Soil Moisture Conditions, Nutrient Uptake and Growth of Sugarbeets as Related to Method of Irrigation of an Organic Soil

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Introduction

Production of sugarbeets on highly organic soils of the Delta region at the mouths of the Sacramento and San Joaquin Rivers of California poses some special problems not encountered on mineral valley soils. The water table is generally within 3 or 4 feet of the ground surface, the topography is very flat and both the moisture and nutrient-supplying characteristics are markedly different from those of mineral soils. The high permeability of the organic soils prevents furrow irrigation, and the most common practice is to subirrigate by controlling the water table level within narrow limits throughout the season.

Previous experiments and observations have pointed to the need for simultaneous improvements in both moisture and nutrient supply. In 1955, an experiment comparing subirrigation alone with subirrigation plus supplemental sprinkling was conducted. There was no response to supplemental sprinkling, but analysis of petioles taken at regular intervals indicated a severe phosphorus deficiency by mid-season. Field trials in 1956, 1959 and 1960 indicated that fertilizer phosphorus was readily taken up by sugarbeets under supplemental sprinkler irrigation. There were yield responses as well as increases in petiole phosphorus when phosphorus deficient soils were fertilized. A field experiment in 1961 demonstrated uptake of phosphorus placed 10 or 16 inches deep by plants grown with subirrigation only. Evaluation was by petiole analysis. In this trial, however, drought, nitrogen deficiency and virus yellows resulted in low yields for all treatments.

It had been observed that under subirrigation an appreciable depth of soil became quite dry and that beets lost older leaves and wilted occasionally on hot days. Because of virtual lack of detailed information on soil moisture conditions and soil characteristics important in supplying plants with water, a detailed evaluation was undertaken. The importance of this was further

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emphasized by the indicated interrelation with nutrient supply and in 1962 a field experiment was conducted involving both irrigation and fertilizer treatments. The experiment was given detailed evaluation for the greatest possible insight into the reasons for the responses obtained.

Experimental Procedures

Plan of the experiment Differential irrigation treatments consisted of (A) subirrigation only, with the water table maintained between 3 and 4 feet below the ground surface, and (B) subirrigation supplemented by sprinkling in a manner which would maintain an adequate soil moisture level in the top 2 feet.

The entire experimental area was fertilized with 100 pounds N per acre applied by airplane as urea on February 2. Differential fertilizer treatments consisted of: (A) no additional fertilizer; (B) 87 pounds per acre P (200 pounds P_2O_5) applied as treble super phosphate placed 13 to 16 inches deep in early November, 1961; and (C) 87 pounds P plus 80 pounds N per acre injected as ammonia just prior to planting.

The plots were laid out in a split-plot design with four replications. Irrigation treatments were applied to the main plots and fertilizer treatments to subplots which consisted of 16 30-inch rows 475 feet long. The beets were planted on March 20.

Evaluation of soil moisture conditions Exploratory evaluation of soil moisture conditions under subirrigation in 1961 showed that both tensiometers and soil moisture resistance blocks functioned in organic soils within their inherent limitations. However, soil moisture tensions exceeded the useful range of the tensiometers within a few weeks after planting. Resistance blocks lacked sensitivity in wetter soil near the water table, but functioned very well under drier conditions at shallower depths. Gravimetric sampling for moisture content gave useful information, although sample variability was greater than that in mineral soils.

Because of the wide range of soil moisture conditions expected, both tensiometers and resistance blocks were used for measurement of soil moisture tension. Two subplots in each irrigation treatment receiving both P and N fertilizers were selected for soil moisture evaluations, and instruments were placed in two locations in each plot. At each location, wells were installed to a depth of 4.5 feet for measurement of water table depth and tensiometers were installed at depths of 12, 24 and 36 inches. Resistance blocks were placed at the 6, 12, 18, 24 and 30-inch depths in the subirrigation treatment and at 12, 18 and 24 inches in the sprinkled plots.

In the subirrigation treatment, samples for gravimetric determination of soil moisture content were taken near each instrument station in 6-inch increments to 3 feet. Twice during the growing season large core samples, for determination of bulk density, were taken from sprinkled plots where soil moisture conditions were favorable for core sampling.

