The Relation of Soil Water Levels to Mineral Nutrition of Sugar Beets[1]

Omer J. Kelley and Jay L. Haddock[2]

General Relationships

Several reviews have recently been made on studies of mineral accumu-lation in plants and factors which affect it (2, 3, 29)[3]. There is general agreement that the two main groups of influences which determine the extent and rate of solute absorption are the external or the environmental conditions and the internal or controlling physiological conditions. The more important external conditions are temperature, aeration, supply of water and amount and type of mineral salts. The more important internal controlling conditions are the hereditary characteristics of the particular plant, its previous physiological history and the supply of stored carbohy-drates which is available for respiratory activity of the roots. While these various factors are all important and in many cases are interrelated, we will consider primarily water and its role in nutrient uptake. Mineral nu-trition is related both directly and indirectly to soil moisture.

Surface Migration and Ion Diffusion

The literature indicates plants may obtain nutrients directly by con-tact exchange or from solution. In any event, the nutrients are usually thought to be taken up in a dissociated form and, therefore, water is nec-essary, whether or not the ions must actually undergo surface migration or pass through a moisture film.

The importance of surface migration or diffusional movement of ions for nutrient absorption by plants was well illustrated by Wadleigh.[4] He refered to an experiment by Dittmer (7) who studied the development of a rye plant on a dark loamy soil. The plants were grown for four months in wooden containers 12x12x22 inches or approximately 1.8 cubic feet. Dittmer made a very careful and detailed study of all of the roots at the end of the growing season. His records showed the plant had approxi-mately 13,800,000 roots with a length of more than 6,600 miles and a surface area of around 4,321 square feet. All of these roots were in approximately 1.8 cubic feet of soil. Certainly one would be justified in considering a root system that exposed more than 6,870 square feet of surface in less than 2 cubic feet of soil as "thoroughly permeating" that soil.

Let us now consider the ratio of the exposed root system area to the specific surface of such a loamy soil as used by Dittmer. Such a soil might have a specific surface of around 20 square feet per cubic centimeter or a total of about 900,000 square feet for the soil in the container. All of the root surface is not in contact with the soil surface, since the soil is not a

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[2] Head, Western Section of Soil and Water Management, Soil and Water Conservation Research Branch, U.S.D.A., Beltsville, Maryland, and Soil Scientist of the same Section and Branch, U.S.D.A., Utah Agricultural Experiment Station, Logan, Utah, respectively.

[3] Numbers in parentheses refer to literature cited.

[4] Talk before American Society of Agronomy. Cincinnati, 1952—unpublished data.

solid mass but is interspersed with pores. It can be shown that in the case of Dittmer's culture, less than 1 percent of the soil surface was in direct con-tact with the roots. Therefore, if the nutrient ions adsorbed on the surface particles were to enter the root, at least 99 percent of them would either have to undergo surface migration or diffusion through a moisture film.

High Water Table and Dry Soil Conditions

In addition to the role of water indicated above, water may well have an effect on the development of the root system. Normally high water tables may confine the roots close to the surface and reduce the root volume per plant and thus reduce the available nutrient supply. The adverse effect of a high water table or prolonged low soil moisture stress is thought to be due primarily to its effect on oxygen content. As the soil moisture tension decreases, the soil pores become increasingly filled with water. The amount of gas is thus reduced and the gaseous exchange is inhibited. Furr and Aldrich (9) , studying irrigated date palms on a very fine sandy loam, noted that the oxygen content of the soil air decreased from 20 to 5 percent at the 6 inch depth as the moisture tension dropped from around 700 cm. to 15 cm. but it increased rapidly again as the soil moisture tension ap-proached 100 cm. of water. Several investigators (12, 24) have shown the necessity of adequate oxygen for the accumulation of both anions and cations in plant roots. However, Chang and Loomis (4) presented data which indicate that increasing carbon dioxide content of the air in nutrient cultures may be toxic per se to plants.

Hoffer (11) believes that the high accumulation of reduced iron and manganese associated with anaerobic soils may also be toxic per se to the plant roots.

