The effect of potassium upon growth and certain mineral and carbohydrate contents of sugar beets
by Eugene C Doll

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Botany
Montana State University

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Sugar beets were grown in sand cultures with nutrient. solu« tions containing 39, 234, and 468 .p.p.m. of potassium. Plants were harvested five, eight, eleven, and sixteen weeks after emergence. Low potassium plants developed symptoms of potassium and manganese deficiencies* Fresh weights of the low potassium plants were significantly less than those of the medium and high potassium plants?-and the.medium potassium plants were generally lower in fresh weight than were ' the high potassium plants. After five weeks? the shoot/root ratio of the low potassium plants was higher than that of the plants of the other treatments, Root growth in low potassium plants was proportionately less than in medium and high potassium plants. Except in the last harvest, the pH of the expressed sap was lowest in the low potassium treatments. The potassium content of the expressed sap was directly correlated with the potassium content of the nutrient solution. The sap-soluble nitrate content of the medium potassium treatment was highest for all harvests. Results of other workers indicate that the absorption of nitrate should be lowest in the low potassium treatment, and highest in the high potassium treatment. The rate of nitrate reduction and assimilation should also be greatest in the high potassium treatment The low potassium plants were found to have the highest content of sap-soluble phosphate. The reducing Sugar content was inversely correlated with the potassium content of the sap Reducing sugars comprised the greater portion of the total sugars in the sap. Both the total sugar and reducing sugar contents of the sap were significantly higher in the low potassium treatment than in the medium and high potassium treatments*

THE EFFECT OF POTASSIUM UPON GROWTH AND CERTAIN MINERAL AND CARBOHYDRATE CONTENTS OF SUGAR BEETS

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ABSTRACT

Sugar beets were grown in sand cultures with nutrient solutions containing 39, 234, and 468 p.p.m. of potassium. Plants were harvested five, eight, eleven, and sixteen weeks after emergence. Low potassium plants developed symptoms of potassium and manganese deficiencies. Fresh weights of the low potassium plants were significantly less than those of the medium and high potassium plants, and the medium potassium plants were generally lower in fresh weight than were the high potassium plants. After five weeks, the shoot/root ratio of the low potassium plants was higher than that of the plants of the other treatments, Root growth in low potassium plants was proportionately less than in medium and high potassium plants. Except in the last harvest, the pH of the expressed sap was lowest in the low potassium treatments. The potassium content of the expressed sap was directly correlated with the potassium content of the nutrient solution. The sap-soluble nitrate content of the medium potassium treatment was highest for all harvests. Results of other workers indicate that the absorption of nitrate should be lowest in the low potassium treatment, and highest in the high potassium treatment. The rate of nitrate reduction and assimilation should also be greatest in the high potassium treatment. The low potassium plants were found to have the highest content of sap-soluble phosphate. The reducing sugar content was inversely correlated with the potassium content of the sap. Reducing sugars comprised the greater portion of the total sugars in the sap. Both the total sugar and reducing sugar contents of the sap were significantly higher in the low potassium treatment than in the medium and high potassium treatments.

INTRODUCTION

The sugar beet is a herbaceous dicotyledon belonging to the Chenopodiaceae family. The plant is a biennial which develops a large, succulent root the first year. Seed is produced the second year. The sugar beet is one of four groups which comprise the species *Beta vulgaris*. The three remaining groups include the garden beets, mangels, and leaf beets.

Sugar beets have been of economical importance for two hundred years, and were first developed commercially in Europe. The sugar content of the beet has been increased principally by selection from progeny tests. The Montana Department of Agriculture, Labor, and Industry (1950) reports that the State of Montana ranked fourth in the United States in sugar beet production in 1948, when 672,000 tons were produced on 55,000 acres. In 1949, 59,000 acres of sugar beets were harvested, and the average yield per acre was 11.8 tons. The cash value of this crop was $4,667,000, not including government payments of approximately $2.47 per ton.

Martin and Leonard (1949, p. 966) state that sugar accumulation in the sugar beet is greatest in regions where the mean summer temperature is between 67° and 72° F. Temperatures above 86° F. retard the accumulation of sugar. In Montana, sugar beets are grown mostly in the irrigated valleys and are usually included in a rotation with a legume and small grains. Increased yields due to nitrogen and phosphate fertilization have been reported in Montana by Afanasiev (1944) and by Nelson, et. al. (1947). Significant increases in yields from the application of potash to sugar beets have not been reported in Montana. However, Nelson, et. al. (1947) report that potassium fertilization of sugar beets may be necessary for high yields in Colorado and Nebraska. A possible response of sugar beets to potassium fertilization was obtained by Afanasiev [1] in 1946.

