generally increasing trend throughout the growing season (Figures 9-12). No pronounced growth spurts or lag periods were observed. This suggests that a nitrogen fertilization program should supply N consistently throughout the season with modest applications early and increasing rates applied through at least mid-season. A slight decline in dry matter accumulation was noted between 18 December (54 days after planting or DAP) and 3 January (70 DAP) when average daily air temperatures were mostly below 40°F (Figure 21).

Collard showed a markedly bimodal growth pattern with rapid dry matter and N accumulation between the 4- and 5-leaf stages and from the 6- to 8-leaf stage through harvest (Figures 13-14). This very marked reduction in growth rate between the 4- and 6-leaf stages again corresponded to the period of cold weather in late December and early January. As average daily air temperatures increased to above 40°F collard growth rate again approached maximum levels when N supply was not limiting. While adequate soil N was required for optimum collard growth, adequate or excessive levels of N fertilization (treatments N2 and N3 respectively) were not able to offset the inhibitory effect of cold air and soil temperatures. Soil N supply appeared to have no effect on conditioning the plant for improved (or decreased) cold hardiness. However, conversely, adequate soil N is needed to insure that collard growth did resume rapidly after temperatures again increased to favorable levels.

The seasonal patterns of dry matter and N accumulation in mustard were similar to those observed in collard. Maximum growth rates occurred during the early to middle portions of the first and second harvest periods (Figures 15 and 16). These maxima occurred when plants had about 5 to 10 true leaves and were not subjected to average daily air temperatures below 40°F. Mustard growth rates appeared to be more affected by cold temperatures than any of the other cultivars grown. Actual decreases in crop biomass were measured prior to the first harvest in the N3 treated plots. This was associated with some visible frost injury to the younger leaves in these plots. By the first harvest on 17 January, these injured leaves had completely senesced and then sloughed off during the hand-harvesting procedure. Excessive N supply did appear to promote rapid, luxuriant early growth of mustard but also greater susceptibility to cold injury. Higher levels of N fertilization only slightly improved mustard regrowth after air and soil temperatures increased. Of the five species grown, mustard showed the highest maximum daily accumulation rates of dry matter and N (188 and 7.4 kg/ha/day respectively). This N flux is one of the highest measured under high yielding conditions in Arizona. Only broccoli, cauliflower and field corn have shown higher maximum N uptake rates, each with a maximum slightly above 9 kg N/ha/day.

Dry matter and N accumulation patterns in leaf lettuce and romaine crops were very similar to those reported for head lettuce by B.R. Gardner (Figures 17 - 20). Early thinning to relatively low plant populations and average daily air temperature below 55°F resulted in very low rates of biomass and nutrient accumulation prior to the formation of early loose heads at about 100 days after planting. For leaf lettuce and romaine, only about 29 and 16% of the total dry matter and 30 and 26% of the total N, respectively, were accumulated by the crop in the first 100 days of the growing season. Maximum daily N fluxes in leaf and romaine lettuce of 3 to 4 kg N/ha/day were very similar to those reported for head lettuce. Maximum N fluxes occurred shortly before or at harvest.

The period of cold weather in late December and early January had no observable effect on these lettuce crops except to lengthen the overall growing season. Plants were very small during this period and differences in growth rates are therefore, very difficult to measure. Most growth and nutrient uptake occurred after 1 February when air temperatures again exceeded 55°F (Figure 21).

Leaf lettuce is probably one of the most difficult vegetable crops to fertilizer with N in an efficient manner. The slow growing nature of the crop and its inextensive root system which occurs for most of the season are the primary reasons for this. Supplying sufficient N for adequate plant nutrition early in the season often necessitates N applications which numerically, greatly exceed the N requirement of the crop biomass. The greatest improvements in N fertilizer use efficiency for crops such as lettuce will involve more precise placement of early season N and better strategies to prolong the positional availability of N within the root zone. This applies especially to furrow-irrigated crops, but also to those under drip irrigation.

Table 1. Nitrogen fertilization schedules for applications of urea, ammonium nitrate (UAN-32) to leafy vegetable test crops.

Crop			Growth Stage					
			1 - 2 Leaf	3-4 Leaf	5-8 Leaf	6-15 Leaf	Pre-Harvest	Total N kg/ha
		Date:	11/13	12/4	12/18	1/15	2/7	
Spinach	N1		0	20	30	30	0	80
	N2		15	40	50	50	20	175
	N3		30	60	70	70	40	270
		Date:	11/13	12/4	12/18	1/10	2/7	
Greens	N1		0	20	30	20	20	90
	N2		15	40	60	40	30	185
	N3		30	60	90	60	40	280
		Date:	11/13	12/4	12/18	1/15	2/7	
Lettuce	N1		0	15	20	0	0	35
	N2		15	30	40	20	15	120
	N3		30	45	60	40	30	205

Table 2. Plant tissue sampling schedules for greens, leaf lettuce and spinach crops grown at the Maricopa Agricultural Center, 1990-91.

Crop		Date	DAP	Growth Stage	Midrib	Leaf	Whole Plant
Spinach	1	6 Dec	42	5- 6 Leaf	X	X	X
	2	18 Dec	54	8- 9 Leaf	X	X	X
	3	10 Jan	77	10-13 Leaf	X	X	X
	4	31 Jan	98	First harvest	X	X	X
	5	13 Feb	111	Second harvest			X
Lettuces	1	13 Dec	49	4- 6 Leaf	X	X	X
	2	27 Dec	63	7- 9 Leaf	X	X	X
	3	24 Jan	91	12-15 Leaf	X	X	X
	4	7 Feb	105	Early harvest	X	X	X
	5	21 Feb	119	Pre-harvest	X	X	X
	6	28 Feb	126	First harvest			X
	7	12 Mar	138	Second harvest			X
Mustard	1	29 Nov	35	3- 4 Leaf	X	X	X
	2	13 Dec	49	5- 6 Leaf	X	X	X
	3	20 Dec	56	8-10 Leaf	X	X	X
	4	17 Jan	84	First harvest	X	X	X
	5	28 Feb	126	Second harvest			X
Collard	1	29 Nov	35	2- 3 Leaf	X	X	X
	2	13 Dec	49	4 Leaf	X	X	X
	3	20 Dec	56	6- 7 Leaf	X	X	X
	4	17 Jan	84	Pre-harvest	X	X	X
	5	31 Jan	98	First harvest	X	X	X
	6	13 Feb	111	Second harvest			X

Table 3. Fresh weight yields of Southern Giant mustard and Vates collard greens in response to varying levels of nitrogen fertilization.

Nitrogen Treatment	Fresh Weight Yields			
	Mustard		Collard	
	Harvest 1	Harvest 2	Harvest 1	Harvest 2
kg N/ha	---------- Mg/ha ----------			
90	12.4c	13.9b	13.2b	18.6c
185	23.6b	21.3b	26.7a	31.4b
280	31.4a	31.2a	29.0a	41.1a
LSD 0.05	2.1	9.0	4.0	4.9

Table 4. Fresh weight yields of Indian Summer and Crystal Savoy spinach in response to varying levels of nitrogen fertilization.

Nitrogen Treatment	Fresh Weight Yields							
	Indian Summer				Crystal Savoy			
	Harvest 1		Harvest 2		Harvest 1		Harvest 2	
	Leaves	Whole Plant	Leaves	Whole Plant	Leaves	Whole Plant	Leaves	Whole Plant
kg N/ha	---------- Mg/ha ----------							
80	8.3b	11.2b	8.8c	11.2c	10.3c	12.8c	12.1c	14.6b
175	16.4a	20.9a	16.4b	20.9b	15.0b	19.1b	20.0b	24.0a
270	16.4a	20.7a	23.6a	29.4a	18.2a	21.8a	23.6a	27.8a
LSD 0.05	3.8	2.9	2.7	3.1	1.9	1.8	5.6	3.8

Table 5. Fresh weight yields and head dimensions for Waldmann's Green leaf lettuce in response to varying levels of nitrogen fertilization.

Nitrogen Treatment	Fresh Weight*		
	Yield	Head Weight	Head Length
kg N/ha	Mg/ha	grams	cm
35	16.8b	209b	16.8b
120	31.9a	400a	22.0a
205	35.5a	445a	22.4a
LSD 0.05	10.6	132	2.6

*weights are for heads trimmed to meet U.S. Fancy grade for leaf lettuce.

Table 6. Fresh weight yields, head dimensions and percent marketable heads for Parris Island Cos romaine in response to varying levels of nitrogen fertilization.

Nitrogen Treatment	HARVEST 1				HARVEST 2			
	Fresh Weight Yield	Heat Wt.	Head Length	% Market-able Heads**	Fresh Weight* Yield	Heat Wt.	Head Length	% Market-able Heads**
kg N/ha	Mg/ha	grams	cm	%	Mg/ha	grams	cm	%
35	17.1b	213b	19.5b	19b	22.9c	286c	18.4b	0b
120	32.6a	409a	26.8a	91a	52.8b	658b	26.1a	91a
205	38.6a	481a	28.8a	100a	62.4a	781a	30.0a	100a
LSD 0.05	6.7	86	3.1	17	7.6	95	5.1	12

*Weights are for heads trimmed to meet U.S. Fancy grade for romaine.

**Heads were considered marketable if they exceeded 22.9 cm (9 inches) length and were free from color or other visual defects.

Table 7. Total and daily dry matter and N accumulation measured in the highest N treatment (N3) for spinach, collard, mustard, leaf lettuce and romaine crops.

Species	Total Accumulation Dry Matter	N	Maximum Daily Flux Dry Matter	N	Growth Stage at Maximum Fluxes
	--------- kg/ha ---------		------- kg/ha/day --------		
Spinach					
Indian Summer	3665	193	103	5.2	2nd harvest
Crystal Savoy	3256	171	63	2.8	pre-harvest
Collard	4830	208	131	6.3	4-5 leaf and pre-harvest
Mustard*	4617	178	188	7.4	6-8 leaf
Leaf Lettuce	2231	84	108	4.3	pre-harvest
Romaine	4102	134	122	3.8	pre-harvest

*Totals are for two harvests.

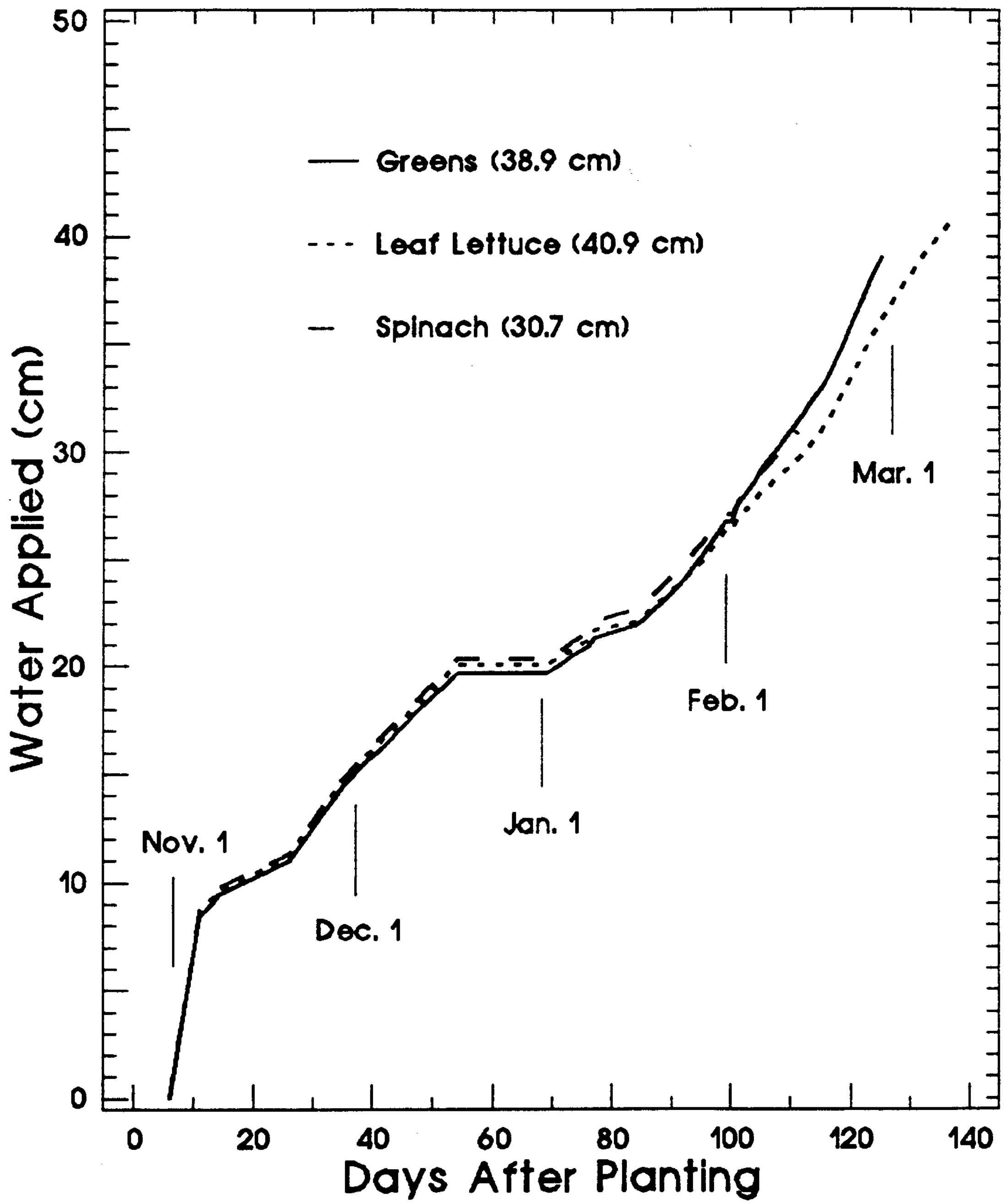


Figure 1. Cumulative water application rates applied through a subsurface drip irrigation system to greens, leaf lettuce and spinach experiments conducted at the Maricopa Agricultural Center in the fall of 1990.