Excess water can have an adverse effect in the leaching of nutrients beyond the root zone (18) . This is evident in the case of nitrate. Other ions removed by leaching in considerable amounts are chloride, calcium, magnesium, sulfate, and bicarbonates. On the other hand, dry conditions in soils may reduce the supply of available nutrients. Root growth at mois-ture contents below the permanent wilting percentage is slow (1) . Dry soil severely reduces root extension and thus limits contact with nutrients. While some nutrient adsorption may take place in dry soil (14, 28) , it is not adequate for normal growth. This is the case even if the roots at lower depths have sufficient water but not nutrients and the nutrient supply is in the upper dry soil.

There is a certain amount of limited evidence (5) which indicates that the soil solution is a necessary and integral part of phosphorus ab-sorption by plants. Hunter and Kelley (13) indicated that phosphate ions are not absorbed from dry soils. Volk (28) concluded that cations, but not anions, may be absorbed from dry soils. This is further substantiated by the "contact exchange theory" which has been proposed by Jenny and co-workers (16, 17) . They showed that with certain clay or soil suspensions containing Na+, K+, or Rb+, the rates of absorption of ions by barley roots were greater than from corresponding salt solutions. Evidence of a corresponding influence of clay particles on anion absorption is not avail-able. Work by Dean and Rubins (6) failed to show a greater phosphorus absorption in the presence of clay suspensions containing fixed phosphorus.

Boron availability is closely related to soil-water relationships since it is the belief that boron is available to plants only in water-soluble form. Olson and Parks (19, 20) have shown a decrease in water-soluble boron by drying. Walker et al. (30) observed that boron deficiencies were more severe in places in the field where soil dried out excessively in dry years. While dry soil conditions may make boron less available for the immediate plant growth, it is doubtful if drying of the plow layer under field condi-tions is sufficient to cause appreciable boron fixation. Schofield and Wilcox (25) found sufficient boron in irrigation water in southern California to cause injury to citrus and walnuts. Similar toxic effects of excess boron in irrigation water are found in many areas of the West.

It is apparent that too much or too little water may alter the effective root zone and thus the nutrient supply. Fluctuations in the moisture level may have an effect on the availability of the nutrients in the soil. For in-stance, fixation of potassium or ammonium in a form unavailable to plants may be accelerated by alternate wetting and drying of soils.

Within the Available Moisture Range

A recent review of the relation of soil water to plant growth has been given by Richards and Wadleigh (23) . This review indicates that a num-ber of growth factors are affected by variations in the soil moisture condi-tion within the available moisture range. The question immediately arises as to the effect of variation in the available soil moisture range on nutrient uptake, in addition to its effect on the availability for plant growth. Reite-meier (22) studied the effect of moisture content on the ionic concentra-tions extracted from various soils. He found an increase in the nitrate and chloride concentration as the moisture content decreased. In general, he found a decrease in concentration of cations and polyvalent anions as the moisture content decreased. Several investigators have found a relation-ship between moisture content and the apparent absorption of minerals in plants (8, 15, 26) . They found plant foliage low in nitrogen and high in phosphorus with high average soil moisture contents. Janes (15) found that calcium, magnesium and sodium decreased in plants with increasing soil moisture. It appears, therefore, that a relationship exists between the availability of the nutrients in the soil water and the moisture tension or content within the available moisture range.

Experimental Results with Sugar Beets[5]

In order to study the effect of soil moisture condition on the nutrient uptake by plants, the authors have selected plant material grown under a variety of irrigation regimes on Millville loam soil at Logan, Utah. The Ulrich method (27) was selected to study the nutritional status of plants as affected by irrigation regime. This procedure attempts to measure the concentration of nutrients moving in the conductive tissue of plants. It has proven to be a sensitive measure of variation in plant environmental conditions.

There were eight irrigation regimes in this study—two methods of irrigation (sprinkler and furrow) and four soil moisture conditions under each method. A description of irrigation treatments is given in Table 1.

[5] The experimental data reported herein were obtained from Regional Research Project W-9 at the Utah Agricultural Experiment Station, Logan, Utah.

