RESPONSE OF CROPS TO POTASSIUM IN MURIATE OF POTASH AND GLASERITE UNDER GREENHOUSE CONDITIONS

By

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Bachelor of Science

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1965

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1970

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CONDITIONS

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ACKNOWLEDGMENTS

The author is sincerely grateful to his parents, Mr. and Mrs. Subasit S. Bhokasiri, for their interest and encouragement, and for their persistent efforts to ensure the higher education of their four children.

The author appreciates the valuable training, advice and constructive criticisms received from his major advisor, Dr. Lawrence G. Morrill, throughout the course of his graduate study at the Department of Agronomy, Oklahoma State University. Appreciation is also extended to Dr. Lavoy I. Croy, for his advice and assistance during this study.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure — Page

CHAPTER I

INTRODUCTION

Potassium is one of the major plant nutrients, present in plants in quantities larger than several other nutrient elements. It is relatively abundant and widely distributed in most soils and rocks. The primary sources of potassium in soils are potash feldspar ($KAlSi_3O_8$), muscovite $[H_2KAl_3(SiO_4)_3]$, and biotite $[(CH, K)_2(Mg, Fe)_2Al_2(SiO_4)_3$.

There are many potassium fertilizer materials commonly used such as KCl, K_2SO_4, KNO_3, $K_2Mg(SO_4)_2$, KH_2PO_4, KNH_4HPO_4, and K_2HPO_4. The comparative value of potassium chloride and other potassium fertilizers has been investigated in many experiments. Recently, the use of glaserite ($Na_2SO_4 \cdot 3K_2SO_4$) as a fertilizer has become of special interest because it is a by-product in the manufacture of potassium chloride fertilizer. Glaserite (42 per cent K_2O) contains approximately 19 per cent sulfur and 6.9 per cent sodium. The sulfur in glaserite is of interest in addition to the content of potassium for use as a fertilizer.

Most of the potassium used as fertilizer is applied as the chloride. Previous work indicates that a soluble source of potassium should be equal to potassium chloride in promoting growth in most crops (Sprague, 1955). The similarity of glaserite to some potassium fertilizer materials like $NaNO_3 \cdot nKNO_3$, K_2SO_4, $MgSO_4$, and $KCl \cdot MgSO_4 \cdot 3H_2O$ led the writer to hypothesize that glaserite can stimulate plant growth as effectively as potassium chloride insofar as supplying potassium to the plant is concerned, and that under many conditions the amount of sodium contained would not be detrimental to plant growth.

The objectives of this experiment were to determine the relative effectiveness of muriate of potash and glaserite as sources of potassium by using field corn, beets, and barley as indicators. Possible beneficial effects of sodium contained in glaserite were also considered a part of this study.

CHAPTER II

LITERATURE REVIEW

Nature of Potassium Absorption by Plants

The luxury consumption or the absorption of nutrients by plants in excessive amounts is a factor to be considered in fertilizing crops. Potassium consumption by plants is a classic example of this phenomenon. Potassium has been known to be accumulated by the cells of plants to a much greater degree than the other ions. Potassium is also absorbed very rapidly and heavily by corn, not gradually and slowly like phosphorus or calcium (Collander, 1941).

Interaction of Potassium with Other Plant Nutrients

Some ions have been observed to depress uptake of other ions by plants when they are simultaneously present in the absorption zone of the roots. Some elements have been reported to have synergistic effects on the absorption of other elements by plants. Potassium is one of those elements known to have depressing effects on the absorption of the other alkaline earth metals.

Interaction of Potassium with Calcium, Magnesium, and Sodium in Plants

Potassium fertilizer dressings have been reported to decrease the calcium and magnesium contents of plants (Hewitt, 1963). This phenonmenon has been termed by plant physiologists as ionic antagonism. York, et al. (1954) showed that increasing potassium has a marked effect in reducing the absorption of calcium in corn. The same investigators reported further that potassium also causes a marked reduction in sodium and magnesium contents in the corn plants. Foy and Barber (1958) showed that added potassium reduced the magnesium content in corn, but did not significantly affect the yield.

Chamber (1953) studied the effects of potassium on magnesium and sodium uptake by wheat. He reported that less magnesium and sodium were absorbed as the Ca/K ratio increased due to ionic antagonism. Calcium, as expected, was antagonistic to potassium and sodium at high concentrations. Dienum (1958) showed that potassium fertilizer greatly depressed the uptake of sodium in some grass species. He reported that by increasing the percent potassium content in dry matter of hay crops from 0.6 to 3.2, the percent of sodium in dry matter decreased from 0.54 to 0.03.

Interaction of Potassium with Nitrogen, Phosphorus and Sulfur in Plants

Potassium, as an individual ion or in conjunction with other elements, also affects the absorption of the other nutrients aside from calcium, magnesium, and sodium. The effect of Ca/K ratio on the absorption of phosphate and other nutrients was studied by some researchers, notably Chamber (1953). The phosphate uptake by wheat was the most pronounced when the Ca/K ratio was two. This may have been due to increased phosphate uptake as a result of improved growth.

Soofi and Fuehring (1964) found a positive interaction of potassium with sulfur, phosphorus, and nitrogen in corn plants. They stated that the positive potassium-anion interactions indicate that when potassium is present at high levels, the yield of corn stover is increased considerably by application of nitrogen, phosphorus, or sulfur. When the level of applied potassium is low, the response to nitrogen, phosphorus, or sulfur is negative.

Smith and Kapp (1951) presented data showing that application of phosphorus and potassium fertilizers in combination with nitrogen gave increases in the yield of coastal Bermudagrass over that which was fertilized with nitrogen alone. Jackson, et al. (1959) found that the rate of depletion of soil potassium and phosphorus when potassium was omitted from the fertilizer, increased with increasing rates of nitrogen application. Potassium, in this case, became critical sooner than phosphorus on the soil studied which was Tifton loamy sand.

Effect of Potassium on Synthesis and Mobility of Protein and Other Elements in the Plant

Potassium is involved in enzyme reactions in the plant, and a high concentration is present in the cells, suggesting some sort of ionic balance property in the cell. Low potassium levels depress the translocation of nitrogen and carbohydrate constituents in the plant (Tisdale and Nelson, 1966). This causes the characteristic potassium symptom deficiency of burning of leaf margins and tip. The burning is due to accumulation of the untranslocated nitrogen in the leaf.

Eaton (1952) found that sunflowers often accumulated carbohydrates in the early stages of growth and depressed protein synthesis when potash was deficient. Cooill and Statlery (1948) noted that guayule (Parthenium argentatium) plants, in the early stage of potassium deficiency, accumulated starch in the phloem, cortex, and medullary rays, but in the later stages of potassium deficiency, starch disappeared from these plant parts. Hartt (1934) reported that potassium deficiency in sugarcane led to increased proportions of reducing sugar, while sucrose level was decreased. Wall (1940) noted that in tomato, potassium deficiency led to higher carbohydrates in the early stages of deficiency, followed by a sharp decline in carbohydrate content of the plant.

Proportion of Potassium in Relation to Some Nutrients in Plants

Plants differ in their power of taking up some cations and translocating them to their different parts above the ground. Collander (1941) found that these differences between plants were most marked for sodium and magnesium, some species being able to take up sixty times as much as the other species studied. It was noted further by Collander (1941) that halophytes could take up very large quantities of sodium while buckwheat, corn and sunflower could take up very little. On the other hand, all plants had about the same power of accumulating potassium when growing in potassium-rich conditions.

The accumulation of elements by the whole plant has been reported in detail by Sayre (1947). More potassium than nitrogen is accumulated during the first 30 days of growth of the young corn (4.9 lb potassium vs. 3.5 lb nitrogen per acre). This suggests a greater requirement for potassium than for nitrogen as a starter element. The same investigator noted a loss of potassium from the plant at the end of the season and that the maximum potassium accumulation in the corn plants was 114 lb/A. The total accumulation of calcium during the season, in comparison, was only about 12 lb/A. The total accumulation of magnesium in the corn during the season was also about 12 lb/A. Meyer, et al. (1952) made a survey on the general mineral composition of corn and stated that corn is most abundant in phosphorus and potassium compared to the other nutrients, except nitrogen.