Some moisture retention characteristics, obtained with the pressure membrane apparatus (3)[2] and by supplementary studies in tanks, are of value in interpretation of this experiment. These tests were conducted with similar soils, but the samples were not taken from the 1962 experimental area.

Evaluation of nutritional status The principal means of evaluation of nutritional status and nutrient uptake was petiole analysis. Each subplot was sampled at 2-week intervals by collecting about 40 petioles from the center four rows. Petioles were analysed for NO_3-N, PO_4-P and K by conventional analytical procedures (4).

Harvesting Small plots consisting of two rows 50 feet in length were hand harvested from each fertility subplot on August 13, September 10 and October 9. Data were collected on fresh weight of tops and roots and water and sugar content of roots. On November 1, four rows of the subplots were machine harvested, and root yields and sugar contents determined.

Results

Soil moisture conditions At the beginning of observations in early May the water table was 37 inches below ground surface. It dropped to 45 inches by early June and remained essentially at that depth until early August. This was followed by a gradual rise to the 34-inch depth by October. The rise after early August is attributed to a general rise in the area and to decreased water use by the beets, since by this time there had been considerable loss of older leaves, and foliar cover was sparse.

Moisture contents in 6-inch increments of depth down to 3 feet are reported in Table 1 at approximately monthly intervals throughout the season for the subirrigated treatment. They are expressed as volume or depth ratios (i.e. cubic feet of water per cubic foot of soil or feet of water per foot depth of soil). The total depth of water in the 0 to 36-inch depth at each date is given in inches. The difference in the totals between dates gives the net depletion of stored water.

The moisture content data in Table 1 show about 1.8 inches of moisture depletion between mid-April and the middle of May when the plants were small and the soil comparatively moist.

[2] Numbers in parentheses refer to literature cited.

Table I.—Soil moisture content (volume ratio) at approximately monthly intervals during the growing season for subirrigated plots.

	Sampling Date					
Depth	4/19	5/16	6/15	7/13	8/23	9/25
0-6	0.38	0.34	0.30	0.24	0.20	0.20
6-12	0.55	0.45	0.37	0.34	0.32	0.31
12-18	0.50	0.41	0.33	0.34	0.34	0.32
18-24	0.47	0.43	0.34	0.30	0.31	0.31
24-30	0.55	0.52	0.41	0.37	0.40	0.45
30-36	0.63	0.61	0.48	0.50	0.49	0.60
Total*	18.4	16.6	13.3	12.5	12.4	13.1

* Expressed as inches of water in the 0-36" depth of soil.

Between mid-May and June 15 depletion was 3.3 inches, but the decrease between mid-June and late August was less than 1 inch. Late in the season there were increases in moisture content in the 2 to 3-foot depth associated with the rise in the water table, but the overall increase in equivalent depth of water in the soil was small.

Soil moisture tensions as interpreted from resistance block readings are presented in Figures 1 and 2 for the subirrigated and sprinkled treatments, respectively. In the subirrigated treatment there were rapid increases in soil moisture tension to the 18-inch depth as the beets developed; tensions throughout this zone exceeded 12 bars by mid-August. Tensions at lower depths lagged but attained values of 5½ and 2½ bars at the 24 and 30-inch depths, respectively. Tensiometers at the 36-inch depth (less than one foot above the water table) reached the top of their functional range (0.8 bar) by mid-June.

After mid-August, soil moisture tensions declined at depths of 18 inches and below, with the decrease greatest at the lower depths. The drop in tension at the 30-inch depth corresponds to the period of water table rise; those at shallower depths lag somewhat but can also be attributed to rise of the water table.

The combined data of Table 1 and Figure 1 show that the soil became very dry throughout most of the top 2 feet of the subirrigated treatment. Much of the water used by the crop early in the season came from stored moisture in the soil. When this was largely depleted, nearly all of the water was supplied by upward rise from the water table. There is no direct means of measuring the relative amounts of water absorbed from various depths of soil. However, dry soil conducts water very slowly and it is probable that most of the late season water was absorbed within a short distance of the water table.