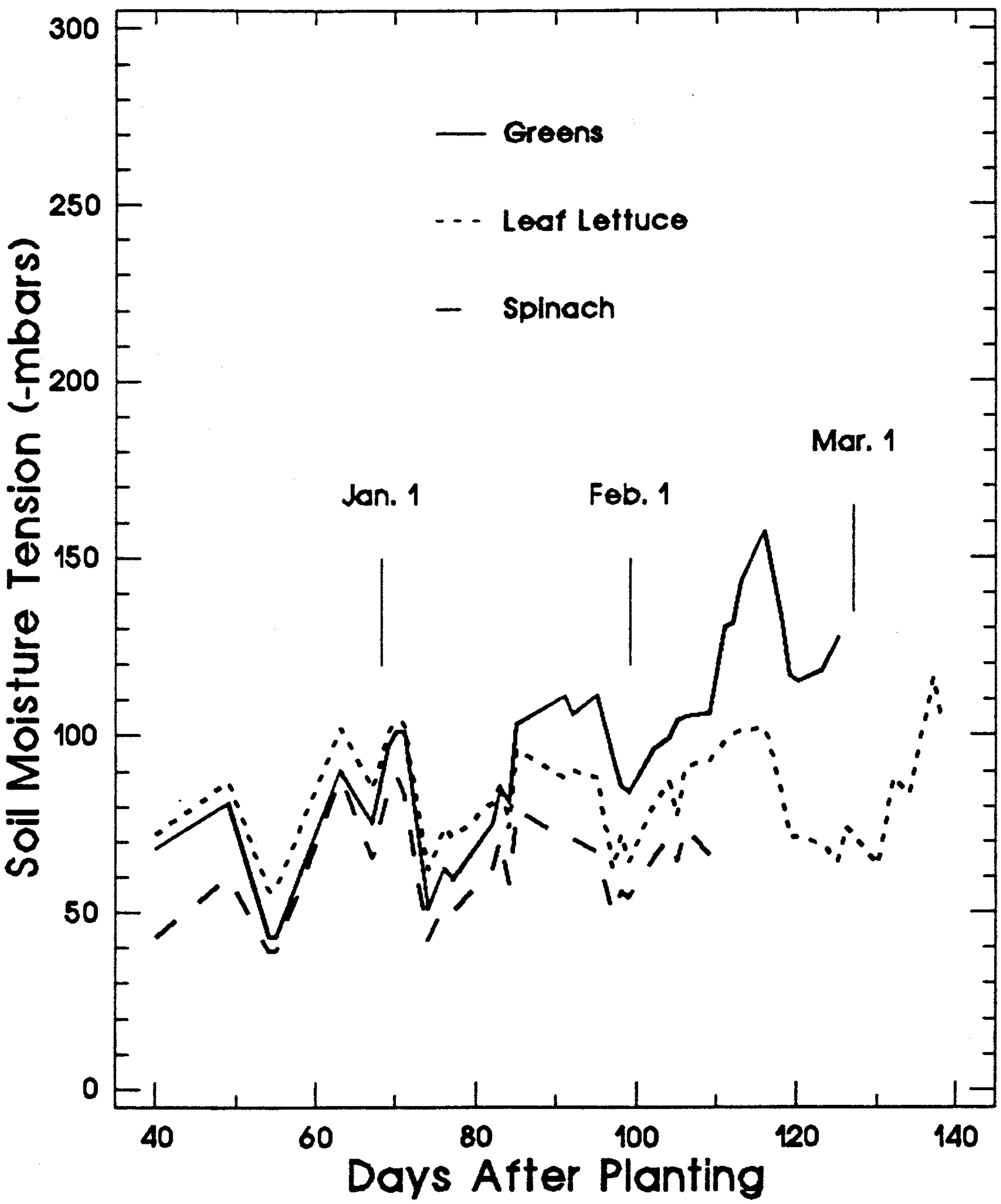


Figure 2. Soil moisture tension readings from greens, leaf lettuce and spinach experiments conducted at the Maricopa Agricultural Center in the fall of 1990.

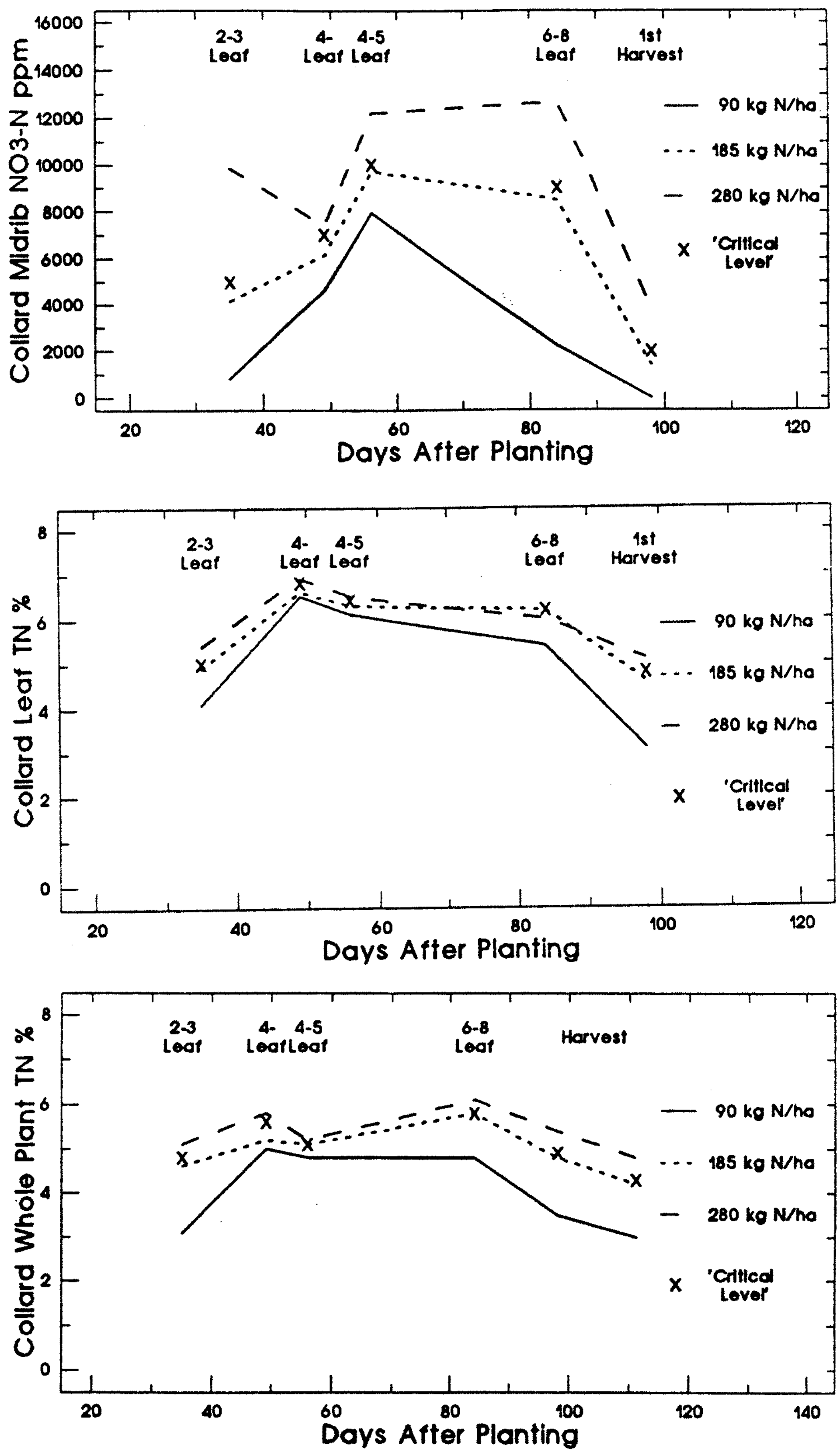


Figure 3. Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Vates collard in response to varying rates of urea-ammonium nitrate fertilizer.

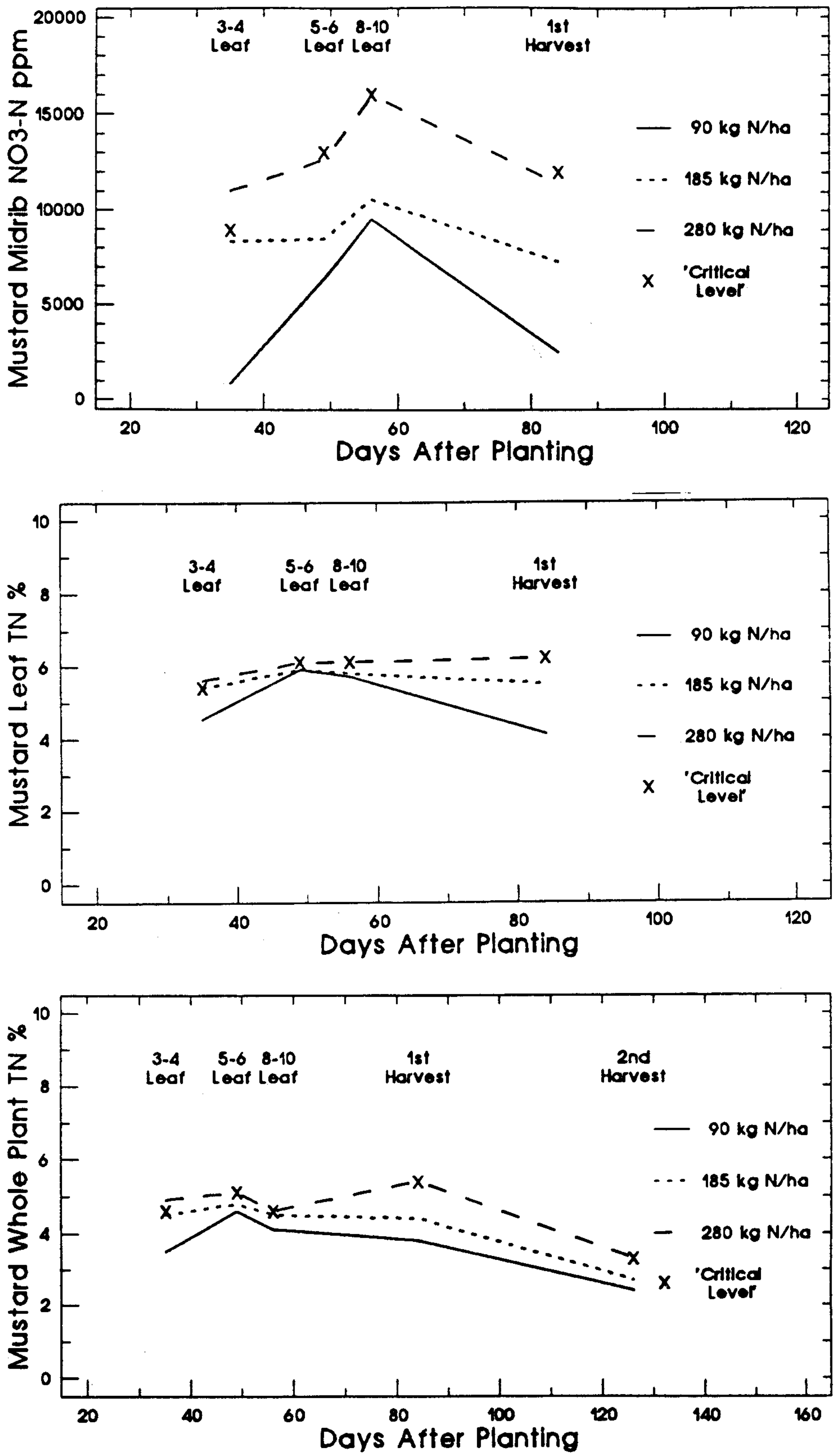


Figure 4. Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Southern Giant mustard in response to varying rates of urea-ammonium nitrate fertilizer.

