Effect of Fall and Spring Applied Nitrogen Fertilizer on Growth and Yield of Sugarbeets*

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INTRODUCTION

The time and amount of nitrogen (N) uptake affects both root and extractable sucrose yield of sugarbeets (*Beta Vulgaris* L.). Either excessive or late N fertilizer applications and subsequent plant N uptake from applied or residual N sources cause an increasing proportion of the photosynthate to be used for top growth at the expense of both root dry matter and sucrose accumulation (6, 7). Adequate but not excessive amounts of soil and fertilizer N available early in the growing season are needed for adequate top and root growth, while maintaining sufficiently high sucrose percentage and purity for profitable sucrose extraction and yield.

For maximum N efficiency and economy, N fertilizer should be applied either near the time of planting or sidedressed early in the season. This reduces the time between N application and N uptake which allows less opportunity for N to be leached out of the root zone, denitrified, or incorporated into soil microorganisms and their by-products.

Fall bedding and fertilization of fields to be used for sugarbeets is a common practice throughout the intermountain area of the western United States. Although this practice increases the time between N application and N uptake, it has the following advantages: 1) possible earlier planting, 2) improved moisture level in the seedbed at planting, 3) less irrigation water is required

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for germination, 4) more even distribution of labor requirement during the fall and spring months, and 5) more even distribution of fertilizer demand.

The objective of this study was to evaluate several rates and times (fall and spring) of N fertilizer application as it affects the location of NO_3-N within the soil profile, N uptake, seasonal growth rates, dry matter production, sucrose concentration and accumulation, and the partitioning of the photosynthate.

MATERIALS AND METHODS

An irrigated field experiment was conducted on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) near Twin Falls, Idaho, in the fall of 1981 and summer of 1982. This soil has a weakly cemented hardpan from about 45- to 90-cm depth that has little effect on water movement when saturated but may restrict root penetration. The plot area had been cropped to barley (*Hordeum vulgare* L.) without fertilizer in 1980 and was fallowed in 1981. Soil tests indicated the plot area required 56 kg P/ha (13) and 112 kg N/ha (4) for an expected maximum yield of 63 metric tons of harvested beet roots per hectare.

The experiment had three replications in a randomized, complete block design, using five N fertilizer rates of 0 (three plots only), 112, 224, 336 and 448 kg N/ha, each having 0, 25, 50, 75 and 100 percent of their total rate in the fall (22 September 1981), and the remainder applied in the spring (19 April 1982). The N treatments were broadcast as ammonium nitrate on plots 9.1 by 9.1 m. Phosphorus was applied uniformly at 56 kg P/ha on 19 April 1982. All fertilizers were incorporated within the upper 10 cm of soil by disking following application.

Soil samples were taken before fertilizer application in the fall (18 September) and again in the spring (12 April) on all check (0 N) and the plots receiving 100 percent of their N fertilizer application in the fall. Twenty-four cores per plot were composited by 15-cm depth increments to the 45-cm depth. In addition, two auger samples per plot were composited from each of these treatments by 15-cm depth increments between 45 and 90 cm and by 30-cm increments between 90- and 150-cm depth. The soil samples were air dried, ground, and stored until analyzed. The NO_3-N and potentially available soil N were determined as previously described (4).

Eight cm of irrigation water was applied by sprinkler to the experimental plot area between 2 and 3 weeks following fall fertilization to move the NO_3-N into the soil profile (Table 1). The irrigation water applied, plus

Table 1. Irrigation water applied and rainfall between fall and spring soil sampling, and fall and spring N fertilizer applications.

Type of Water Applied	Fall N Application To: Spring soil sampling Normal			Spring N application Normal		
	Normal	1981-82		Normal	1981-82	
	----cm----		%†	----cm----		%†
Total irrig. water	0	8.0	-	0	8.0	-
Total rainfall‡	17.2	25.1	146	17.2	26.3	153
Total irrig. and rain	17.2	33.1	192	17.2	34.3	200

†Percent of normal rainfall or rainfall and irrigation.
‡Rainfall to frozen soil between 12/22/81 to 2/19/82 = 6.4 cm. Rainfall includes snow during winter months.

the rainfall received between fall fertilization and spring N application, was 200 percent of the water normally received during a similar period.

Sugarbeets (Amalgamated WS-76) were planted (23 April) in 56 cm rows that had previously been treated with aldicarb insecticide at 2.24 kg of active ingredient per hectare. The sugarbeets were thinned to a 23- to 30-cm within-row spacing in early June.

