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SOME EFFECTS OF POTASSIUM UPON THE GROWTH OF SUGAR CANE AND UPON THE ABSORPTION AND MIGRATION OF ASH CONSTITUENTS[1]

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(WITH ONE PLATE AND TWENTY-NINE FIGURES)

Introduction

An account was published in 1929 (**28**) dealing with the effect of varying amounts of potassium upon the growth, enzyme activity, moisture percentage, sugar content, cellular structure, and microchemistry of the sugar cane, variety Louisiana Purple. Suggestions were offered regarding the causes of the symptoms of potassium starvation, and an attempt was made to connect as cause and effect several derangements in the morphology and the physiology of sugar cane which were found to accompany the lack of potassium. The object of the present investigation was to repeat and expand the former study and thus to approach a better understanding of the rôle of potassium in the sugar cane plant.

The research program, of which this is the first report, included determinations of the enzymes invertase, amylase, and ereptase; analyses of moisture content, ash, total and amino nitrogen, reducing sugars and sucrose; the hydrogen ion concentration, titratable acidity, and titration curves of the juices expressed from the leaves, stems, and roots; some microchemical and histological observations, and studies conducted during the growth of the plants. As indicated by the title, this paper reports some effects of potassium upon the growth and ash constituents of sugar cane; the following paper deals with the nitrogenous and carbohydrate metabo-

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[1] This investigation was conducted in 1931–1932 with the aid of the Sarah Berliner Research Fellowship of the American Association of University Women, at the Experiment Station of the Hawaiian Sugar Planters' Association, and is published at the expense of the Hawaiian Sugar Planters' Association. To both of these organizations the writer desires to express gratitude.

lism and enzyme activity of cane as affected by varying amounts of potassium.

METHODS.—*Saccharum officinarum,* variety H 109, was used in this investigation. This is the most important commercial variety grown in Hawaii at the present time under irrigated conditions. Healthy cane was gathered in the field July 14, 1931, cut to three-eye pieces and soaked in water for one hour. It was then given the hot water treatment (52° C. for 20 minutes) to destroy the stalk mite and to hasten germination. It was planted in quartz sand in flats in the greenhouse and watered daily with tap water.

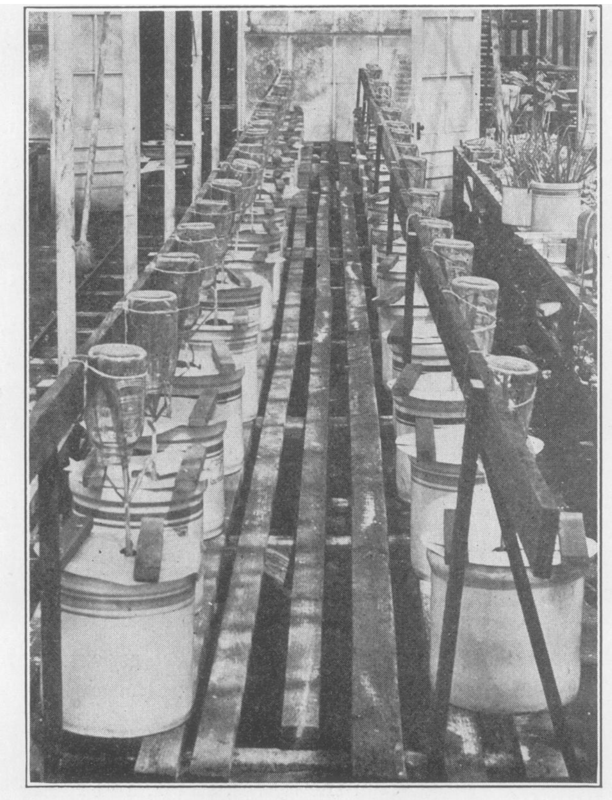


FIG. 1. Arrangement of sugar cane plants at time of transplanting, September 3, 1931.