Table 1.—Irrigation Treatment and Accompanying Soil Moisture Conditions.

Irrigation Method and Inches Water Entering Soil	Soil Moisture Condition	Soil Moisture Condition Symbol	Soil Moisture Condition at the 12" Depth Before Irrigation
IF[1] and IS[2] 18.1" 16.2"	Low Moisture High Tension	(W_1)	Allowed to Approach Wilting Percentage.
2F and 2S 20.0" 17.1"	Medium-Low Moisture	(W_2)	About 25 percent of Available Soil Moisture Remaining.
3F and 3S 24.0" 17.6"	Medium-High Moisture	(W_3)	About 75 percent of Available Soil Moisture Remaining.
4F and 4S 33.8" 24"	High Moisture (Low Tension)	(W_4)	Maintain at about Field Capacity.

[1] F refers to furrow irrigation [2] S refers to sprinkler irrigation.

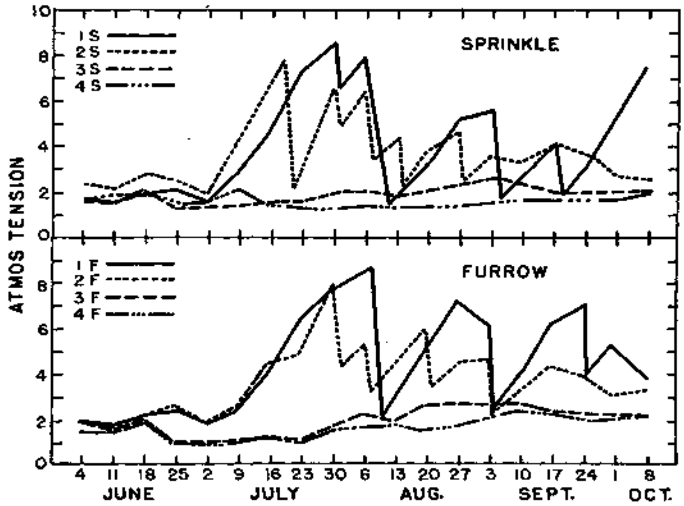


Figure 1.—Variations in seasonal soil moisture tension at 12-inch depth under two irrigation methods and four soil moisture conditions. (Sugar beets 1952.)

A graphical representation of the soil moisture conditions present for each of these irrigation regimes is shown in Figure 1. It will be noted that there was some variation in the soil moisture tensions for a given moisture

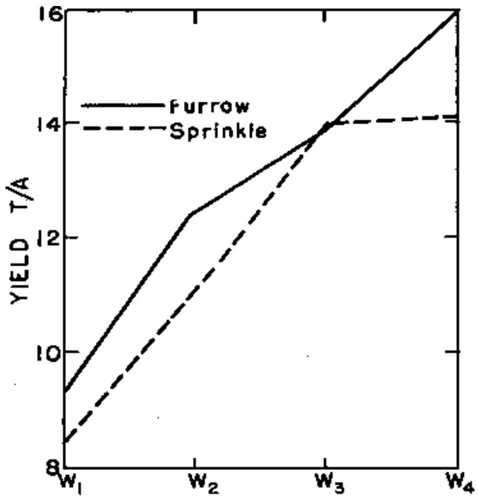


Figure 2.—Yield of sugar beets as affected by methods of irrigation and soil moisture condition. 1952.

treatment between the two irrigation methods. However, there is con-siderable similarity between the seasonal tension record of the furrow and sprinkle plots. This graph should be kept in mind as reference is made to the nutritional condition of plants grown on the several plots. Although soil moisture conditions were maintained at the approximate moisture level, there appeared to be a greater difference between W2 and W3 relative to the other soil moisture conditions than intended.

Soil Moisture Condition and Yield

Although yield is not of special concern to this discussion, it is of inter-est to note the effect of soil moisture condition on yield of sugar beets. It is obvious from the data in Figure 2 that yields are highly correlated with soil moisture condition regardless of the method of irrigation.