Every other row furrow irrigation was used for the first five irrigations (30 April to 13 July), and alternate row furrow irrigation (every other furrow, alternating furrows at each irrigation) was used during the remainder of the season. Plots were adequately irrigated based on previous irrigation experiments. Irrigation dates were based on estimated soil moisture depletion (8) and irrigation duration depended on the amount of water to be applied.

Twenty-four of the youngest, fully mature petioles were randomly sampled from each plot at weekly intervals during the season. The petioles were cut into 0.5-cm sections, dried at 65°C, ground to pass through a 40-mesh sieve, subsampled, and analyzed for NO_3-N using a nitrate specific ion electrode (10).

Root and top samples were manually harvested from six uniform, 3-m row sections from each check and fertilized areas receiving 100 percent of their N fertilizer application either in the fall or spring on 27 July and 31 August, and on all plots between 18 to 21 October. Enough plot area was provided so that the plant sampling did not influence subsequent yield measurements. Root samples were washed, root and crown tissues were separated at the lowest leaf scar, and all fresh tissue was weighed before and after drying. Triplicate root samples (14 to 18 roots per sample) were used for sucrose and purity analyses. The sucrose concentration in the roots and crowns was determined by the Amalgamated Sugar Company by methods previously described (5).

Beet tops, roots, and crowns were dried at 65°C and their dry weight determined. The dried samples were ground to pass through a 40-mesh sieve and the total N was determined by the semimicro-Kjeldahl procedure modified to include nitrate (2). Nitrogen uptake was calculated by assuming that the N concentration was the same in both the fibrous and storage roots, and the weight of the unharvested fibrous roots was equal to 25 percent of the total harvested storage root weight (9).

RESULTS AND DISCUSSION

Irrigation water applied and rainfall received between fall fertilization and spring soil sampling was 192 percent (200 percent to spring N application) of that normally received during an average year (Table 1). The water was applied and was received by the plots at a time when the majority of the applied and residual N was in the NO_3-N form. The climatic records also show that 80 percent of the irrigation water and rainfall received was during periods when the soil was not frozen and available for infiltration into the soil. Consequently, the increased amount of water applied or received by the plot area would be expected to move the residual and fall applied NO_3-N to a greater depth in the soil profile than during an average season.

Generally, the root zone for sugarbeets on this soil type has been considered to be above the hard layer. If this were the case, then the majority of the NO_3-N located within and below the hard layer would not be available for plant uptake and plant growth. However, recent experiments have shown that some roots were able to extract water from the hard layer and below by penetrating the hard layer, perhaps in small cracks or in holes made by roots from a previous crop with a stronger rooting system such as alfalfa (5). The ability of the sugarbeet plant to extract water from the hard layer and below would indicate that any NO_3-N located within these zones should also be available for plant uptake.

The residual and fall applied N was distributed throughout the soil profile in the spring with some variation caused by N application rate (Figure 1). The average

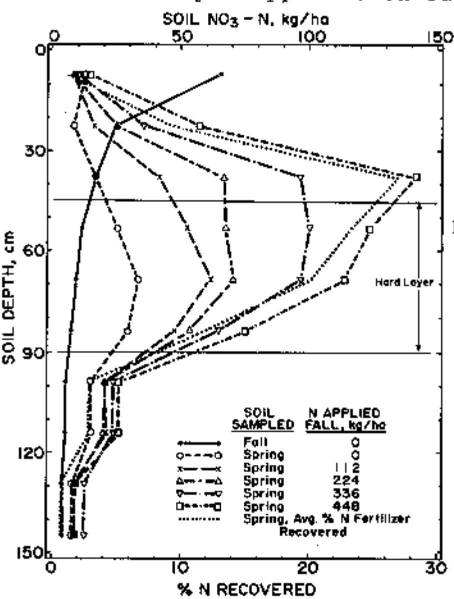

Figure 1. Location of residual and added fertilizer NO_3-N within the soil profile in the spring from fall N fertilizer applications.

N fertilizer recovery was 33, 53, and 8 percent for above, within, and below the hard layer. The 94 percent average total recovery of the applied N by soil sampling indicates that little of the fall applied N was lost during the fall, winter and spring months in the gaseous form, by immobilization, by denitrification, or by leaching below the sampling zone (150 cm).