Potassium and Plant-Water Relations

Potassium has been known to improve the physiological reaction of plants to adverse environmental conditions. This is especially so in the case of the effects of potassium in increasing the resistance of plants to frost and drought. Williams (1961) found that plants grew well in culture solutions with a potassium content of only 0.01 ug/ml. Potassium fertilizer also improved the water relations of plants as reported by the same worker. He noted further that the leaves from potassium-deficient plants lost water more rapidly than those from potassium-sufficient plants.

Fertilization Aspects of Potassium

In most fertilizers, potassium is supplied as chloride but little is definitely known about the effects of chloride on the growth of plants. In soils with low sulfur, supplying excessive potassium chloride may depress sulfur uptake and reduce the yield of crops. Heavy applications of chloride may damage early growth because it is not adsorbed by the soil and raises the salt concentration of the soil solution (Barber, 1968). The same investigator reported further that in addition to injury to young plants resulting from increased salt concentration and osmotic pressure by chloride, chloride may also decrease the intake of other nutrient anions such as phosphate and nitrate.

Sodium and Nutrition of Some Species

There is no conclusive evidence that sodium is an essential nutrient for any crop, but some crops give higher yields when they have access to it. Barley and cotton seem to benefit from sodium dressings when they get too little potassium. Sugar beets and mangolds give larger yields with sodium application even if they have adequate potassium. Therefore, sodium performs distinct functions in these plants. Cooke (1967) stated that sodium dressings increased the amount of water held in plant leaves and kept sugar beets more turgid in dry weather. This is similar to the effect of potassium on plant-water relations reported by Williams (1961).

Morrill and Baker (1968) summarized the benefits of sodium thus: (1) Sodium may be more efficient in a particular function than some other element that is essential for other reasons, (2) Sodium may stimulate the production of a substance which has beneficial effects, either ecologically in relation to competition or in a metabolic sense, (3) Sodium may antagonize the toxic effects of some other elements, and (4) Sodium may replace another element whose action has been specifically inhibited. The same investigators suggested that potassium uptake from glaserite treatments averaged slightly better than from potassium chloride treatments and that glaserite proved to be as good as potassium chloride as a source of potassium for the growth of forage sorghum under nutrient culture and greenhouse conditions.

CHAPTER III

MATERIALS AND METHODS

Sand culture experiments were conducted in the greenhouse to compare the effectiveness of glaserite and potassium chloride as potassic fertilizers. No. 10 cans were lined with polyethylene bags to prevent direct contact of the sand and plant roots with the walls of the cans. The pots were filled with fine acid-washed flint-shot sand with a drain at the bottom of each to permit flushing with fresh nutrient solution daily.

Three plant indicators were used: field corn, barley, and table beets. The same nutrient solution and levels of potassium from potassium chloride and glaserite were used in all three experiments. The potassium levels were: 0, 15, 30, 60, 120, and 240 ppm of potassium, applied as solution. Five replications were provided for each level of potassium from each source in a randomized complete block design. Each plant indicator, therefore, had 60 pots, 30 for each potassium source. The crops were planted one after the other: corn first, followed by table beets, and last by barley.

The other essential nutrients were provided through a modified Hoagland's solution as follows:

$Ca(NO_3)_2 \cdot 4H_2O$	30.6 g	) - diluted to 4 liters = main solution.
$MgSO_4 \cdot 7H_2O$	9.8	)
$Ca(H_2PO_4)_2 \cdot H_2O$	2.4	)

$FeCl_3$ + EDTA . . . . 12.5 + 12.5 g/2 liters = iron solution.

$MnCl_2 \cdot 4H_2O$	1.18 g	) - diluted to 1 liter = micronutrient solution.
H_3BO_3	2.86	)
$ZnSO_4 \cdot 7H_2O$	0.22	)
$CuSO_4 \cdot 5H_2O$	0.08	)
$H_2MoO_4 \cdot H_2O$	0.09	)

Ten ml of iron solution and five ml of micronutrient solution were added to the four liters of main solution to prepare the stock solution for dilution before watering the plants.

The final solution was again diluted 10 times for watering the plants together with the potassium fertilizer solution. Daily flushings with 250 ml of nutrient solution (modified Hoagland's + potassium fertilizer solution) were used to provide a continuous supply of nuttients in the sand culture and to prevent potassium build-up due to evaporation and transpiration water removal.

Corn was planted on September 28, and the plants harvested on November 18, 1969. Five seeds/pot were planted and the plants finally thinned down to two plants/pot.

A substantial number of beet seeds were spread on filter paper on top of the sand in the pots and the seeds covered with approximately one-fourth inch layer of sand. The filter paper was used to prevent the tiny seeds from being splashed down deeper into the cans with the percolating solution. The filter paper also helped to improve germination and early growth by stabilizing moisture conditions near the sand surface. The beet seeds were planted on October 12, 1969 and the plants harvested on January 12, 1970.

A number of barley seeds were planted in each pot and the plants finally thinned down to four plants/pot. Planting was on January 2, and the harvesting of the plants was on February 15, 1970.

The harvested plants were dried in a forced air oven at 80°C to constant weight. After weighing the plants were ground to 20-mesh in a Wiley Mill for chemical analyses.

Nitric-perchloric acid digestion was used on the plant tissue to destroy organic matter. Micro-Kjeldahl method was used to determine total nitrogen and the modified Kitson and Millon (1944) procedure was used for total phosphorus analysis. Potassium, sodium, and calcium in the digest were analyzed with a Model 303 Perkin-Elmer atomic absorption spectrophotometer.

CHAPTER IV

RESULTS AND DISCUSSION

A preliminary greenhouse study was made to compare the effects of potassium chloride and glaserite on the growth of corn. The results suggested further studies. The subsequent experiments are the ones discussed in this chapter.

Corn Experiment

The results of the experiment on corn include dry matter yield and uptake of potassium, calcium, and sodium expressed as percent of dry matter.

Dry Matter Yield

Table I and Figure 1A show the dry matter yield of corn treated with potassium chloride and glaserite. In general, there was no significant difference between the dry matter yields of the corn plants receiving potassium chloride and glaserite (Table I). However, there were statistically highly significant differences in yields between levels of potassium from both sources. The trend in the dry matter yields across levels was similar for both potassium carriers as indicated in Figure 1A. This trend was increasing for dry matter yield from zero, reaching a maximum at 60 ppm potassium, and then decreasing to 240 ppm potassium level. The multiple range test at the bottom of Table I

TABLE I

THE AVERAGE DRY MATTER YIELD (GM/POT) OF CORN FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.44	2.94	3.74	4.84	4.32	3.88
Glaserite	0.44	3.08	4.12	4.40	4.12	3.24

Analysis of variance

SV	df	MS	F
Blocks	4	0.1936	
K sources (K)	1	0.2406	1.1462 n. s.
K levels (L)	5	22.6339	107.8318**
K x L	5	0.3555	1.6937 n. s.
Error	44	0.2099	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average dry matter
Potassium chloride	60	4.84
Glaserite	60	4.40
Potassium chloride	120	4.32
Glaserite	120	4.12
Glaserite	30	4.12
Potassium chloride	240	3.88
Potassium chloride	30	3.74
Glaserite	240	3.24
Glaserite	15	3.08
Potassium chloride	15	2.94
Check	0	0.44

*Mean values for dry matter not joined by a common line are significantly different at 5% level.

