EFFECT OF APPLIED NITROGEN AND SODIUM AND IRRIGATION FREQUENCY ON THE DEVELOPMENT AND YIELD OF SUGAR BEETS

by

A. K. Shafique Ahmed Khan

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Approved:

H. D. Fuehring
In Charge of Major Work

Salim Makdisi

Marcel Awad

A. H. Knight

Chairman, Graduate Committee

American University of Beirut

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SUGAR BEET PRODUCTION

KHAN

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A. K. Shafique Ahmed Khan

ABSTRACT

The effect on sugar beets of various levels and combinations of N and Na and irrigation interval were studied. The oil drop penetration method as an indicator of the degree of stomatal opening was related to the degree of soil moisture stress. The application of N increased the yield of roots, tops, sucrose and nitrate N concentration of petioles and nitrogen content of beet roots considerably. Return above fertilizer cost was found to be relatively constant over the range of 150 to 450 kg./ha. of applied N. The application of either N or Na tended to increase the resistance of sugar beet to increased moisture stress. It was found that sugar beet plants were relatively insensitive to moisture stress within the range tested. The stomatal opening technique worked well as an indicator of soil moisture status but this would have more practical value in the case of crops that were more sensitive to moisture stress. The method needs to be calibrated with each species of plant.

The nitrate N concentration was found to be a good indicator of the N status of the plant. When all the fertilizer was applied at planting, 5,000 ppm. of nitrate N in the petioles on the dry basis was indicated to be the critical level early in the season decreasing to 1,000 ppm. at a time about one month before harvest.

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INTRODUCTION

The production of sugar beets in Lebanon was started in 1947. Average yields for the country have varied from 20 to 40 tons per hectare while experimental yields of 100 to 150 tons per hectare have been obtained by research workers. Probable reasons for the relatively low commercial yields are inadequate irrigation and poor cultural practices in general.

Nitrogen application for sugar beets is a major problem in that large amounts are necessary for maximum plant growth depending on the yield potential as influenced by other growth factors. However, excess nitrogen, especially near the end of the growing season, has resulted in sugar beet processing difficulty because of poor juice quality. Also the sugar concentration in the beets has been adversely affected. The level of nitrate-nitrogen in the leaf petiole is a good index of the nitrogen nutrition of the plant throughout the season but this procedure needs to be further correlated with local yield levels and potential yields.

The specific function of sodium is not known but several crops including sugar beets show increase in yield from sodium application. However, more information is needed on the conditions under which yield benefits occur.

It appears that the amount and frequency of irrigation may be important factors in the relatively low yields of sugar beets obtained locally. Additional information is needed on these factors along with a method whereby the moisture status of the soil and plant can be readily determined in the field. Field determination of soil water adequacy by the extent of stomatal opening has shown promise but more work is needed.

The present experiment was conducted at the American University Farm, Beka'a Plain, during 1963 to study the effect of nitrogen and sodium application and frequency of irrigation on:

1. The yield of beets and beet sugar as affected by each factor individually or by interactions among them.
2. The composition of sugar beet plants as affected by various levels of the factors and to estimate the "critical levels" of nitrogen and sodium throughout the growing period.
3. The optimum rates of fertilizers for maximum yields.
4. The use of the stomatal opening technique as a method for field determination of soil moisture adequacy.

REVIEW OF LITERATURE

Considerable research has been done on application of nitrogen and sodium for sugar beet production but the requirement for these two nutrients needs to be related to the potential yield level of the area and particularly to the supply of soil moisture.

Nitrogen for Sugar Beets

Research workers (11, 17, 19, 46, 57, 71, 72, 83, 84) have found that sugar beets respond well to application of nitrogen. Recommended application rates of 40 up to 200 lbs. of N per acre have been stated depending on the soil fertility level, length of growing season and the general potential yield level. Under optimum experimental conditions and high yield potential in the Beka'a, AUB workers (16, 21, 35, 87) obtained profitable increases in yield up to 300 to 450 lb. N/acre at yields around 50 tons / acre.

Many research workers (3, 5, 25, 36, 37, 38, 39, 49, 54, 61) have shown that there is an inverse relation between nitrogen application and sugar beet quality. Some of these research workers are in general agreement that this reduction in quality may be due to lower percentage of sucrose while many of them believe that this reduction in quality is due to both decrease in sucrose percentage and an increase in non-sugars.

Rounds et al. (64) and Ogden et al. (59) indicated that there is a direct relationship between the amount of applied nitrogen, nitrate N in the petiole and the concentration of non-sugar in the beet. Glutamine is one of the important non-sugar constituents of the sugar beet. The glutamine and ammonia fractions appear to be most highly related to changes in sugar beet quality (28). Each increment of nitrogen fertilizer increased the glutamine content of sugar beets progressively (20, 80, 86). McAllister _et al._ (53) studied the effect of soil and fertilization on the following constituents of sugar beet: marc, sucrose, total nitrogen, amino nitrogen, total glutamate, total anionic constituents, moisture, malic acid, oxalic acid, raffinose, and glactinol. They found "negative correlations between the sucrose concentration and all other constituents except galactinol. Sucrose and marc were positively correlated but no relationship was evident between sucrose x beet weight and sucrose x beet girth. Sucrose was the only constituent which was consistently changed in the same direction (in this case downward) by an increase in nitrogen fertilization".

Rounds _et al._ (64) used three levels of nitrogen namely 64, 140 and 280 lbs. per acre in a sugar beet experiment. Beets in the lower level of nitrogen (65 lb./acre) gave 20.7 tons/acre and high nitrogen fertility plots (140 and 280 lbs/acre) gave 26.4 to 27.3 tons/acre but the sucrose concentration in the high level was 15.6% and that for low level 16.8%. This reduction in sucrose percentage for high nitrogen level depressed the yield of sugar per acre. Application of 140 lbs. of nitrogen per acre produced high yield (26.4 tons/acre) of root with little reduction in percentage of sucrose (16.7%), which resulted in the highest amount (8820 lbs/acre) of sugar. Economic analysis showed that the application of 140 lbs. nitrogen per acre was most beneficial to both grower and processor for all varieties tested. Tolman _et al._ (73) in a similar experiment, came to the general conclusion that in short season areas 80 to 100 lbs. of nitrogen per acre will provide a most profitable yield. In long season areas and on new land the requirement for nitrogen may go as high as 200 lbs. per acre.

The nitrate N content of sugar beet petiole is a good criterion for the estimation of nitrogen nutrition of sugar beets and the ability of soil to supply nitrogen to plants (24, 26). This has been extensively investigated in field and pot experiments by Ulrich (75, 76) who concluded that the critical nitrogen concentration for the recently matured sugar beet petiole in the field was approximately 1000 ppm. of nitrate N, and in the pot experiment it was approximately 2000 ppm. nitrate N. Below this critical concentration the growth of the plant was retarded and above this level growth was maintained at a maximum. The concentration of sucrose was inversely related to the nitrate N concentration of the petioles. Consistency of the critical level of nitrogen has been found by many workers (2, 8, 24, 45, 62, 75, 77) over a period of 15 years. That is, when the nitrate N content of sugar beet petioles fell below the critical level, the sugar beet plant was found to response to N application and resulted in larger yields.

Krantz and Mackenzie (45) who found a close relation between nitrate N in the petiole of beet, nitrogen application and degree of response, also observed that for optimum yield, the nitrate N concentration of beet petiole should be kept above 1000 ppm. until about 11 to 12 weeks before harvest. But the beet yield was decreased, when the nitrate N was maintained above the critical level over a period of 3 to 9 similar experiment, came to the general conclusion that in short season areas 80 to 100 lbs. of nitrogen per acre will provide a most profitable yield. In long season areas and on new land the requirement for nitrogen may go as high as 200 lbs. per acre.

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As a rule roots from nitrogen-deficient beet plants have higher sucrose concentration than from those adequately supplied with nitrogen. Therefore, one of the most important ways of "ripening" or "sugaring up" is to deprive the sugar beet plant of an adequate supply of nitrogen before harvest. Ulrich et al. (78) have found in several recently conducted pot-experiments that the increase in sugar content due to four to six weeks of preharvest nitrogen deficiency offset tonnage losses as high as 20 to 25 per cent. Therefore, in the case of "non controlled feeding", a definite amount of N fertilizer should be added such that the concentration of nitrate N in the petioles four to six weeks before harvest falls below the critical level in order to have a high yield of sugar (51). Haddock (26) found the critical level of nitrate N for the early growth stage to be 8,000 to 10,000 ppm. and Hashimi (35) estimated it to be 7,420 ppm. of nitrate N when all N was applied at planting time.

Sodium for Sugar Beets

The beneficial effect of sodium on certain crops has been reported by many workers (34, 65, 66, 67). Adams of the Rothamstad Experiment Station (70) concluded, based on more than 200 field experiments carried out between 1929 and 1960, that after nitrogen, sodium was the most important nutrient for sugar beets. Sodium gave more yield-increase than potassium and also increased the effect of nitrogen.

Harmer et al. (34) divided the crops according to their tolerance of sodium salts into four groups and grouped sugar beets with those giving a large response even when the potash supply was ample. Harmer and Benne (33) found that on muck soil and ample supply of potassium, the yield of sugar beets increased with the addition of sodium chloride. On the contrary, treatment with salt but without potassium gave lower yields than the control. They concluded that even though sodium could not perform all the functions of potassium in the metabolism of the sugar beet plant, it was almost as important as potassium as a nutrient. Similar results were also obtained by Larson et al. (47), Kandy (43), Truog et al. (74) and Lehr (48). In 1949, Crowther found that sodium increased the yield of sugar beets without increasing the uptake of potassium (70). Data obtained by Adams (1) showed that sodium application increased the yield of sugar beets but did not act by mobilizing the soil potassium reserve. These results demonstrate that sodium is not merely a substitute for potassium but is an independent nutrient for sugar beet growth.

Doxtator and Carlton (12) found that the sodium content was positively associated with yield and negatively correlated with sucrose concentration. Brown and Wood (6) found high negative correlations ($r = -0.7$ to -0.9) between sugar and sodium contents within a given variety. These results were confirmed by many workers (13, 14, 15, 85).

Shepherd et al. (68) found an inverse relationship between the potassium and sodium contents of sugar beet roots and tops in that a high level of one tended to decrease the level of the other. They also reported that on an organic soil, the yield response to salt decreased with the increasing application of potassium. Sayre et al. (65) in their review of literature mentioned that the uptakes of N and P and K were stimulated by NaCl. Based on his experiments with different sodium fertilizers in 1944 (65) and 1949 (67) Sayre concluded that nitrate of soda was the most important source of sodium and was the only form of nitrogen which increased the yield significantly without salt. Application of nitrogen without sodium neither increased the yield nor corrected the abnormal purple spots and maroon color of the leaves of beets. Sodium in the form of sodium chloride increased the yield of beets only when it was supplemented with nitrogen. Sodium chloride at 500 lb. per acre or its equivalent amount of nitrate of soda, sodium sulphate or soda ash gave very good results in Western New York. He further added that there was improvement in the color and flavor of beet leaves and that sodium made the leaves more erect and more suitable for harvesting by machine.

The critical level for sodium has not yet been determined. Ulrich (79) found a sodium concentration (dry basis) range of 0.02 to

9.0% in the petioles of sugar beets without deficiency symptoms. Magnitski (51) reported a concentration (wet basis) range of 0.20 to 0.16% of K + Na in the petioles as the critical level during the growing season for sugar beets.