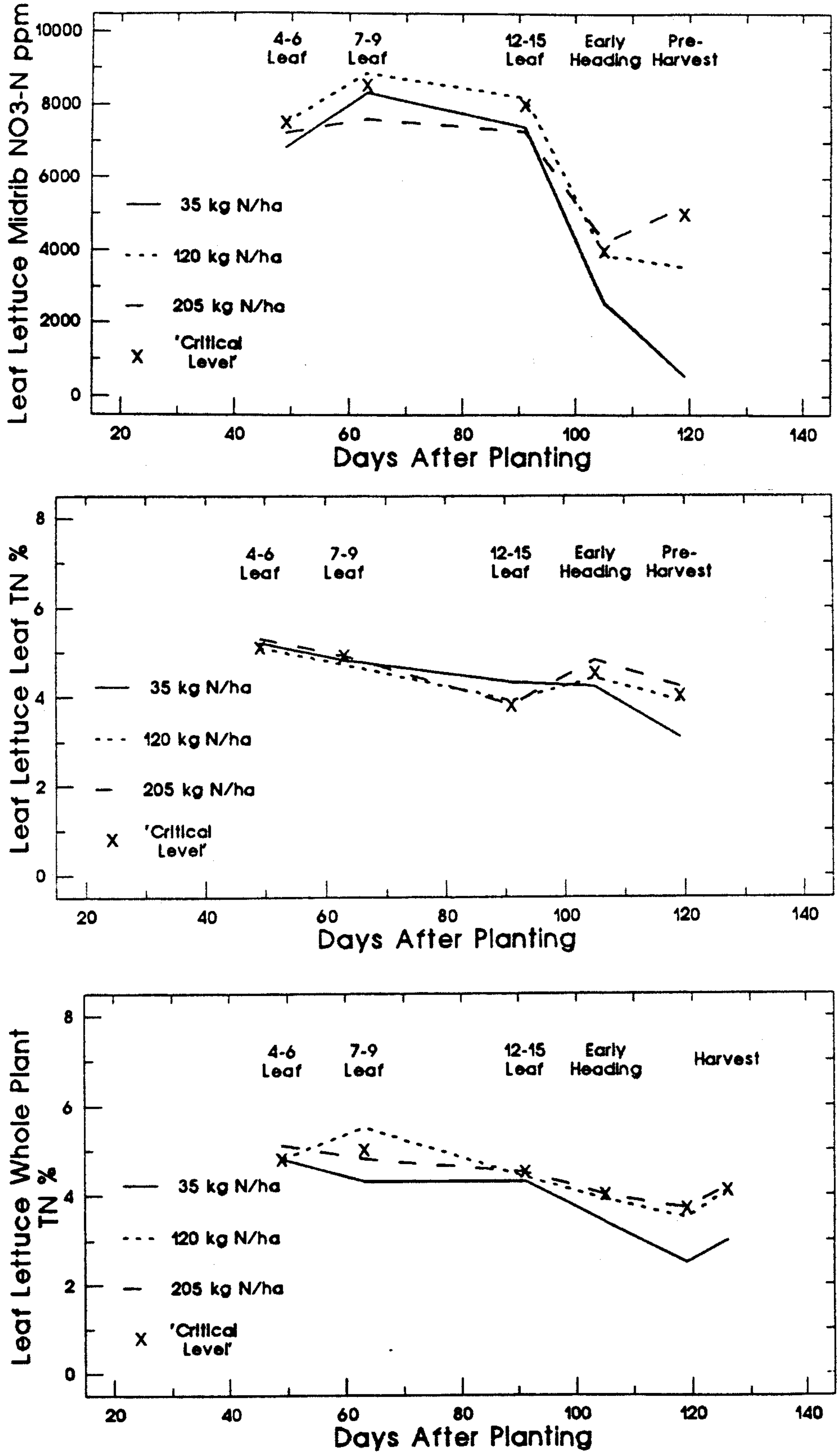


Figure 5. **Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Waldmann's Green leaf lettuce in response to varying rates of urea-ammonium nitrate fertilizer.**

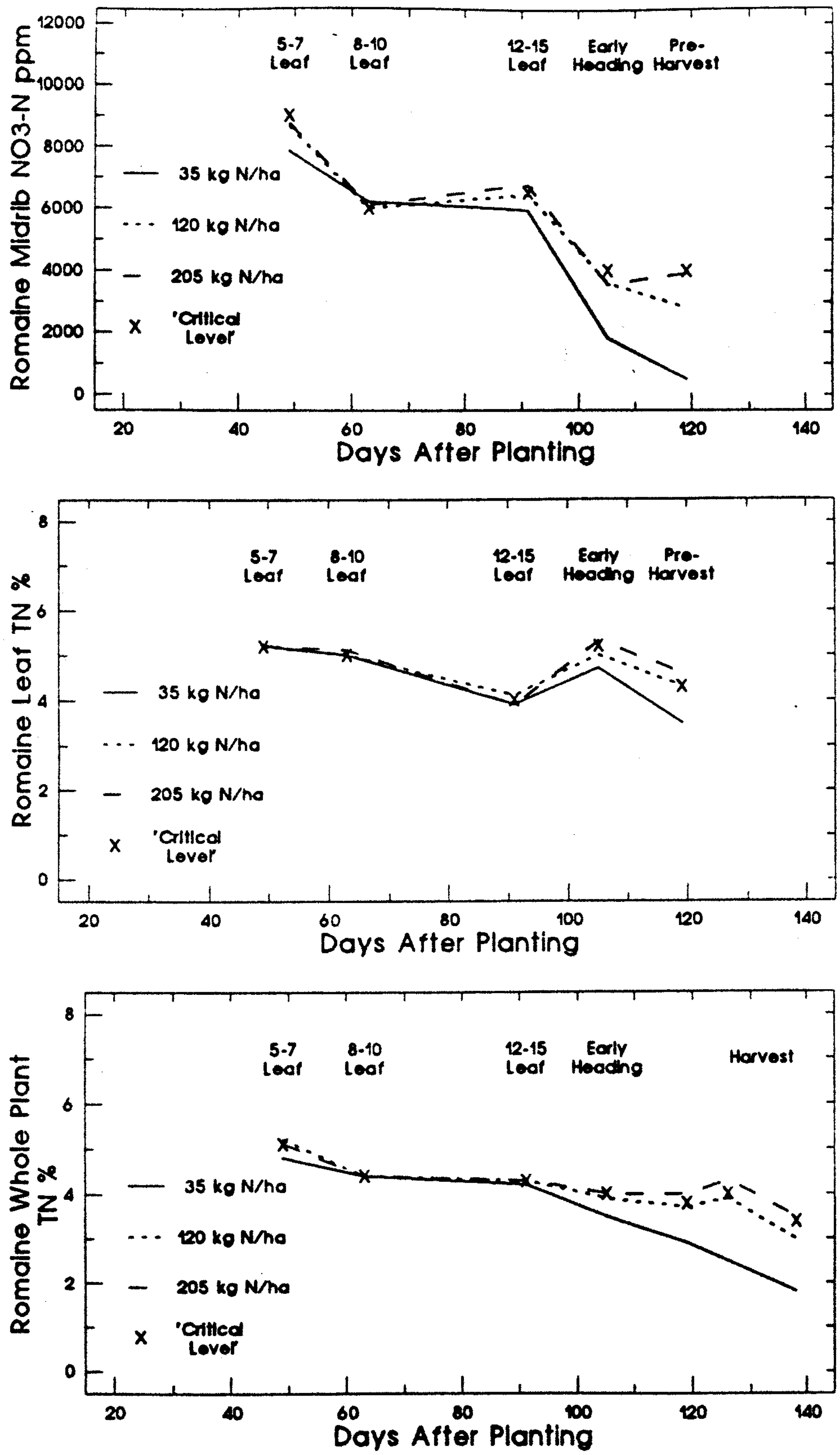


Figure 6. **Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Parris Island Cos Romaine in response to varying rates of urea-ammonium nitrate fertilizer.**

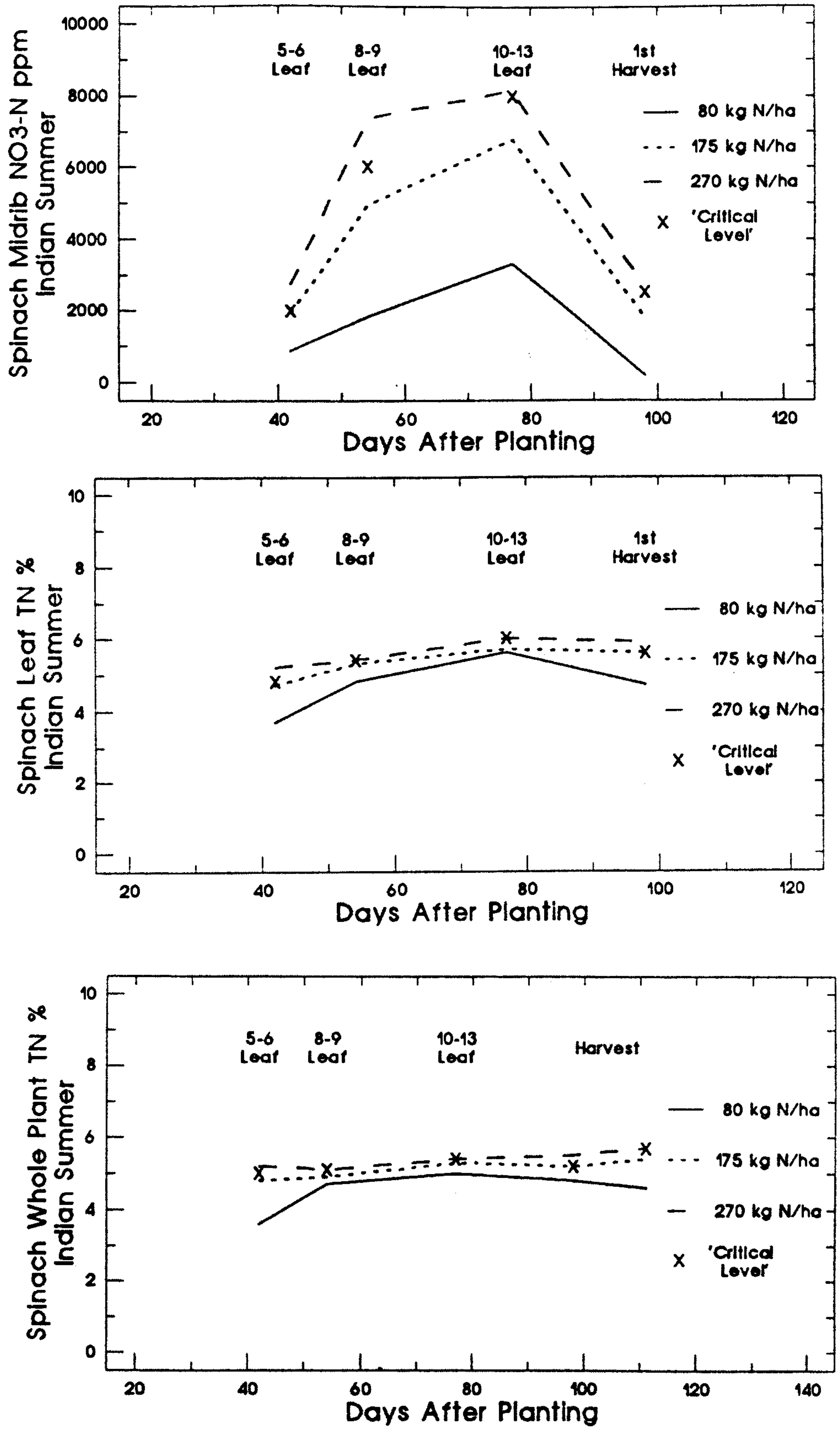


Figure 7. Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Indian Summer spinach in response to varying rates of urea-ammonium nitrate fertilizer.