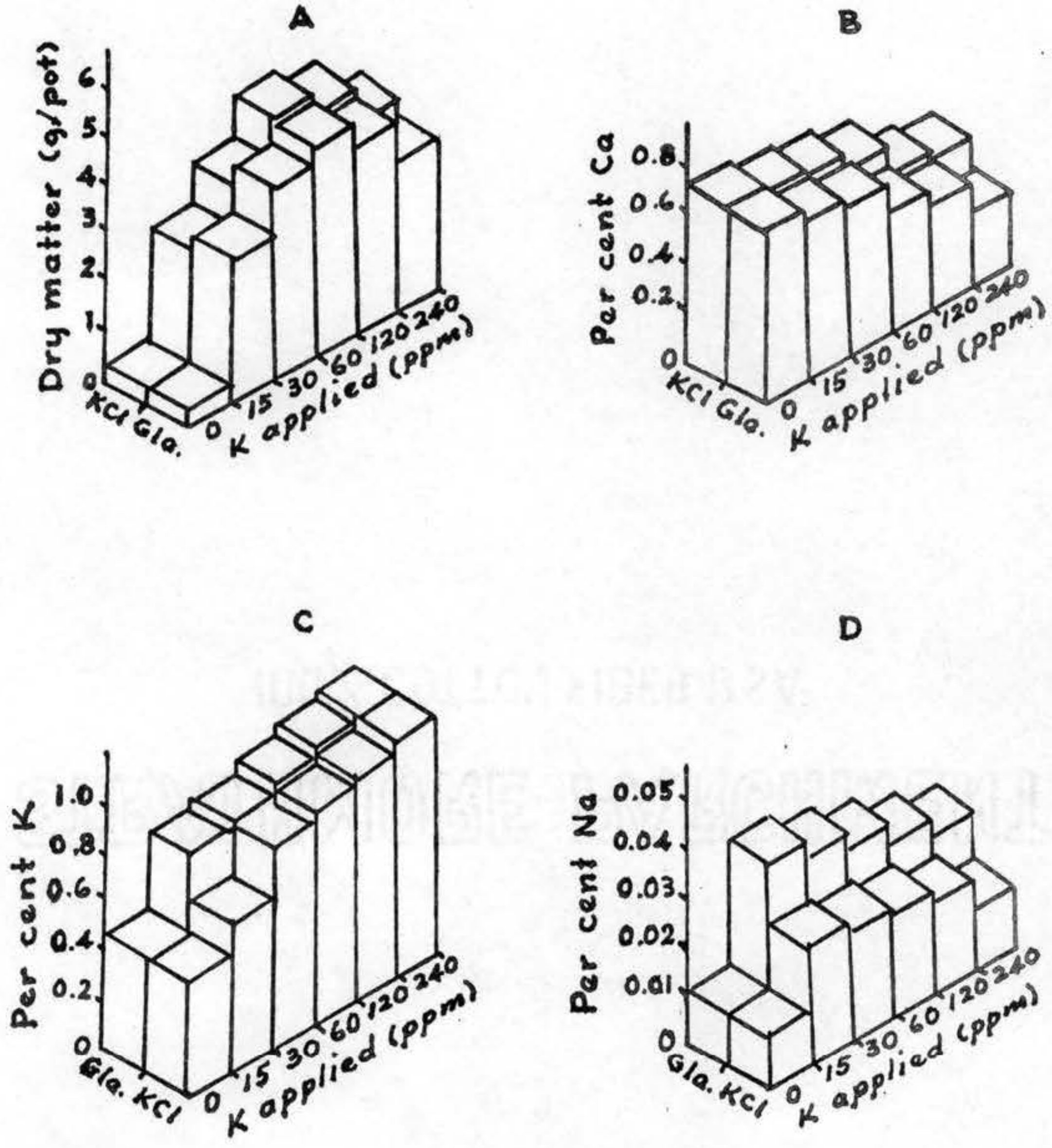

Figure 1. The Dry Matter Yield and Potassium, Calcium, And Sodium Contents of Corn Fertilized with Glaserite and Potassium Chloride

indicate the significant differences at five percent level between the various rates and sources of applied potassium.

Under the conditions that this experiment was conducted, glaserite is as good as potassium chloride in effecting a yield response in field corn, especially at lower levels of applied potassium. At the lower potassium levels of treatment (15 and 30 ppm) glaserite tended to produce higher dry matter yields than comparable treatments with potassium chloride. The opposite was true for the three remaining higher potassium treatment levels (60, 120, and 240 ppm), potassium chloride treatments showing higher dry matter yields.

Potassium Uptake

Figure 1C and Table II show the average percent of potassium content in corn fertilized with potassium chloride and glaserite as potassium sources. The pattern in potassium uptake from both sources was similarly increased with increasing rates in potassium application from zero to 240 ppm. There were statistically highly significant differences between potassium uptakes from all levels as indicated in the analysis of variance in Table II. The multiple range test at the bottom of Table II shows some significant differences between the levels and sources of applied potassium.

The rate of increase in percent potassium in corn receiving glaserite was abrupt from zero to 15 ppm potassium (Figure 1C). At potassium levels higher than 15 ppm, the rate of increase of potassium percent in corn from the glaserite-treated pots diminished considerably.

In the potassium chloride-treated pots, the percent potassium in the corn plants increased markedly from zero to 30 ppm potassium and

TABLE II

THE AVERAGE POTASSIUM CONTENT (%) OF CORN FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm) 0	15	30	60	120	240
Potassium chloride	0.489	0.618	0.824	0.892	0.936	0.954
Glaserite	0.489	0.815	0.835	0.913	0.940	0.949

Analysis of variance

SV	df	MS	F
Blocks	4	0.115	
K sources (K)	1	0.028	2.80 n. s.
K levels (L)	5	1.080	108.00**
K x L	5	0.016	1.60 n. s.
Error	44	0.010	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average potassium (%)
Potassium chloride	240	0.954
Glaserite	240	0.949
Glaserite	120	0.940
Potassium chloride	120	0.936
Glaserite	60	0.913
Potassium chloride	60	0.892
Glaserite	30	0.835
Potassium chloride	30	0.824
Glaserite	15	0.815
Potassium chloride	15	0.618
Check	0	0.489

*Mean values for potassium content not joined by a common line are significantly different at 5% level.

then at rates higher than 30 ppm, the rate of increase was greatly reduced.

It is also of interest to note that even though sodium was added with the glaserite, the ability of the plant to take up potassium was not interfered with as indicated by comparing the potassium contents. The percent potassium taken up from galserite was higher than for the comparable rate for potassium chloride in all cases except 240 ppm rate.

Calcium Uptake

The analysis for calcium in the corn plants is expressed as percent of dry matter and is shown in Figure 1B. Both glaserite and potassium chloride appear to depress the percent calcium in corn with increasing potassium applications. This trend of calcium is the reverse of that of the potassium content. It is evident that this inverse relationship between calcium and potassium and/or sodium contents is due to ionic antagonism between the elements.

As far as the percent of calcium in the corn plants is concerned, it appears that the plants at the zero level of potassium from both sources (the check pots) had the highest amount of calcium since they had the highest calcium percentage. However, taking the total calcium absorbed, by multiplying the percent calcium with dry matter, it can be shown that the check plants had the lowest total calcium.

Sodium Uptake

The results of the analysis for total sodium in the corn plants are in Figure 1D and Table III. There was a decreasing trend of sodium percentage in corn when higher rates of potassium were applied from both

TABLE III

THE AVERAGE SODIUM CONTENT (%) OF CORN FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm) 0	15	30	60	120	240
Potassium chloride	0.0129	0.0279	0.0253	0.0222	0.0197	0.0145
Glaserite	0.0129	0.0367	0.0328	0.0298	0.0264	0.0233

Analysis of variance

SV	df	MS	F
Blocks	4	171.600	
K sources (K)	1	64157.400	424.400**
K levels (L)	5	49437.240	327.220**
K x L	5	2727.560	18.054**
Error	44	151.082	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average sodium (%)
Glaserite	15	0.0367
Glaserite	30	0.0328
Glaserite	60	0.0298
Potassium chloride	15	0.0279
Glaserite	120	0.0264
Potassium chloride	30	0.0253
Glaserite	240	0.0233
Potassium chloride	60	0.0222
Potassium chloride	120	0.0197
Potassium chloride	240	0.0145
Check	0	0.0129

*Mean values for sodium content not joined by a common line are significantly different at 5% level.

sources. The analysis of variance showed that potassium sources, potassium levels, and the interaction between potassium sources and potassium levels were statistically highly significant for sodium uptake. The significant differences between levels of potassium from both sources are reflected in the multiple range tests at the bottom of Table III.