The relationship between sodium, nitrogen, irrigation and yield of sugar beets needs further investigation.

Irrigation for Sugar Beets

In 1963, Hobbs et al. (40) found no significant difference in yield from the treatments where irrigation was done when the soil moisture was depleted to 25, 50 and 75 percent of the available moisture range. Watson (82) reported that Owen at the Rothamsted Experiment Station (1958) in a pot experiment found that repeated withholding of water for short periods did not affect the dry weight or leaf area. Based on this and several other experiments, Watson (82) and others (27, 69) concluded that sugar beet plants were relatively insensitive to water stress. Miller et al. (56) found no reduction in yield for moisture tension up to 4 atms. at 6" depth. However, a definite and consistent reduction in yield was obtained for soil moisture tension of 8 atms. Similarly Haddock (29) who worked over a wide range of soil moisture, found a significant decrease in yield, sucrose percentage and purity when he used only 16.3" of irrigation water during the season.

Reeve and Kidder (60) reported that where irrigation was provided when the available soil moisture recorded by Bouyocous moisture blocks at 5" and 10" depth of soil reached 50 percent or less, too much moisture was more of a factor for decreased yield than lack of it. Robins et al. (63) found that water in excess of that storable in the root zone in the early growing season reduced the yield and nitrate N content of petioles considerably but the sucrose concentration increased appreciably. On the other hand, late season application of excess water did not affect the yield, however, there was a slight reduction of the nitrate-N content of petioles.

Kelley and Haddock (44) in their experiment used four soil moisture conditions, ranging from wilting percentage to field capacity. They found that yield of sugar beets was highly correlated with soil moisture condition regardless of method of irrigation used. Similar results were obtained by several workers (4, 10, 22, 23, 28, 32). Walker et al. (81) found an increase in yield and in glutamic acid content of beets with decreasing moisture stress. Loomis and Worker (50) reported that both soil moisture stress and nitrogen deficiency decreased the growth of sugar beet and the effects were independent and additive. Nitrogen deficiency increased the sucrose concentration and purity, but moisture stress did not.

Hansen (32) in 1954 reported that phosphorous seemed to increase yields at all soil moisture conditions while nitrogen appeared to have a favorable effect only under high soil moisture conditions. Haddock (30) found a decrease in the sodium content of petioles at increasing soil moisture.

Sprinkler irrigated-plots produced higher yield, higher nitrate N in the early season petioles but lower sucrose concentration than non-sprinkler irrigated plots. However, total sugar per acre produced by the sprinkler irrigated plots was more than from non sprinkler plots. This improvement in the production of yield associated with sprinkler irrigation could be due to improvement in the nitrogen nutrition because of less leaching of N from the root zone (44, 58).

Problems are involved in each irrigation field with the length of run, size of stream, frequency of irrigation, and the time allowed for penetration of water, but the total requirement ranges from 24 to 60 inches (27).

Stomatal Opening and Irrigation Time

Halevy (31) reviewed the literature on stomatal behavior as affected by moisture stress and reported that the use of changes in stomatal opening as an indicator for beginning of moisture stress was first suggested by Loftfield in 1921. In 1941, Oppenheimer and Elge developed a practical technique whereby they used an infiltration method for determining the stomatal aperture as an indicator for irrigation of orange trees. They used only one kind of liquid (Kerosene) and determined the degree of opening by the time elapsed from the time of application to the starting of absorption and also by measuring the shape and number of spots.

In 1936, Maximox and Zernova (52) studied the stomatal movements of irrigated wheat plants in order to relate certain characteristic changes in stomatal movement to the time of irrigation need. Their results showed that stomata of non-irrigated plants opened very little and only early in the morning, whereas stomata of irrigated plants remained wide open throughout the day. Dry weights and yield of grain of the plants at harvest showed that this difference in stomatal behavior between the non-irrigated and irrigated plants seemed to have affected their assimilation. Finally, they concluded that the degree of stomatal opening during the day may indicate how much water is available to the plants and data from this might help in working out a definite schedule for irrigation of wheat.

Halevy (31) in 1960, in his experiment on moisture relations in gladiolus, used an infiltration method with a series of 11 liquids which were mixtures of odorless kerosene and medicinal paraffin oil resulting in a range of viscosities. The degree of stomatal opening of the leaves was determined by applying mixtures of decreasing viscosity to the median portion of leaves. The liquid which was infiltrated first within 5 seconds, was recorded as representative of the degree of stomatal opening of the plant leaf and each recorded figure was the average of 10 such readings. From this study Halevy found that if an infiltration mixture of 65% kerosene and 35% paraffin oil did not penetrate within 5 seconds into at least half of the plants examined, then irrigation was necessary.

On the other hand Bybordi (7) who conducted a similar experiment on corn and potatoes found that the stomatal opening of the potato leaves was greater than that of the corn leaves. This indicates that the method must be correlated with each species since there is considerable diffefence in size of stomata.

MATERIALS AND METHODS

Each of three variables nitrogen, sodium and irrigation interval, was varied at five different levels which were coded as -1.68, -1, 0, +1 and 1.68 (table 1) in order to simplify analysis of the data. The experimental design was a central composite, rotatable, incomplete factorial with fifteen treatments. One of these treatments was replicated six times in order to allow estimation of the experimental error.

Table 1. Rates of application of nitrogen and sodium for sugar beets.

Level	Coded rate	Kg./ha.
1	- 1.68	20.2
2	- 1.0	40.6
3	0	110.0
4.	+ 1.0	300.0
5	+ 1.68	590.0

Treatments were randomly assigned to 20 plots, each 3 m. wide by 8 m. long with 6 rows. Each plot was a basin in order to allow individual irrigation.

The statistical analysis was according to Cochran and Cox (9) whereby the regression equations of the quadratic form were computed: $Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3$

$+ b_{23}x_2x_3$. .

Where x_1 = coded level of N

x_2 = coded level of Na

x_3 = coded level of irrigation interval

b = regression coefficient for treatment effect.

In order to find the significance of the individual regression coefficients the "t" test was used. The nature of the response surfaces for the important interactions was determined from the regression equations.

On March 29, 1963, the 20 plots were prepared and planted. The fertilizers were distributed by hand in furrows between the ridges. Then, the ridges were split which covered the fertilizers with about 10 cm. of soil. Seeds of the sugar beet variety, Kleinwanzleben, were drilled with a planet Jr. seeder at a depth of about 2 cm. in the upper part of the ridges directly above the fertilizer bands.

The carriers for nitrogen were NH_4NO_3 and $NaNO_3$ and those for sodium were NaCl and $NaNO_3$. In addition to nitrogen and sodium, 200 kg/ha. of phosphorous and 227.5 kg/ha. of chlorine were also applied. All these fertilizers were applied in one application in a band at the time of planting.

The first thinning was done 5 weeks after planting and the final thinning to single plants with a total of 40 plants per 8 m. was done 7 weeks after planting.

Metasystox was spread by sprayer twice to control cutworms and leaf hoppers and karathane was applied four times during the experimental period against powdery mildew.

From the four center rows of each plot 20 "recently matured" leaves for petiole samples were collected at random on July 4, August 8, September 8 and October 10, 1963, for determination of the concentrations of nitrate N and Na in the petioles at different stages of growth.

On the 7th of November, the beets from the middle 6 meters of the two center rows of each plot were harvested. Three representative beets and four representative top samples were taken from each plot for moisture, sugar and nitrogen analysis.

The daily irrigation requirement was calculated to be about 8.74 cubic feet per plot. The method of irrigation was the furrow system and the irrigation was done according to the schedule (table 2) given below. Enough water was applied each time to bring the soil moisture to field capacity. The total amount of water applied was about the same in all cases. The regular irrigation for the experiment started on June 20. The four weeks before this all the plots were sprinkled each week.

Table 2. Irrigation Schedule

Level	Days of interval	Time required/ irrigation, min.	Amt. of water applied each time (approx.)	No. of Irrg.	Total amt. of water applied (approx.) (inches)
1	1	8 - 10	0.4 ins.	126	51
2	3.5	30	1.4 "	36	51
3	7	60	2.8 "	18	51
4	10.5	90	4.2 "	12	51
5	14	120	5.7 "	9	51

Petiole Analysis

Nitrate-nitrogen: The nitrate-nitrogen in the presence of chlorine was determined by the phenol-disulphonic acid method according to the procedure given by Ulrich et al. (78).

Sodium: Sodium was determined in the water estract solution by a Beckman DU emission spectrophotometer (42).

Tops and Roots Analysis

Total nitrogen: Total nitrogen was determined according to the Kjeldahl procedure given by Jackson (42).

Sodium: Sodium was determined from a water extract as described for petioles.

Sugar Analysis:

The concentration of sucrose of the roots was determined according to the procedure given by A.O.A.C. (55).

Stomatal Opening

A series of eleven liquids were used for measurement of stomatal opening. These liquids were mixtures of kerosene and paraffin oil (table 3).

Table 3: Oil mixtures (paraffin + kerosene)

Grade	% Paraffin	% Kerosene
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	40	60
8	30	70
9	20	80
10	10	90
11	0	100

Grade 1 was pure liquid paraffin (highest viscosity) and No. 11 pure kerosene (lowest viscosity). In between, the grades differed from each other by steps of 10% by volume. Medicinal paraffin and locally available kerosene were used. The relative viscosities compared to water were 6.161 and 0.613, respectively. The greater the degree of opening of the stomata of the leaves the more viscous the liquid (lower the grade) that can be absorbed. The mixture of decreasing viscosity was applied to the median portion of leaves for determining the degree of stomatal opening. The lowest grade which was absorbed within 5 seconds and the average of 10 readings was reported as representative of the degree of stomatal opening of the plant leaf.

RESULTS AND DISCUSSION

The experiment reported here was designed to study the effect of N and Na and irrigation interval on the growth of sugar beets, yields of roots, tops and sugar, sucrose concentration in the roots and chemical composition of roots, tops, and petioles. A central composite, rotatable, incomplete factorial design was used. In the discussion, the term "highly significant" will be used for an effect with a probability of 0.99 or more of being true and "significant" will be used for a probability of 0.95 to 0.99 of being true. The term moisture tension and soil moisture stress have been used interchangeably in this paper since it was assumed that the osmotic pressure of the soil solution was negligible in this case.

Results of Soil and Water Analysis

The soil pH at a 1:2.5 dilution was 8.2 and the calcium carbonate concentration was 39.3 per cent (table 4). The total nitrogen of the soil was found to be 0.131 per cent indicating a relatively low supply of N. The organic matter content was also low, 1.29 per cent by the wet combustion method. The cation exchange capacity and the exchangeable calcium, magnesium, potassium and sodium were 42.36, 26.80, 13.34, 1.02 and 1.20 m.e./100 g. of soil, respectively. The water was considered to be of good quality (35) (table 4).

Table 4. Results of chemical analysis of the surface soil for the experimental plots and of the irrigation water.

