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Determining Nitrogen Fertilizer Needs for Sugarbeets from Residual Soil Nitrate and Mineralizable Nitrogen[1]

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ABSTRACT

Soil nitrate and mineralizable nitrogen are used to predict the root yield potential and N fertilizer needs of sugarbeets. Predicting the required N fertilizer for optimum refined sucrose production based on soil test procedures is needed because inadequate N limits root yield and high levels of N may reduce both extractable sucrose and sucrose yield.

Sugarbeets (*Beta vulgaris* L.) were grown at 14 residual and fertilizer N rates to determine the root yield, sucrose percentage, sucrose yield, and N uptake in relation to the residual, mineralizable, and fertilizer N. A soil test to measure both the mineralizable and NO_3-N level of a soil was found to serve as a valuable guide in recommending N fertilizer for sugarbeets. The amount of N supplied from mineralizable sources in a uniformly cropped and fertilized field is expected to remain reasonably constant if adequate but not excess N fertilizer is supplied each year to the crop grown. Therefore, repeating the test for mineralizable N each year may not be necessary. Determining the amount of NO_3-N in the root zone, which is now feasible with rapid and accurate methods of soil analysis, combined with the predetermined mineralizable N, would increase the accuracy of N fertilizer recommendations.

Additional index words: Nitrogen uptake, Petiole analysis, Nitrogen balance.

SOIL and fertilizer nitrogen management is extremely important in sugarbeet (*Beta vulgaris* L.) production. Low levels of N limit root yields, whereas high levels of N can maximize root yield but may reduce both sucrose percentage and sucrose production (7). High levels of N also increase soluble N compounds in the extracted beet juice which interfere with the crystallization process, decreasing the yield of refined sucrose. Increasing rates of N fertilizer applications appears to have caused a gradual decline in sugarbeet quality. A reversal of this decline would require lower rates of N fertilizer or accuate methods of predicting the N level needed for optimum root, sucrose, and refined sucrose production.

Previous investigations have shown close agreement between the soil NO_3-N level and sucrose production (8, 12). However, a direct measurement of the mineralization capacity of the soil was not included in these experiments. Stanford and Smith (14) showed that the mineralization capacity varies widely with soil type and location. Their results indicate that for a N soil test to be applicable over many soil types and management practices, it must include an estimate of the mineralization capacity of the soil, whereas soil NO_3-N may suffice for a given soil type and management level.

This paper summarizes N fertilizer studies and soil test procedures that can be used to predict the N needs for optimum root and sucrose production by sugarbeets which is expected to be applicable to different soil types.

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MATERIALS AND METHODS

Experiments involving 14 N treatments were conducted during 1968 and 1969 on a Portneuf silt loam soil (Xerollic Calciorthid; coarse-silty, mixed, mesic) near Twin Falls, Idaho. This soil has a weakly cemented hardpan beginning at the 40 to 45-cm depth that has little effect on water movement when saturated but restricts root penetration. Phosphorus fertilizer was broadcast at a rate of 50 kg P/ha before seedbed preparation. Other nutrients, except N, were adequate from soil and irrigation water sources.

A N fertility study on potatoes (*Solanum tuberosum* L.) conducted in 1967 provided five residual nitrogen levels (Table 1). The potato study involved four replications of four levels of urea N (90, 135, 180, and 360 kg N/ha) applied all preplant, 1/2 preplant and 1/2 on July 11, and 1/3 preplant followed by 1/3 on June 11 and 1/3 on August 8. This established three similar groups of 4 residual N levels and 2 checks (0 N) for a total of 56 plots, each 9 × 13 m.

One group of four N treatments (90, 135, 180, and 360 kg N/ha) and a check plot received no additional N fertilizer (Table 1). The second group was fertilized with 56 kg N/ha, and the third group, including a check treatment, received 112 kg N/ha in 1968. The treatments fertilized with 0 and 56 kg during 1968 were not fertilized in 1969. Those areas receiving 112 kg in 1968 were fertilized with 56 kg N/ha in 1969. Urea N fertilizer was distributed with a mechanical spreader and disked into the soil, and the seedbed was prepared.

Each plot was sampled to the 40-cm depth or to the hardpan in the spring of 1968 and 1969 before applying fertilizer. In addition, soil samples were taken at weekly intervals during 1969 on all replications of the highest level of residual and applied N. Twelve cores per plot were composited by 20-cm deep increments. The soil samples were air-dried, ground, and stored until analysis.