Sugar beet requirements for nitrogen, phosphorus, and potassium are relatively heavy. Nitrogen and phosphorus are required soil amendments in Montana at the present time. Increased beet yields will probably result from improvements in cultural and fertilizer practices and from improved sugar beet varieties. Therefore, it is highly probable that potassium fertilization will eventually become necessary for the profitable production of sugar beets in Montana.

1. Unpublished results obtained at Huntley Branch Station, Huntley, Montana.

LITERATURE REVIEW

Potassium is not known to occur in plants in organic compounds other than as salts of simple organic acids, according to Nightingale (1943). The greater portion of the potassium found in plants is in soluble inorganic forms in the cell sap. Potassium is freely translocated within the plant.

The highest concentrations of potassium were found by Cooil (1948a) in the cambial regions. Potassium is necessary for cell division. Cooil states that cells deficient in potassium will elongate, but will not divide. Stems of potassium-deficient plants elongate, but increase very little in diameter. Potassium is also necessary for root development. Russel (1915) reported in Soil Conditions and Plant Growth, quoted by Curtis and Clark (1950, p.368) that the root weight of mangels was much greater in proportion to the top weight when the mangels were supplied with adequate amounts of potassium. Nightingale (1943) states that potassium probably affects growth only as it affects the carbohydrate content, and especially as it affects the cellulose content.

A deficiency of potassium may cause a breakdown of chlorophyll. Brown spots occur on the older leaves, and Cooil (1948a) found that premature death of older leaves resulted from cases of severe deficiency. Alten, Goeze, and Fischer (1937) reported in Vol. V, Ztschr. Bodenk. u. Pflanzenernahr., quoted by Curtis and Clark (1950, p.45) that potassium may be necessary for the formation of chlorophyll. They also found that the rate of photosynthesis, determined by the absorption of CO_2, was greatly depressed by low potassium concentrations. Above a critical potassium content, however, there was very little change in the rate of photosynthesis. Loustalot, Gilbert, and Drosdoff (1950) also found that a low level of potassium decreased the rate of apparent photosynthesis as determined by CO_2 uptake. Wall (1940) has stated that the rate of respiration is increased in plants deficient in potassium.

Bear (1950) has presented evidence showing the total cation content of alfalfa to be a constant under average environmental and nutritional conditions. However, this constant varied at different stages of growth. Variations in the cation concentrations of the nutrient medium resulted in variations of the individual cation concentrations in the plant, but the total cation content, expressed as milliequivalents, remained constant. Thus, if the potassium concentration in the nutrient medium was decreased, a compensating increase in the uptake of other cations, chiefly calcium, magnesium, and sodium, resulted. Under certain conditions, the absorption of a cation may be great enough to be toxic to the plant, even though no other cations are deficient. Data presented by Bear indicate a minimum requirement for each ion, below which further replacement of that cation by another cation results in injury to the plant. An uptake of a cation in excess of its minimum requirement will not result in increased plant growth. Fluctuations of a particular cation between its minimum and toxic concentrations do not seem to affect the plant.

Bear (1950) has also shown that for certain plants the ratio of cations to anions is a constant at any stage of growth under average conditions of growth and fertility. The cations used by Bear to compute the constant are potassium, calcium, magnesium, and sodium. The anions used are nitrate, phosphate, sulfate, chloride, and silicate. Bear states than while other inorganic cations and anions are found in the plant they are present in such low concentrations that the value of the constant is not altered by disregarding them.

Nightingale (1943) has stated that potassium is directly or indirectly involved in the reduction of nitrate in the plant. Curtis and Clark (1950, p. 407) say that the oxidation of carbohydrates furnishes the energy for reduction of nitrates. Cooil and Slattery (1948) believe that a relation between nitrate reduction and malic acid accumulation may exist. If potassium affects the organic acid metabolic cycle, nitrate reduction might also be affected. Sideris and Young (1946) found a higher content of alpha-amino nitrogen in all portions of low potassium plants than in the corresponding parts of high potassium plants. This would seem to concur with Wall (1940), who writes that the lack of potassium interrupts the condensation of amino acids to proteins. However, Cooil and Slattery (1948) found no significant difference in protein content of low and high potassium plants. Data reported by Sideris and Young (1946) substantiate that reported by Cooil and Slattery.