Soil Analysis		Water Analysis (35)	
p^H (1:2.5)	8.2	Sodium	0.282 m.e./liter
Calcium carbonate, %	39.3	Calcium	0.705 "
Organic matter, %	1.29	Magnesium	0.833 "
Total nitrogen, %	0.131	Potassium	0.056 "
		Sulfur	0.125 "
		Chlorine	0.318 "
Cation Exchange			
Capacity m.e./100 g.	42.36		
Exchangeable			
Cations m.e./100 g.		Electrical conductivity	
Calcium	26.80		0.155 m.mho/cm.
Magnesium	13.34		
Potassium	1.02		
Sodium	1.20		

Effect of Nitrogen Application

The application of N had a considerable positive effect on yield of sugar beet roots, tops and sucrose as indicated by the respective first order regression coefficients (table 5, figure 1). The greatest effect was on the yield of tops, however (figure 2). Economic analysis of the data indicated a wide range of application, 150 - 450 kg./ha., at which return above fertilizer cost remained relatively constant, thus minimizing the effect of a poor estimation of the optimum application rate. As found by many workers (3, 20, 21, 35, 41, 64, 77), N application tended to decrease the sucrose concentration and to increase the N concentration of the roots (table 6). The decrease in sucrose percentage was not of large magnitude and the positive and highly significant interaction between N and irrigation interval indicated that the decrease was nullified at the longer intervals (figure 3). In only one plot was the N concentration of the fresh roots greater than 0.2% the level above which the sedimentation rate in the sugar extraction process was undesireably low as found by Goodban et al. (18). However, the first order and interaction effects were all positive and of considerable magnitude although only the first order N effect was statistically significant. Thus, the higher application rates of N and Na and longer irrigation intervals all tended to increase the amount of N in the roots (table 6, figure 4).

The nitrate N concentration of petioles was found to be a sensitive indicator of the N status of the plant as was also found by Ulrich (76, 77), Hashimi (35) and others (24, 26). When all the N fertilizer

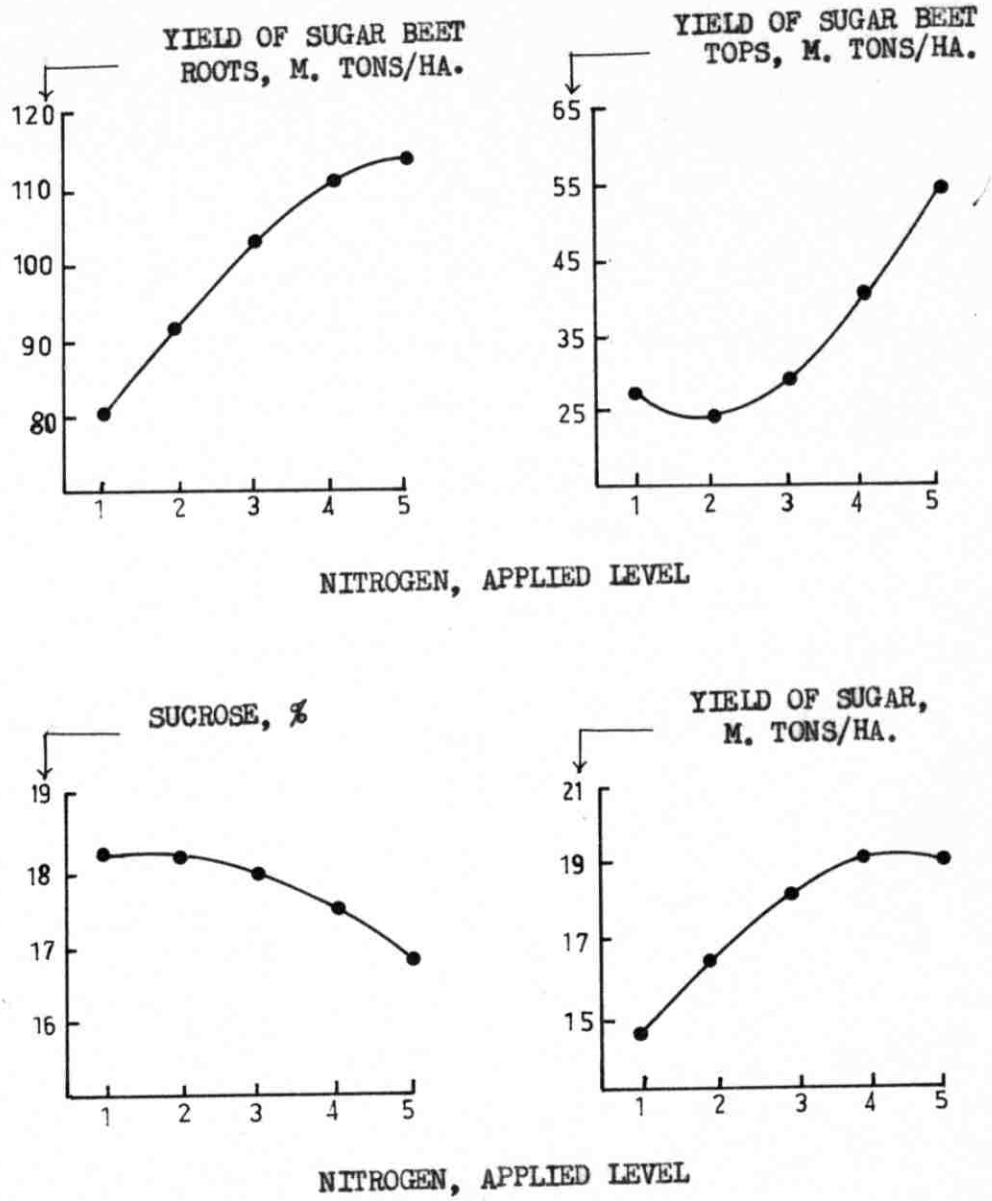

Figure 1. Effect of applied nitrogen on yields of sugar beet roots (fresh basis), tops (wet basis), and sugar and per cent sucrose in the roots. Data were calculated from the regression equations. Levels of sodium and the irrigation interval were held at the third of five levels.

Table 5. Regression coefficients (b) and the probability of a true effect (p) for yield of roots (fresh basis), yield of tops (wet basis), and yield of sucrose as affected by various combinations of levels of N and Na and irrigation interval.

Coefficient	Roots m. tons/ha b	p	Tops m. tons/ha b	p	Sucrose m. tons/ha b	p
Mean	102.04		27.62		18.21	
N	+ 9.73	.98	+8.07	.99	+1.34	.94
Na	+ 0.64	.16	-0.06	.02	+0.05	.06
X[1]	- 2.37	.56	-1.19	.46	+0.85	.82
NN	- 1.69	.44	+4.68	.95	-0.51	.62
NaNa	+ 1.60	.42	-0.41	.16	+0.39	.50
XX	+ 0.20	.05	-1.52	.57	+0.11	.16
N-Na	- 4.76	.75	+0.19	.06	-1.24	.86
N-X	+ 3.94	.66	-0.46	.14	+1.36	.88
Na-X	+ 3.94	.66	+1.86	.52	+1.64	.93

1. X is the irrigation interval.

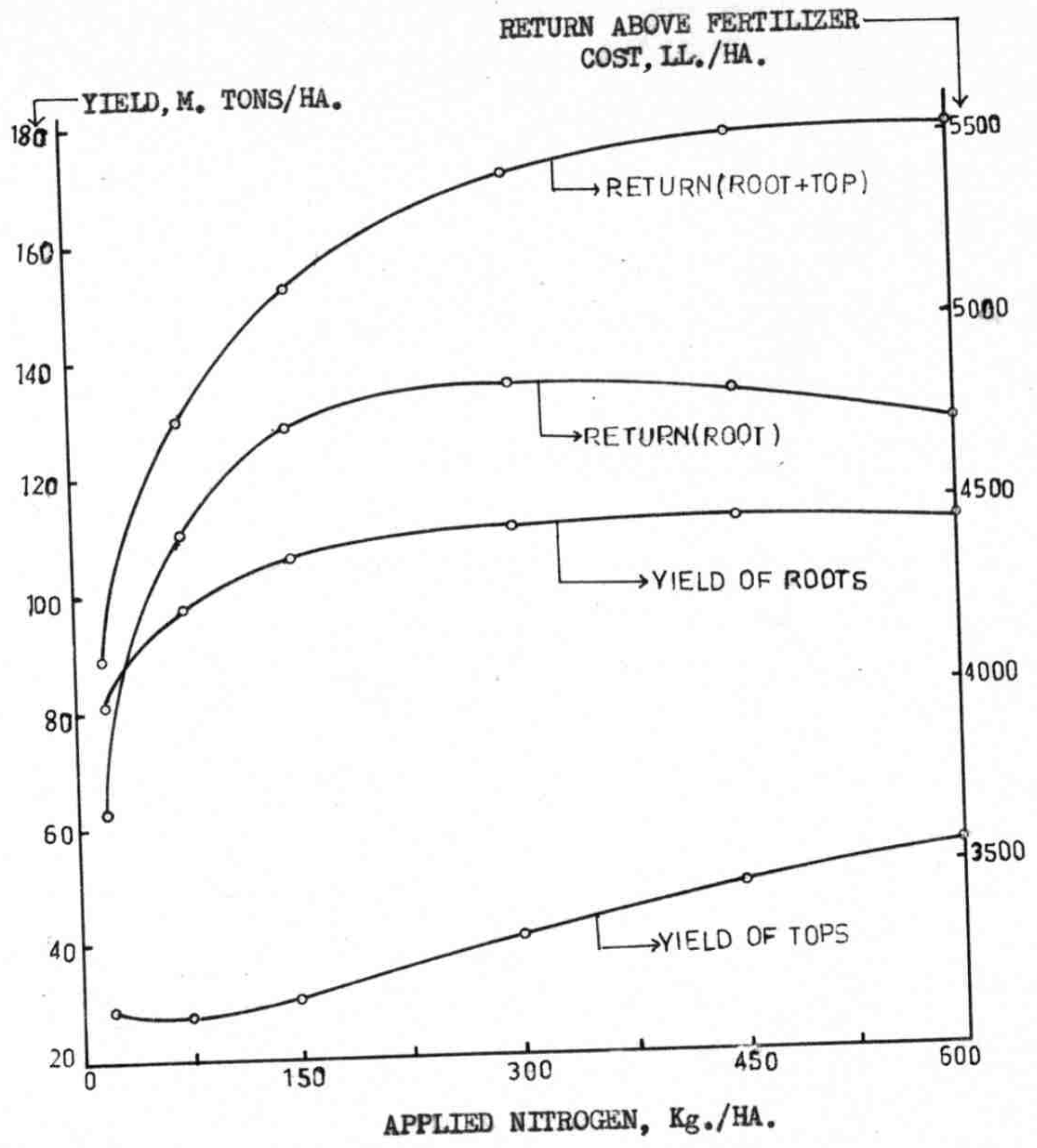

Figure 2. Effect of nitrogen on yield of sugar beet roots and tops and return above fertilizer cost. Data were calculated from the regression equations. Levels of irrigation interval and Na were held at the third of five levels of application. Prices used were: beets at 49.50 LL/ton, tops at 15.00LL/ton, N at 1.00 LL/Kg., P at 1.45 LL/Kg., and NaCl at 0.15 LL/Kg.