The potentially available soil N was determined by extracting NO_3-N from air-dried soil and by incubating 50 g of soil in a 500-ml Erlenmeyer flask for 21 days at 30 C with moisture maintained at approximately 1/3 atm. Moisture loss was minimized by using a one-hole rubber stopper in the flask for aeration during the incubation. The NO_3-N was extracted from the air-dried and incubated soil with a $CuSO_4 \cdot 5H_2O$ (2.5 g/liter) and Ag_2SO_4 (0.167 g/liter) solution. A 50-g soil sample was shaken for 10 minutes with 200 ml of extractant; then 1.2 g of precipitating mixture composed of 10 parts $MgCO_3$ and 4 parts $Ca(OH)_2$ was added and the sample was again shaken for 5 minutes. Samples were then filtered through Whatman No. 2 filter paper and an aliquot taken for NO_3-N determination. NO_3-N was determined by the phenoldisulfonic acid method essentially as described by Bremner (3).

The difference between the incubated and air-dried NO_3-N concentration was considered to be mineralizable N. Small amounts of ammonium-N normally found in these soils were considered to be oxidized to NO_3-N during incubation and, therefore, were included in the mineralizable N fraction. In soils where ammonium-N makes up a significant part of the soil N, it should be extracted and determined separately.

The sugarbeets were planted in rows with a 60-cm spacing on April 11, 1968 and April 21, 1969, and were thinned to a spacing of about 30 cm within rows. Water was applied to alternate furrows at each irrigation. The experimental area was irrigated when the soil moisture reached prescribed levels, based on estimated evapotranspiration (9). The duration of each irrigation was based on soil moisture depletion and the amount of water to be applied.

Root and top samples from a uniform 3-m section of row were taken from each treatment near the end of the 1968 season and at weekly intervals on all replications of the highest level of residual and applied N in 1969. Sufficient plot area was provided so that the plant samplings did not influence final yield measurements. The plant samples were washed, weighed, cut into small sections, and dried at 65 C. After determining the dry weight, the plant samples were ground to pass a 40-mesh sieve. Total N in these samples was determined by the Kjeldahl procedure modified to include nitrate. N uptake was determined by assuming that the amount of N in the fibrous root system was 25% of the N in the root (10).

Petiole samples consisting of 24 of the youngest fully mature petioles were selected at random from each plot at each weekly plant sampling. 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 (15).

The beet roots, harvested on October 22, 1968 and October 22, 1969, were selected randomly from each plot during harvest for sucrose analysis. Sucrose analyses were made by the Amalgamated Sugar Company using their standard procedures.

RESULTS AND DISCUSSION

The average mineralization capality of the soil was 216 kg N/ha in 1967, 214 kg N/ha in 1968 when the soil from the highest level of applied N fertilizer was excluded, and 207 kg N/ha in 1969 (Table 1). The mineralization capacity of the highest N fertility level soil in 1969 was 216 kg N/ha before planting in March and 211 kg N/ha at harvest in October. The average of all weekly soil samples in 1969 was 209 kg N/ha. Previous N fertility treatments greater than 135 kg N/ha increased the total available N levels in the root zone, but the mineralization capacity of the soil was not materially affected except at the highest level of applied N.

The amount of N required to produce a metric ton of fresh beet roots has been reported as 4.38 kg in central Washington (2), 5.00 kg in Utah and Colorado (6, 12), and 7.00 kg in the Imperial Valley of California (11). These values probably vary with the soil, climatic conditions, and irrigation practices of the areas. Previous studies (unpublished) in southern Idaho indicate that approximately 336 kg of N or 6.00 kg of N per metric ton of roots are needed for a 56-metric ton yield.

The N in the beet tops increased from 55 to 62% of the total N uptake as N fertilizer increased in 1968

Table 1. Effect of N fertilization levels on the residual NO_3-N, mineralization capacity, plant N uptake, root yield, and sucrose production by sugarbeets in 1968 and 1969; Min. N = mineralizable N, mt = metric tons.