It can be seen in Figure 1D and Table III (analysis of variance) that glaserite was superior to the potassium chloride-treated pots in supplying sodium to the corn plants at all levels of applied potassium. However, comparing the potassium and sodium uptakes in Figure 1C and 1D shows interesting interaction between these two elements in the corn plant. High percentage of sodium in plants generally indicates problems and not benefits under normal circumstances, i.e., high sodium (too high for maximum production) or low potassium indicates that the plant is "trying" to compensate for the low potassium by using sodium. Such seems to be the case here as shown in Figure 1C and 1D. By comparing these data with the dry matter yield obtained it is apparent that the corn plant did benefit from the uptake of sodium at low potassium levels (15 ppm potassium) from glaserite which gave a higher yield than the same level of potassium chloride. Furthermore, 30 ppm potassium from glaserite produced a dry matter yield that was not statistically different from the highest yield obtained by potassium chloride. This, again, indicates a beneficial use of sodium by the corn plant.

It is also interesting to note that the percentage sodium contained in the plant was reduced as the potassium level increased when the potassium source was glaserite even though more sodium was also present. It seems that since the corn plant was more nearly able to obtain the potassium it needed its uptake of sodium was reduced.

Barley Experiment

The discussion of the results of the experiment on barley includes dry matter yield, and potassium and sodium contents in the plant.

Dry Matter Yield

The dry matter yield of the barley plants are shown in Figure 2A and Table IV. The yield responses to potassium by the barley plants were similar for both potassium sources. The response curves were also similar for both potassium sources, generally speaking (Figure 2). Study of these results shows an increase in dry matter yield for glaserite (sodium). The only treatment out of place is 120 ppm potassium from glaserite. This may be the result of salt effect at high concentrations. Glaserite at 60 ppm potassium produced a yield not statistically different from 120 ppm potassium from potassium chloride--the highest yield--but statistically different higher from 60 ppm potassium from potassium chloride. This is a benefit that is attributable to sodium.

There were statistically highly significant differences in yields at the different levels of potassium from both sources. The differences between levels and sources are shown in the multiple range test at the bottom of Table IV.

Potassium Uptake

Figure 2B and Table V show the potassium uptake of barley. There was increasing potassium content in barley with increasing rates of applied potassium from both sources. The potassium uptakes from both sources varied measurably with glaserite significantly lower than

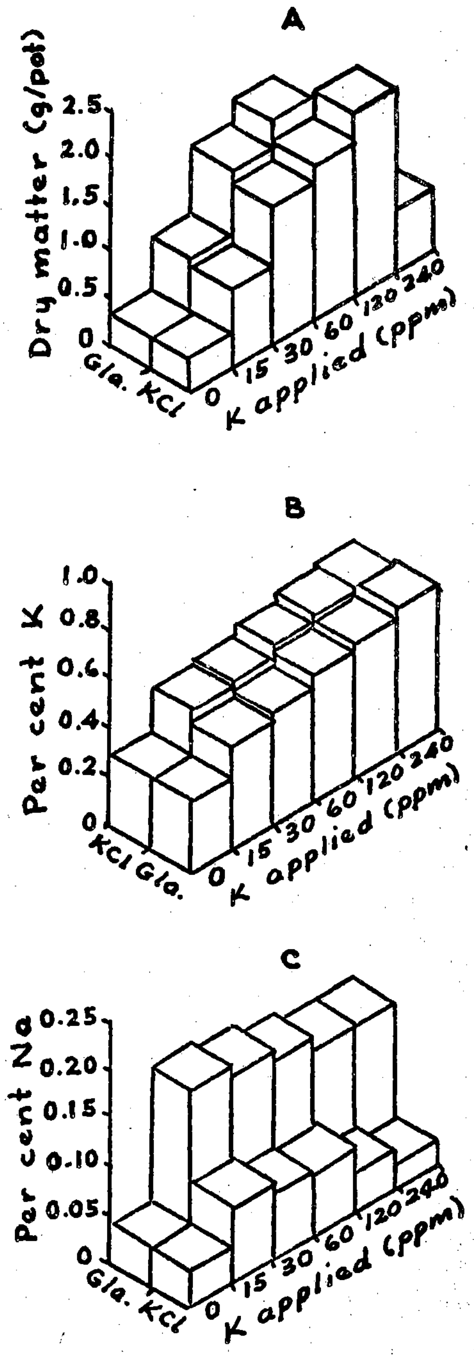

Figure 2. The Dry Matter Yield and Potassium and Sodium Contents of Barley Fertilized with Glaserite and Potassium Chloride

TABLE IV

THE AVERAGE DRY MATTER YIELD (GM/POT) OF BARLEY FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm) 0	15	30	60	120	240
Potassium chloride	0.403	0.947	1.500	1.672	1.967	0.621
Glaserite	0.403	0.951	1.626	1.929	1.600	0.627

Analysis of variance

SV	df	MS	F
Blocks	4	0.048	
K sources (K)	1	0.001	
K levels (L)	5	3.723	148.92**
K x L	5	0.108	4.32**
Error	44	0.025	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average dry matter
Potassium chloride	120	1.967
Glaserite	60	1.929
Potassium chloride	60	1.672
Glaserite	30	1.626
Glaserite	120	1.600
Potassium chloride	30	1.500
Glaserite	15	0.951
Potassium chloride	15	0.947
Glaserite	240	0.627
Potassium chloride	240	0.621
Check	0	0.403

*Mean values for dry matter not joined by a common line are significantly different at 5% level.

TABLE V

THE AVERAGE POTASSIUM CONTENT (%) OF BARLEY FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.341	0.445	0.467	0.490	0.531	0.567
Glaserite	0.341	0.429	0.442	0.474	0.514	0.570

Analysis of variance

SV	df	MS	F
Blocks	4	0.0005	
K sources (K)	1	0.0030	10.00**
K levels (L)	5	0.0636	212.00**
K x L	5	0.0002	
Error	44	0.0003	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average potassium (%)
Glaserite	240	0.570
Potassium chloride	240	0.567
Potassium chloride	120	0.531
Glaserite	120	0.514
Potassium chloride	60	0.490
Glaserite	60	0.474
Potassium chloride	30	0.467
Potassium chloride	15	0.445
Glaserite	30	0.442
Glaserite	15	0.429
Check	0	0.341

*Mean values for potassium content not joined by a common line are significantly different at 5% level.

potassium chloride at the one percent level. There were statistically highly significant differences in potassium contents of barley at the different potassium rates of both sources (analysis of variance of Table V). These differences between levels and sources are indicated in the multiple range test at the bottom of Table V.

For barley, both sources of potassium caused a marked increase in percent potassium in the plant from zero to 15 ppm of applied potassium (Figure 2B). This increase in percentage of potassium decreased in the rates from 15 to 240 ppm potassium level. Relating potassium uptake to yield (Figure 2A), it is obvious that the most beneficial levels of applied potassium was 60 ppm for glaserite and 120 ppm for potassium chloride.

Sodium Uptake

The results of the plant analysis for sodium are in Figure 2C and Table VI. Glaserite showed a significant increase in sodium uptake by barley over potassium chloride at all levels. However, the patterns for sodium uptake at the different levels of glaserite showed higher response at the lower levels than at the higher rates. This trend of sodium uptake by barley also showed up in corn.

In the potassium chloride-treated plants, there was a general inverse relationship between percentage sodium in the plant and the rates of application. This is strong evidence of potassium antagonizing sodium.