As shown in Figure 2, soil moisture tensions in the sprinkled plots were lower throughout much of the growing season, in-

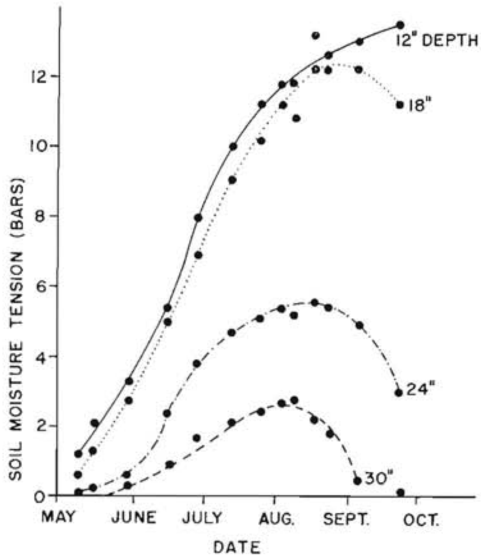

Figure 1.—Soil moisture tension conditions in the subirrigation treatment.

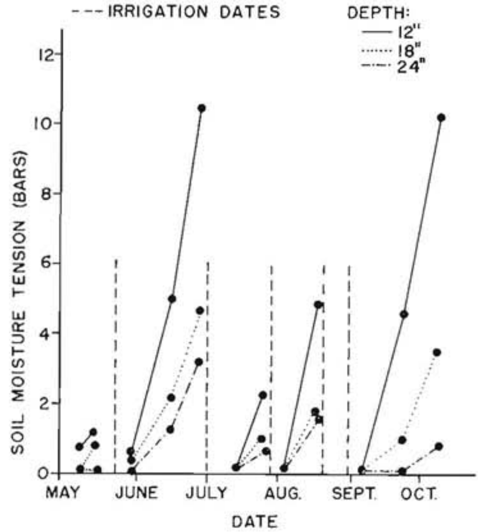

Figure 2.—Soil moisture tension in the treatment receiving supplemental sprinkler irrigation.

dicating that the plants were more adequately supplied with water. However, twice during the season, tensions exceeded 10 bars at the 12-inch depth and reached appreciable values at lower depths. Within their operating range, the tensiometers confirmed the data obtained with resistance blocks.

Nutrient uptake Nitrate-nitrogen contents of petioles at intervals throughout the season are given in Tables 2 and 3. All treatments started at high, uniform levels which were maintained until late May. Differences began to appear following the first irrigation, with both nitrogen fertilization and sprinkling increasing nitrogen uptake. These differences persisted throughout the season until the last sampling date on October 31, which was preceded by heavy rains on all plots on October 10. This rain caused a marked increase in the NO_3-N levels of the subirrigated plots but had no effect on the nitrogen status of the sprinkled plots.

In the sprinkled treatment, petiole NO_3-N did not drop below the 1000 ppm critical level until very late in the season regardless of the nitrogen treatment. At such levels, the beets were adequately supplied with nitrogen (4). However, in the treatments receiving only subirrigation, petiole nitrate was at deficient levels after early July in the N_0P_{87} treatment and after mid-July in the $N_{80}P_{87}$ treatment.

It is interesting to note that sprinkler irrigation without nitrogen was more effective in supplying nitrogen than was the application of 80 pounds N per acre to unsprinkled sugar beets.

The same general effect of both fertilizer and irrigation treatments on phosphorus uptake is apparent (Table 2), but levels in all treatments were adequate to prevent deficiency. As with nitrogen, there was a large increase in petiole phosphorus of subirrigated plots following heavy rain in early October, but only small increases in the sprinkled treatments.

Potassium levels in petioles were not influenced by irrigation or fertilizer treatment, and K levels in petioles were adequate throughout the season (Table 2).

Disease conditions On June 13 from 38 to 52% of the plants showed symptoms of the yellows viruses. By July 23, 80 to 100% of the plants were infected and the viruses may have limited growth sufficiently to reduce the differences between treatments.

Harvest data Harvest data are presented in Table 4.

Supplemental sprinkler irrigation increased root yields an average 2.7 tons per acre by August 13. The difference increased to 7.5 tons by October 9 because of lack of root growth in the subirrigated treatment after September 10. In the subirrigated treatment there was a yield response to nitrogen application,

Table 2.—Nutrient content of petioles of recently matured leaves of plants of the machine harvested plots. Values (dry weight basis) are means of four replications. Dates of sprinkler irrigation: 5/25, 6/29 7/26, 8/17 and 9/13. Heavy rain on 10/10.