N Application			1968								1969†				
			Soil N, 40 cm			Plant N Uptake			Yield		Soil N, 40 cm			Yield	
1967*	1968	1969	NO_3-N	Min N	Roots	Tops	Roots	Roots	Roots	Sucrose	NO_3-N	Min N	Roots	Roots	Sucrose
		kg N/ha			kg N/mt‡	%		kg N/mt§	mt/ha‡		kg N/ha		kg N/mt‡	mt/ha‡	
0	0	0	84	213	6.4	55	45	4.5	46.1	7.66	49	200	5.8	43.2	7.41
90	0	0	93	227	6.4	56	44	5.8	49.7	8.00	50	211	5.8	44.8	7.68
135	0	0	75	212	5.7	56	44	5.6	50.6	8.24	53	203	5.2	49.1	8.40
180	0	0	96	207	5.7	60	40	5.1	52.9	8.71	68	203	5.1	52.9	8.85
360	0	0	143	206	6.1	61	39	7.3	56.9	8.96	77	228	5.6	54.4	9.41
90	56	0	83	198	6.0	55	45	5.5	55.8	9.30	64	211	5.3	52.2	8.83
135	56	0	90	199	5.9	54	46	5.6	58.7	9.72	69	209	5.4	51.7	8.87
180	56	0	80	231	6.6	57	43	6.5	55.6	9.14	60	214	5.5	50.0	8.60
360	56	0	147	259	8.0	58	42	7.0	57.6	8.87	78	205	5.0	56.7	9.50
0	112	56	76	221	8.3	61	39	5.8	49.1	7.86	59	207	6.0	53.8	9.32
90	112	56	88	213	7.4	58	42	5.8	56.0	9.07	57	208	5.9	54.7	9.34
135	112	56	87	207	7.3	58	42	6.2	55.3	9.23	71	190	5.5	57.3	9.70
180	112	56	128	220	8.3	59	41	6.4	55.3	8.85	60	197	5.7	55.3	9.27
360	112	56	192	246	10.0	62	38	8.4	54.9	8.67	105	216	6.1	61.4	10.15

* Average 1967 mineralizable N was 216 kg/ha. † In 1969, plant uptake data were available only for the 360-112-56 kg N/ha treatment, where 52% of the N was located in the tops, 48% in the roots, and 4.4 kg total N uptake was required per metric ton of root yield. ‡ Harvested yield. § Yield measured from 3-m section of row.

(Table 1). With more N in the tops, there was a corresponding increase in the plant N uptake required to produce a metric ton of beet roots. Approximately 5.6 kg of N (54% tops and 46% roots) were taken up for each metric ton of root production for maximum surcrose yields. In 1969, only 4.4 kg of N were required. During 1969, there was less top growth, with a corresponding lower percentage of N in the tops (52%) and a greater percentage in the roots (48%). Other unpublished results of the authors indicate that 5 kg N/metric ton of fresh beet roots is a more typical average uptake of N by the sugarbeets grown in this area.

In addition to N uptake by the sugarbeet crop, N may be lost by leaching or volatilization. If we assume that 20% (1) of the N uptake by the sugarbeet crop, or 1 kg N/metric ton of beet roots, will be lost by leaching and denitrification, then 6 kg N/metric ton of fresh roots should be available from soil and fertilizer sources for optimum root and sucrose yields. However, this loss factor from leaching and denitrification can be increased or decreased by N and irrigation water management.

The amount of N required to produce a metric ton of fresh roots can also be evaluated by considering the available N in the soil. Assuming the total supply of N came from the 0 to 40-cm depth, the method used to determine mineralizable N represented field conditions, and there were no losses of N, approximately 6.0 kg of N were available from the soil for each metric ton of roots in 1968 and 5.4 in 1969 when no N fertilizer was applied. The amount of N required would depend on the variable response growth patterns due to year-to-year differences in climate. Most of the treatments varied from 5 to 6, indicating an expected variation of 0.5 kg/metric ton. However, the sampling depth (limited by a cemented layer) may not represent the total supply of soil N available to the crop, and some of the available N in the sampling depth may be left at the end of the season. N uptake (N_{up}) by the crop from various sources can be expressed as:

$$N_{up} = E_f\, N_f + \alpha_n\, N_n + \alpha_m\, N_m \qquad [1]$$

where E_f = the efficiency of applied N fertilizer (N_f),

- α_n = crop extractable NO_3-N/NO_3-N in the soil depth sampled
- N_n = soil NO_3-N in the soil depth sampled
- α_m = (crop extractable mineralizable N)/(field mineralizable N in soil depth sampled) $\times$ field mineralizable N/laboratory mineralizable N
- N_m = mineralizable N in the soil depth sampled as determined by the laboratory mineralization test.