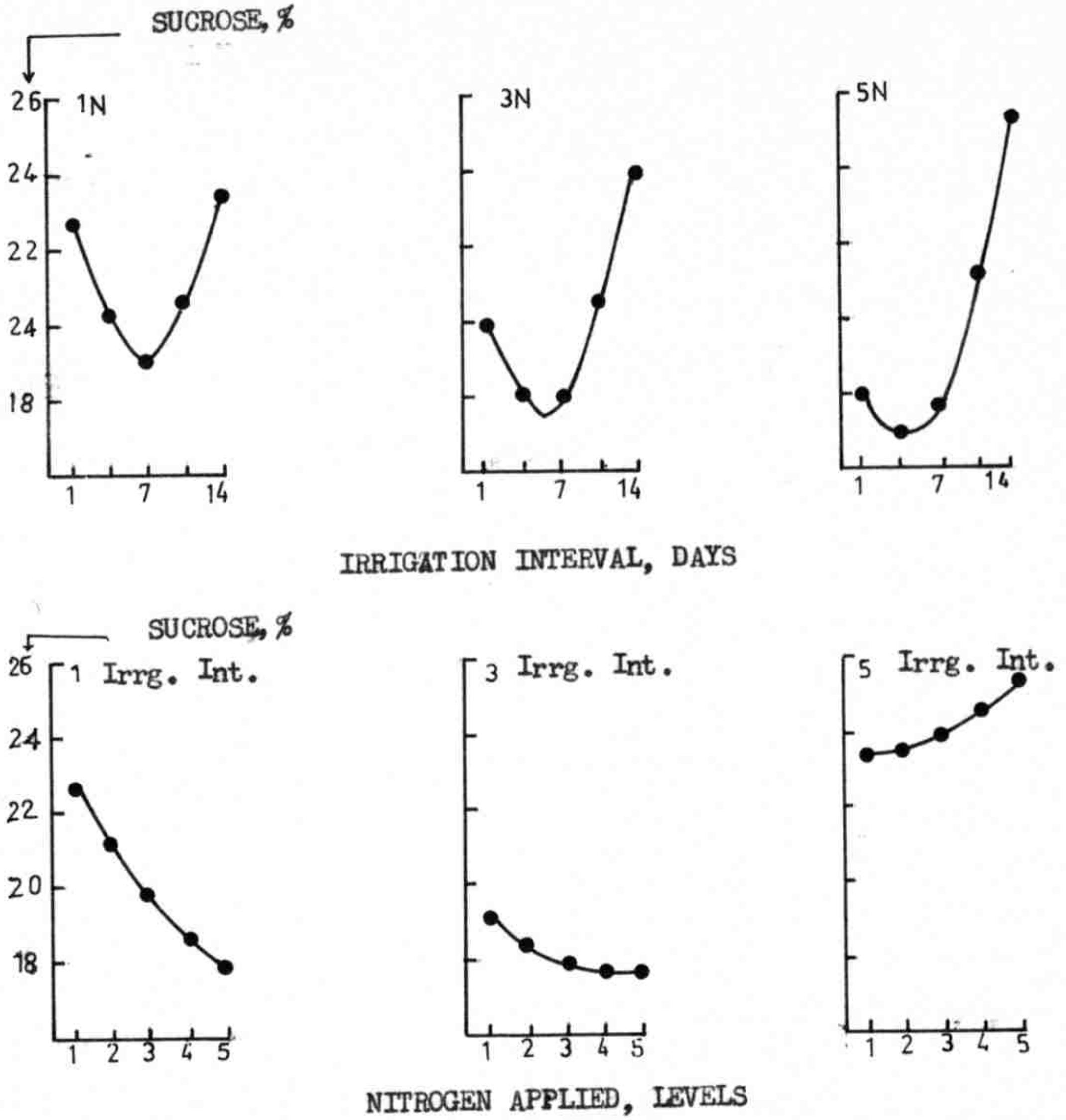

Figure 3. Sucrose concentration in the roots as affected by irrigation intervals at constant levels of applied nitrogen (above) and by levels of applied nitrogen at constant irrigation intervals (below). Level of sodium was held at the third of five levels of application. Data were calculated from the regression equation.

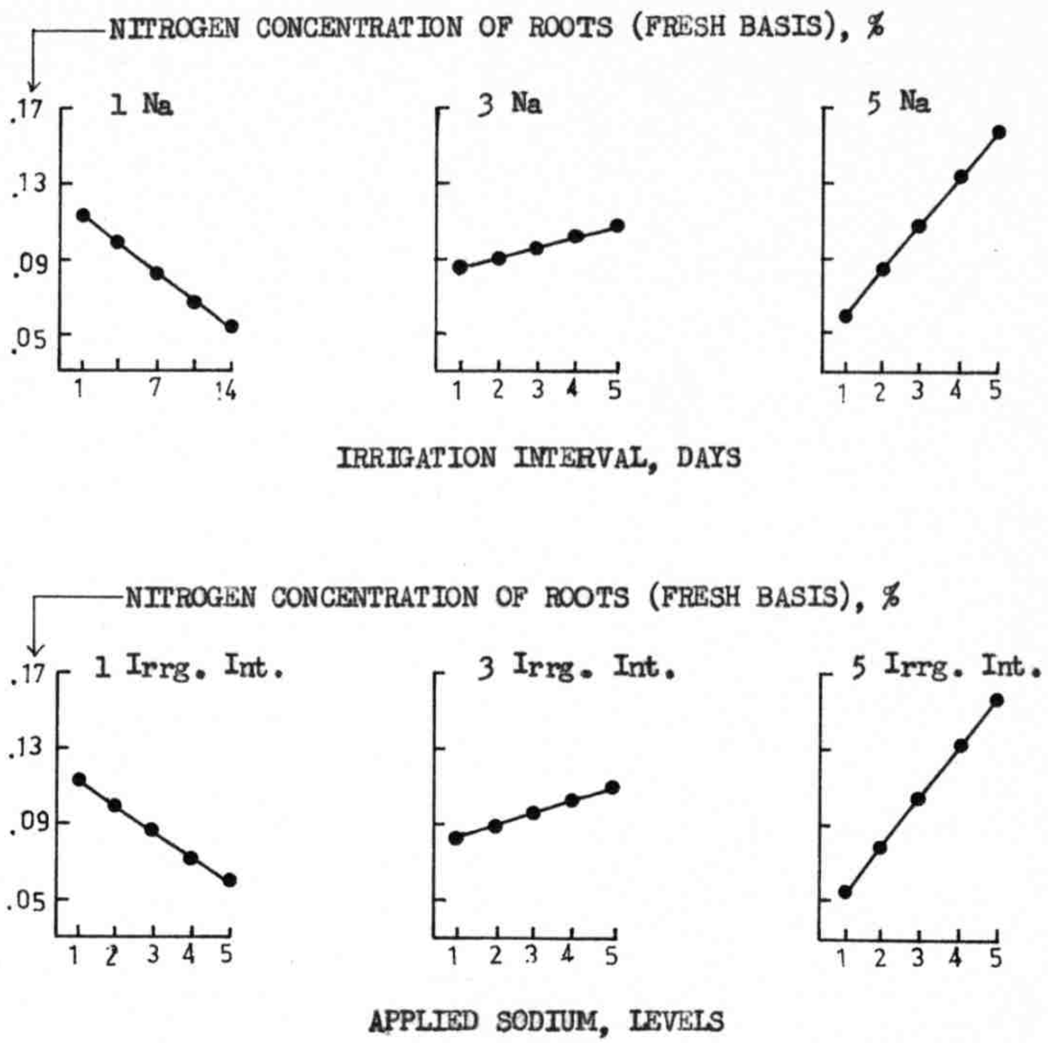

Figure 4. Nitrogen concentration of roots (fresh basis) as affected by irrigation intervals at constant levels of applied sodium (above) and by levels of applied sodium at constant irrigation intervals (below). Levels of nitrogen was held at the third of five levels of application. Data were calculated from the regression equation.

was applied at planting time the critical level of nitrate N in the petioles was found to be 5,000 ppm. on the dry basis early in the season decreasing to about 1,000 ppm. at a time about one month before harvest (figure 5). The direct effect of N application on the average seasonal nitrate-N concentration of petioles was positive and highly significant (table 6). The N Na interaction (table 6, figure 6) was significantly negative indicating that Na application tended to reduce the uptake of nitrate at high N levels and to increase it at low N levels. The interaction between N and irrigation interval was positive and highly significant for the seasonal nitrate concentration of petioles (tables 6, 7, figure 7) indicating that increasing the irrigation interval increased nitrate at high N levels and decreased it at low N levels. Since the total amount of water applied was approximately the same regardless of the interval between irrigations, difference in the leaching of nitrate was probably not involved. The different effects of irrigation interval on petiole nitrate concentration at low and high N application levels were confirmation that differences in leaching of nitrate were negligible. Application of N increased both yield and the total N concentration of sugar beet tops resulting in considerably more feed production per hectare and also in high feeding quality through higher protein content (tables 5, 6, figure 2). The application of N increased the Na concentration of sugar beet roots, tops and petioles and in the case of the roots and petioles, N application had a greater positive effect than Na application.

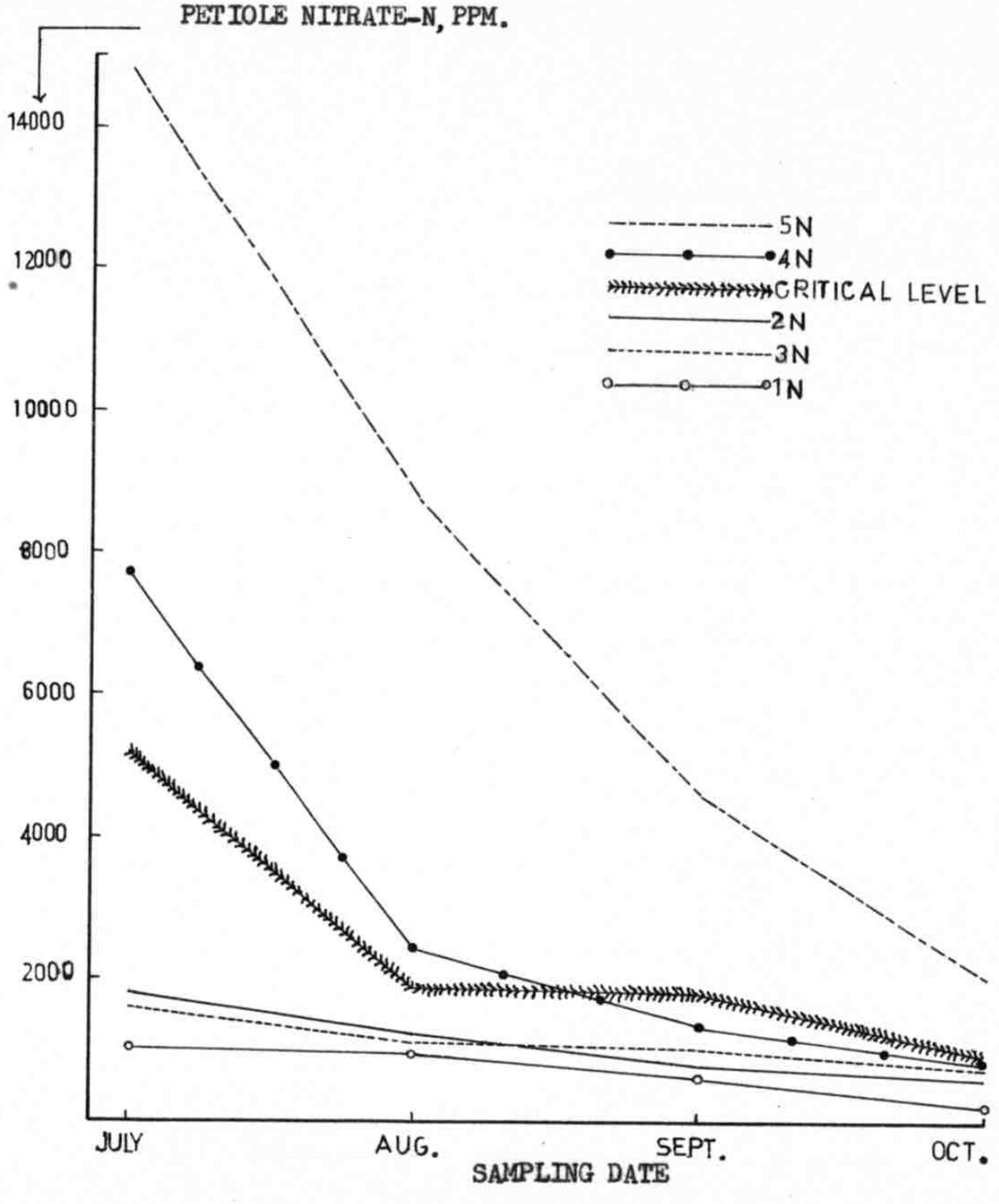

Figure 5. Observed seasonal change in average nitrate nitrogen concentration of petioles (recently mature, ppm., dry basis) and the calculated seasonal critical level.