Irrigation	Fertilizer, lb/acre N	Fertilizer, lb/acre P	Sampling dates Apr. 30	May 21	June 13	July 9	July 23	Aug. 17	Sept. 10	Oct. 31
					ppm, NO_3-N					
Sub	0	0	12400	14400	3020	560	260	270	340	2700
	0	87	12600	13800	2070	740	280	350	330	2390
	80	87	12500	14300	4080	1660	650	370	340	2520
Sprinkle	0	0	11800	14900	6910	1510	1360	840	610	640
	0	87	12400	14700	5910	1320	1370	740	560	640
	80	87	12400	15200	8090	2030	1850	930	610	720
F values:[1] Irrigation			1.35	31.68*	82.57**	2.52	2.43	32.37**	19.78*	229.4**
Fertilizers			0.40	5.43*	12.35**	3.83	3.76	0.67	0.03	1.63
I × F			0.09	0.83	0.02	0.38	2.04	0.57	0.01	2.08
					ppm, PO_4-P					
Sub	0	0	2040	1350	1060	1580	640	1200	580	1620
	0	87	2300	1580	1450	2080	790	1520	910	1600
	80	87	2260	1590	1600	2050	760	1450	860	1750
Sprinkle	0	0	2160	1440	1480	1950	790	1680	1280	1400
	0	87	2040	1640	1850	2400	980	1920	1220	1400
	80	87	2050	1490	1620	2320	1060	2120	1190	1420
F values:[1] Irrigation			5.95	0.66	2.94	19.12*	4.94	18.36*	13.41*	2.69
Fertilizers			0.38	1.28	5.22*	386.35**	3.23	2.67	1.54	0.40
I × F			3.18	0.28	1.89	0.27	0.42	0.39	3.92*	0.20
					%K					
Sub	0	0			3.7		3.2	3.5		
	0	87			3.0		2.8	3.1		
	80	87			3.2		2.6	2.6		
Sprinkle	0	0			4.0		3.1	3.1		
	0	87			3.7		2.6	3.0		
	80	87			3.3		2.2	2.7		
F values: Irrigation					27.84*		6.95	1.01		
Fertilizers					1.08		15.01**	12.97**		
I × F					0.19		0.62	2.23		

[1] F values required for significance at the 5% and 1% level respectively: Irrigation: 10.13, 34.12. Fertilizers or I × F: 3.88, 6.93.

Table 3.—Nutrient content of petioles of recently matured leaves of plants of hand harvested plots. Values (dry weight basis) are means of four replications. Dates of sprinkler irrigations: 5/25, 6/29, 7/26, 8/17 and 9/13.

Irrigation		Fertilizer, lb/acre N	P	Sampling (and harvest dates) Aug. 13	Sept. 10	Oct. 9
					ppm, NO_3-N	
Sub		0	0	280	360	250
		0	87	370	440	300
		80	87	310	460	280
Sprinkle		0	0	920	660	370
		0	87	870	730	340
		80	87	1250	920	350
F values: [1]	Irrigation			15.29*	45.57**	4.75
	Fertilizers			1.59	2.96	0.05
	I × F			2.04	0.77	1.04
					ppm, PO_4-P	
Sub		0	0	1210	740	1220
		0	87	1390	900	1950
		80	87	1280	1120	1700
Sprinkle		0	0	1840	1790	2210
		0	87	1890	1900	1800
		80	87	1900	1710	1920
F values: [1]	Irrigation			16.17*	262.61**	2.28
	Fertiilizers			0.31	1.19	0.18
	I × F			0.14	2.58	2.40

[1] F values required for significance at the 5% and 1% levels, respectively. Irrigation: 10.13, 34.12. Fertilizers or I × F: 3.88, 6.93.

but there was no effect in the sprinkled treatment. There was no yield response to phosphorus in either treatment. These responses are in accord with the nutritional status shown by petiole analysis.