Analysis of the 1968 data indicated that $E_f = 0.65$, $\alpha_n = 1.2$, and $\alpha_m = 0.95$. These values were obtained using the five 1967 treatments (0, 90, 135, 180, and 360), first solving for just E_f. Since inadequate data were available to independently evaluated α_n and α_m, α_n was determined by first assuming $\alpha_m = 1.0$ and correcting the N uptake based on $E_f\, N_f + \alpha_m\, N_m$. After correcting the N uptake for both $E_f\, N_f$ and $\alpha_n\, N_n$, α_m was determined and compared with the initial assumption (1.0 vs 0.95). If the assumed and determined values differed substantially, a second trial value of α_m would have been used.

If 5.5 ± 0.5 kg of N are needed to produce a metric ton of fresh roots, then the potential yield, Y, for a sugarbeet field will be:

$$Y = N_T/(5.5 \pm 0.5),\ N_T/(5.5 \pm 0.5) \leqslant Y_E \qquad [2a]$$

or

$$Y/Y_E = N_T/Y_E\,(5.5 \pm 0.5),\quad N_T \leqslant Y_E\,(5.5 \pm 0.5) \qquad [2b]$$

where Y_E is the expected maximum yield under a given management level when N is not limiting, and N_T is the total net N available to the crop ($N_T = E_f\, N_f + \alpha_n\, N_n + \alpha_m\, N_m$). After harvest, the evaluation of the yield response to N can be made by substituting Y_{max} for Y_E in equation [2b]. If maximum yields to be expected from a farmer's level of management are desired and $(\alpha_n\, N_n + \alpha_m\, N_m) \leqslant 5.5\, Y_E$, the N fertilizer needed to make up the deficit, $(5.5 \pm 0.5)\ (Y_E - Y)$, will be:

$$N_f = [Y_E\ (5.5 \pm 0.5) - (\alpha_n\, N_n + \alpha_m\, N_m)]/E_f \qquad [3]$$

where N_f is the needed N fertilizer and E_f is the N fertilizer efficiency, expressed as a fraction. The E_f value can be expected to range from 0.5 to 0.7 depending on management practices (13) and was previously found to be 0.65 in the 1968 study.

Since about 56 kg/ha (50 lb/acre) is the smallest increment of fertilizer that is practical to apply mechanically, no fertilizer would be applied if $N_f < 28$, and the next higher increment would be added if $N_f >$ 28kg. When other plant nutrients are being applied or where N fertilizer can be added to the irrigation water, it may then be practical to apply N fertilizer increments of less than 28 kg N/ha.

Equation [2b] is evaluated in Fig. 1, assuming that 336 kg N/ha are needed for maximum sucrose production and $Y_{max} = Y_E = 56$ metric tons/ha. A yield response similar to that obtained in 1968 was obtained by regression analysis using all 1969 yield data where insufficient soil and fertilizer N was present for maximum root yield ($\hat{Y} = -0.499 + 0.0032\, N_T$, $r = 0.88$). The relative root yield predicted from N levels agreed with harvested beets for both seasons.

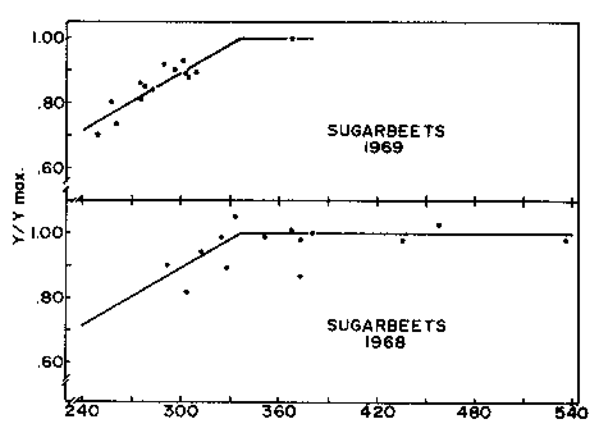

Fig. 1. Effect of available N (N_T) on the root yield potential of sugarbeets.