TABLE VI

THE AVERAGE SODIUM CONTENT (%) OF BARLEY FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.048	0.080	0.078	0.076	0.033	0.020
Glaserite	0.048	0.184	0.181	0.176	0.153	0.153

Analysis of variance

SV	df	MS	F
Blocks	4	0.0002500	
K sources (K)	1	0.1310000	5770.925**
K levels (L)	5	0.0108000	475.771**
K x L	5	0.0056000	246.696**
Error	44	0.0000227	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average sodium (%)
Glaserite	15	0.184
Glaserite	30	0.181
Glaserite	60	0.176
Glaserite	120	0.153
Glaserite	240	0.153
Potassium Chloride	15	0.080
Potassium chloride	30	0.078
Potassium chloride	60	0.076
Check	0	0.048
Potassium chloride	120	0.033
Potassium chloride	240	0.020

*Mean values for sodium content not joined by a common line are significantly different at 5% level.

Beet Experiment (Top)

The discussion for the experimental results in beets (top) includes dry matter yield, and potassium and sodium uptake.

Dry Matter Yield

The dry matter yield for beets (top) is reported in Table VII and Figure 3A. Glaserite showed a significantly higher yield response in beets than potassium chloride especially at rates lower than 60 ppm potassium. This is indicated by the relatively large increase in dry matter production stimulated at low potassium levels by glaserite. The difference between the dry matter yields at 15 ppm potassium rate from the two sources was highly significant, with glaserite higher than that of potassium chloride.

The trend in dry matter yield of the beet top from both potassium sources was bery similar which was a more or less linear increase from zero to 60 ppm potassium and then a linear decrease from 60 to 240 ppm of applied potassium. The differences between yields at the different potassium levels were highly significant as indicated in the analysis of variance and shown in detail in the multiple range test at the bottom of Table VII.

Using the dry matter yield of beet top as the basis, the most beneficial level for both potassium carriers was 60 ppm of potassium. At potassium rates higher than 60 ppm, the dry matter yield of beet top was adversely affected.

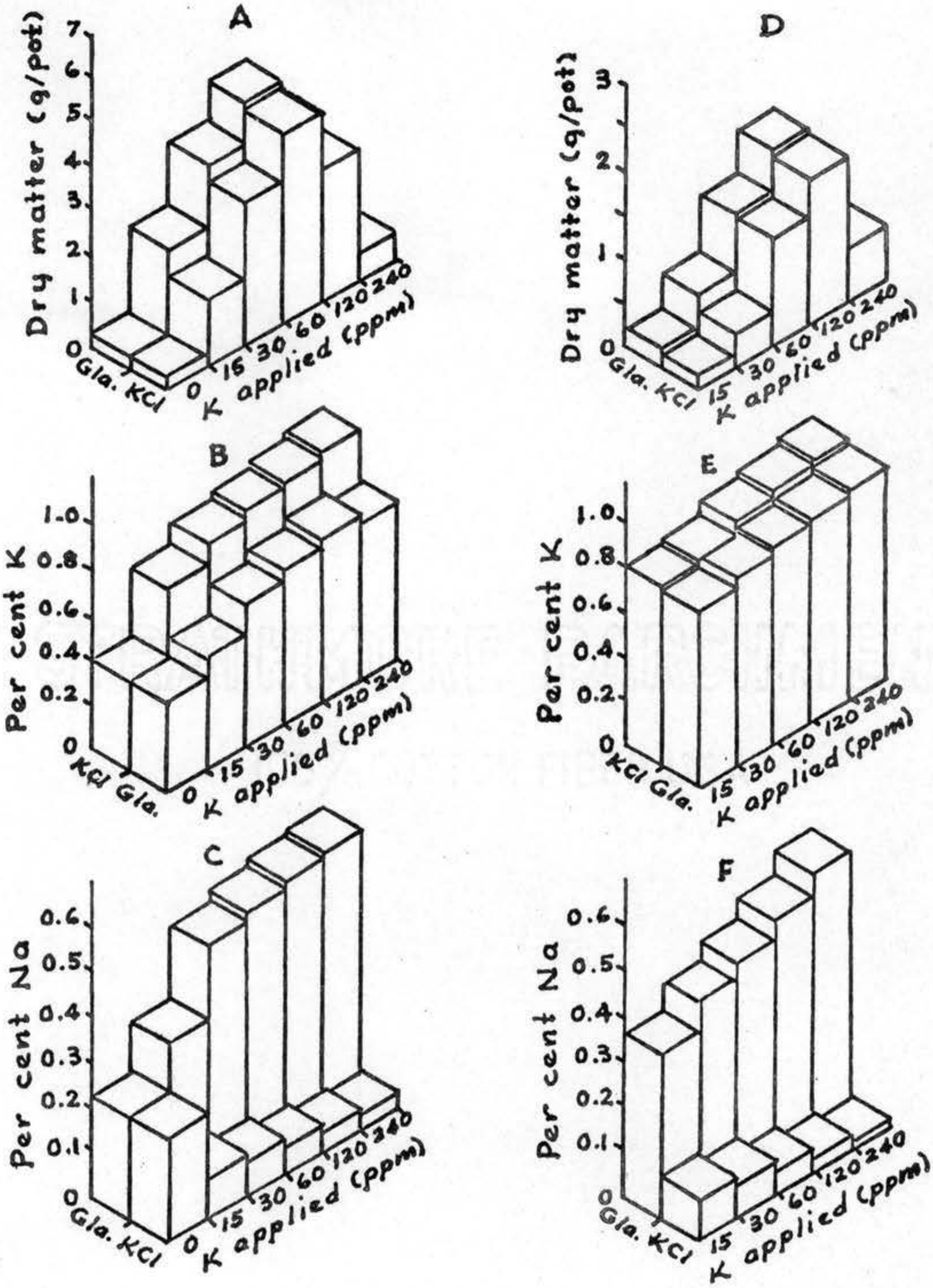

Figure 3. The Dry Matter Yield, Potassium, and Sodium Contents in the Tops and Roots of Beets

TABLE VII

THE AVERAGE DRY MATTER YIELD (GM/POT) OF BEET TOP FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.228	1.639	3.376	4.236	3.259	0.830
Glaserite	0.228	2.150	3.439	4.503	3.567	0.868

Analysis of variance

SV	df	MS	F
Blocks	4	0.0340	
K sources (K)	1	0.5820	15.236**
K levels (L)	5	26.5936	696.168**
K x L	5	0.0988	2.586*
Error	44	0.0382	

**Significant at 1% level.
*Significant at 5% level.

Duncan's Multiple Range Test[1]

K source	K applied (ppm)	Average dry matter
Glaserite	60	4.503
Potassium chloride	60	4.236
Glaserite	120	3.567
Glaserite	30	3.439
Potassium chloride	30	3.376
Potassium chloride	120	3.259
Glaserite	15	2.150
Potassium chloride	15	1.639
Glaserite	240	0.868
Potassium chloride	240	0.830
Check	0	0.228

[1]Mean values for dry matter not joined by a common line are significantly different at 5% level.

Potassium Uptake

The potassium content in the top of beets receiving potassium chloride and glaserite is in Table VIII and Figure 3B. There were highly significant differences in percentage potassium in plant between the two sources of potassium, potassium levels, and interaction between the sources and levels of potassium applied. Potassium chloride effected a significantly higher percentage potassium in the top of beets than glaserite at all levels of applied potassium above zero (Figure 3B). There were statistically highly significant differences in potassium percentages at the various potassium levels for both sources of potassium. The potassium uptake from both potassium fertilizers rapidly increased from zero to 30 ppm potassium and more or less leveled off thereafter. The multiple range test for the potassium levels of both potassium-bearing materials are at the bottom of Table VIII.