On the fresh-weight basis, sucrose concentration in roots was appreciably lower in the sprinkled plots except for the last harvest date after the heavy rain; irrigation treatment averages differed by 2.2, 1.6, and 1.0 percent respectively on August 13, September 10 and October 9. While the data are inadequate for firm conclusions, they suggest that in the sprinkled treatment the sugar concentration was influenced by soil moisture conditions just prior to harvest. The September 10 harvest date was preceded by two closely spaced irrigations which kept soil moisture tension at low levels. The average sucrose concentration for all sprinkled treatments was 14.0 on September 10 as compared to 14.9 and 14.8 on August 13 and October 9, respectively. Sugar concentration dropped markedly at the November 1 harvest, which followed heavy rains by about 2 weeks. The decline was greatest in the subirrigated plots.

Nitrogen fertilization also tended to cause a lower sucrose concentration although the differences were small in the subirrigated treatment after the first harvest.

Table 4.—Top and root yield and root composition at different harvest dates. Values are means of four replications. Dates of sprinkler irrigation: 5/25, 6/29, 7/26, 8/17 and 9/13. Heavy rain on 10/10.

Treatments							Sucrose		
	Fertilizer, lb/acre		Fresh weight, tons/acre		Root, % dry				
Irrigation	N	P	Tops	Roots	matter	% fresh weight	% dry weight[5]	Tons/acre
			August 13 (Hand harvest)					
Sub	0	0	10.3	13.4	26.1	17.4	66.7	2.33
Sub	0	87[6]	9.9	12.9	26.1	17.4	66.7	2.24
Sub	80	87	14.8	15.2	25.0	16.5	66.0	2.52
Sprinkle	0	0	22.4	16.7	23.3	15.0	64.4	2.50
Sprinkle	0	87	21.7	15.9	23.5	15.1	64.2	2.39
Sprinkle	80	87	28.0	16.9	22.8	14.6	64.0	2.46
			September 10 (Hand harvest)					
Sub	0	0	7.9	16.3	25.0	16.6	66.4	2.71
Sub	0	87	7.2	16.1	25.2	16.7	66.3	2.68
Sub	80	87	8.9	18.2	24.6	16.4	66.7	2.98
Sprinkle	0	0	19.5	21.3	22.7	14.0	61.7	2.99
Sprinkle	0	87	19.1	21.5	23.2	14.3	61.6	3.08
Sprinkle	80	87	24.6	21.4	22.5	13.7	60.9	2.93
			October 9 (Hand harvest)					
Sub	0	0	8.1	16.0	24.5	16.0	65.3	2.56
Sub	0	87	7.1	16.0	24.2	15.9	65.7	2.54
Sub	80	87	8.5	18.5	24.0	15.6	65.0	2.88
Sprinkle	0	0	20.8	24.4	23.1	15.0	64.9	3.66
Sprinkle	0	87	18.4	24.4	23.3	15.1	64.8	3.69
Sprinkle	80	87	20.1	23.3	22.7	14.2	62.6	3.30
LSD's for means of hand harvested plots, %5 level: [1]			3.0	2.4	1.0	0.7		0.39
[2]			5.1	2.4	0.9	0.8		0.43
			November 1 (machine harvest)					
Sub	0	0		16.9		12.9		2.18
Sub	0	87		16.4		13.3		2.19
Sub	80	87		19.3		13.2		2.56
Sprinkle	0	0		23.3		13.0		3.03
Sprinkle	0	87		24.3		13.4		3.26
Sprinkle	80	87		24.6		13.2		3.24
LSD's for means of machine harvested plots, 5% level: [3]				2.2		N.S.		0.28
[4]				2.3		N.S.		0.33

[1] Between fertilizers for the same irrigation treatment and date of harvest.

[2] Between fertilizers for different irrigation treatments and the same or different dates of harvest.

[3] Between fertilizers for the same irrigation treatment.

[4] Between fertilizers for different irrigation treatments.

[5] % sucrose, fresh weight $\times$ 1/% dry matter $\times 10^{-2}$. Calculated from treatment means.

[6] 200 lb P_2O_5.

Dry matter contents of roots followed the same general trend as fresh-weight sugar concentrations, showing that both irrigation and nitrogen fertilization increased root water content. However, sucrose concentration on the dry-weight basis likewise was influenced by the treatments. Sprinkling decreased dry-weight sugar concentration on all of the three harvest dates for which data are available.