Soil Moisture Condition and Sugar Percentage

Reference is made to sugar percentage at this time because it has been shown repeatedly that sugar percentage is highly correlated with the nitro-gen content of both roots and tops of sugar beets. Again, it is obvious from the data of Figure 3 that sugar percentage of the root increases as the quan-tity of soil moisture is increased. This is true regardless of the method of irrigation. This phenomenon is probably a result of greater utilization of the available nitrogen in producing plant tissue early in the season on

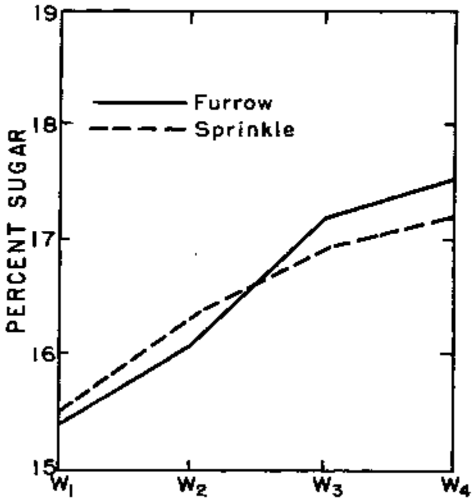


Figure 3.—Sucrose percentage of sugar beets as affected by method of irrigation and soil moisture condition. 1952.

the more moist plots. This in turn encourages greater sugar storage in mature plants. It is possible, also, that the excess water results in down-ward movement of available nitrogen, beyond the reach of plant roots, as irrigation water in increased.

Soil Moisture, Condition and Phosphorus Uptake

The influence of stage of growth as related to phosphorus uptake and soil moisture condition is shown effectively by the data in Figure 4. The soil moisture condition had a marked influence upon the uptake of phos-phorus from soils early in the season. The wetter the soil, the greater the uptake of phosphorus. Late in the season, the phosphorus content of sugar beet petioles is low and relatively independent of soil moisture condition, method of irrigation and fertilization. The season of the year or probably more exactly the stage of plant growth then is an important factor in de-termining the effect of soil moisture condition on the uptake of phosphorus.

In 1950, three soil moisture conditions were maintained on Millville loam—(1) wet (15 irrigations), (2) medium (5 irrigations) , and (3) dry (2 irrigations) . Three fertilizer phosphorus conditions were placed on each soil moisture condition—(1), no phosphorus, (2) 100 pounds of P_20_5 drilled into the surface, and (3) 100 pounds of P_20_5 , placed four inches deep and four inches to the side of the row. The crop was harvested October 21,

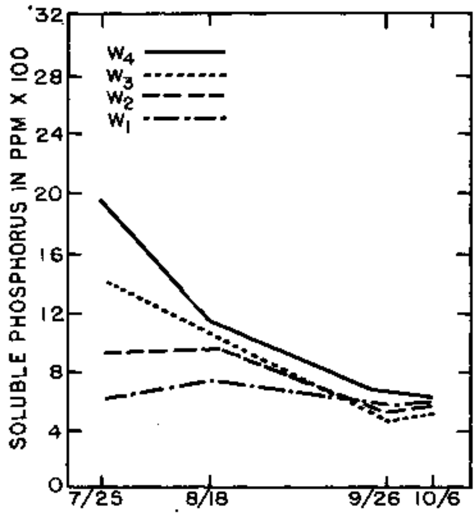


Figure 4.—Seasonal soluble phosphorus content of sugar beet petioles as affected by soil moisture condition. 1952.

yielding 10 to 18 tons per acre. The lowest yields tome from the no phosphorus and dry treatment, the highest from 4-inch placement and wet treatment. The whole tops were analyzed for total phosphorus. The data are plotted in Figure 5. It is evident that soil moisture condition is an important factor in the uptake of phosphorus regardless of the method of placement.