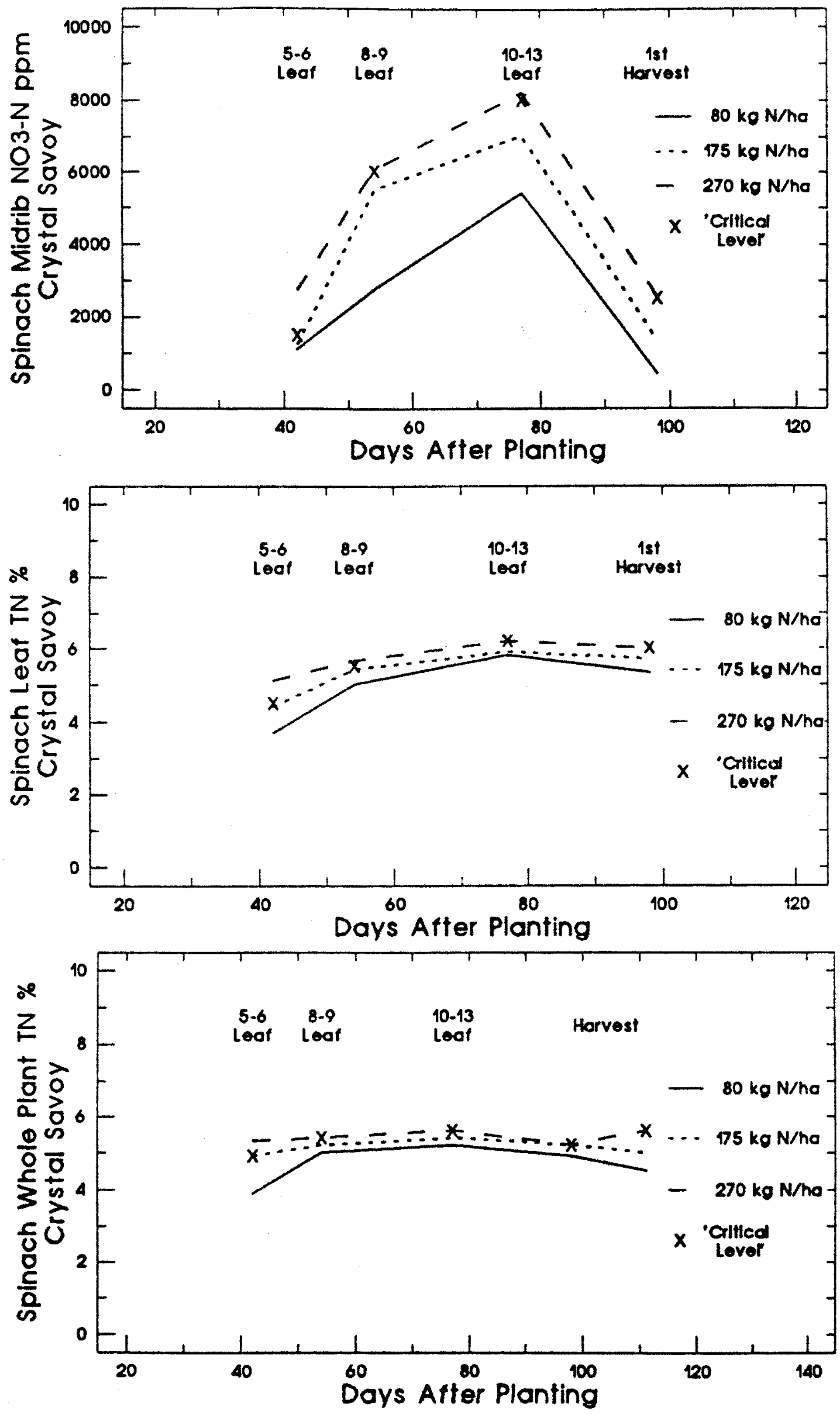


Figure 8. Seasonal patterns of midrib NO_3-N (top), leaf blade TN (middle) and whole plant TN (bottom) concentrations for Crystal Savoy spinach in response to varying rates of urea-ammonium nitrate fertilizer.

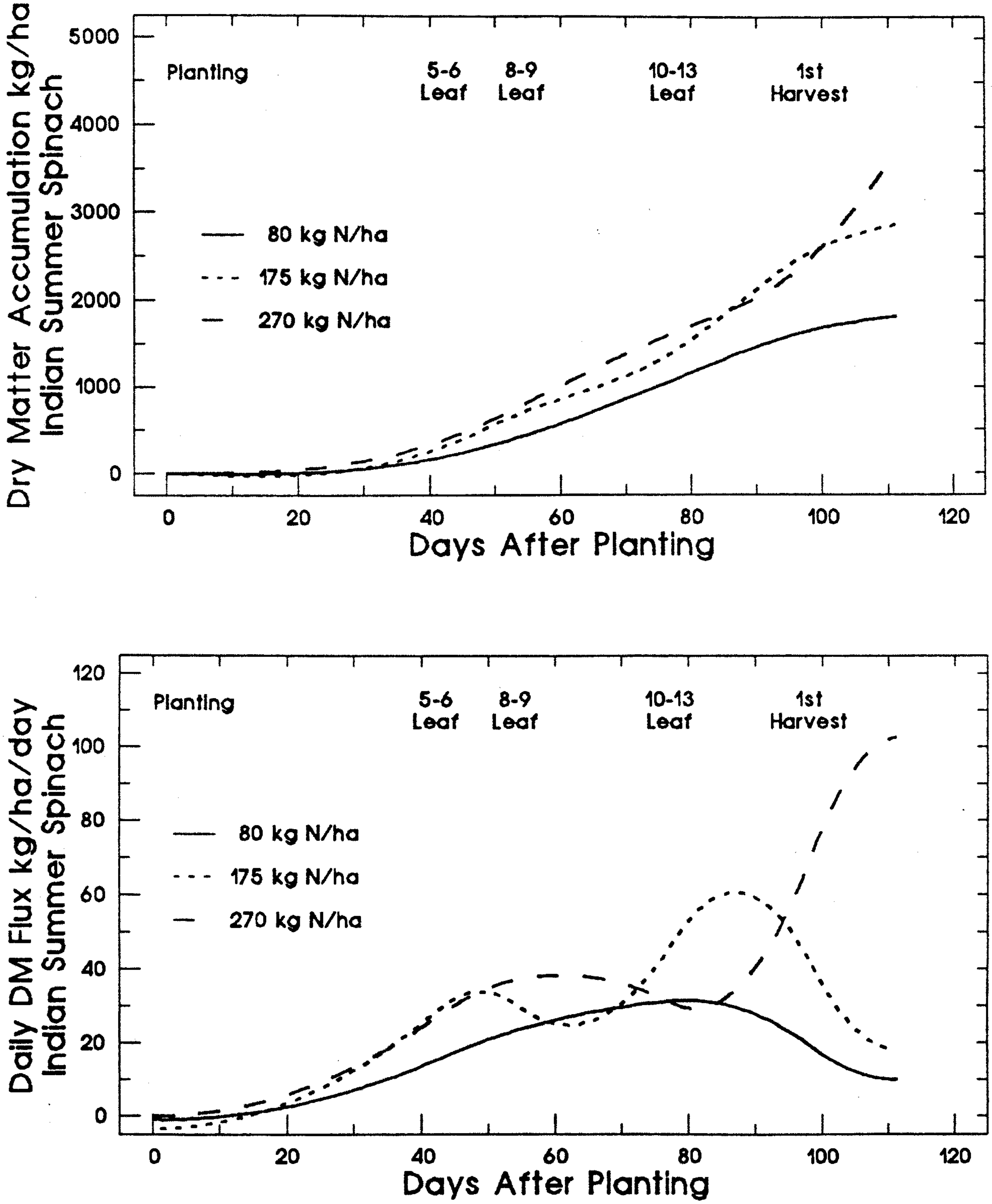


Figure 9. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Indian Summer spinach in response to varying rates of urea-ammonium nitrate fertilizer.

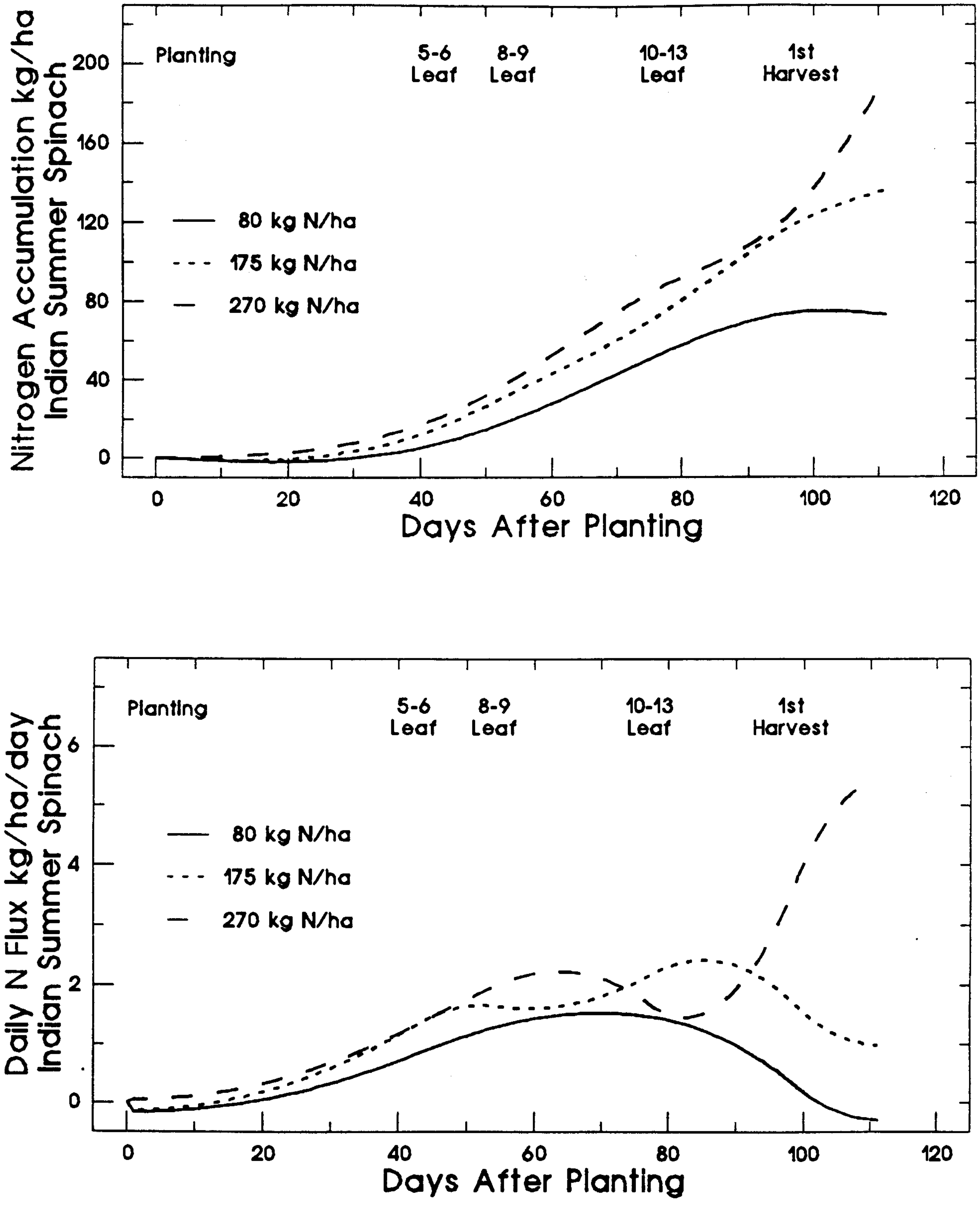


Figure 10. Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Indian Summer spinach in response to varying rates of urea-ammonium nitrate fertilizer.