Cooil and Slattery (1948) reported higher values for total carbohydrates in low potassium guayule plants. Reducing sugars comprised a higher percentage of the total sugars in the low potassium plants. These authors stated that potassium restricted the condensation of reducing sugars to disaccharides and polysaccharides. Reed (1907) reported that potassium was essential for the formation of starch in certain fungi. Cooil and Slattery (1948) stated that potassium accelerated some enzymatic reactions. No other element could substitute for potassium in these reactions. Sideris and Young (1945) reported that plants totally deficient in potassium had lower reducing sugar values than plants supplied with low concentrations of potassium. These investigators also indicated that phosphorylation is apparently very important in carbohydrate metabolism. They stated that the better growth of plants supplied with adequate potassium was probably due to better synthesis and polymerization of carbohydrates.

Potassium is unique among the essential mineral elements because it is not known to be a component of organic compounds. It is found in plants either in free inorganic form or as salts of simple organic acids. The absorption of potassium depends upon both the concentration of potassium and the concentration of other absorbable cations and anions in the external medium. Potassium is involved either directly or indirectly in the reduction of nitrate in the plant, with some evidence indicating that the organic acid respiratory cycle may also be involved. Differences of opinion exist as to the relation of potassium to protein synthesis. While some workers believe that potassium is essential for the condensation of amino acids to proteins, other workers have found no difference between the protein contents of low and high potassium plants. It is generally agreed, however, that potassium is necessary for the condensation of monosaccharides to disaccharides and polysaccharides. Low potassium plants are generally higher in reducing sugars than high potassium plants, but high potassium plants are usually higher in total sugars. The reducing sugar content of plants totally deficient in potassium has been found to be lower than that of low potassium plants. Potassium may, therefore, be required for the synthesis of monosaccharides.

METHODS

Three replications of sugar beets were grown in the green house in pure quartz sand. Quartz sand obtained from Ottawa, Illinois was used without treatment. Sand from the same source which had previously been used for nutrient experiments was washed and leached by the method described by Robbins (1946). Two replications were planted in galvanized steel pots, twelve inches wide, fifteen inches long, and eight and one-half inches deep. The third replication was planted in round aluminum pots, sixteen inches in diameter and twelve inches in depth. The inside of each pot was coated with asphaltum. Drainage was through a piece of glass tubing in the side of the pot, which was placed as near the bottom of the pot as possible. The pots were filled with sand to within one inch of the top. Each replication consisted of six pots, and contained two pots for each treatment. The plants from the two pots for each treatment within each replication were combined for analysis. After the sugar beets had emerged and were growing rapidly, the pots within each replication were rotated once each week to minimize bench effect.

The nutrient solution used was a variation of that given by Hoagland and Arnon (1950) for a solution completely lacking potassium. The potassium content of the solution was varied by the addition of potassium sulfate, and all other components were kept constant. The potassium concentrations were 39 p.p.m.

in the LK (low potassium) treatment, 234 p.p.m. in the MK (medium potassium) treatment, and 468 p.p.m. in the HK (high potassium) treatment. The composition of the nutrient solution is given in Table I.

TABLE I

Composition of Nutrient Solutions

Stock Solution	Ml. of Stock Solution per Liter of Nutrient Solution		
	LK	MK	HK
1.00 M $Ca(NO_3)_2$	5	5	5
1.00 M $MgSO_4$	2	2	2
0.05 M $Ca(H_2PO_4)_2$	10	10	10
1.00 M KNO_3	1	1	1
0.50 M K_2SO_4	0	5	11
Supplementary Solution	1	1	1

The supplementary solution of Hoagland and Arnon (1950) providing minor elements was used. Twice each week one milliliter of 0.5% solution of ferrous sulfate was added to each liter of nutrient solution. The pH of the solutions was adjusted to 6.5 with NH_4OH to correspond in pH with a solution used by Ulrich (1942) for sugar beets. Once each week the pots were flushed three times with distilled water before the nutrient solutions were added.

A remnant of F_1 hybrid seed was used.[1] The seed was treated with 0.31 grams of New Improved Ceresan per 100 grams of seed.