Variations in soil moisture had no effect on phosphorus uptake for the plots which received no added phosphorus, and, for the broadcast treatment, were of importance only insofar as a comparison of the medium and dry moisture levels is concerned. The phosphorus uptake of the plants from the medium moisture plots was about 20 percent greater than that for the dry plots. For the 4-inch deep placement, there was an increased uptake of phosphorus with increased moisture throughout the range of moisture studied. The phosphorus content of the sugar beet tops of the wet plots contained nearly 50 percent more phosphorus than those of the dry plots.

Soil Moisture Condition and Nitrogen Uptake

The soluble nitrogen content of sugar beet plants appears to be affected to a greater extent by environmental condition than is the phosphorus.

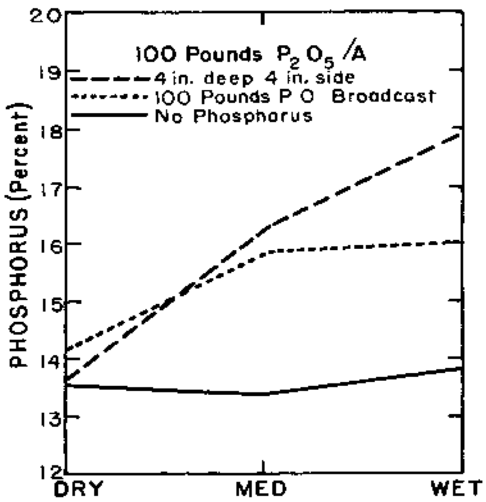


Figure 5.—Phosphorus content of sugar beet tops as affected by soil moisture condition and fertilizer placement. 1950.

There is a marked variation in the soluble nitrogen content of sugar beet petioles as affected by soil moisture condition and method of irrigation.

It is easily seen from the data in Figure 6 that at any given season of the year beet petioles taken from plants growing on dry plots are relatively high on nitrate-nitrogen in contrast to those obtained from wet plots.

Sugar beets grown under sprinkle irrigation generally appear to have a better nitrogen nutritional condition than beets grown under furrow irrigation. Such observations are supported by petiole analyses which indicate that petioles taken from sprinkle irrigated beets on August 18th had a higher nitrogen content. (See Figure 6.) This difference is probably caused by the fact that under furrow irrigation, 30 to 40 percent of total water applied is lost by deep percolation carrying soluble nitrogen materials beyond the reach of the sugar beet plant.

A somewhat similar relationship to that noted above for nitrate nitrogen holds between the soil moisture condition of the soil and the organic-nitrogen content of sugar beet petioles. This relationship is shown in Figure 7. It is interesting to note that if the soil is kept sufficiently dry the soluble organic-nitrogen content of beet petioles does not decrease as the season advances. The amount of the decrease appears to be somewhat pro-

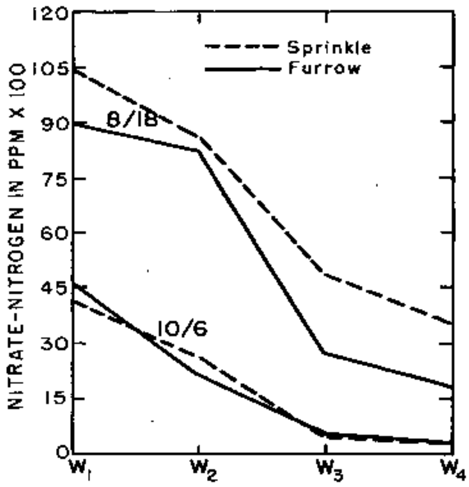


Figure 6.—Nitrate-nitrogen in sugar beet petioles as affected by method of irrigation, soil moisture condition and sampling date. 1952.