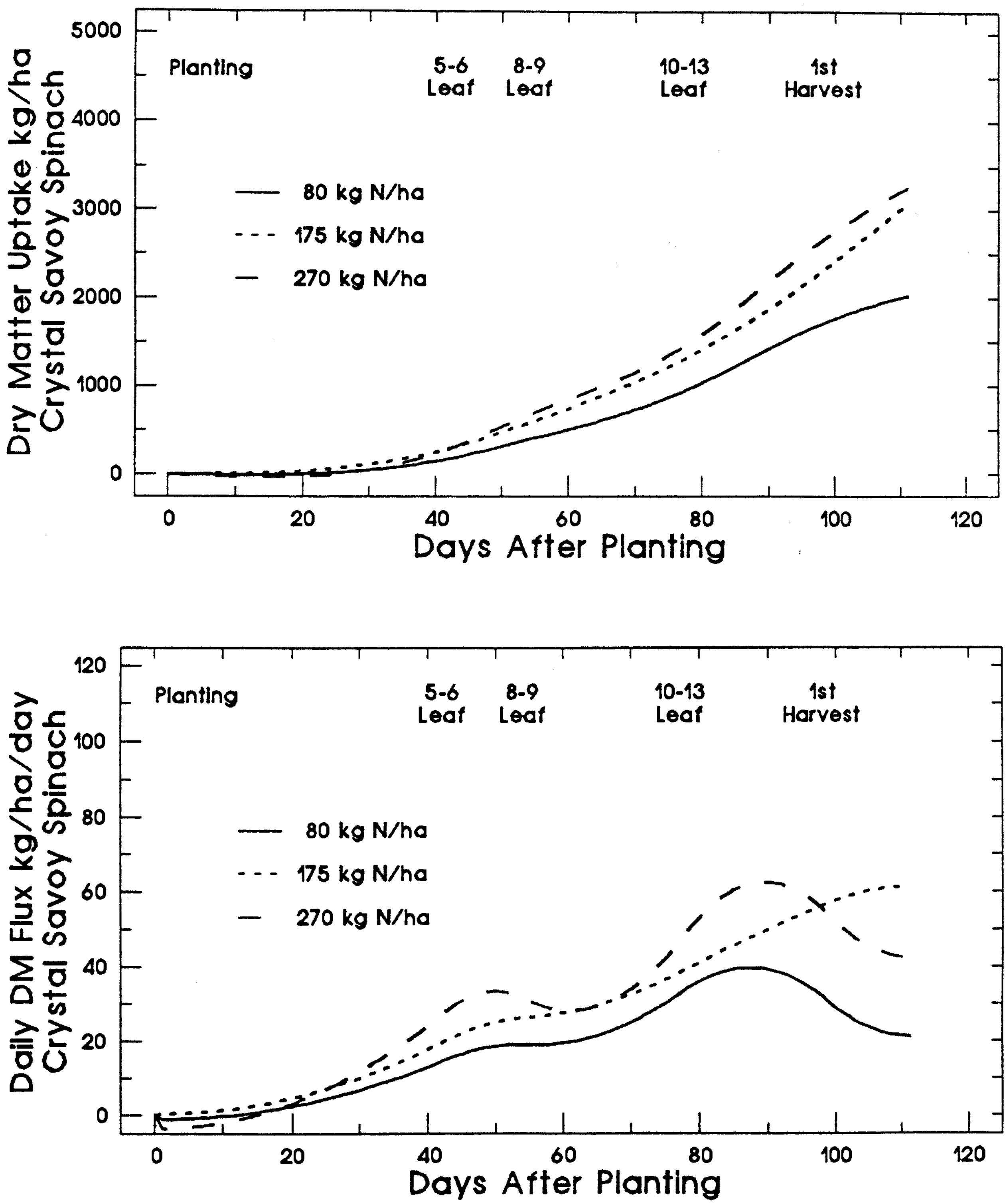


Figure 11. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Crystal Savoy spinach in response to varying rates of urea-ammonium nitrate fertilizer.

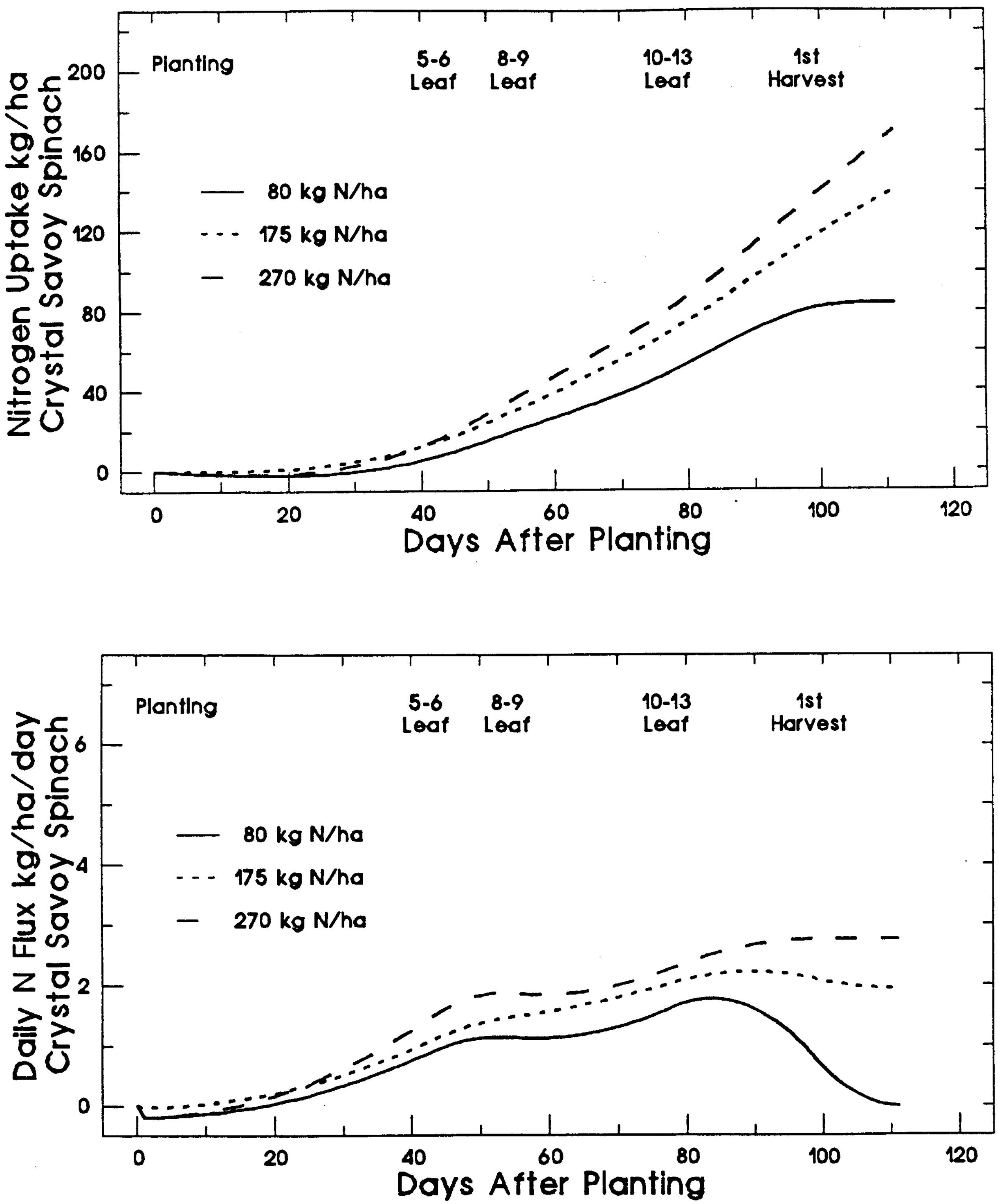


Figure 12. Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Crystal Savoy spinach in response to varying rates of urea-ammonium nitrate fertilizer.

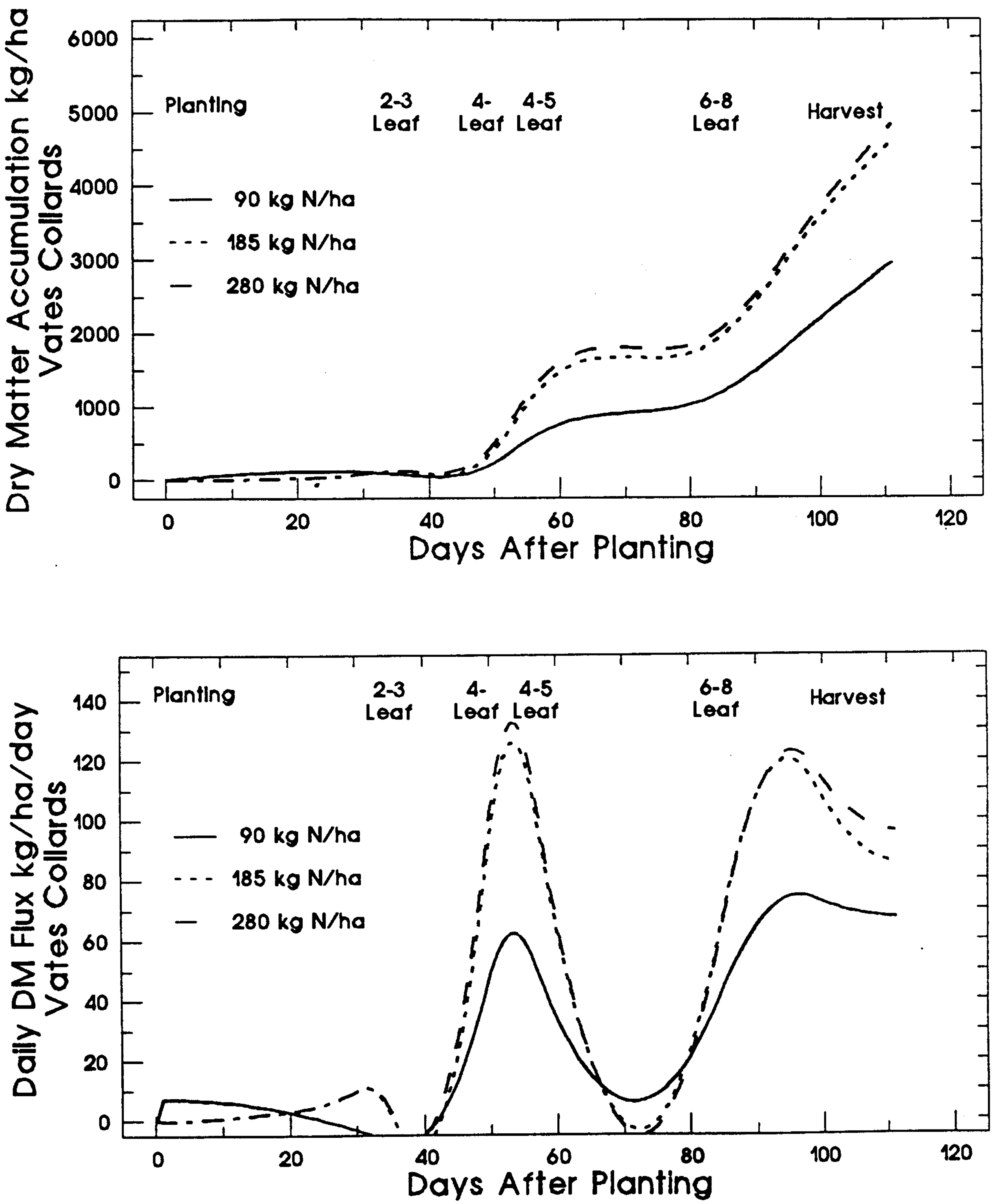
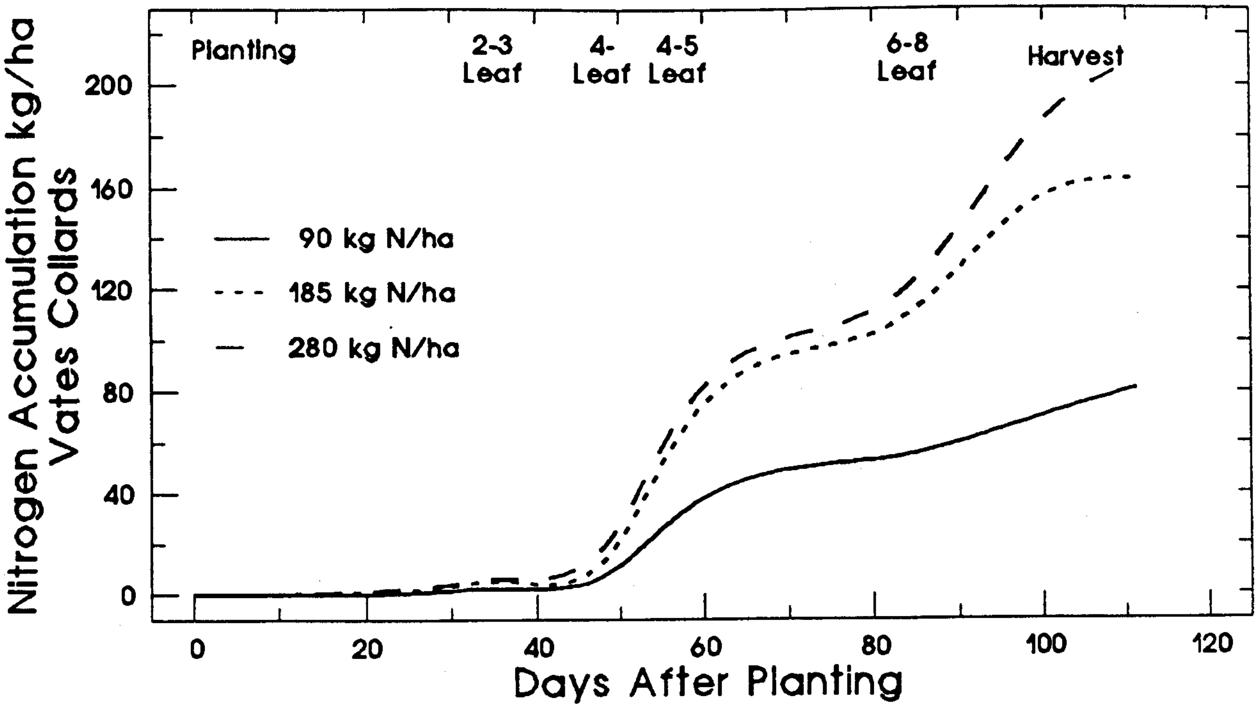