1. A seed remnant of S.L. 6105 was furnished by courtesy of Dr. F. L. Owen, U.S. Sugar Plant Field Laboratory, Salt Lake City, Utah.

Seven rows of seeds were planted in each pot, with a two-inch spacing between rows. After emergence, the plants were thinned to an interval of one inch. Each rectangular pot contained 84 plants, and each round pot contained 94 plants.

The different harvests were made by further thinning of the plants. The plants were removed, and the tops were cut off at the crown. The sand was rinsed off the tops with tap water, and the tops were then shaken to remove the excess water. The roots were washed thoroughly and blotted with dry towels. Fresh weights were determined immediately. The tops and roots were sealed in jars, which were placed in a deep freeze locker, at 10° F., within two hours of harvest.

Prior to analysis, the beets were thawed at room temperature. The plants were then wrapped in cheese cloth, and the sap was extracted by means of a Carver laboratory press operated at a pressure of 1300 lbs. per sq. in. The hydrogen ion concentration of the sap was measured with a Beckman pH meter. The sap was then placed in a refrigerator at 40° F., and the analysis was begun within 24 hours.

Potassium was determined by the cobaltinitrite method described by Ulrich (1948). One milliliter of 10% sulfuric acid was added to a sample of sap in a porcelain crucible. The sample was evaporated to dryness in a drying oven, and then heated below redness with a locomotive burner until all traces or organic matter were removed. Five milliliters of 2% acetic acid was added to the residue to dissolve the potassium. The potassium was then precipitated and determined by the titration procedure described by Hibbard and Stout (1933).

The colorimetric method using amidol (2,4 diaminophenol dihydrochloride) was used to determine phosphate. A sample of sap was evaporated to dryness, then dissolved in 25 ml. of 2% acetic acid. The solution was filtered, and an aliquot taken for analysis. The color was developed as described by Allen (1940).

Nitrates were determined colorimetrically by the 3,4 xylenol (4 hydroxy-1, 2 dimethylbenzene) method. For the determination, a sample of sap was diluted to 25 ml. One-fourth teaspoon of magnesium oxide was added. The solution was shaken for ten minutes to precipitate organic matter, and then filtered through double filter paper. An aliquot of the filtrate was placed in the distilling flask and evaporated to one milliliter. The nitrates were then determined by the procedure given by Holler and Huch (1949).

Sugars were determined by oxidation with ferricyanide and titration with ceric sulfate, as described by Hassid (1937). Reducing sugars were reported as milligrams of glucose. Total sugars included reducing sugars and sucrose, and were reported as milligrams of sucrose. The sucrose was hydrolyzed enzymatically by invertase. A sample of sap for sugar analysis was acidified with 2% acetic acid until a faint pink color developed with methyl red. For total sugar determinations, invertase was added and the sample was placed in an oven at 35° C. for two hours. To clarify the sample, seven drops of saturated neutral lead acetate were added. After shaking, one milliliter of saturated disodium phosphate and a pinch of charcoal were added. The sample was filtered through folded paper and washed with hot water. The filtrate was diluted to 100 ml., and an aliquot was taken for the titration procedure.

RESULTS

A record of the greenhouse temperatures during the experimental period was kept by means of a recording thermograph. Figure 1 gives the average weekly maximum and minimum temperatures.

The sugar beets were planted May 6, 1950, and scattered emergence was first noted May 10. Germination was very irregular. The pots were moistened with distilled water until the first nutrient solution was applied May 16. The pots were not continuously drained until June 12. After that date, surface encrustations of salts made continuous drainage and daily applications of nutrient solutions necessary. After June 12, 500 ml. of nutrient solutions were added to each pot daily.