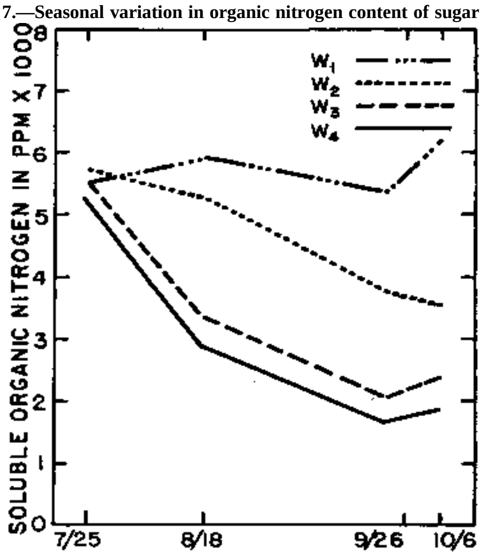
portional to irrigation water used (see Table 1) . This is in contrast to the nitrate-nitrogen content of sugar beet petioles which drop precipitously late in the season, regardless of soil moisture conditions.

Discussion

The observations noted above on the interrelationships between soil moisture condition, method of irrigation and nutritional status of sugar beet plants are of practical as well as academic interest.

It is generally assumed that when plants are growing in a soil there is a continuous process of nutrient absorption by plants accompanied by a concomitant release of soil nutrients from an insoluble or unavailable to a soluble or available form. It was observed by Pierre and Parker (21) that phosphorus may exist in the soluble form only to the extent of one to three pounds per acre in fairly fertile soils. In order for plants to obtain sufficient phosphorus for their total seasonal requirements, it is estimated that the process of re-solution must be repeated 25 to 30 times in the course of a season. It appears that the amount of available soil moisture present in a soil at any given time determines, to a considerable extent, the amount of phosphorus which can be in solution at that time and, hence, the total amount which is immediately available to plants. The rate at which insoluble soil phosphorus becomes soluble in different soils may be an important factor modifying the relationships observed on Millville loam between

Figure 7.—Seasonal variation in organic nitrogen content of sugar beet petioles



as affected by soil moisture condition under furrow irrigation.

available soil moisture and phosphorus uptake by plants. The solubility of soil phosphorus is so low that even with large quantities or irrigation water, little is carried from the soil with water lost by deep percolation.

Since the quantity of soil water available to plants is closely related to the quantity of available phosphorus, it is frequently difficult to know whether plant growth is dominated by soil moisture tension or by the availability of phosphorus.

The effect of soil moisture condition on the uptake of phosphorus is in marked contrast of its effect on nitrogen uptake. Although nitrate-nitrogen is probably not the only form of nitrogen which sugar beets absorb from the soil solution, nitrogen is absorbed largely in this form. Apparently nitrification can proceed at relatively low soil moisture conditions. Plants growing in relatively dry soil show a high nitrogen concentration in their tissues, as compared to plants growing on moist soils. This may result from the fact that when any water percolates through a soil it may carry with it large quantities of nitrate-nitrogen which may be taken beyond the reach of plant roots. Soil nitrates are highly soluble while soil phosphorus compounds are only slightly soluble. On the other hand, it may be that when plants are grown on dry soils, the rate of growth is slowed by high soil moisture tension, allowing nitrates to accumulate in plant tissue.

Factors favoring the accumulation of the plant nutrients nitrogen and phosphorus are in sharp contrast. The soil moisture condition which is favorable to high phosphorus accumulation is, as a rule, unfavorable to high nitrogen accumulation. This may mean that when all plant nutrients are considered, there will be found a narrow soil moisture condition which is best suited to the development of high yield and good quality in crops. It has been shown elsewhere (10) that for both yield and quality of roots in sugar beets, the optimum quantity of available nitrogen is nor-rowly limited, but this can be modified considerably by irrigation practice.

Summary Jn summary, therefore, we can state that water is important in nutrient uptake of plants in the following ways.

1. It is the medium through which nutrients must pass to be taken from the surface of the root into the inner vacuole.

2. Too much water may have an adverse effect insofar as root accumulation of nutrients is concerned in the following ways:

A. Limiting root growth by low oxygen concentrations or development of toxic substance.

B. Leaching of nutrients below root zone.

3. Too little water affects the concentration of nutrients in soil and their availability to plants.

4. There appears to be a relation between nutrient uptake and variations of moisture content between field capacity and wilting percentage. In sugar beets ,the phosphorus content is increased with increasing soil moisture content, while the nitrogen content is decreased and is affected to a greater extent than phosphorus.

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