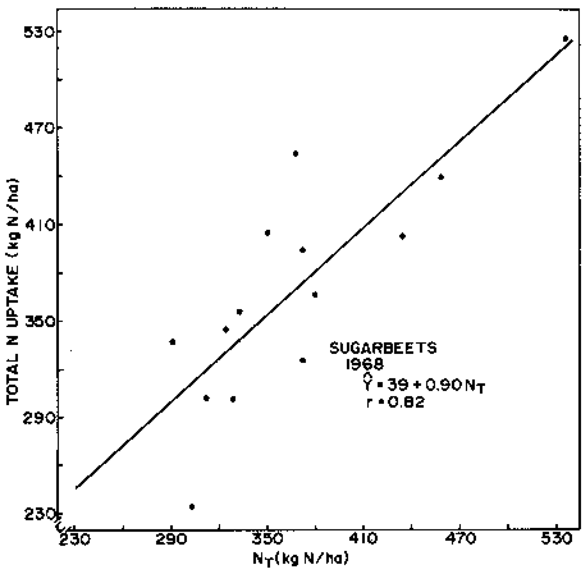

Fig. 2. Effect of available N (N_T) on total N uptake by sugarbeets.

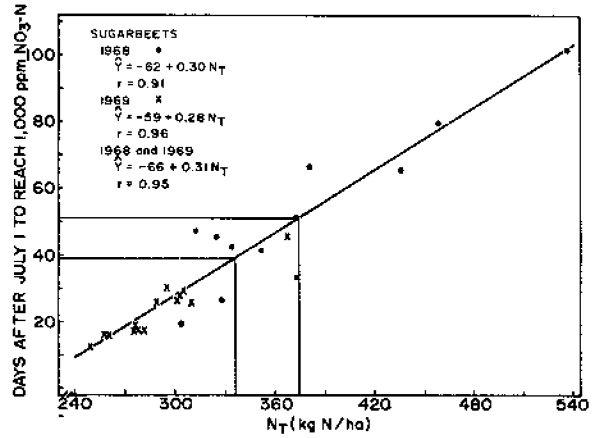

Fig. 3. Relationship between available N (N_T) and the N nutrition status of sugarbeets as measured by petiole NO_3-N.

The total N uptake in 1968 was linearly related to the estimated net N available to the crop from the soil and fertilizer N (Fig. 2). The NO_3-N level in the soil has been shown to be a major source of N. The amount of N mineralized is expected to remain reasonably constant from one year to the next if adequate but not excess N fertilizer is applied each year for the crop grown. Once the mineralization capacity of a soil has been determined, this test need not be repeated each year. The determination of the amount of NO_3-N in the root zone of the soil, which is now feasible with rapid and accurate methods of analysis in soil testing laboratories, would be adequate when combined with predetermined mineralizable N for accurate N fertilizer recommendations. However, the amount of N supplied from mineralizable sources should be redetermined every few years, particularly following forage legumes or unusual fertilizer practices.

The more difficult parameters in equation [1] to determine are E_f, α_n, and α_m. E_f can be evaluated by determining total N uptake from about 4 rates of N_f (0, 0.5, 1.0, and 1.5 times the rate needed for optimum production) or by assuming a value between 0.5 to 0.7 (13). The method and time of fertilizer application should be similar to the usual practice for the field. Determining α_n is more difficult since $\alpha_m N_m$ is not easily separated from $\alpha_n N_n + \alpha_m N_m$. At least two levels of N_n are needed. These may be approximated by two fertilizer treatments on the crop to be grown prior to sugarbeets to give two levels of N_n. After the total N uptake by sugarbeets on these two treatments is determined and assuming N_m to be the same on both treatments, α_n and α_m can be determined by a trial-and-error procedure. The sampling depth for determining N_n and N_m need not be uniform over a wide area involving many soil types and conditions, but should represent normal sampling depths for the area involved and remain uniform in future sampling and analysis.

Petiole analysis has been shown to be an excellent indicator of the N nutrition status of sugarbeets (15). Previous results indicated that maximum yields of sucrose are obtained in southern Idaho if the NO_3-N concentration in the petioles is above 12,000 ppm early in July and about 1,000 ppm 4 to 6 weeks before harvest or on about August 20 (4). Concentrations below these critical levels for any appreciable time appeared to lower root and sucrose yields. The August 20 value and the time required to reach 1,000 ppm are predictable from two petiole NO_3-N levels earlier in the season (5).

The relationship between the available soil N and time required for the petiole NO_3-N to reach 1,000 ppm is shown in Fig. 3. Close agreement exists between the soil and tissue methods of determining N needs during the 2 years of this study. This study indicates that if 336 kg N/ha of available N are sufficient for maximum yields, then 1,000 ppm on August 20 would be slightly higher than necessary. The regression equations in Fig. 3 indicate that 1,000 ppm on August 9, 1968, August 6, 1969 and August 8 when both years were combined would be sufficient NO_3-N in the petioles for maximum yields. However, 1,000 ppm on August 20 (375 kg N/ha) would add a safety factor without being high enough to decrease sucrose percentage and production.