The first evidence of nutrient deficiency in the LK treatment was a slight browning of the tips of a few cotyledons on June 9. By June 12, the cotyledonous leaves of the beets of the LK treatment showed general necrosis of the tips. The new leaves of the LK plants were a lighter green than were the corresponding leaves in the MK and HK plants. OneJune 22, a slight indication of potassium deficiency was found in one MK pot. The daily application of nutrient solution was increased to 750 ml. in all treatments; and after four days, all MK plants again appeared normal. The daily application of nutrient solution was again increased on July 3 to one liter for the rectangular pots and to one and one-half liters for the round pots. These applications proved adequate for the

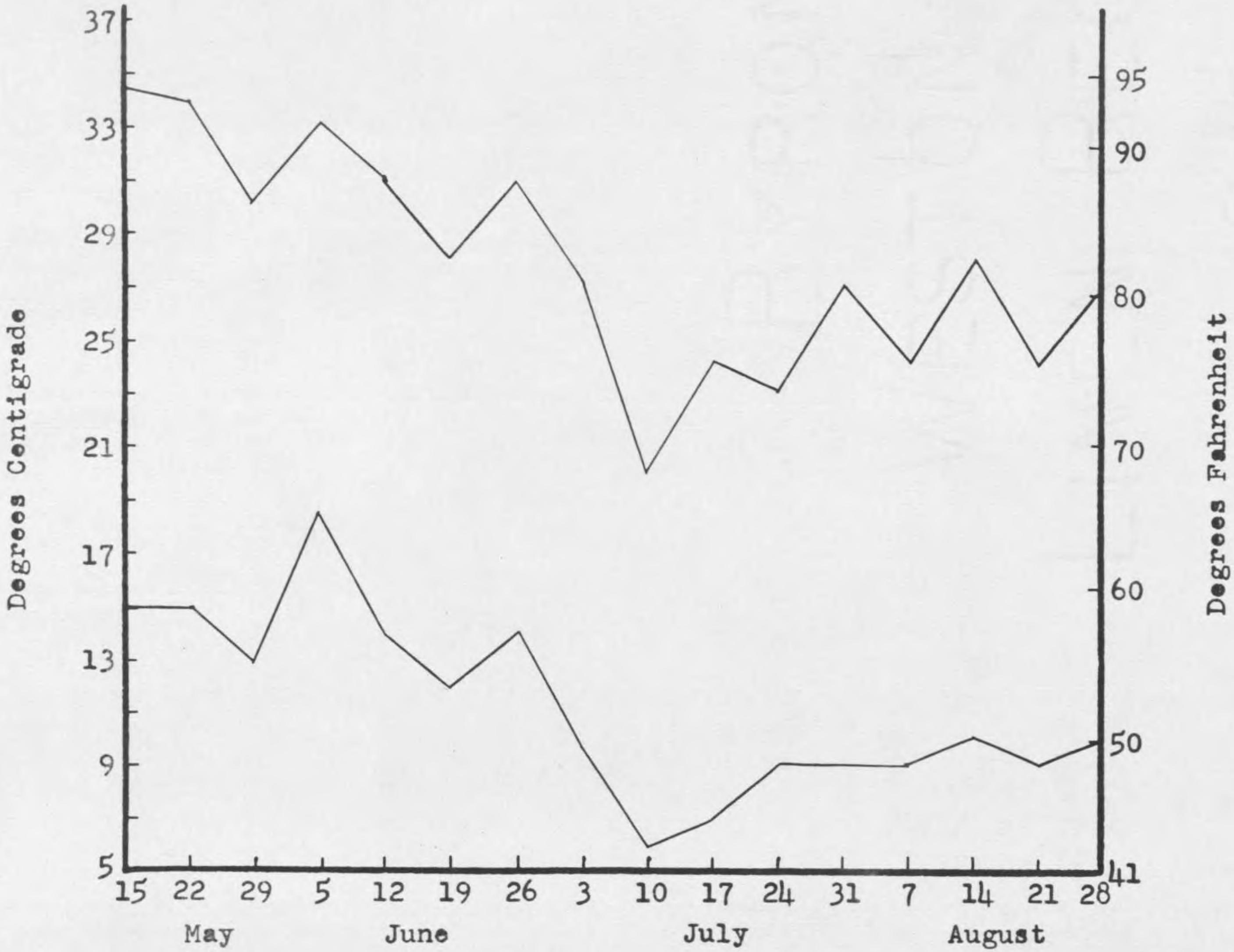

Figure 1. Average maximum and minimum greenhouse temperatures from week beginning May 15, 1950 to week beginning August 28, 1950.

remainder of the experimental period.