Figure 13. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Vates collard in response to varying rates of urea-ammonium nitrate fertilizer.



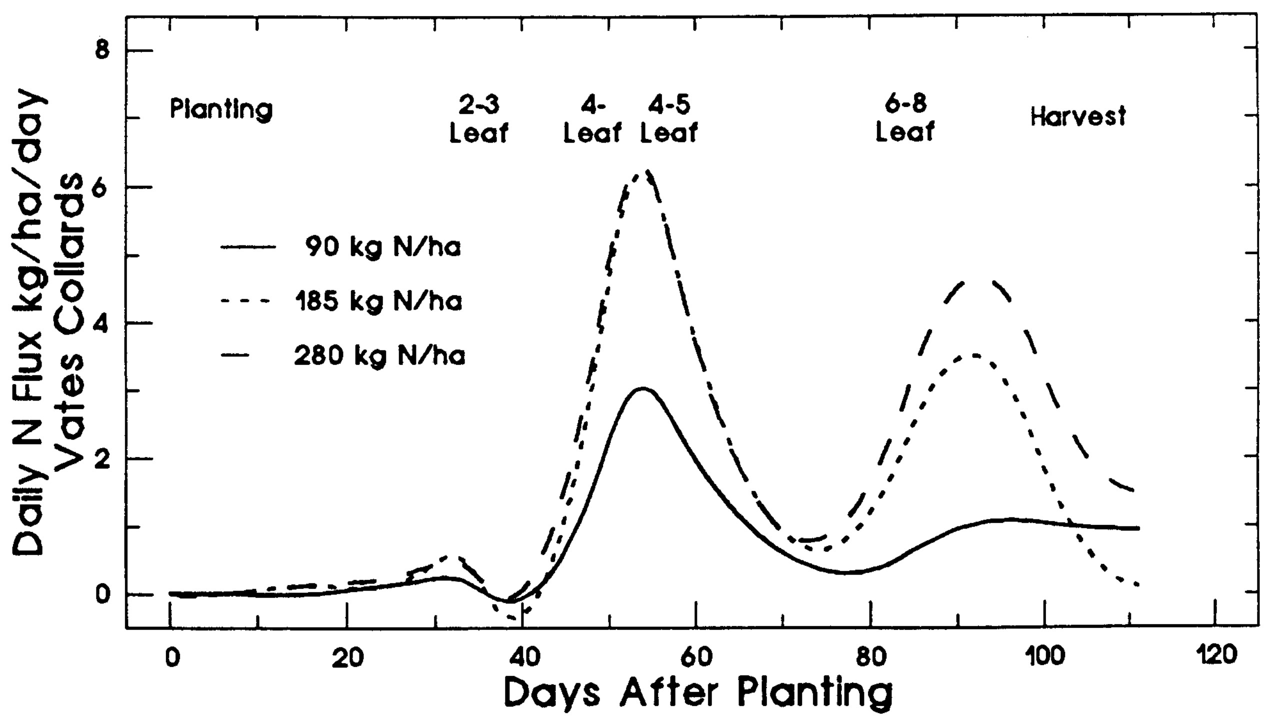


Figure 14. Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Vates collard in response to varying rates of urea-ammonium nitrate fertilizer.

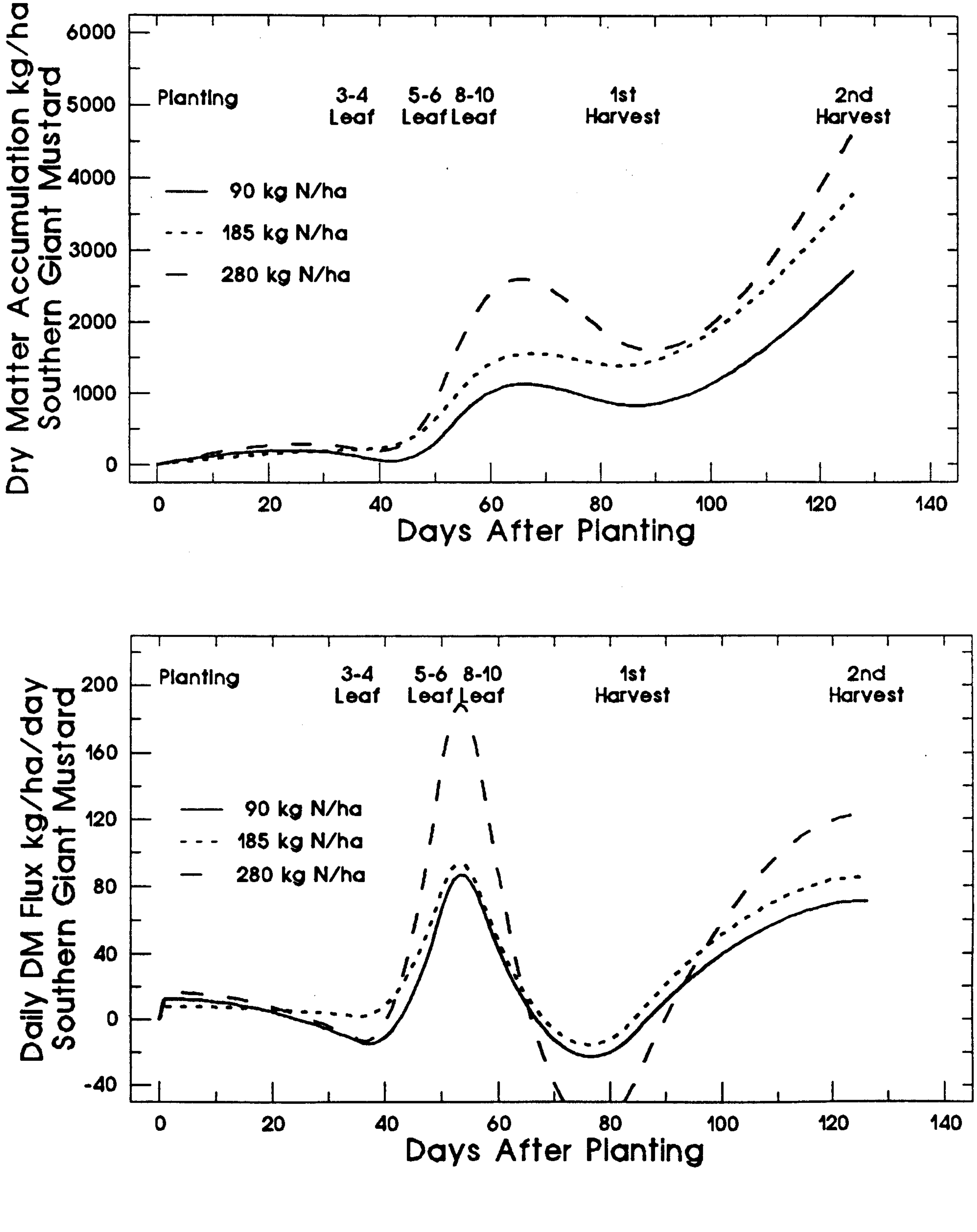
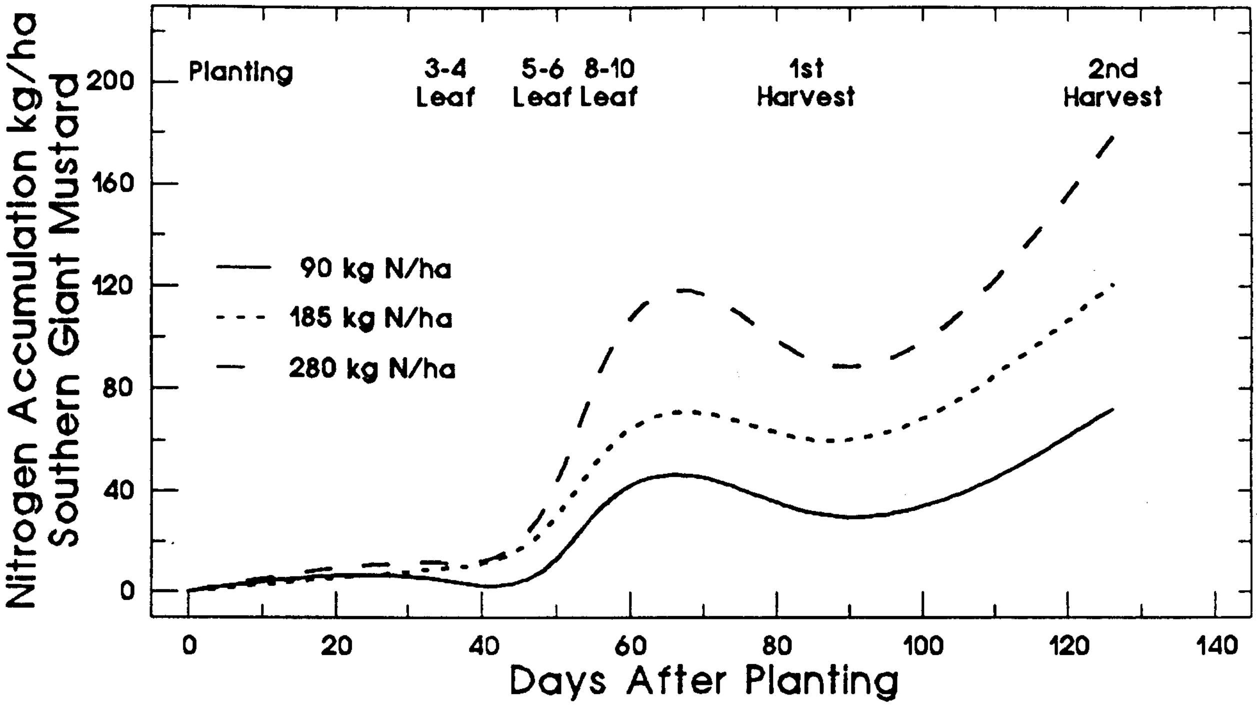


Figure 15. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Southern Giant mustard in response to varying rates of urea-ammonium nitrate fertilizer.