Petiole NO_3-N is an excellent indicator of the N status of the sugarbeet plant during the season and reflects the net N uptake and assimilation rates (3, 11, 12). The NO_3-N content of petiole samples indicated a higher N availability and uptake during June and July by the sugarbeet plants with fall N fertilizer application when compared with those fertilized in the spring (Table 2). Starting in late July and for the remainder of the sampling period, time of N application had little effect

Table 2. Effect of time and rate of fall and spring N fertilizer applications of NO_3-N concentration in sugarbeet petioles throughout the growing season.

N Treatment % N Applied		Petiole NO_3-N PPM Actual, Avg. 7/6-7/20	7/6-9/8	7/26-9/8	Calculated, 7/26-9-8† 7/26	9/8	Int. Avg‡	C	r
Fall	Spring				Avg All N Treatments				
100	0	13270	10309	9039	11920	6460	8880	0.015	0.96
75	25	10927	9149	8387	12010	5310	8180	0.020	0.95
50	50	9731	9455	9337	12620	6420	9160	0.016	0.96
25	75	8082	8612	8839	12840	5470	8600	0.021	0.96
0	100	7262	8339	8801	13470	5000	8510	0.024	0.95
Avg		9854	9173	8881	12572	5732	8666	0.019	0.96

†$N = N_o e^{-Ct}$ where N is the NO_3-N concentration at time t, N_o is the concentration at the first sampling date after the peak occurs, t is any time after the first sampling date, and C is a constant for any given treatment or beet field (3).

‡$\bar{N} = \frac{N_o}{C} \frac{(e^{-Ct_2} - e^{-Ct_1})}{t_2 - t_1}$ where $\bar{N}$ is the integrated average petiole NO_3-N

$t_1 = 7/26$, $t_2 = 9/8$

on petiole NO_3-N concentration. However, there was a tendency for higher petiole NO_3-N concentration early and greater rates of decrease on the spring N treatments as shown by the calculated NO_3-N values and by the level of the constant (C) in the equation given in Table 2. The early difference in the availability of N, as shown by petiole NO_3-N, was probably caused by its distribution within the soil profile (1). Fall applied N was equally distributed and readily available for uptake by the expanding root system; whereas, spring applied N was mainly in the upper layer of the soil profile. With every other row furrow irrigation, some of the NO_3-N moves with the water to the soil surface of the dry row with evaporation and becomes unavailable for uptake by the sugarbeet plant. This effect can be partially overcome by the use of sprinkler irrigation, by changing rows at each irrigation as was done in this experiment after 13 July, or by having sufficient rainfall during this period to redistribute the NO_3-N within the soil.

Field observations showed that sugarbeets receiving fall applied N developed a greater leaf area during midseason and maintained this increased leaf area for the remainder of the season when compared with those receiving spring applied N. The increase in available N with fall application, as previously indicated by petiole NO_3-N and by observation, was verified by the increased N uptake and dry matter production by the tops at all stages of plant growth (Figure 2 A,C). However, the N uptake and dry matter production by the roots were greater for the spring than the fall applied N (Figure 2 B,D). This indicated that the increased N supply from fall application caused a greater partitioning of the photosynthate to the tops at the expense of that translocated to the roots.

The greater partitioning of the photosynthate to the roots with spring applied N increased the root yield at all stages of plant growth when compared with fall applied N (Figure 3 A). The difference in N uptake and dry matter production caused by the timing of N application was not great enough to affect sucrose concentration in the root (Figure 3 B). Consequently, total sucrose and extractable sucrose yields at all stages of plant growth were in rela-

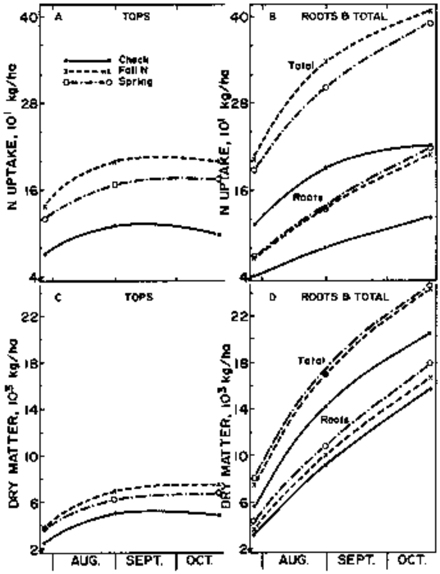

Figure 2. Top, root, and total N uptake (A,B) and dry matter production (C, D) as affected by time of sampling and time of N fertilizer application. Average values used for all N fertilizer rates.