Sodium Uptake

In Figure 3C and Table IX are the sodium contents in the top of beets fertilized with potassium chloride and glaserite. The glaserite-treated plants had very much higher sodium content than the potassium chloride-treated plants and this difference was statistically highly significant. Across levels, the trends in the sodium uptake of beets from the two fertilizers showed a reversing pattern which increased for glaserite and decreased for potassium chloride with increasing potassium rates. These trends of sodium and potassium percentages in relation to the two sources have not been observed in the other crops studied. The increase in sodium uptake from glaserite was very rapid from zero to 30 ppm potassium and more or less leveled off from 30 to 240 ppm. The

TABLE VIII

THE AVERAGE POTASSIUM CONTENT (%) OF THE BEET TOP FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.401	0.756	0.817	0.857	0.862	0.874
Glaserite	0.401	0.499	0.653	0.708	0.784	0.754

Analysis of variance

SV	df	MS	F
Blocks	4	0.00025	
K sources (K)	1	0.24500	1750.000**
K levels (L)	5	0.26180	1870.000**
K x L	5	0.01860	132.857**
Error	44	0.00014	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average potassium (%)
Potassium chloride	240	0.874
Potassium chloride	120	0.862
Potassium chloride	60	0.857
Potassium chloride	30	0.817
Glaserite	120	0.784
Potassium chloride	15	0.756
Glaserite	240	0.754
Glaserite	60	0.708
Glaserite	30	0.653
Glaserite	15	0.499
Check	0	0.401

*Mean values for potassium content not joined by a common line are significantly different at 5% level.

TABLE IX

THE AVERAGE SODIUM CONTENT (%) OF BEET TOP FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.249	0.089	0.082	0.076	0.067	0.064
Glaserite	0.249	0.365	0.520	0.568	0.584	0.590

Analysis of variance

SV	df	MS	F
Blocks	4	2040.400	
K sources (K)	1	210847509.600	128562.732**
K levels (L)	5	1900304.160	1158.697**
K x L	5	10560724.800	6439.325**
Error	44	1640.036	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average sodium (%)
Glaserite	240	0.590
Glaserite	120	0.584
Glaserite	60	0.568
Glaserite	30	0.520
Glaserite	15	0.365
Check	0	0.249
Potassium chloride	15	0.089
Potassium chloride	30	0.082
Potassium chloride	60	0.076
Potassium chloride	120	0.067
Potassium chloride	240	0.064

*Mean values for sodium content not joined by a common line are significantly different at 5% level.

sodium uptake in the top of beets from potassium chloride was a marked decrease from zero to the first increment of potassium (15 ppm) and then more or less leveled thereafter. This may have been due to the growth and antagonistic effects of sodium and potassium ions.

There were statistically highly significant differences in sodium uptake of the beet top at the various levels of potassium from both sources. There were also highly significant differences in the sodium percentage of the beet top insofar as interaction between potassium sources and levels were concerned. This highly significant interaction was primarily due to the reversed trends in the sodium content of the beet top from pots receiving potassium chloride and glaserite. The significant differences between levels of potassium from both sources are indicated at the bottom of Table VIII in the multiple range test.

Beet Experiment (Root)

Dry Matter Yield

Figure 3D and Table X show the increase in yield with increase in applied potassium up to 120 ppm and then leveled off, regardless of source of potassium. The various levels of potassium applied to beets showed highly significant differences in dry matter of beet root while the sources did not show any appreciable difference. The glaserite proved to be superior to potassium chloride as a potassium source for beet root, particularly at 120 ppm level of potassium as indicated in the Duncan's multiple range test (Table X, bottom).

The beet root showed a higher optimum level of both potassium fertilizers than the top. The dry matter yield for root was highest at 120 ppm applied potassium while that of the top was at 60 ppm potassium.

TABLE X

THE AVERAGE DRY MATTER YIELD (GM/POT) OF BEET ROOT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	-	0.192	0.432	1.299	1.637	0.578
Glaserite	-	0.243	0.586	1.373	1.769	0.433

Analysis of variance

SV	df	MS	F
Blocks	4	0.03750	
K sources (K)	1	0.03600	3.571 n. s.
K levels (L)	4	3.99680	396.508**
K x L	4	0.03525	3.497*
Error	36	0.01008	

**Significant at 1% level.
*Significant at 5% level.

Duncan's Multiple Range Test[1]

K source	K applied (ppm)	Average dry matter
Glaserite	120	1.769
Potassium chloride	120	1.637
Glaserite	60	1.373 |
Potassium chloride	60	1.299 |
Glaserite	30	0.586 |
Potassium chloride	240	0.578 |
Glaserite	240	0.433 |
Potassium chloride	30	0.432 |
Glaserite	15	0.243 |
Potassium chloride	15	0.192 |

[1]Mean values for dry matter not joined by a common line are significantly different at 5% level.

This indicates that beet root requires higher amount of potassium than the top. Examination of the table shows glaserite to consistently produce higher yields than potassium chloride except for the 240 ppm level. The highes yield obtained with 120 ppm potassium from glaserite was statistically significantly different from the yield obtained from 120 ppm potassium from potassium chloride.

Potassium Uptake

Figure 3E and Table XI show the same trend of potassium content in beet root with increasing potassium from both sources. The potassium chlloride-treated and glaserite-treated beets were highly significantly different as regards percentage potassium. There were also significant differences in the percentage potassium of beet root at the various levels of potassium from both sources as shown in the analysis of variance of Table XI (middle). The detailed representation of these differences between levels are shown in the multiple range test at the bottom of Table XI.

It is striking that the root of beets showed no preference, taking into consideration the percentage potassium, for any of the potassium sources compared to the top where potassium chloride was superior to glaserite in percent potassium absorbed. This probably indicates that the potassium availability of glaserite was different from (lower than) that of potassium chloride. The potassium absorbed from glaserite may have been held up mostly in the roots. Only when the potassium requirement of the roots was met did some of the potassium go to the top. However, since the dry matter yield of root was more or less the same for both top and root regardless of potassium carrier, potassium from

TABLE XI

THE AVERAGE POTASSIUM CONTENT (%) OF BEET ROOT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	-	0.812	0.856	0.897	0.922	0.938
Glaserite	-	0.805	0.862	0.874	0.897	0.902

Analysis of variance

SV	df	MS	F
Blocks	4	0.000250	
K sources (K)	1	0.004000	71.428**
K levels (L)	4	0.020250	361.607**
K x L	4	0.000750	13.393**
Error	36	0.000056	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average potassium (%)
Potassium chloride	240	0.938
Potassium chloride	120	0.922
Glaserite	240	0.902
Potassium chloride	60	0.897
Glaserite	120	0.897
Glaserite	60	0.874
Glaserite	30	0.862
Potassium chloride	30	0.856
Potassium chloride	15	0.812
Glaserite	15	0.805

*Mean values for potassium content not joined by a common line are significantly different at 5% level.

glaserite was sufficient to meet the growth requirements of both root and top of beets.

Sodium Uptake

Figure 3F and Table XII show the decreasing sodium content in beet root with increasing rates of potassium applied from potassium chloride, and the reverse trend for glaserite. Table XII (analysis of variance at the middle) shows highly significant differences in sodium content in the root of beets treated with glaserite and potassium chloride. There were also significant differences in sodium content between levels of potassium from both sources. The Duncan's multiple range test indicated these differences at all levels of the two potassium sources were significantly different. It is evident that beet root absorbs a large amount of sodium even if its potassium requirement is satisfied.

Beet Experiment (Whole Plant)

The results of the beet experiment for the whole plant analyses include dry matter yield, potassium percentage, and percent sodium.

Dry Matter Yield

Table XIII and Figure 4 show a definite superiority of glaserite over potassium chloride as a source of potassium to beets. The dry matter yields from both potassium sources were highest at 60 ppm of applied potassium. Statistically speaking, there were highly significant differences from both potassium carriers with respect to dry matter yield. The potassium levels were also highly significant as shown in Table XIII. The beet plants showed a better response to glaserite than

TABLE XII

THE AVERAGE SODIUM CONTENT (%) OF BEET ROOT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	-	0.089	0.075	0.051	0.036	0.030
Glaserite	-	0.396	0.448	0.482	0.512	0.553

Analysis of variance

SV	df	MS	F
Blocks	4	2629.080	
K sources (K)	1	222318132.480	78638.784**
K levels (L)	4	315346.680	111.545**
K x L	4	1813090.680	641.330**
Error	36	2827.080	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average sodium (%)
Glaserite	240	0.553
Glaserite	120	0.512
Glaserite	60	0.482
Glaserite	30	0.448
Glaserite	15	0.396
Potassium chloride	15	0.089
Potassium chloride	30	0.075
Potassium chloride	60	0.051
Potassium chloride	120	0.036
Potassium chloride	240	0.030

*Mean values for sodium content not joined by a common line are significantly different at 5% level.