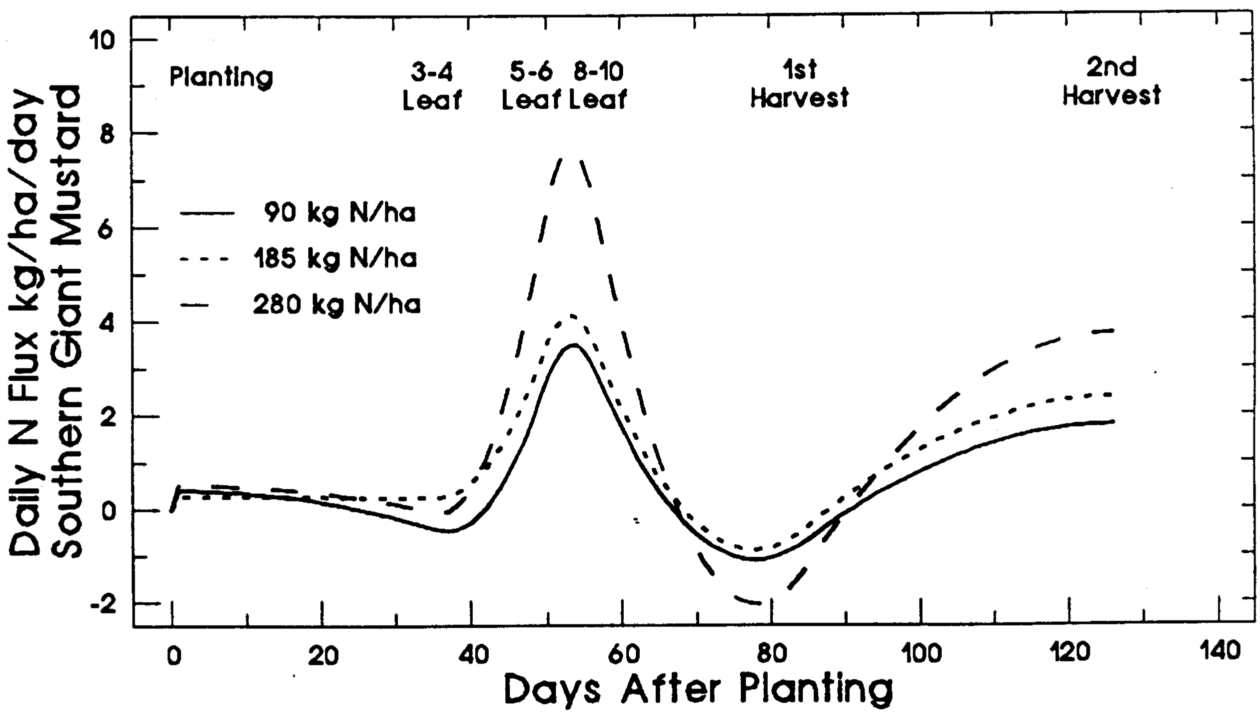


Figure 16. Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Southern Giant mustard in response to varying rates of urea-ammonium nitrate fertilizer.

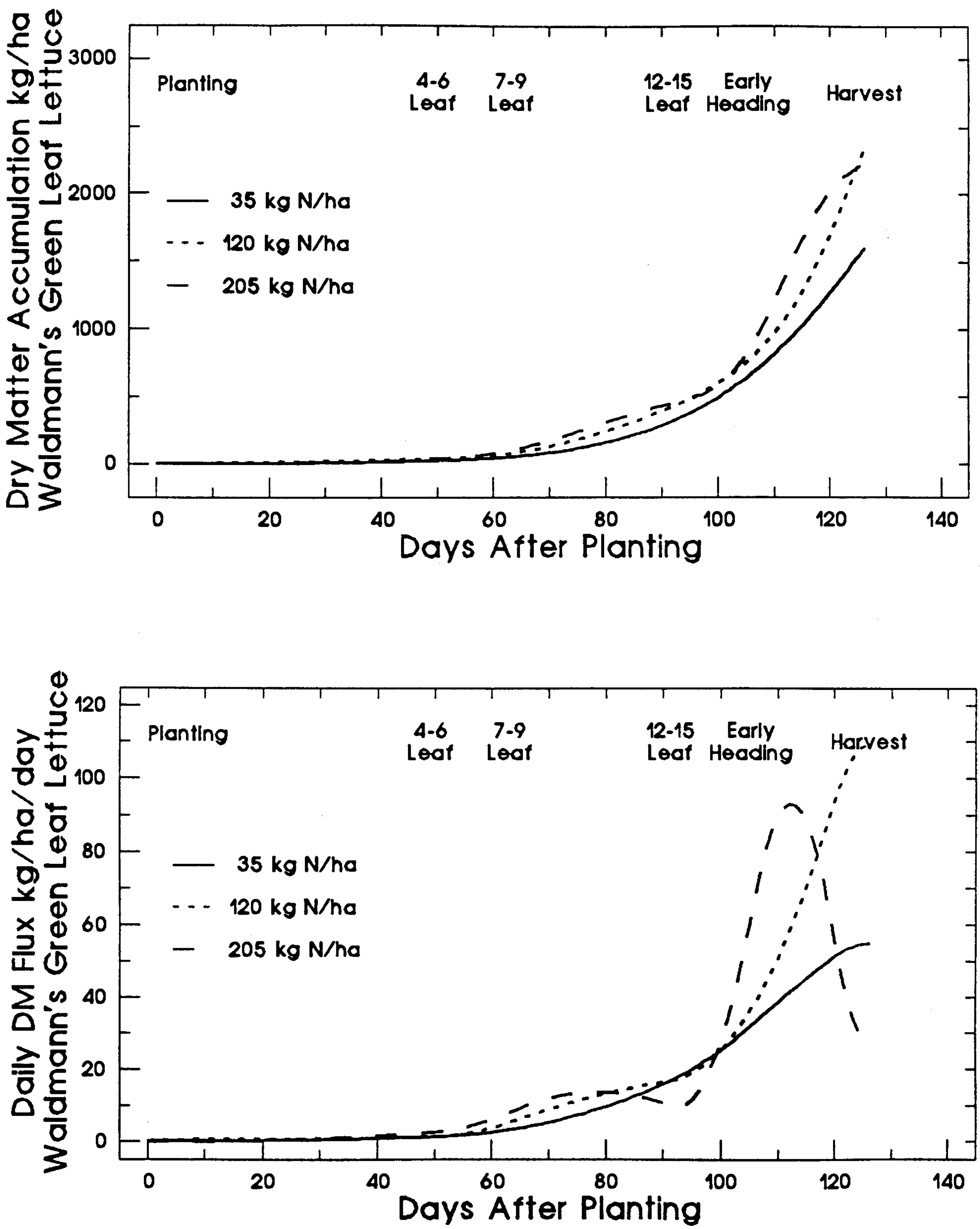


Figure 17. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Waldmann's Green leaf lettuce in response to varying rates of urea-ammonium nitrate fertilizer.

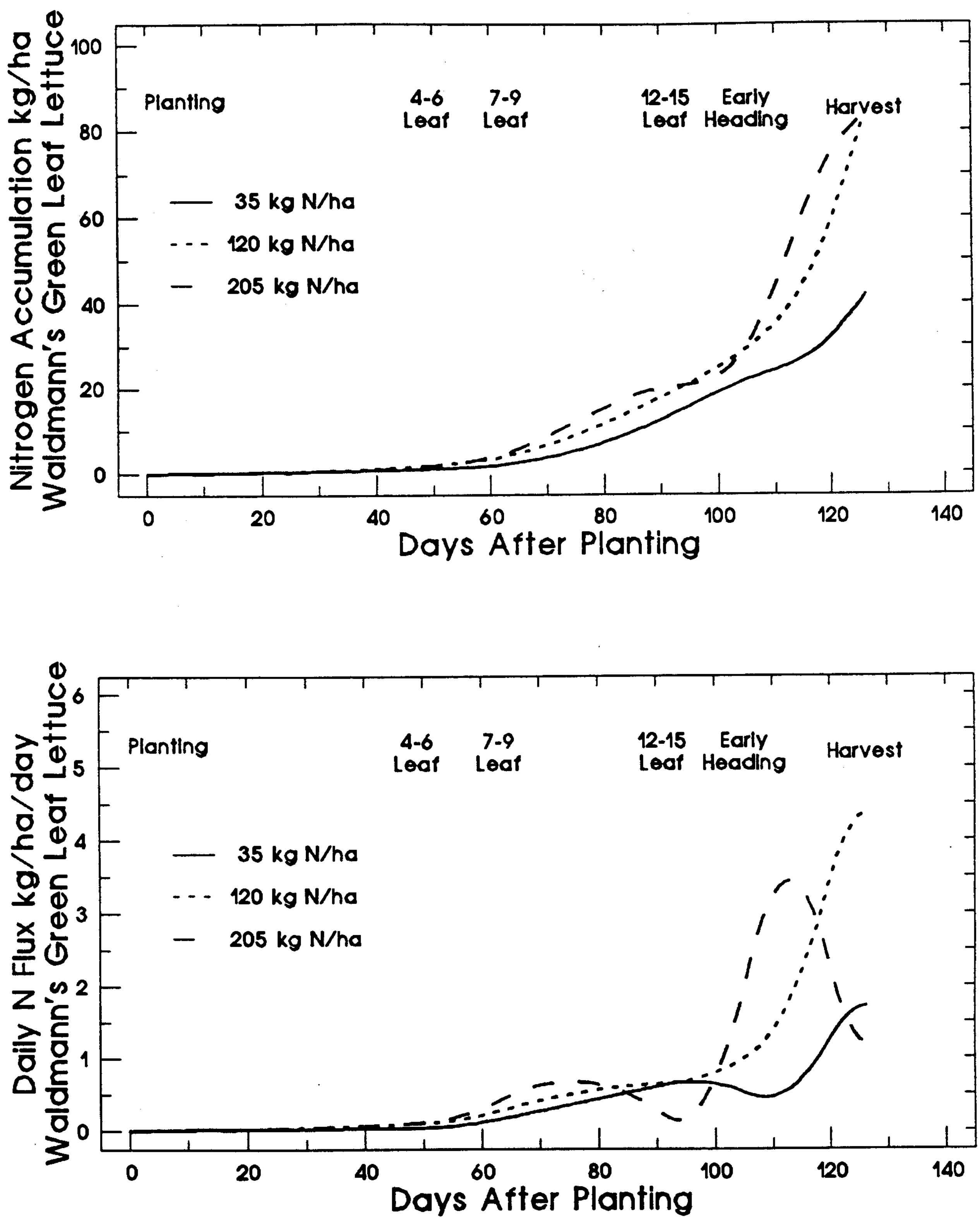
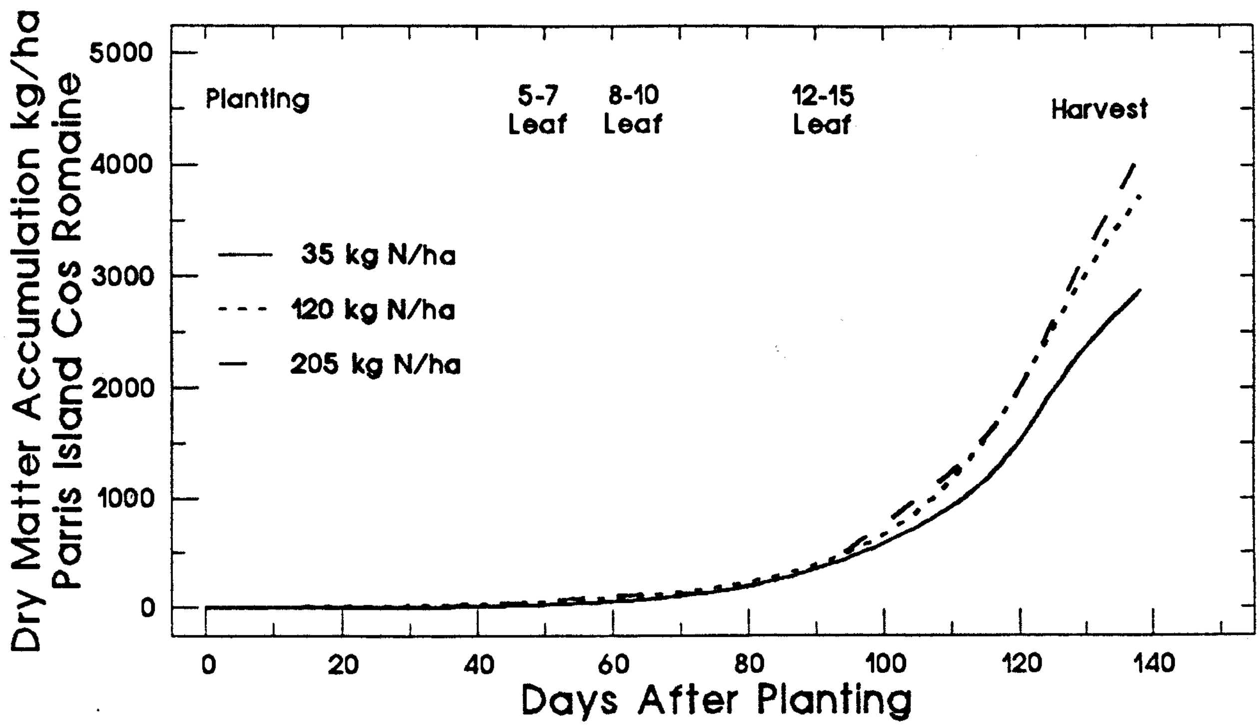


Figure 18. Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Waldmann's Green leaf lettuce in response to varying rates of urea-ammonium nitrate fertilizer.