Table 6. Regression coefficients (b) and the probability of a true effect (p) for sucrose concentration of roots (fresh basis), nitrogen concentration of roots (fresh basis), mean seasonal nitrate-nitrogen concentration of petioles (dry basis), and nitrogen concentration of tops (dry basis).

Coefficient	Sucrose %		N-Roots %		Nitrate-N log ppm.		N-Tops %	
	b	p	b	p	b	p	b	p
Mean	17.85		0.0967		3.031		1.786	
N	-0.42	.94	+0.0307	.99	+0.2446	.99	+0.244	.98
Na	-0.06	.24	+0.0075	.88	-0.0143	.50	+0.047	.49
X[1]	+1.20	.99	+0.0062	.82	-0.0112	.42	-0.142	.91
NN	-0.13	.52	+0.0025	.45	+0.1415	.99	+0.195	.97
NaNa	+0.08	.34	-0.0045	.70	-0.0212	.68	-0.033	.36
XX	+0.04	.18	+0.0082	.91	+0.0770	.99	+0.098	.81
N-Na	-0.46	.90	+0.0096	.87	-0.0576	.95	-0.135	.82
N-X	+0.59	.95	+0.0069	.76	+0.0924	.99	+0.055	.44
Na-X	+0.99	.99	+0.0136	.94	-0.0274	.67	+0.070	.54

1. X is the irrigation interval

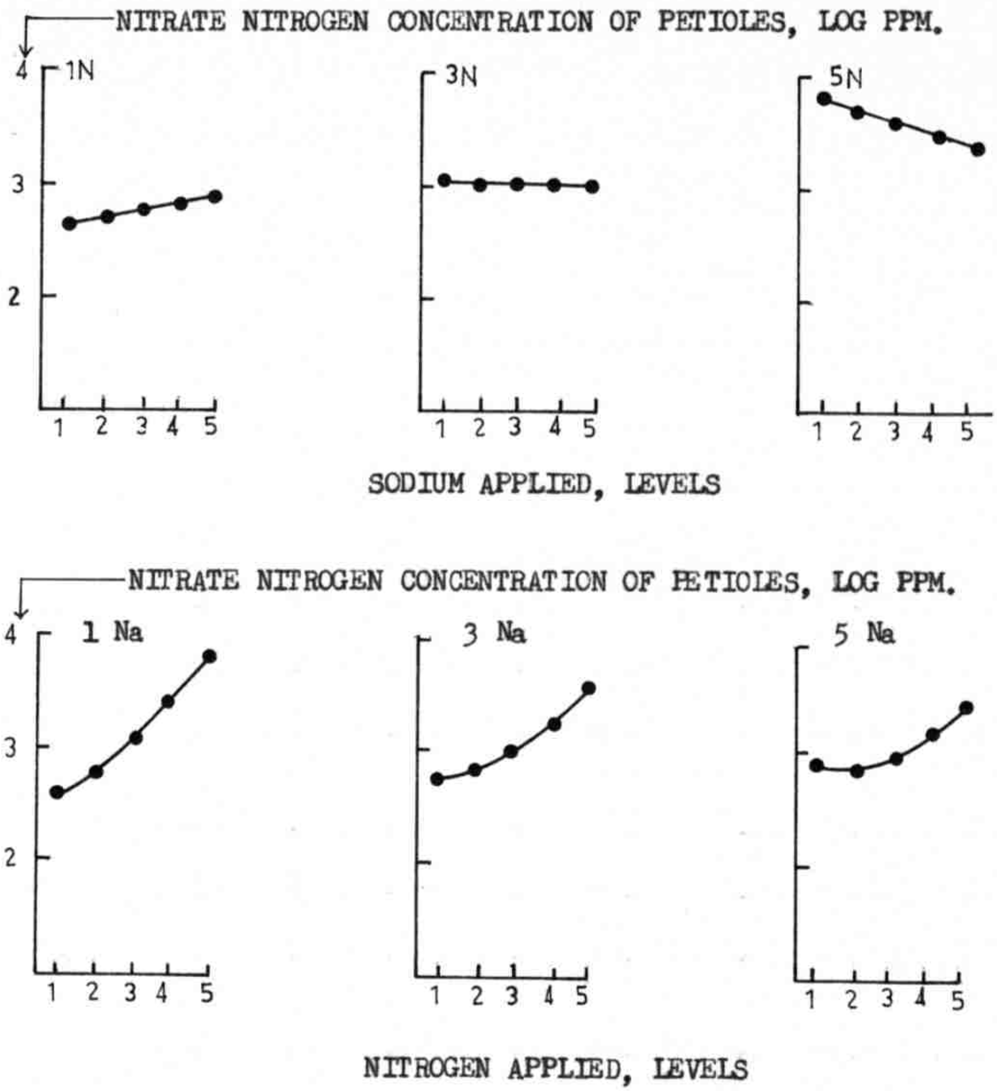

Figure 6. Seasonal average of nitrate nitrogen concentration of petioles of recently mature leaves (dry basis) as affected by applied sodium at constant levels of nitrogen (above) and by levels of applied nitrogen at constant levels of sodium (below). Irrigation interval was held at the third of five levels. Data were calculated from the re - ression equation.

Table 7. Regression coefficients (b) and the probability of a true effect (p) for nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, log ppm.) as affected by various combinations of levels of N and Na and irrigation interval.

Coefficient	July		August		September		October	
	b	p	b	p	b	p	b	p
Mean	3.188		2.905		3.068		2.881	
N	+0.331	.99	+0.193	.99	+0.160	.99	+0.118	.99
Na	-0.009	.16	-0.021	.48	+0.002	.07	+0.020	.48
X[1]	-0.018	.36	+0.039	.74	-0.036	.80	-0.025	.56
NN	+0.191	.99	+0.201	.99	+0.039	.83	-0.001	.01
NaNa	-0.023	.44	-0.002	.04	-0.070	.96	-0.023	.55
XX	+0.096	.95	+0.114	.98	+0.019	.54	+0.017	.44
N-Na	-0.100	.90	-0.043	.67	+ .024	.51	+0.043	.67
N-X	+0.124	.94	+0.094	.93	+0.011	.21	+0.086	.92
Na-X	-0.062	.74	-0.010	.18	+0.006	.13	+0.006	.12

1. X is the irrigation interval

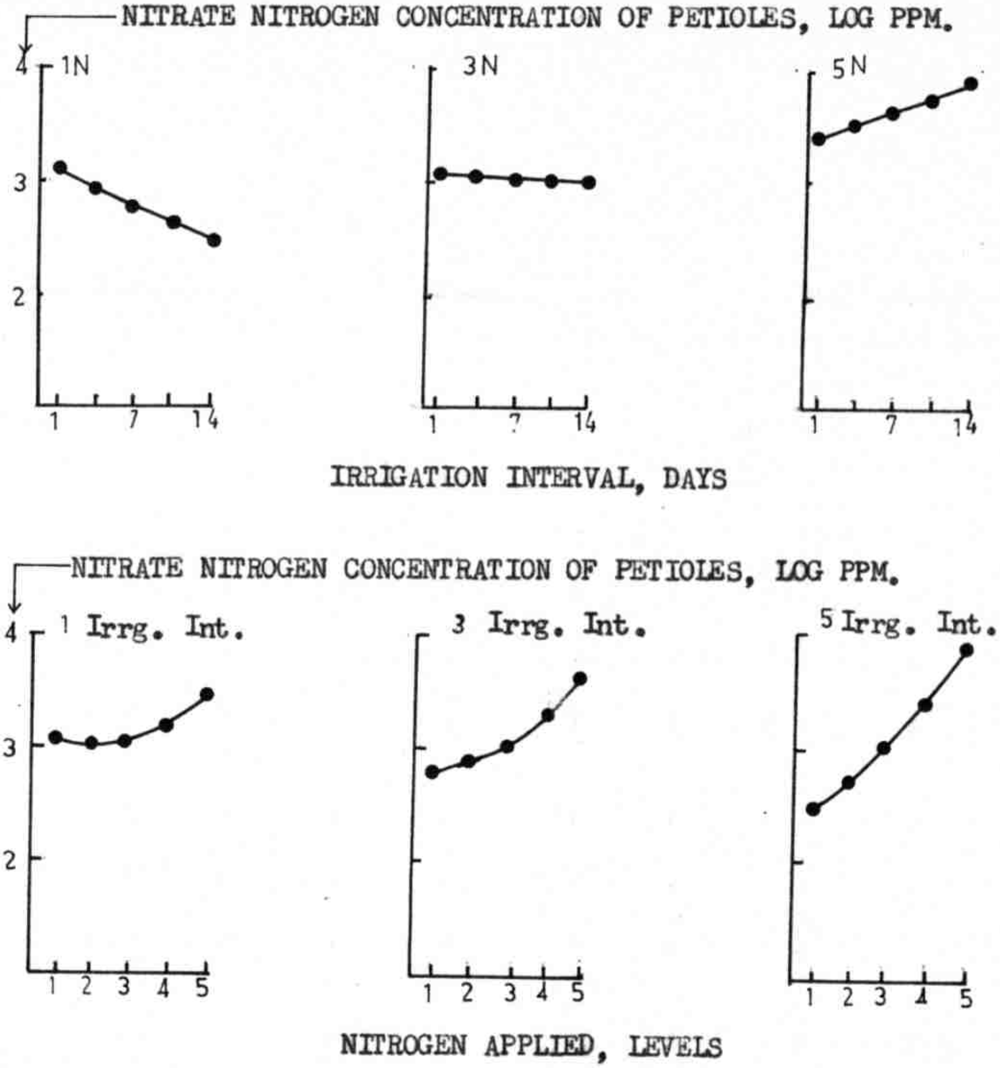

Figure 7. Seasonal average of nitrate nitrogen concentration of petioles of recently mature leaves (dry basis) as affected by irrigation intervals at constant levels of nitrogen (above) and by levels of applied nitrogen at constant irrigation intervals (below). Level of sodium was held at the third of five levels of application. Data were calculated from the regression equation.

Effect of Sodium

The application of Na to sugar beets had very little first order effect on yields of roots, tops or sugar or on per cent sucrose (table 5, figure 8). Fuehring (16) and Hashimi (35) had similar results on root yield but Hussaini (41) and Adams (1) found a significant positive response to Na application in the case of root yield and sucrose concentration.