Differences in sugar yield were small at the August 13 harvest date. By September 10, sugar production had increased by about one-half ton per acre with both irrigation treatments, and the difference between them increased slightly. A subsequent loss of sugar per acre in the subirrigated treatment and a further increase in the sprinkled treatment resulted in a difference of 0.88 ton per acre on October 9. While sugar yields of the large plots on November 1 were lower for both treatments, the 0.88 ton per acre increase by the sprinkled treatment persisted.

Discussion

Soil moisture conditions While general applicability of these data to other muck soils is not known, these soils have some special moisture characteristics that are important in evaluating their ability to supply moisture to plants, especially under subirrigation.

Organic matter contents average about 20 percent, and bulk densities range from near 1.0 in the surface foot to as low as 0.65 at lower depths. At saturation, the moisture content on a volume basis is typically about 65 percent. Typical 15-bar moisture contents average about 30 percent so that water-holding capacity between saturation and 15 bars is approximately 4 inches per foot depth of soil. However, both field and laboratory data show that one inch or more is drained at low tensions (on the order of 0.1 bar). Of the remaining 3 inches, nearly 2.5 are retained at 0.8 bar (the upper limit of tensiometers) and over 2 inches are held at 1.0 bar tension. The net result in the field is that soil moisture tensions tend to increase very rapidly through the range from about 0.1 to 0.8 bar as moisture is absorbed by plant roots. Tensiometers thus have limited value.

The effect on plant growth of having much of the available water held at comparatively high tensions is difficult to assess. If, as is frequently assumed, plant growth rates are inversely related to soil moisture tension, much of the available water would be better suited to plant survival than to rapid growth. On the other hand, if one looks at availability of soil moisture in the dynamic sense, higher moisture contents of muck soils could mean more rapid movement of water through the soil to plant roots. Consequently plants could be better supplied with water in muck than in mineral soils at the same soil moisture tension. Peters (2) concluded that rate of moisture movement was an important factor in water availability to plants in mineral soils of different texture.

In this experiment, there was an obvious top-growth response to the first irrigation which was apparent visually by early June. By this time soil moisture tension to a depth of 18 inches was about 4 bars in the subirrigated treatment (see Figure 1). Measurement would have shown reduced growth rate at still lower tension; the growth response was probably not related to nitrogen status since the NO_3-N content of petioles was still quite high at this time.

Soil moisture data show that this muck soil cannot transmit water upward rapidly enough under subirrigation to maintain high moisture levels near the surface under actively transpiring plants. In the early season, soil moisture depletion was probably sufficient to account for all the water used by the crop. From mid-May to mid-June soil moisture depletion was not sufficient to supply the water used so that water was obtained by a combination of net depletion and upward rise. After mid-July most of the water used was supplied by upward rise, but there are indications that most of the water was absorbed within about a foot of the water table, or below the 36-inch depth. This is confirmed by a tank study at Davis with sudangrass, in which a tracer was added to water applied by subirrigation. None of the tracer rose more than one foot above the water table.

Most crops in the area are grown with subirrigation only, and it is a common belief that only occasional supplemental sprinkling is required. Even discounting water supply to plants from the water table, muck soils have high water-holding capacities, suggesting the need for only infrequent irrigation. It is thus rather surprising that in spite of five thorough irrigations soil moisture tensions exceeded 10 bars twice at the 12-inch depth. In general, tension values were low for about 7 to 10 days following irrigation, then rose rapidly. This phenomenon is largely attributable to the relatively small amount of water retained between 0.1 and 1.0 bar tensions. However, the data likewise demonstrate the marked preferential absorption of water from near the surface even after roots have reached the water table. The water table in the sprinkled plots did not rise following any irrigation, precluding root injury by rising water.

Nutrition This experiment confirms the existence of interrelations between soil moisture conditions and nitrogen and phosphorus nutrition. There was a yield response to applied nitrogen in the subirrigated treatment but not in the sprinkled treatment. Thus the response to sprinkling was a combined nitrogen and soil moisture response. Increased petiole phosphorus under sprinkling indicates that a similar response would be obtained on phosphorus-deficient soil.