TABLE XIII

THE AVERAGE DRY MATTER YIELD (GM/POT) OF THE WHOLE BEET PLANT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm) 0	15	30	60	120	240
Potassium chloride	0.228	1.832	3.809	5.539	4.896	1.409
Glaserite	0.228	2.394	4.025	5.877	5.337	1.301

Analysis of variance

SV	df	MS	F
Blocks	4	0.128	
K sources (K)	1	0.875	19.022**
K levels (L)	5	47.594	1033.674**
K x L	5	0.167	3.630 n. s.
Error	44	0.046	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average dry matter
Glaserite	60	5.877
Potassium chloride	60	5.539 |
Glaserite	120	5.337 |
Potassium chloride	120	4.896
Glaserite	30	4.025 |
Potassium chloride	30	3.809 |
Glaserite	15	2.394
Potassium chloride	15	1.832
Potassium chloride	240	1.409 |
Glaserite	240	1.301 |
Check	0	0.228

*Mean values for dry matter not joined by a common line are significantly different at 5% level.

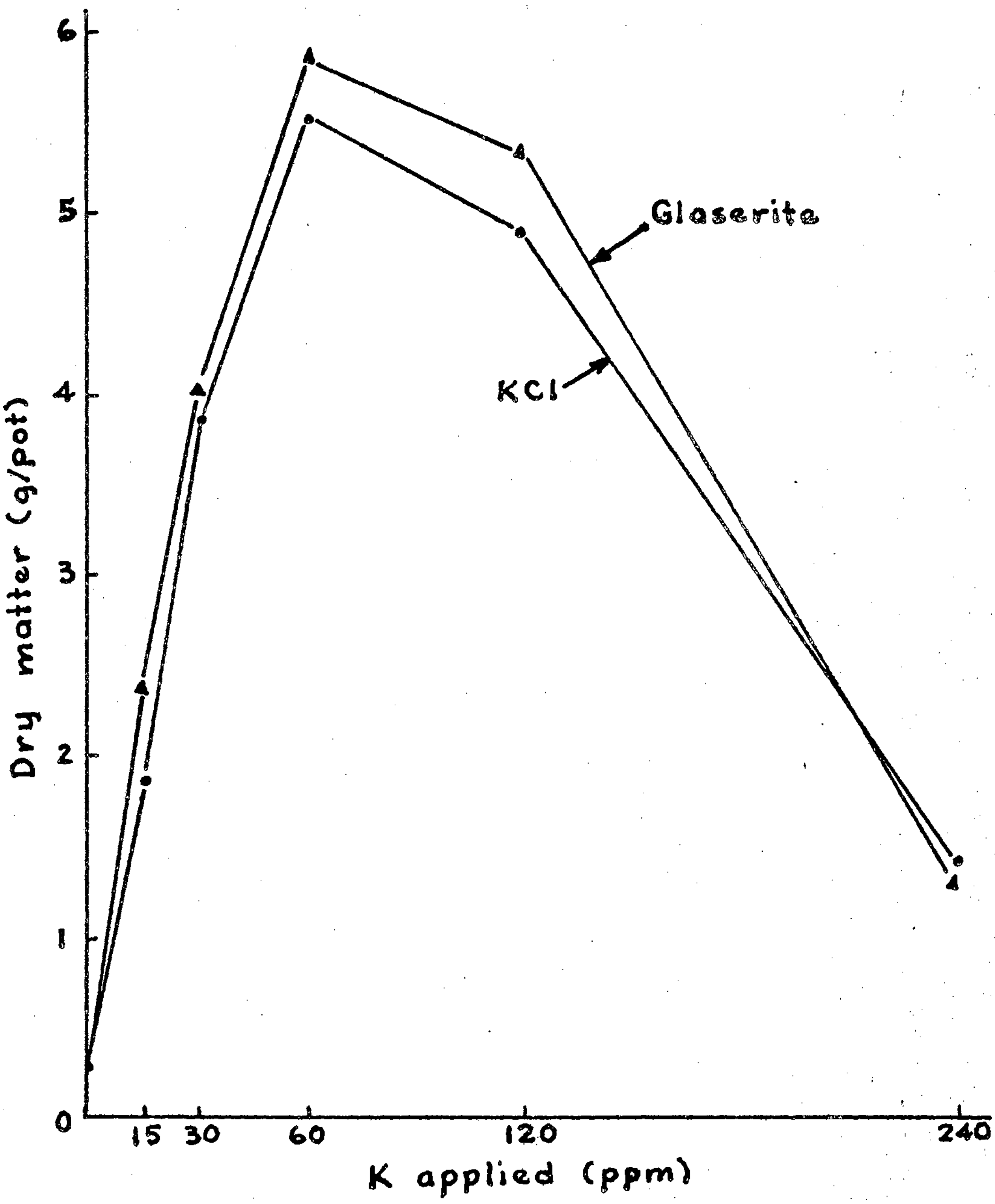

Figure 4. The Dry Matter Yield of Whole Beet Plant Fertilized with Glaserite and Potassium Chloride

potassium at most levels, particularly at the lower rates as indicated in Duncan's multiple range test at the bottom of Table XIII.

It is interesting to note that beets have different optimum levels of applied potassium for the top and for the root and that this optimum level is the same for both potassic fertilizers. This conclusion is based upon the dry matter yields of top and root. In the top, beets had an optimum level of 60 ppm applied potassium while in the root, the optimum level was 120 ppm potassium. Evidently, the root of beets has a higher internal requirement for potassium than the top.

Potassium and Sodium Uptake

Table XIV and Figure 5 show the increasing trend of potassium uptake in the whole beet plant at the various levels of potassium applications. The sources of potassium (glaserite and potassium chloride) and levels of applied potassium showed highly significant differences in potassium uptake by beets. The Duncan's multiple range test show these differences as indicated at the bottom of Table XIV.

Table XV and Figure 5 show the reverse trends of sodium uptake with respect to the potassium uptake by the whole beet plant. The effects of potassium sources and applied potassium on sodium percentage of the whole beet plant were both highly significant. Duncan's multiple range test indicated the differences between levels to be significant in many cases (Table XV).

Figure 5 shows a striking contrast in percent sodium in the beets from glaserite compared to potassium chloride. Even if percent sodium from potassium chloride-treated pots was much lower than that of the glaserite-treated pots, the yields obtained from the two potassium

TABLE XIV

THE AVERAGE POTASSIUM CONTENT (%) OF THE WHOLE BEET PLANT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.401	0.783	0.837	0.877	0.892	0.906
Glaserite	0.401	0.652	0.757	0.791	0.846	0.819

Analysis of variance

SV	df	MS	F
Blocks	4	0.0126	
K sources (K)	1	0.3060	74.634**
K levels (L)	5	2.6520	646.829**
K x L	5	0.0200	4.878**
Error	44	0.0041	

**Significant at 1% level.

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average potassium (%)
Potassium chloride	240	0.906
Potassium chloride	120	0.892
Potassium chloride	60	0.877
Glaserite	120	0.846
Potassium chloride	30	0.837
Glaserite	240	0.819
Glaserite	60	0.791
Potassium chloride	15	0.783
Glaserite	30	0.757
Glaserite	15	0.652
Check	0	0.401

*Mean values for potassium content not joined by a common line are significantly different at 5% level.