Study of the effect of the positive Na-Irrigation Interval interactions (tables 5, 6) on sucrose concentration (figure 9) and yield of sugar (figure 10) revealed that increasing the irrigation interval at a low sodium level decreased the sucrose concentration in the root and the yield of sugar while this effect was reversed at high sodium levels. Also, at the shorter irrigation intervals, increasing Na application resulted in a general reduction in sucrose concentration and yield. However, a high positive response to Na was indicated when the irrigation interval was long. Therefore it appeared that application of Na permitted lengthening of the irrigation interval without decreasing the yield of sugar. Possibly one of the main beneficial effects of Na on sugar beet yield is increased resistance or tolerance to periods of moisture stress.

The interactions of N-Na on the yields of roots and sugar (table 5) and on sucrose concentration (table 6) were negative which indicated that sodium tended to depress the positive effect of nitrogen fertilization on yield and also the decreasing effect of nitrogen on the sucrose concentration.

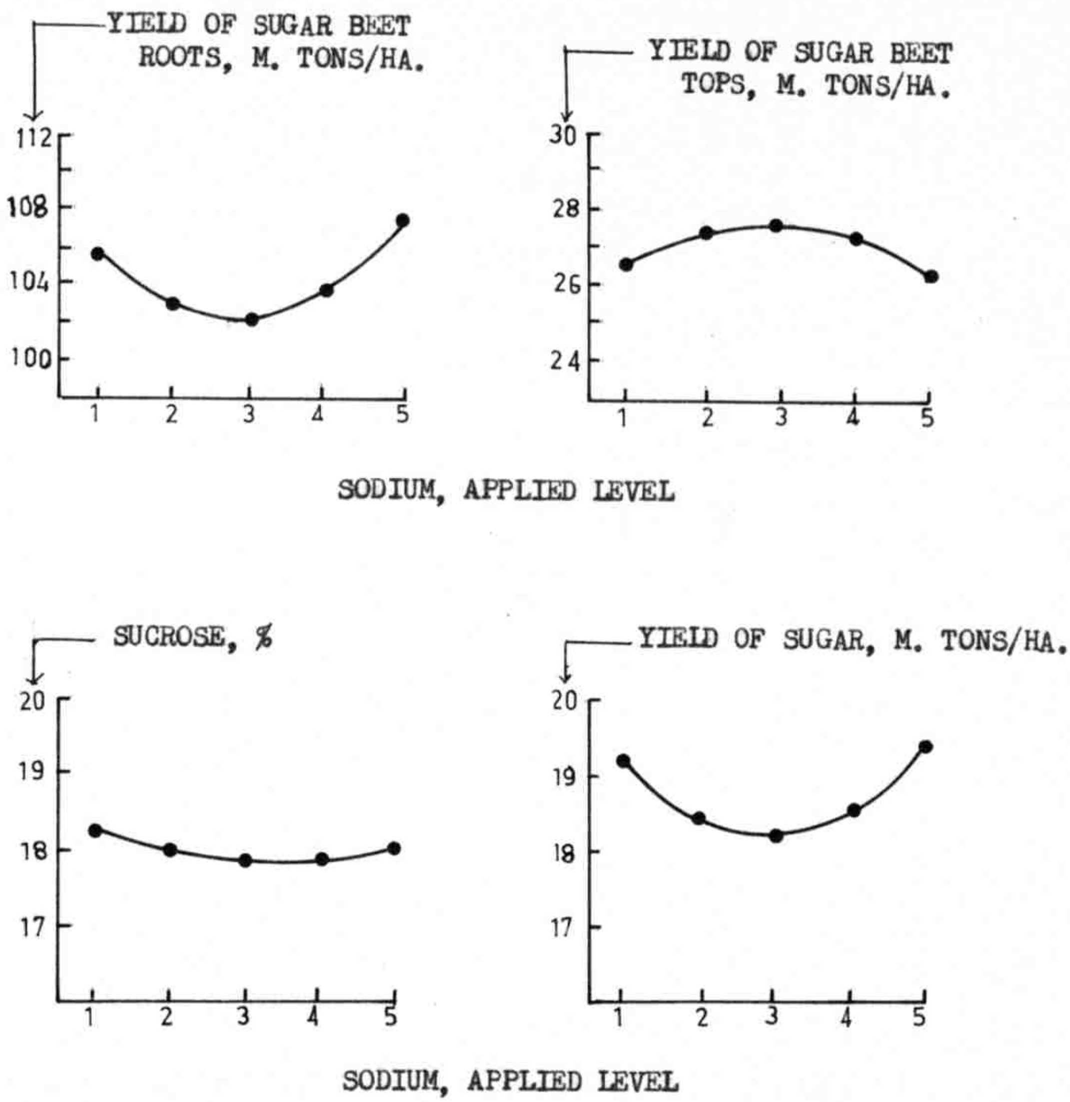

Figure 8. Effect of applied sodium on yield of sugar beet roots (fresh basis), tops (wet basis), and sugar and per cent sucrose in the roots. Data were calculated from the regression equations. Levels of nitrogen and water were held at the third of five levels of application.

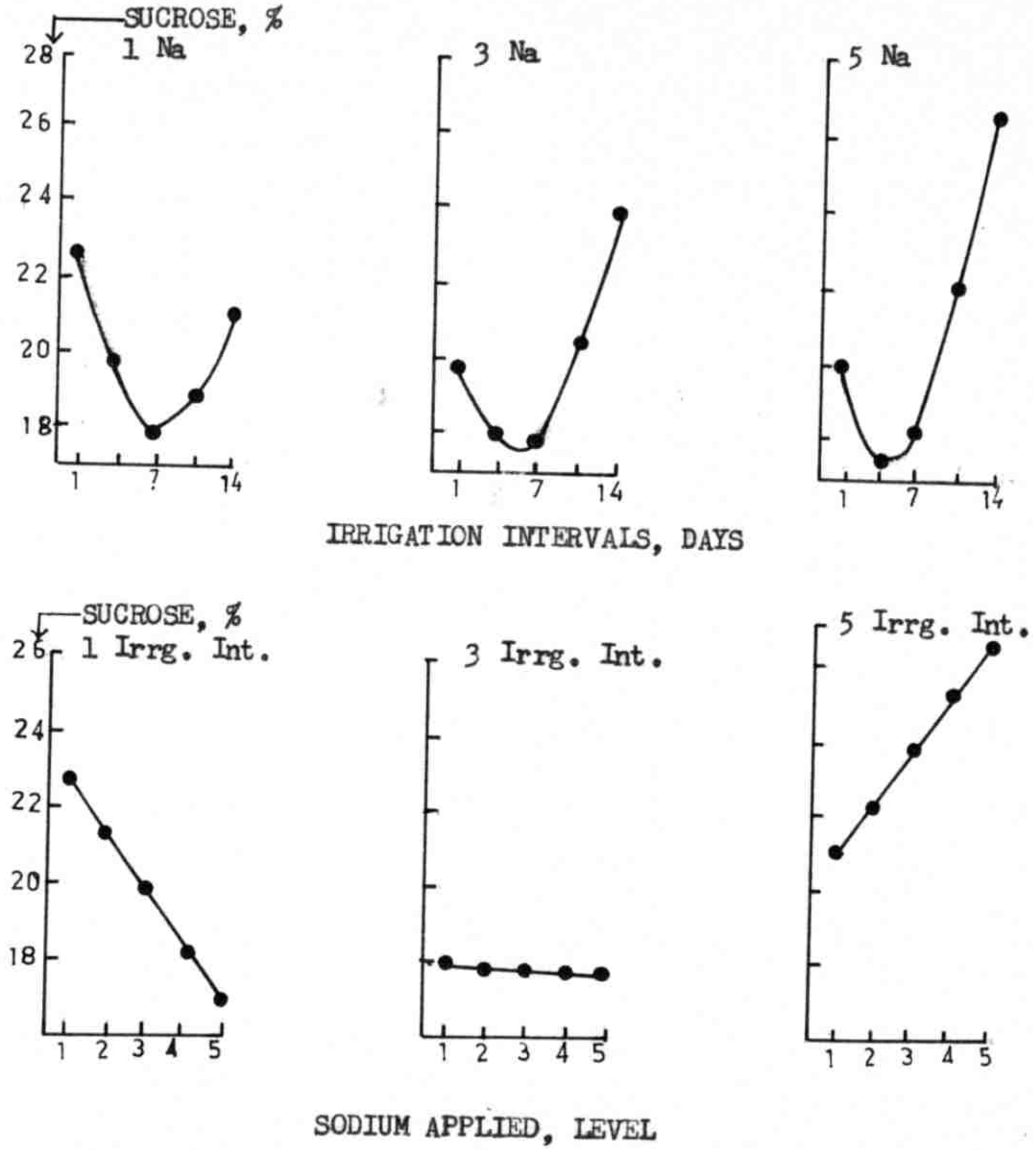

Figure 9. Sucrose concentration in the roots as affected by irrigation intervals at constant levels of applied sodium (above) and by levels of applied sodium at constant irrigation intervals (below). Level of nitrogen was held at the third of five levels of application. Data were calculated from the regression equation.

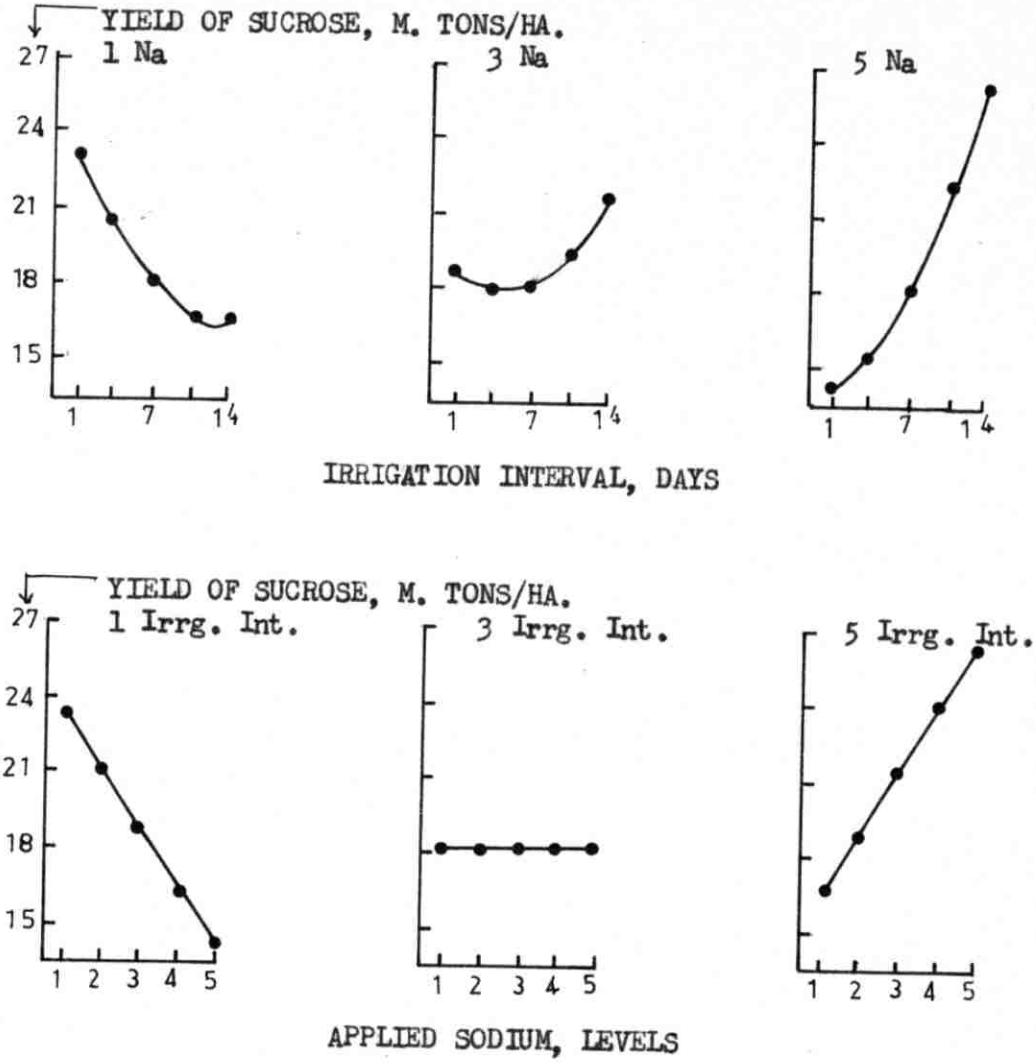

Figure 10. Yield of sucrose as affected by irrigation intervals at constant levels of applied sodium (above) and by levels of applied sodium at constant irrigation interval (below). Level of nitrogen was held at the third of five levels of application. Data were calculated from the regression equation.