On September 3, 1931, young shoots were cut from the original "seed pieces," or cuttings, with about 1 inch of the cutting remaining attached to each plant, and were planted singly in 5-gallon, glazed, earthenware crocks and were watered with distilled water. The plants were not absolutely uniform at the time of transplanting, varying from 54 to 99 cm.

in length, this measurement being taken to the tip of the longest leaf. Most of the plants had well developed shoot roots. The few which were still dependent upon the seed-piece roots survived transplanting and grew as well as the others. The sand had been cleaned by the method described in the former paper. The pots were covered with overlapping pieces of lacquered cardboard, 4 mm. thick, with a central hole fitting the plant. This hole was enlarged and shaped when necessary to accommodate the developing secondary shoots. Drainage was maintained as described in the former paper. The condition and set-up of the experiment at the time of transplanting, September 3, 1931, are shown in figure 1.

Forty plants were grown in this experiment, eight in each of five different treatments. They were watered with the nutrient solutions for the first time on September 15, 1931. At first each plant received 1 liter of solution twice a week. This amount was increased from time to time, until in April, when the plants were finally harvested, the control plants were each receiving 3 liters every day. Because this amount was generally insufficient for the plants in series 2, there being none left to drain out the following day, these plants were each given 4 liters per day at the end of the experiment. The plants in the other series required less water because of their smaller size. The series of plants were numbered 1 to 5, corresponding to the solutions, in the order of decreasing amounts of potassium. Beginning January 13, 1932, two of the most poorly developed plants in series 4 and 5 were given the control solution regularly in order to study their recovery from potassium starvation. The two plants which were changed from solution 4 to solution 1 were then designated series 6; those changed from solution 5 to the control solution were then called series 7.

The plants were grown in a well ventilated glasshouse and were kept on ant-proofed benches.

The nutrient solutions were a modification of SHIVE's "best solution" (65) and were prepared from the following stock solutions:

KH_2PO_4	Volume molecular solution
$NaH_2PO_4 \cdot H_2O$	" " "
$Ca(NO_3)_2 \cdot 4H_2O$	" " "
$MgSO_4 \cdot 7H_2O$	" " "
$CaH_4(PO_4)_2 \cdot H_2O$	0.05 Volume molecular solution
$Ca(OH)_2$	Saturated solution

The composition of the nutrient solutions is given in table I.

The reaction of the solution varied from pH 6.3 to 6.5, using chlorphenol red and bromthymol blue as indicators.

Iron was originally added as ferric phosphate but by September 24 some of the plants were beginning to become chlorotic. Washing the

TABLE I

COMPOSITION OF NUTRIENT SOLUTIONS, IN CC. PER 2 LITERS

No. of solution	Potassium	Potassium phosphate	Sodium phosphate	Calcium phosphate	Calcium nitrate	Magnesium sulphate	Calcium hydroxide
	p.p.m.	*cc.*	*cc.*	*cc.*	*cc.*	*cc.*	*cc.*
1 (control)	87.9	4.5	......	....	10.4	10	50
2	39.0	2.0	2.5	....	10.4	10	50
3	3.9	0.2	4.3	....	10.4	10	50
4	0.0	......	4.5	....	10.4	10	50
5	0.0	......	......	44.8	10.4	10	50

chlorotic leaves with a 5 per cent. solution of ferrous sulphate produced a deeper shade of green within two or three days. Possibly ferric phosphate is not a satisfactory source of iron because it is too insoluble to supply the need of cane. Beginning October 7, 1931, enough iron in the form of ferrous sulphate was added to the sand to keep the plants green.

Since in the latter part of December the plants developed typical symptoms of Pahala blight (described later in this paper), the nutrient solutions were modified in several ways. Beginning January 4, 1932, 0.1 p.p.m. manganese was added to the solutions as $MnSO_4 \cdot 4H_2O$. Beginning March 3, the amount of manganese was doubled in solutions 1 and 2, and on March 23 the quantity was again doubled so that thereafter the plants in series 1 and 2 received 0.4 p.p.m. In addition, some of the leaves were washed with manganous sulphate, others with ferrous sulphate, and finally all of the leaves were dusted with a mixture of manganous sulphate and sulphur. The relative value of these treatments will be discussed later; suffice it to say at this point that by the time of the final harvest, April 27, the symptoms of Pahala blight had practically disappeared.