In these soils, a large part of the nitrogen supply, and perhaps phosphorus, is apparently derived from reactions involving organic matter. Low moisture conditions retard decomposition of organic materials and nitrification, and this effect is possibly the principal mechanism of the relationships noted. This is indicated by the very rapid increase in nitrogen and phosphorus uptake following October rains in the subirrigated treatment. The corresponding increase was very moderate in the sprinkled treatment. This is the pattern of events one would expect in release of nitrogen and phosphorus from organic matter, since the readily decomposable organic substances in the sprinkled treatment already would have been released because of more favorable moisture conditions and utilized by the plants.

On this basis, it seems probable that the interrelation between nitrogen and phosphorus nutrition and soil moisture conditions is more pronounced in muck soils than in soils low in organic matter. Subirrigation tends to accentuate the effect because of prolonged dry conditions in the upper soil, whereas with surface or sprinkler irrigation the upper soil is moistened intermittently. However, deep-rooted crops in mineral soils often experience long periods of dry surface soil without yield loss, indicating adequate levels of nitrogen nutrition. Frequently, nitrogen levels in droughted plants are higher than those grown under favorable moisture conditions (5).

Many experiments have been conducted on influence of soil moisture conditions on plant nutrition. The results with phosphorus in particular have been conflicting. It is difficult to segregate the effects of low soil moisture levels on the ability of soils to supply nutrients from the ability of plants to absorb them. The conflicting results of various experiments tend to indicate that the ability of dry soils to supply nutrients is the dominant factor, but this can not be confirmed from the present experiment. Some of the processes which affect nutrient availability may be markedly influenced by soil moisture levels whereas others may not—in this experiment, nitrogen and phosphorus uptake were influenced by soil moisture conditions, but the uptake of potassium apparently was not (Table 2).

Root yields and composition The data of this experiment clearly illustrate the effects of soil moisture conditions and nitrogen nutrition on sugar concentration and yield. They confirm the conclusion of Loomis and Worker (1) that drought and nitrogen deficiency both tend to reduce water content of root tissue and that this is a factor in increased fresh-weight sugar content. However, in this experiment similar conditions increased sugar content on a dry-weight basis as well.

The farmer growing beets on muck soils with high water table has a possible advantage in that moderate drought may be induced near maturity if desired without fear of extreme drought. At the same time, he effectively reduces the nitrogen supply. On the other hand, there is the disadvantage that the two variables cannot be controlled entirely independently. In any case, intelligent fertility and irrigation management are highly interrelated.

Summary

Soil moisture conditions, nutrient uptake, top growth and root and sugar yields of sugarbeets were evaluated under subirrigation alone (water table at 3 to 4 feet) and under subirrigation plus sprinkling. With subirrigation only, the upper soil was relatively dry for a major portion of the growing season. Sprinkler irrigation increased top growth, root and sugar yields and nitrogen and phosphorus content of petioles, but had no effect on petiole potassium content. Under subirrigation only, there was a response to applied nitrogen fertilizer but none with subirrigation plus sprinkling.

It is concluded that the response to sprinkler irrigation was caused by both higher soil moisture levels and more favorable conditions for nitrogen uptake. While petiole phosphorus contents for all treatments were above deficient levels, the increased P uptake with sprinkling points to the possibility of a similar response on phosphorus-deficient organic soils.

Acknowledgments

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Literature Cited

(1) Loomis, R. S. and G. F. Worker, Jr. 1963. Responses of the sugar beet to low soil moisture at two levels of nitrogen nutrition. Agron. J. 55: 509-515.

(2) Peters, D. B. 1957. Water uptake of corn roots as influenced by soil moisture content and soil moisture tension. Soil Sci. Soc. Am. Proc. 21: 481-484.

(3) Richards, L. A. 1947. Pressure membrane apparatus—construction and use. Agr. Engr. 28: 451-454, 460.

(4) ULRICH, A., D. RIRIE, F. J. HILLS and M. D. MORSE. 1959. Plant analysis. Univ. California Agr. Expt. Sta. Bull. 766.

(5) WADLEIGH, C. H. and L. A. RICHARDS. 1953. Soil moisture and the mineral nutrition of plants. In Mineral Nutrition of Plants, pp. 411-450, Univ. of Wisconsin Press.