The application of Na significantly increased its concentration in the petioles, and in the roots (table 8). However, Na had less positive effect on the Na concentration in different parts of the plant than N had (table 14).

Table 8. Regression coefficients (b) and the probability of a true effect (p) for sodium concentration of roots (dry basis), sodium concentration of tops (dry basis), and mean seasonal sodium concentration of petioles (dry basis) as affected by various combinations of levels of N and Na and irrigation interval.

Coefficient	Na-Roots, %		Na-Tops, %		Na-petioles, %	
	b	p	b	p	b	p
Mean	0.135		2.098		1.9108	
N	+0.108	.99	+0.118	.86	+0.3134	.99
Na	+0.042	.92	+0.244	.99	+0.2175	.99
X[1]	+0.002	.07	+0.226	.98	+0.1794	.98
NN	+0.095	.99	+0.154	.93	+0.0820	.86
NaNa	-0.011	.42	+0.071	.67	+0.0289	.44
XX	-0.001	.03	-0.056	.56	+0.0202	.30
N-Na	-0.001	.02	+0.120	.76	-0.0163	.19
N-X	+0.016	.45	+0.107	.72	+0.0862	.67
Na-X	+0.027	.67	+0.080	.59	+0.0212	.24

1. X is the irrigation interval.

Effect of Irrigation Interval

Increasing the irrigation interval, as was found by other workers (50, 69), tended to decrease the yield of roots and tops (table 10, figure 11). In accordance with the results of Loomis and Worker (50), higher soil moisture stress increased sucrose concentration considerably ($p = 0.99$, table 6). The increased sugar percentage obtained in this experiment was more than enough to offset the decreased root yield and the yield of gross sugar tended to increase (table 10, figure 11). These results confirmed the general conclusion made by Watson (82) and others (40, 69) that sugar beets are relatively insensitive to moisture stress. Haddock et al. (29) on the otherhand, using a higher soil moisture stress than that used in the present experiment, found a significant decrease in yield with increasing moisture stress.

In the long interval plots, plants were in a state of temporary wilting during a part of each day after 7 to 10 days from irrigation. Soil moisture determinations showed that this wilting state occured at a soil moisture tension of 6.5 atm. at a depth of 16 inches which corresponded to the loss of about 80 per cent of the available (15 atm.) moisture at that depth (figure 12).

Increasing irrigation interval tended to increase the N in the roots and to decrease N in the tops (table 6). The first order effect of irrigation interval was significantly positive for Na concentration in the tops and petioles (table 8).

An attempt was made to relate the degree of stomatal opening to the length of the time since irrigation or the degree of soil moisture

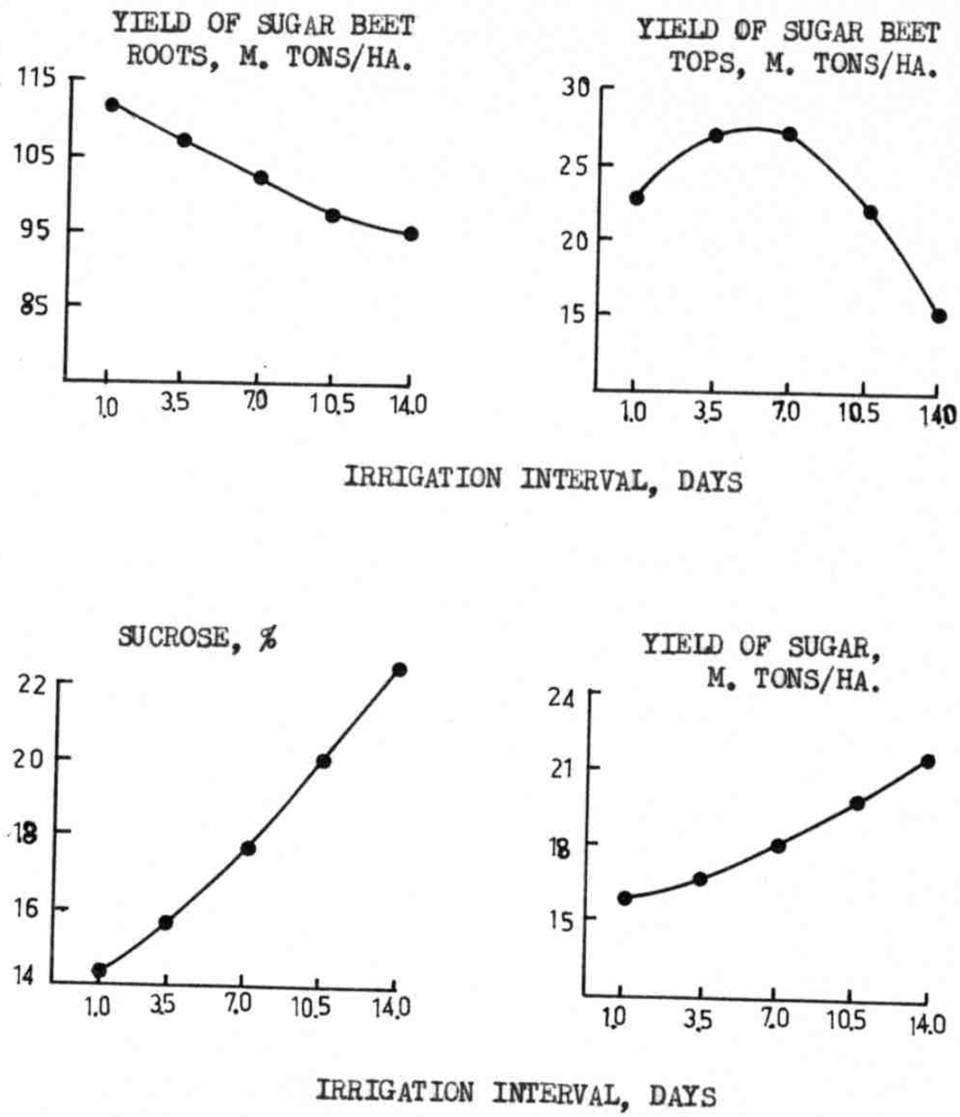

Figure 11. Effect of irrigation interval on yield of sugar beet roots (fresh basis), tops (wet basis), and sugar and per cent sucrose in the roots. Data were calculated from the regression equations. Levels of nitrogen and sodium were held at the fourth and third of five levels of application respectively.

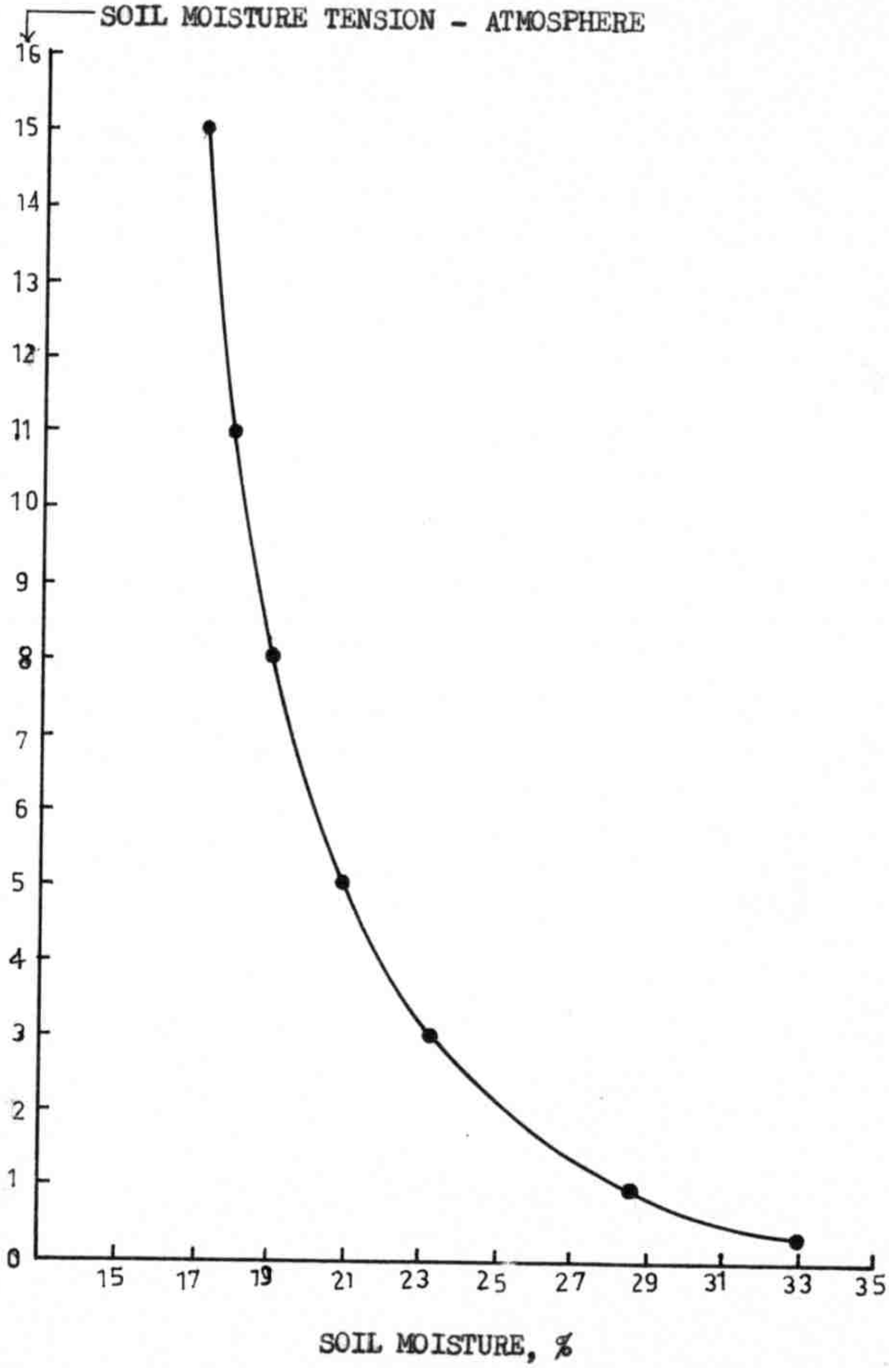

Figure 12. Relation between the soil moisture tention and the moisture content of the soil.

stress (table 9). The degree of stomatal opening was determined by noting the most viscous grade of oil (mixture of paraffin oil and Kerosène, table 3) which could be absorbed by the leaves in 5 seconds between 8 and 11 o'clock each day. A definite gradual decrease in viscosity of the oil that could be absorbed was observed in each irrigation cycle indicating that the oil absorption test was a sensitive and rapid field method for estimating the moisture status of the plants. It was found with sugar beets that the plants wilted during the hottest part of the day when maximum viscosity oil absorbed was grade 4 (early in the season) or grade 5 (late in the season) and this occured at a soil moisture tension of about three atmospheres at 16 inches depth (table 3, figure 12). At three atmospheres tension, about 60 per cent of the potentially available water at that depth had been used. There was a tendency for the degree of plant moisture stress to increase with the average air temperature and the associated increase in the rate of transpiration.