Because many of the sheaths showed a tendency to rot, this condition becoming apparent early in March, 1932, and because the ash analyses of the plants harvested on November 20, 1931, indicated that the leaves might be deficient in silicon, on March 22 dialyzed silica was added to the solutions. This was added at the rate of approximately 33 p.p.m. Si.

Several staff members of this Station have found that titanium aids in overcoming certain types of chlorosis in sugar cane (unpublished data). Beginning April 4, 1932, titanium nitrate was included in the solutions, at the rate of 10 p.p.m. Ti.

Several sugar cane insects gave trouble during the growing of the plants. These included the armyworm, *Spodoptera mauritia* Boisd.; the cane aphis, *Aphis sacchari* Zehnt.; the gray sugar cane mealybug, *Trionymus boninsis* Kuwana; the pink sugar cane mealybug, *Trionymus sacchari* Ckll.; the stalk mite, *Tarsonemus spinipes* Hirst; and the so-called red spider or leaf mite, *Tetranychus exsiccator* Zehnt. An attempt was made to combat the leaf mite and cane aphis by spraying the plants with distilled water but without success. The plants were thereafter sprayed once a week with Black Leaf 40. This was found to check the insects but not to prevent their development entirely.

COLLECTION AND PREPARATION.—The plant material was harvested at three different intervals, being collected between 10 and 12 o'clock on sunny mornings.

On November 20, 1931, two plants of each of the series were harvested. The tops were cut from the roots, photographed, weighed, and separated into blades, sheaths, and stems. These were chopped separately in an

Athol chopping machine. Duplicate samples of blades and stems to be used for moisture determinations were placed in weighed aluminum boxes, treated with 1 cc. 95 per cent. alcohol, and weighed immediately. Weighed samples of blades and stems for sugar and nitrogen determinations were taken in duplicate, placed in Erlenmeyer flasks, each containing 1 gm. of calcium carbonate (to neutralize acids), and boiled with 100 cc. 95 per cent. alcohol. These samples were stored in the dark until ready for analysis. The remainder of the ground material was spread out between layers of filter paper and dried in a current of air at room temperature. It was then stored in desiccators in the dark. This material was used for enzyme determinations and for ash analyses. The roots were removed from the sand the following day and were dried without being ground.

On December 4, two plants from each of series 1 and 3 were removed from the crocks, the roots included. Photographs and weights were taken. The plants were separated into blades, sheaths, stems, and roots and were ground as just described, the sheaths being discarded. The ground material was placed in large Pyrex test tubes, stoppered, and the tops covered securely with wax paper. They were then frozen in a salt-ice mixture. The juice was expressed and used for determining the titratable acidity, hydrogen ion concentration, and titration curves, the results of which are reported in the second paper of this series.

On April 27, 1932, the final harvest was conducted, which consisted of all the remaining plants. The method was essentially the same as that of the November collection, except that the tops and roots were removed together from the sand. The blades were ground with a Russwin food cutter no. 3. The stems were sliced with a Sterling slicer no. 2 before being ground. As before, the roots were dried without being ground. Samples were taken in the same way as in the November harvest. The material for enzyme and ash analyses was dried in a current of air at a temperature not exceeding 43° C. and generally somewhat lower.

Results

1. Studies during growth

A. Symptoms of potassium deficiency.—The symptoms of potassium starvation which developed in this investigation were depressed growth of the entire plant, discoloration of the leaves, and dieback of the leaf tips. The plants grew rapidly and at first showed no real differences in their growth rates. Watering with the nutrient solutions was started on September 15, 1931. By October 7, *i.e.,* three weeks after starting the plants in the nutrient solutions, a slight gradation in growth was found, corresponding to the amount of potassium supplied, as shown in table II. This gradation was noticeable in the figures for average size but could not be detected by just glancing at the plants. Growth in length is a measurement taken to the tip of the longest leaf. The total growth in length was determined by adding the growth in length of the main shoot to the total length of the tillers. This gave the total growth in length for the period from September 23 to October 7, because on September 23 the few secondary shoots were all still under the covers. Length measurements were all taken from the top of the cover because of the variation in the depth of the sand.