The regression equation in Fig. 3 further indicates that 3.2 kg N/ha are required to eliminate each day of N deficiency as shown by petiole analysis. If N fertilizer is to be applied to eliminate this deficit, then 4.9 kg N/ha would be required ($3.2/0.65 = 4.9$) because of the efficiency factor previously given.

During the early stages of plant growth, soil and fertilizer N may be subject to gaseous loss and leaching below the root zone. Although these losses may occur at all stages of growth, they are probably higher during early growth because the NO_3-N concentation in the soil usually is higher than later in the season. If inadequate N is available to meet crop needs, then the addition of N fertilizer just before the period when the demand rate increases should augment the efficiency of sucrose production and N fertilizer use.

The estimated cumulative values of the various N components vs time from soil and plant samples taken

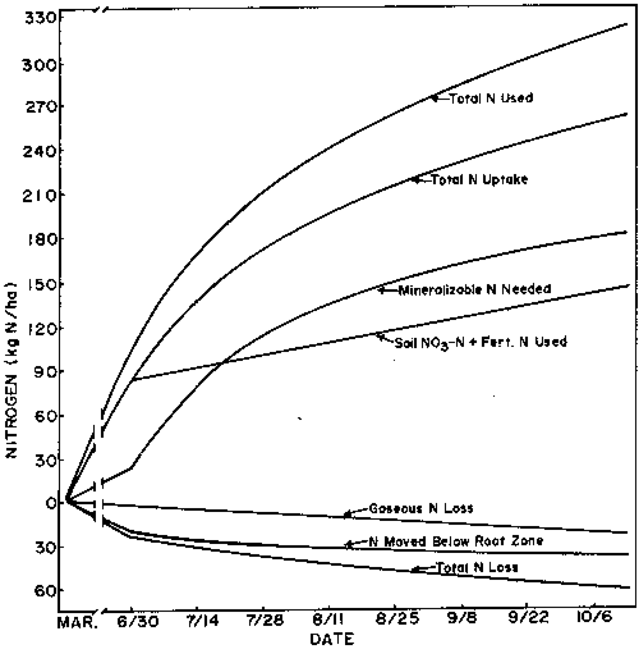

Fig. 4. Estimate of N balance throughout the 1969 season on a Portneuf silt loam soil growing sugarbeets.

throughout the 1969 season are shown in Fig. 4. The gaseous loss is estimated to occur at the rate of 15% of the combined initial and fertilizer NO_3-N (1). N leached below the root zone is estimated from the NO_3-N concentration and drainage rate. Total loss of N due to leaching and denitrification was 20% of the total N used. All other values given in Fig. 4 are the results of measured values. The rate of N uptake, under conditions where N does not limit plant growth, increases rapidly beginning early in June, reaches a peak early in July, and begins to decrease in late July. By the first sampling date of June 30, 51% of the soil and fertilizer NO_3-N had been either taken up by the plants, leached, or lost in a gaseous form. The additional 22 kg N that were used during this period came from mineralizable sources and/or from below the soil depth sampled. Throughout the remainder of the season, a greater proportion of the N used came from mineralizable sources and/or from below the depth sampled than from the initial fertilizer and soil NO_3-N in the depth sampled. A total of 324 kg N/ha would be used for the growth of the crop, leaving 18 kg of unused NO_3-N in the soil at the end of the season. This 324 kg of N/ha is very close to the 336 estimated to be needed for maximum production.

In conclusion, the use of a soil test to measure both the mineralizable and NO_3-N level of a soil can be a valuable guide in recommending N fertilizer for sugarbeets. The use of this test would enable the optimum application of N fertilizer before planting or as a side-dressing early in the season before the period of maximum N uptake. The soil NO_3-N level can also be a valuable guide to sugarbeet production if the mineralization capacity of the soil is known with reasonable accuracy. However, determining the optimum N fertility level by soil test alone does not reflect irrigation practices in which excess leaching may be involved. The use of tissue tests in conjunction with soil tests will enable a midseason verification of the N status of the crop and should permit maximum refined sucrose production and profits to both the producer and manufacturer.

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