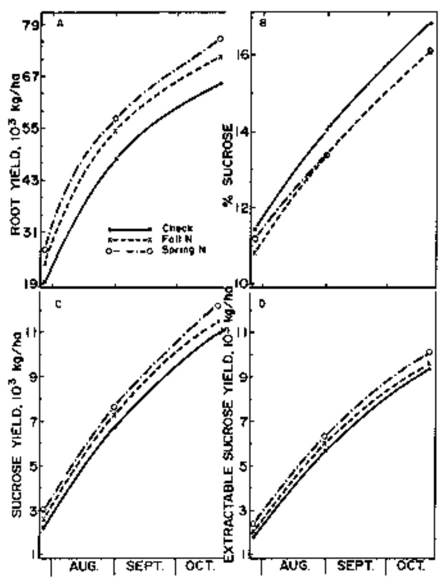

Figure 3. Root yield (A), percent sucrose (B), sucrose yield (C), and extractable sucrose yield (D) as affected by time of sampling and time of N fertilizer application. Average values used for all N fertilizer rates.

tion to the increase in root yield (Figure 3 C,D). Although differences in N uptake and yields due to timing of N application were measured during all stages of plant growth, their significance could not be shown at final harvest (Table 3).

Percent fertilizer N recovery by the plant at final harvest followed a rather typical pattern in decreasing with increasing rates of N application (Table 4). The N recovery caused by time of application varied, but the overall results indicated very little difference in the recovery values. There was no indication that spring applied N was more efficient or available for uptake than fall applied N. The 112 kg N/ha fall applied treatment had over 100 percent N recovery by both soil sampling and plant uptake methods, indicating that an additional supply of N became available on these plot areas that could not

Table 4. Soil sampling and plant N recovery as affected by time and rate of N fertilizer applications.

N Treatment	% Fall applied						
	100	100	75	50	25	0	Avg
kg/ha	% N recovery						
	Soil	Plants					
112	106	103	76	77	55	74	77
224	82	67	70	77	50	70	67
336	91	71	65	65	65	57	65
448	96	55	56	57	52	55	55
Avg	94	74	67	69	56	64	66

be accounted for by the soil and plant methods used.

Final harvest data, analyzed by multiple regression techniques (Figures 4 A,B,C, Table 5) and by combining rates of N application into groups based on percent fall and spring N application (Table 3), showed an increased N uptake by the tops, a decreased N uptake by the roots, and no change in the total N uptake by the plant when fall was compared with spring application of N fertilizer. Although these changes in N uptake are consistent throughout the growing season (Figure 2 A,B) and at final harvest, the significance of these data could not be shown between times of N application and N uptake.

Total N uptake by the sugarbeet plant at harvest was also linearly related to the total available N that was varied by fall and spring N fertilizer additions (Figure 5 A). Increasing the N available to the plant by fall or

Table 3. Effect of time and rate of fall and spring N fertilizer applications on final sampling parameters of sugarbeets; mt = metric tons.

Treatment % N Applied		Root Yield†	Sucrose†				Dry Matter				N Uptake		
			%	Total	Extractable		Tops	Roots‡		Total	Tops	Roots	Total
Fall	Spring	mt/ha	%	mt/ha	%	mt/ha	mt/ha	mt/ha	%	mt/ha	kg/ha	kg/ha	kg/ha
0	0	65.1	16.8	10.96	85.1	9.32	4.90	15.62	21.8	20.52	98	124	222
100	0	71.5	16.1	11.49	83.4	9.59	7.50	16.76	20.8	24.26	199	209	408
75	25	74.0	16.3	12.04	83.3	10.04	7.15	17.36	20.8	24.51	184	215	399
50	50	73.2	15.9	11.66	82.8	9.65	7.12	17.08	20.8	24.20	191	214	405
25	75	71.6	16.2	11.60	83.0	9.63	6.86	16.72	20.7	23.58	178	200	378
0	100	75.8	16.1	12.18	82.8	10.09	6.71	17.81	20.8	24.52	175	217	392
Avg §		73.2	16.1	11.79	83.1	9.80	7.07	17.15	20.8	24.21	185	211	396
LSD (0.05)		5.6	0.3	NS	1.2	NS	0.95	NS	NS	1.83	29	33	51

†Harvested root (root - crown).
‡Total root (root + crown).
§Average of treatments where fertilizer was applied.