Tip browning of the oldest leaves was noticed in one LK pot July 6 and was generally prevalent in all LK pots by July 10. Typical potassium deficiency symptoms were moderately severe by July 17. These symptoms eventually spread to three or four sets of leaves on each plant. After July 6, the new leaves of the LK plants were light green between the veins upon emergence. By July 17, some of the new leaves were definitely chlorotic between the veins. As the tip browning and necrosis of the older leaves became more pronounced, the chlorosis of the younger leaves became less pronounced. The chlorotic symptoms of the newer leaves agreed with symptoms described for manganese deficiency in sugar beets by Cook and Millar (1949). Potassium deficiency symptoms in the LK plants persisted for the duration of the experiment. However, after thinning the plants for each harvest, the potassium deficiency symptoms became less pronounced for several days, after which the symptoms again became more pronounced.

Harvests were made June 20, July 6, July 29, and September 2. The ages of the plants when harvested were five, eight, eleven, and sixteen weeks, respectively. Fresh weights of the plants are given in Tables II, III, IV, and V. The weights of the tops and the roots of the LK plants were consistently lower than those of the MK and HK plants. All differences between the LK treatment and the MK and HK treatments were

TABLE II

Fresh Weights of Sugar Beets at Five Week Harvest

Weight per Plant in Grams

Replication	Potassium Treatment	Number of Plants	Top	Root	S/R[1]
I	LK	85	0.55	0.10	5.7
	MK	86	1.12	0.11	10.5
	HK	85	0.89	0.10	8.7
II	LK	85	0.62	0.09	6.5
	MK	86	1.10	0.11	9.8
	HK	88	1.18	0.12	9.9
III	LK	97	0.77	0.11	7.0
	MK	96	1.58	0.17	9.6
	HK	98	1.65	0.19	8.8
Average	LK	89	0.64	0.10	6.4
	MK	89	1.27	0.13	10.0
	HK	90	1.24	0.14	9.1
DRFS[2]	0.01		NS[3]	NS	NS
	0.05		0.34	NS	0.6

1. Shoot/root Ratio.
2. Difference required for significance.
3. No significance.

TABLE III

Fresh Weight of Sugar Beets at Eight Week Harvest

Weight per Plant in Grams

Replication	Potassium Treatment	Number of Plants	Top	Root	S/R
I	LK	45	4.24	0.38	11.3
	MK	45	6.97	0.63	11.0
	HK	43	7.94	0.64	12.4
II	LK	42	4.73	0.40	12.0
	MK	42	8.93	0.82	10.9
	HK	42	9.54	0.92	10.4
III	LK	47	4.63	0.43	10.8
	MK	49	9.72	0.96	10.2
	HK	49	10.30	1.19	8.6
Average	LK	45	4.53	0.40	11.4
	MK	45	8.54	0.80	10.7
	HK	45	9.26	0.92	10.5
DRFS	0.01		2.39	NS	NS
	0.05		1.44	0.28	0.6

TABLE IV

Fresh Weight of Sugar Beets at Eleven Week Harvest

Replication	Potassium Treatment	Number of Plants	Weight per Plant in Grams Top	Root	S/R
I	LK	32	24.0	2.35	10.2
	MK	32	45.2	7.83	5.8
	HK	32	41.0	7.45	5.5
II	LK	32	22.5	2.23	10.1
	MK	32	37.6	5.70	6.6
	HK	31	39.1	6.60	5.9
III	LK	37	24.4	2.91	8.4
	MK	37	46.5	8.82	5.3
	HK	38	50.6	9.04	5.6
Average	LK	34	23.6	2.50	9.6
	MK	34	43.1	7.45	5.9
	HK	34	43.5	7.70	5.7
DRFS	0.01		12.1	2.61	NS
	0.05		7.3	1.57	0.6

TABLE V

Fresh Weight of Sugar Beets at Sixteen Week Harvest

Weight per Plant in Grams

Replication	Potassium Treatment	Number of Plants	Top	Root	S/R
I	LK	6	100.6	23.3	4.3
	MK	6	145.1	40.0	3.6
	HK	6	150.8	50.8	3.0
II	LK	6	76.1	15.0	5.1
	MK	6	159.9	52.6	3.0
	HK	6	183.7	76.0	2.4
III	LK	6	144.0	33.3	4.3
	MK	6	192.7	67.8	2.9
	HK	6	247.4	102.1	2.4
Average	LK	6	106.9	23.9	4.6
	MK	6	165.9	53.4	3.2
	HK	6	194.0	76.3	2.6
DRFS	0.01		NS	NS	NS
	0.05		42.5	25.3	0.6