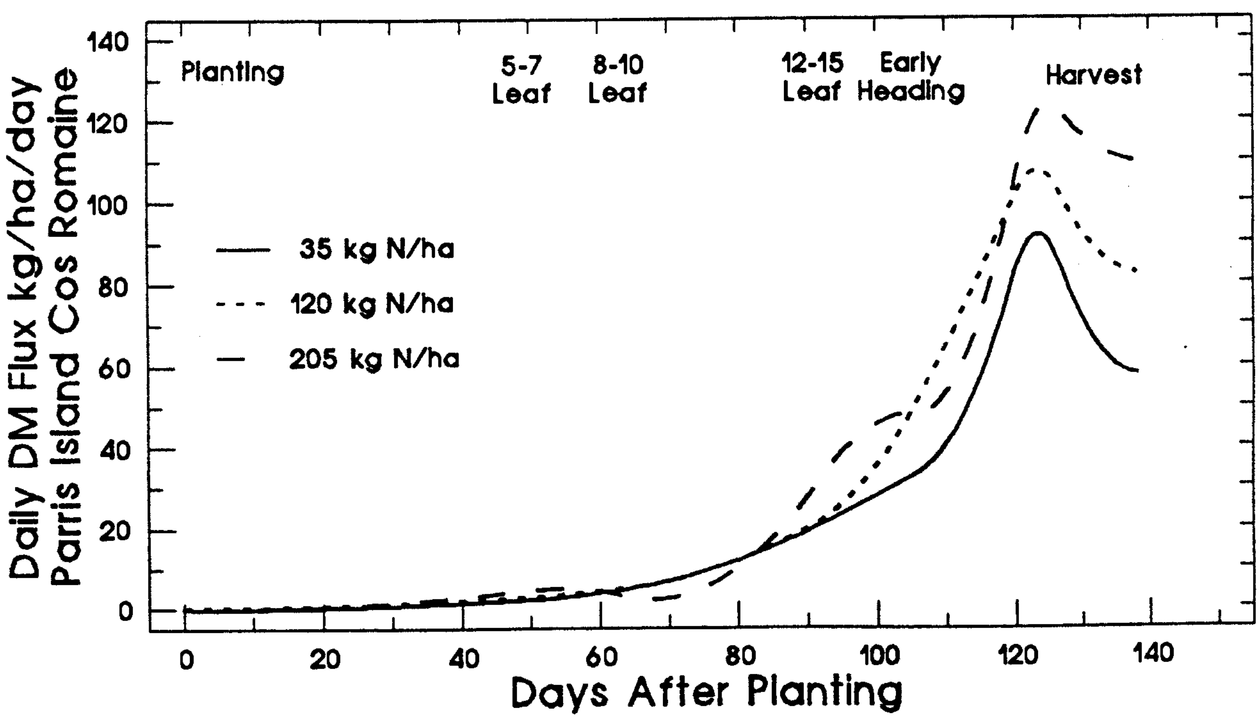


Figure 19. Seasonal patterns of cumulative (top) and daily (bottom) dry matter accumulation for Parris Island Cos Romaine in response to varying rates of urea-ammonium nitrate fertilizer.

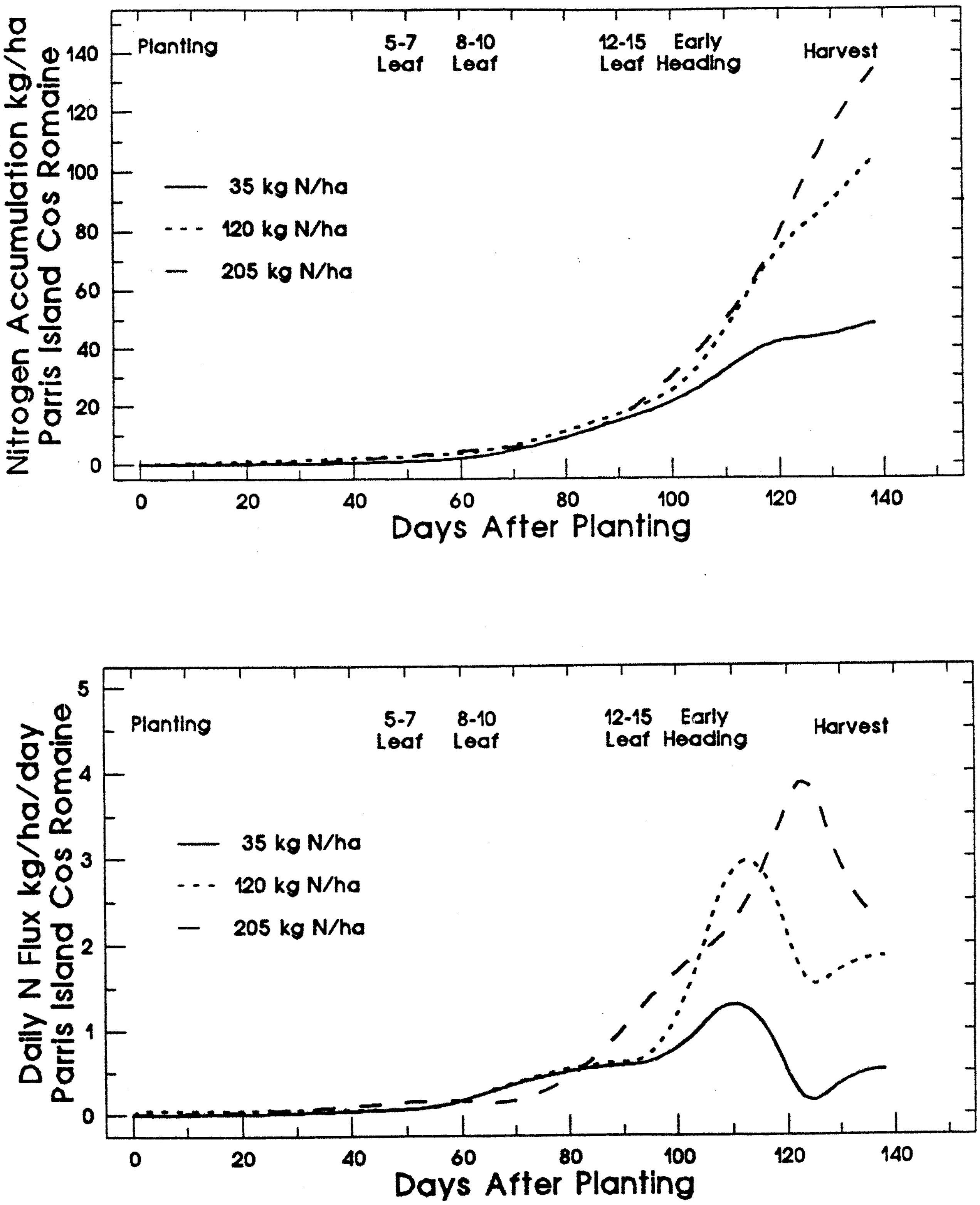


Figure 20. **Seasonal patterns of cumulative (top) and daily (bottom) nitrogen accumulation for Parris Island Cos Romaine in response to varying rates of urea-ammonium nitrate fertilizer.**

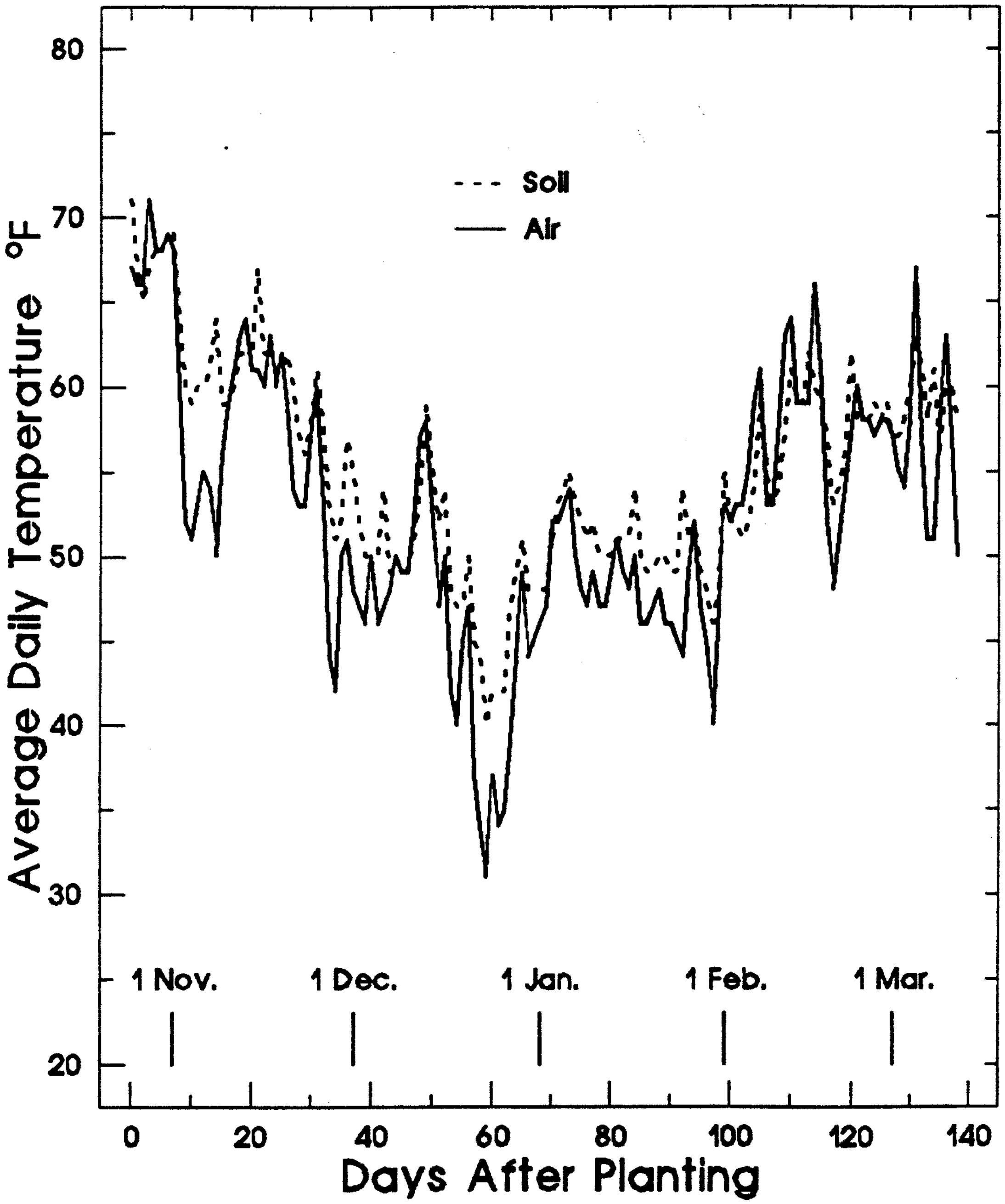


Figure 21. Average daily air and soil (4" depth) temperatures measured during the vegetable experiment growing season at Maricopa 1990-1991 (from AZMET).