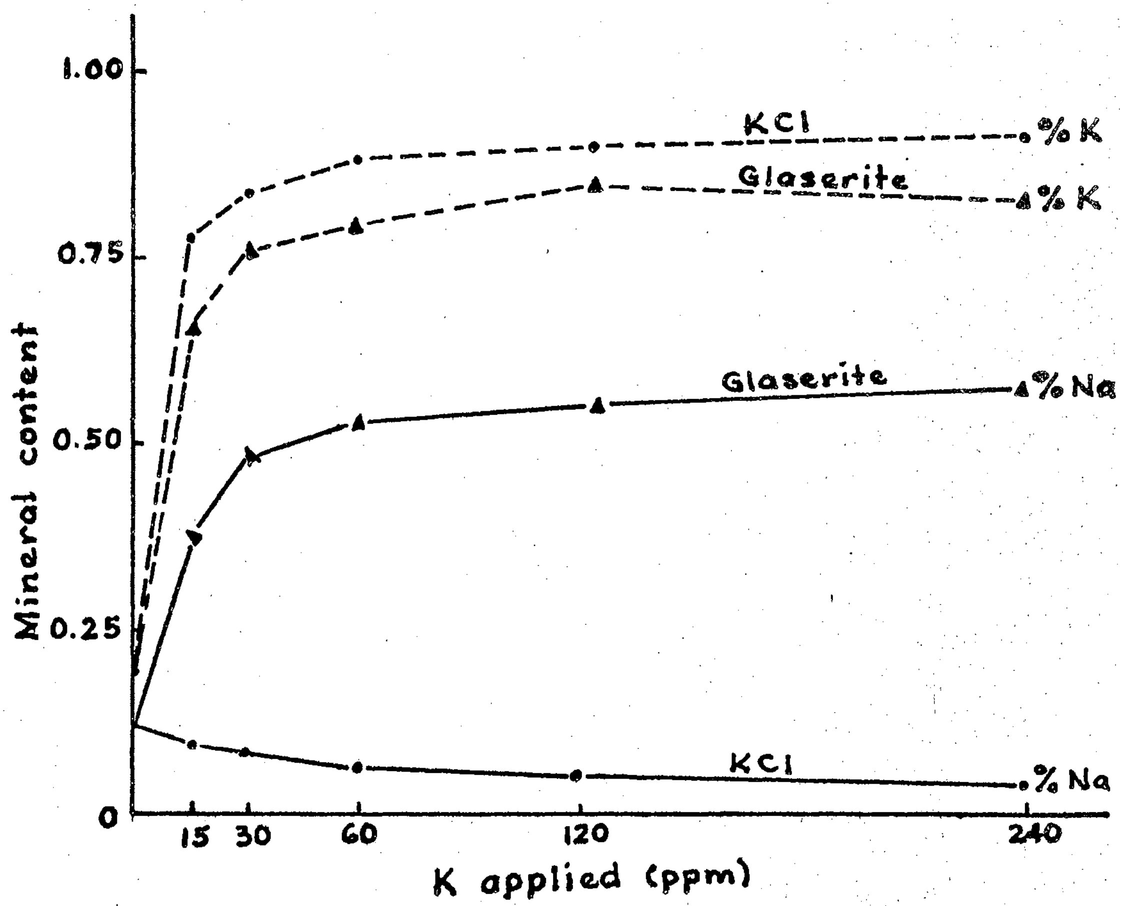

Figure 5. The Potassium and Sodium Contents of the Whole Beet Plant Fertilized with Glaserite and Potassium Chloride

TABLE XV

THE AVERAGE SODIUM CONTENT (%) OF THE WHOLE BEET PLANT FERTILIZED WITH GLASERITE AND POTASSIUM CHLORIDE

Source of potassium	K applied (ppm)					
	0	15	30	60	120	240
Potassium chloride	0.249	0.089	0.087	0.063	0.051	0.047
Glaserite	0.249	0.380	0.484	0.525	0.548	0.571

Analysis of variance

SV	df	MS	F
Blocks	4	0.0050	
K sources (K)	1	791.3980	247311.875**
K levels (L)	5	19.7130	6160.312**
K x L	5	38.4770	12024.062**
Error	44	0.0032	

**Significant at 1% level

Duncan's Multiple Range Test*

K source	K applied (ppm)	Average sodium (%)
Glaserite	240	0.571
Glaserite	120	0.548
Glaserite	60	0.525
Glaserite	30	0.484
Glaserite	15	0.380
Check	0	0.249
Potassium chloride	15	0.089
Potassium chloride	30	0.087
Potassium chloride	60	0.063
Potassium chloride	120	0.051
Potassium chloride	240	0.047

*Mean values for sodium content not joined by a common line are significantly different at 5% level.

sources were significantly different i. e., potassium chloride had higher yield than glaserite. This seems to show the adverse salt effect of high sodium in beets. This high sodium uptake in beets is similar to the luxurious consumption for potassium. These two elements (potassium and sodium) are therefore absorbed by beets at relatively large quantities compared to many other crops.

CHAPTER V

SUMMARY AND CONCLUSIONS

A comparative study of the response of crops to potassium from muriate of potash and glaserite was completed under greenhouse conditions. Sand culture experiments were conducted with three different crops namely, field corn, barley, and table beets. Modified Hoagland's solution was used to supply nutrient elements, except potassium, to the crops. Potassium treatments of 0, 15, 30, 60, 120 and 240 ppm in the nutrient solution were supplied from both sources. Each treatment for each source was replicated five times.

The dry matter yield of corn produced from the glaserite source of potassium averaged slightly higher than that obtained from comparable treatments with potassium chlloride at the two lower levels of applied potassium (15 and 30 ppm). The plants apparently benefited from the presence of small amounts of sodium when potassium was very limiting. The average potassium content of corn plants using glaserite as the potassium source was higher than that from muriate of potash in all treatments except the 240 ppm rate. The average difference was small and not statistically significant. Sodium content of corn grown with glaserite as the source of potassium was much greater than was the case with potassium chloride, since glaserite provides an additional amount of sodium.

Barley produced higher yields of dry matter from glaserite at the applied rates of 15, 30, and 60 ppm potassium than were obtained using potassium chloride as a source of potassium. Moreover, glaserite gave near maximum yield at 60 ppm added potassium while muriate of potash required 120 ppm potassium to give a slightly higher but statistically equivalent yield. Barley apparently benefits from the presence of sodium at low levels of glaserite (not in excess of 60 ppm applied potassium). Above 60 ppm of potassium in glaserite the yield decreased, presumably due to salt effect at higher concentration of sodium or possible "toxicity" effects of sodium.

In both corn and barley, it was noted that as potassium content increased, the sodium content decreased, indicating a partial replacement of potassium by sodium in these two types of plants.

The beet experiment indicated a greater benefit from the use of glaserite over muriate of potash with respect to dry matter production than either of the other crops. Significantly better yield responses from glaserite were obtained at the rates of 15, 30, 60, and 120 ppm of applied potassium. Both potassium sources showed a reduced yield at 240 ppm potassium due, apparently, to adverse effects of salts at the higher concentration.

The trend of sodium uptake by beets from both sources of potassium demonstrates that beets can take up relatively large quantities of sodium and potassium at the same time without any apparent adverse effects. A decrease in sodium content with increased potassium content is not noted in the case of beets where glaserite was used as the source of potassium. The decrease noted for potassium chloride is a consequence of sodium scarcity.

For the muriate of potash treatment the sodium content in all three crops was higher in the low potassium treatments. This is undoubtedly a result of growth limitation caused by low levels of potassium, coupled with sodium availability, and the "attempt" by plants to substitute sodium for potassium to the extent possible.

In conclusion, it should be noted that potassium from glaserite, based on the experimental results obtained, is as available for plant uptake as potassium from muriate of potash. It would further appear that when potassium is limiting and low levels of potassium are to be applied glaserite may stimulate more growth than potassium chloride for a given level of applied potassium. Though, to a limited extent, such case is indicated by corn and barley, it is shown to be statistically significant for beets. No detrimental effects were noted, in any case, at the lower levels of application. The use of glaserite as a fertilizer material could, therefore, be recommended in many cases if the cost per unit of potassium is equal to or lower than that for muriate of potash. This is especially true if a benefit from sulfur is indicated. Recommendations for use of glaserite could not, however, be based on this study, be justified for soils containing appreciable amounts of sodium. This would be especially true if soil structural problems might be encountered. These conclusions should be verified by field trials.

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