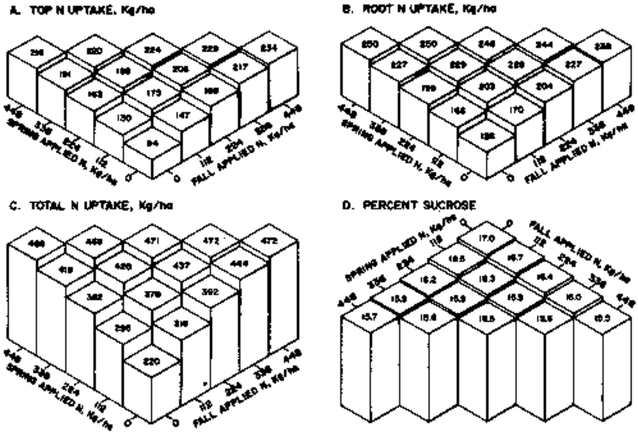

Figure 4. The response effects of fall and spring N fertilizer applications on N uptake by the tops (A), roots (B), total plant (C), and on sucrose concentration (D) in sugarbeet roots. (Equation, coefficients, constants, and r^2 values given in Table 5).

Table 5. Regression coefficients, constants, and r^2 values showing the response effects of fall and spring N fertilizer applications on N uptake by the tops, roots, total plants, and on sucrose concentrations in sugarbeet roots.

Plant Part	Regression Coefficients					Regression	
	b_1	b_2	b_3	b_4	b_5	C	r^2
	N Uptake						
	$X10^{-1}$	$X10^{-4}$	$X10^{-1}$	$X10^{-4}$	$X10^{-4}$	$X10^{1}$	
Tops	5.31	-4.83	3.42	-1.53	-6.70	9.36	0.84**
Roots	4.45	-4.37	3.75	-2.23	-5.78	12.63	0.73**
Total	9.76	-9.20	7.17	-3.76	-12.48	21.99	0.85**
	% sucrose						
	$X10^{-3}$	$X10^{-6}$	$X10^{-3}$	$X10^{-6}$	$X10^{-6}$	$X10^{0}$	
Roots†	-1.86	-3.15	-3.81	2.06	-2.15	16.96	0.53**

† Root -Crown **Significant at the 0.01 probability level.
Response effects determined using the multiple regression equation:

$$\hat{Y} = C + b_1F + b_2F^2 + b_3S + b_4S^2 + b_5FS$$

where $\hat{Y}$ is the estimated value, C is a constant, b_1 to b_5 are coefficients, and F and S are Fall and Spring N fertilizer applications variables, respectively.

spring N additions increased plant part N content and the amount of N uptake. However, there were no significant differences between the times of N addition and total N uptake by the plant.

The measured root yields during the growing season and at final harvest were higher from spring N when compared with fall applied N fertilizer (Table 3). These differences in root yield at all stages of plant growth were probably caused by the changes in the partitioning of the photosynthate between the tops and roots as previously described for dry matter. However, no significant changes in root yield could be demonstrated that were caused by time of N fertilizer application.

The sucrose concentration of beet roots during the growing season and at final harvest (Figure 4 D and 5 B,D) decreased with each increase in fall and spring N fertilizer addition and with the resulting N uptake by the plants (Figure 5 A). However, there were no noticeable or significant differences in sucrose concentration during the season or at final harvest caused by the time of application of N fertilizer (Table 3).