Since the yield of beet roots was only slightly reduced and yield of sugar even increased when the irrigation interval extended beyond the time when temporary wilting occured, it was concluded that wilting was a good indicator that irrigation needed to be done soon but a short period (3 or 4 days) of temporary wilting would have little detrimental effect. However, with more sensitive crops such as corn and potatoes (7) the onset of temporary wilting would be too late and here the use of oil as an indicator for plant moisture stress would have practical value. This method must be calibrated with each plant species because of considerable difference in size of stomatal opening (7, 31).

SUMMARY AND CONCLUSIONS

The effects of various levels and combinations of N and Na and irrigation interval on sugar beets on a calcarious soil were studied. The oil drop penetration method as an indicator of the degree of stomatal opening was related to the degree of soil moisture stress.

The application of N considerably increased the yield of sugar beet roots, tops and sucrose. Economic analysis showed a wide range, 150-450 Kg./ha. of N over which return above fertilizer cost was relatively constant. The application of N tended to decrease the sucrose concentration and to increase the N concentration in the roots. The nitrate N concentration was found to be a good indicator of the N status of the plant. When all the N fertilizer was applied at planting, 5,000 ppm. of nitrate N in the petioles on the dry basis was estimated to be the critical level early in the season decreasing to about 1,000 ppm. at a time about one month before harvest.

The application of either N or Na increase the resistance of sugar beet plants to increased moisture stress.

Increasing irrigation interval tended to decrease the yield of roots and tops and to increase yield of sugar through increased sucrose concentration of the roots. It was concluded that sugar beet plants were relatively insensitive to moisture stress even though temporary wilting occured for short periods in each irrigation cycle. The stomatal opening technique worked well as a method for field determination of soil moisture status showing a steady and progressive difference throughout the cycle. However, with more sensitive crops such as corn and potatoes the onset of temporary wilting would be too late as an indicator of irrigation need and here the use of oil as an indicator for plant moisture stress would have practical value. The method must be calibrated with each species of plant because of difference in the stomatal size.

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APPENDICES

Table 10. Observed yield of roots (fresh basis), yield of tops (wet basis), and yield of sucrose as affected by various combinations of levels of N and Na and irrigation interval.

Treatment levels			Roots	Tops	Sucrose
N	Na	Irrg. Int.	m. tons/ha.	m. tons/ha.	m. tons/ha.
2	2	2	102.1	26.8	17.1
4	2	2	117.2	32.1	19.2
2	4	2	99.4	19.7	15.8
4	4	2	103.2	33.3	14.6
2	2	4	78.2	20.8	13.1
4	2	4	116.8	31.8	22.3
2	4	4	99.0	28.7	20.0
4	4	4	110.8	32.9	22.6
5	3	3	114.5	66.5	18.6
1	3	3	76.7	21.2	15.3
3	5	3	108.1	28.3	19.3
3	1	3	101.7	30.6	19.7
3	3	5	96.4	20.8	18.8
3	3	1	105.5	31.8	18.6
3	3	3	101.7	22.7	18.5
3	3	3	87.7	27.2	14.7
3	3	3	93.7	21.5	17.5
3	3	3	116.0	35.9	20.3
3	3	3	110.4	35.5	19.9
3	3	3	103.2	21.9	18.3

Table 11. Analysis of variance for yield of roots (fresh basis), yield of tops (wet basis), and yield of sucrose as affected by various combinations of levels of N and Na and irrigation interval.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	Equation Sufficiency, %
d.f.	19	3	6	5	5		
Roots m. tons/ha							
S.S.	2529.840	1375.570	508.724	104.127	541.419	10.20	94.8
M.S.		458.523	84.787	20.825	108.284		
Tops m.tons/ha							
S.S.	1989.450	910.034	409.242	445.139	225.035	24.44	74.8
M.S.		303.345+	68.207	89.028	45.007		
Sucrose m. tons/ha							
S.S.	119.038	34.334	55.071	9.494	20.140	10.99	90.4
M.S.		11.445	9.178	1.899	4.028		

+Statistically significant at the 5% level.

Table 12. Observed sucrose concentration of roots (fresh basis), nitrogen concentration of roots (fresh basis), mean seasonal nitrate-nitrogen concentration of petioles (dry basis), and nitrogen concentration of tops (dry basis) as affected by various combinations of levels of N and Na and irrigation interval.

Treatment Levels N	Na	Irrg. Int.	Sucrose %	N-Root %	Nitrate-N ppm.	N-Tops %
2	2	2	16.7	0.059	1024	1.78
4	2	2	16.4	0.120	2730	2.62
2	4	2	15.9	0.076	1858	2.23
4	4	2	14.1	0.118	1968	2.09
2	2	4	16.7	0.066	989	1.49
4	2	4	19.1	0.097	4162	2.11
2	4	4	20.2	0.080	942	1.78
4	4	4	20.4	0.207	3472	2.30
5	3	3	16.2	0.151	7643	2.78
1	3	3	19.9	0.057	744	1.89
3	5	3	17.9	0.073	713	1.76
3	1	3	19.4	0.095	957	1.62
3	3	5	19.5	0.122	1297	1.79
3	3	1	17.6	0.118	1887	2.33
3	3	3	18.2	0.105	956	2.20
3	3	3	16.8	0.093	907	1.75
3	3	3	18.7	0.070	929	1.64
3	3	3	17.5	0.096	1220	1.59
3	3	3	18.0	0.105	1241	1.58
3	3	3	17.7	0.111	1313	1.96

Table 13. Analysis of variance for sucrose concentration of roots (fresh basis), nitrogen concentration of roots (fresh basis), nitrate-nitrogen concentration of petioles (average for the season, log ppm. dry basis), and nitrogen concentration of tops (dry basis).

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	Equation Sufficiency, %
Sucrose, %							
d.f.	19	3	6	5	5		
S.S.	50.429	22.373	12.436	13.512	2.108	3.56	72.0
M.S.		7.458^{++}	2.072	2.702^{+}	0.422		
N-Roots, %							
d.f.	19	3	6	5	5		
S.S.	0.0231	0.0142	0.0040	0.0038	0.0011	15.29	82.5
M.S.		0.0047	0.0007	0.0008	0.0002		
Nitrate-N, log ppm.							
d.f.	19	3	6	5	5		
S.S.	1.4144	0.8221	0.462	0.1035	0.0260	2.37	92.5
M.S.		0.274^{++}	0.077^{++}	0.021	0.005		
N-Tops, %							
d.f.	19	3	6	5	5		
S.S.	2.433	1.123	0.896	0.108	0.305	13.83	94.9
M.S.		0.374^{+}	0.149	0.022	0.061		

$^{+}$ Statistically significant at the 5% level.

$^{++}$ Statistically significant at the 1% level.

Table 14. Observed sodium concentration of roots (dry basis), sodium concentration of tops (dry basis), and mean seasonal sodium concentration of petioles (dry basis) as affected by various combinations of levels of N and Na and irrigation interval.

Treatment N	Na	Irrg. Int.	Na-Roots, %	Na-Tops, %	Na-petioles, %
2	2	2	0.172	1.88	1.32
4	2	2	0.184	1.67	1.93
2	4	2	0.177	2.05	1.79
4	4	2	0.237	1.91	2.21
2	2	4	0.116	2.20	1.61
4	2	4	0.244	2.01	2.44
2	4	4	0.279	2.28	2.04
4	4	4	0.355	2.98	2.93
5	3	3	0.759	3.17	2.61
1	3	3	0.045	2.31	1.70
3	5	3	0.172	3.06	2.39
3	1	3	0.030	1.95	1.62
3	3	5	0.074	2.48	2.18
3	3	1	0.187	1.81	1.78
3	3	3	0.047	2.12	2.11
3	3	3	0.176	2.32	2.13
3	3	3	0.050	1.78	1.79
3	3	3	0.191	1.77	1.89
3	3	3	0.210	2.27	1.87
3	3	3	0.136	2.26	1.67

Table 15. Analysis of variance for sodium concentration of roots (dry basis), sodium concentration of tops (dry basis), and mean seasonal sodium concentration of petioles (dry basis) as affected by various combinations of levels of N and Na and irrigation interval.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	Equation Sufficiency, %
Na-Roots, %							
d.f.	19	3	6	5	5		
S.S.	0.474	0.184	0.146	0.119	0.025	52.37	73.5
M.S.		0.061++	0.024	0.024	0.005		
Na-Tops, %							
d.f.	19	3	6	5	5		
S.S.	3.513	1.697	0.728	0.774	0.314	11.96	75.8
M.S.		0.566+	0.121	0.155	0.063		
Na-petioles, %							
d.f.	19	3	6	5	5		
S.S.	2.818	2.422	0.166	0.067	0.162	9.44	97.5
M.S.		0.808++	0.0276	0.0134	0.032		

+ Statistically significant at the 5% level.

++ Statistically significant at the 1% level.

Table 16. Observed nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, ppm.) as affected by various combinations of levels of N and Na and irrigation interval.

Treatment levels			Time of Sampling			
N	Na	Irrg. Int.	July	August	September	October
2	2	2	1350	1025	844	651
4	2	2	7620	1464	1257	579
2	4	2	4145	1345	1064	876
4	4	2	4624	1348	1273	628
2	2	4	1259	1097	976	625
4	2	4	11066	3878	1028	676
2	4	4	1093	1362	830	484
4	4	4	7648	3126	1701	1414
5	3	3	14834	8917	4763	2057
1	3	3	1059	1045	536	337
3	5	3	880	628	675	670
3	1	3	1098	1046	913	771
3	3	5	2085	1417	1012	673
3	3	1	2193	2086	1971	1299
3	3	3	1252	991	1003	576
3	3	3	1265	731	1050	581
3	3	3	1047	730	1267	672
3	3	3	1996	914	1166	1003
3	3	3	1938	518	1647	862
3	3	3	2310	1056	924	963

Table 17. Analysis of variance for nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, log ppm.) as affected by various combinations of levels of N and Na and irrigation interval.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	Equation Sufficiency, %
d.f.	19	3	6	5	5		
July S.S.	2.7051	1.5007	0.8713	0.2361	0.0969	4.37	90.9
M.S.		0.5003++	0.1452+	0.0472	0.0194		
August S.S.	1.5811	0.5384	0.8006	0.1764	0.0657	3.96	88.4
M.S.		0.1795++	0.1334+	0.0353	0.0131		
September S.S.	0.7329	0.3679	0.1071	0.2172	0.0408	2.95	68.6
M.S.		0.1226++	0.0178	0.0434+	0.0082		
October S.S.	0.5810	0.2061	0.0799	0.2357	0.0593	3.78	54.8
M.S.		0.0687+	0.0133	0.0471	0.0118		

\+ Statistically significant at the 5% level.

++ Statistically significant at the 1% level.