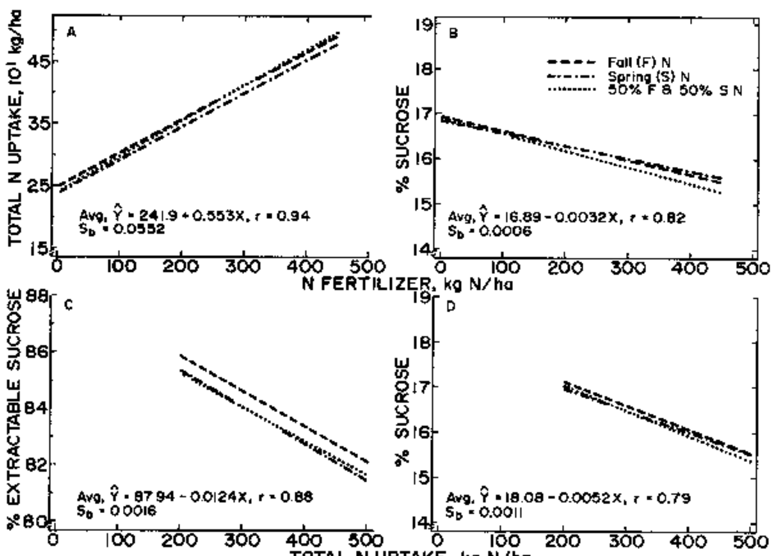

Figure 5. Effect of: A) N Fertilizer rate on total N uptake, B) N fertilizer rate on percent sucrose, C) total N uptake on percent extractable sucrose, and D) total N uptake on percent sucrose as affected by time of N fertilizer application. Sb = common standard error of the slopes.

The root yield and sucrose concentration levels resulted in a slightly higher but insignificant sucrose yield change during the season and at final harvest (Table 3) for the spring N when compared with the fall applied N fertilizer. The extractability of the sucrose for the fall applied N was slightly higher but again insignificant (Figure 5 C, Table 3). Thus, there were no significant differences in the extractable sucrose yield during the season or at final harvest (Table 3) caused by timing of N fertilizer application.

The overall results of this experiment showed clearly that fall applied N fertilizer was just as efficiently used by sugarbeets as that applied in the spring. In fact, the N uptake data and growth factors indicated that the distribution of the NO_3-N in the soil profile caused by fall application actually favored, under the conditions of this experiment, the early uptake of the added N. There was no indication that the increased amount of time the fall applied N was in the soil caused greater gaseous loss or loss by denitrification. Although the fall applied N was moved to greater depth in the soil profile than spring applied N, the roots were able to penetrate this layer and extract both the water and NO_3-N. There was very little indication that the fall applied N was leached below the root zone, even with twice the normal amount of water during the fall, winter and spring months.

There was no significant effect on yield factors caused by the time of N application or the location of the available N within the soil profile. Sucrose concentration in the beet root is normally affected by the amount of available N as well as the time that it is available and taken up by the sugarbeet (6, 7). The time of N uptake caused by the location of the N within the profile was not great enough to affect significantly the sucrose concentration or other yield parameters.

The ability of the sugarbeet root to penetrate the hard layer and extract the NO_3-N deep in the soil profile, as shown in this experiment and by Winter (14), emphasizes the need of soil testing at all depths within the root zone. Soil tests that do not take into consideration NO_3-N below the sampling zone but within the root zone may over recommend N fertilizer and thereby cause excessive N uptake and lower sucrose concentration and extractability compared to those receiving optimum N application and plant N uptake. Soil testing by universities, commercial consultants, and fertilizer companies normally sample to 60 cm so farm managers should keep and use accurate records of past N fertilizer management, carefully select fields which have low available N, or prepare fields for sugarbeets by extracting the deep N with crops that have an extensive root system.

The majority of the soils in the intermountain area of the west either have no hard layer or one that is similar to the soil used in this experiment. The results from this experiment would be applicable on soils with no hard layer or ones similar to the Portneuf series. However, in soils where a hard layer or other conditions exist that cannot be penetrated by the roots of sugarbeets, the N moved within and below this layer would not normally be available for plant uptake and plant growth. Under these conditions, application of the N fertilizer at the time of planting or during early plant growth would probably be desirable for maximum economy of N fertilizer use.

SUMMARY

This sugarbeet (*Beta vulgaris* L.) experiment, involving five N fertilizer rates, each applied at 0, 25, 50, 75 and 100 percent of the total rate in the fall and spring, was used to evaluate the location of the NO_3-N within the soil profile as it affects N uptake, seasonal growth rates, dry matter production, sucrose concentration and accumulation, and the partitioning of the photosynthate. The residual and applied fall N was found in the spring soil sampling distributed throughout the soil profile with an average N fertilizer recovery of 33, 53 and 8 percent for above, within, and below the hard layer which indicated very little loss during the winter months.

There were no significant differences between fall and spring applications of N during the season or at final harvest in plant N recovery, N uptake by individual plant parts or total uptake, dry matter production, and other parameters that affect total extractable sucrose yield. The overall results showed clearly that fall applied N fertilizer was just as efficiently used by sugarbeets as that applied in the spring under the soil and climatic conditions for this experiment. However, in soils where a hard layer or other conditions exist that cannot be penetrated by the roots, the N moved below this layer would not be available and spring application would be desirable for maximum economy of N fertilizer use.

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