Differences in colors were hard to detect on October 7. Some of the lower leaves of the plants in series 4 and 5 were a little yellow, but whether this was the first discoloration due to potassium deficiency is hard to say because some of the leaves of series 1 were also slightly yellow.

On October 10 it was noticed for the first time that several of the leaves of the plants of series 3, 4, and 5 had conspicuous red areas on the upper surfaces of the midribs. There was no such discoloration on the midribs of series 1 and 2. The course of the development of red midribs and the histological studies and other investigations dealing with them will be considered later. They are illustrated in the plate.

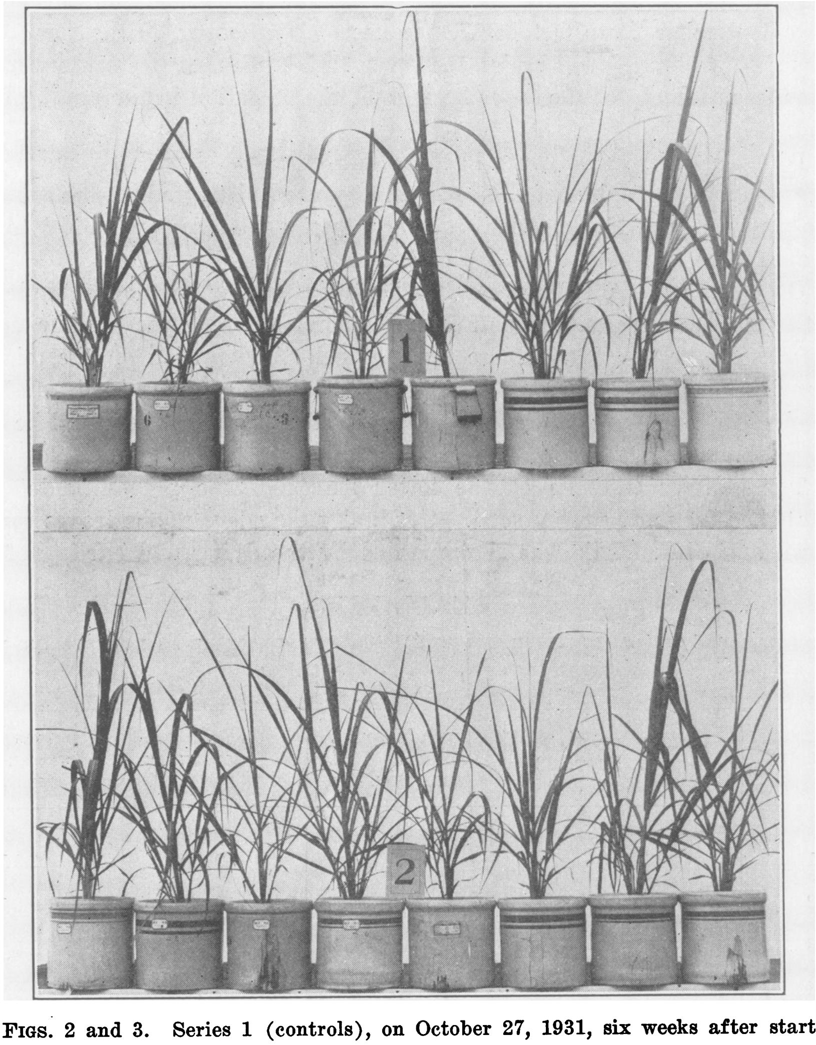
The yellow condition of the lower leaves of the potassium-deficient plants became more pronounced. Gradually the edges of the leaves turned brown and died. This was accompanied by the dying and curling of the tips of the leaves, a condition known as dieback. Small red and red-brown spots developed in the laminae of the blades of the plants deficient in potassium. These symptoms were most fully developed in the plants of series 4 and 5, between which no difference could be observed. At first they were

TABLE II

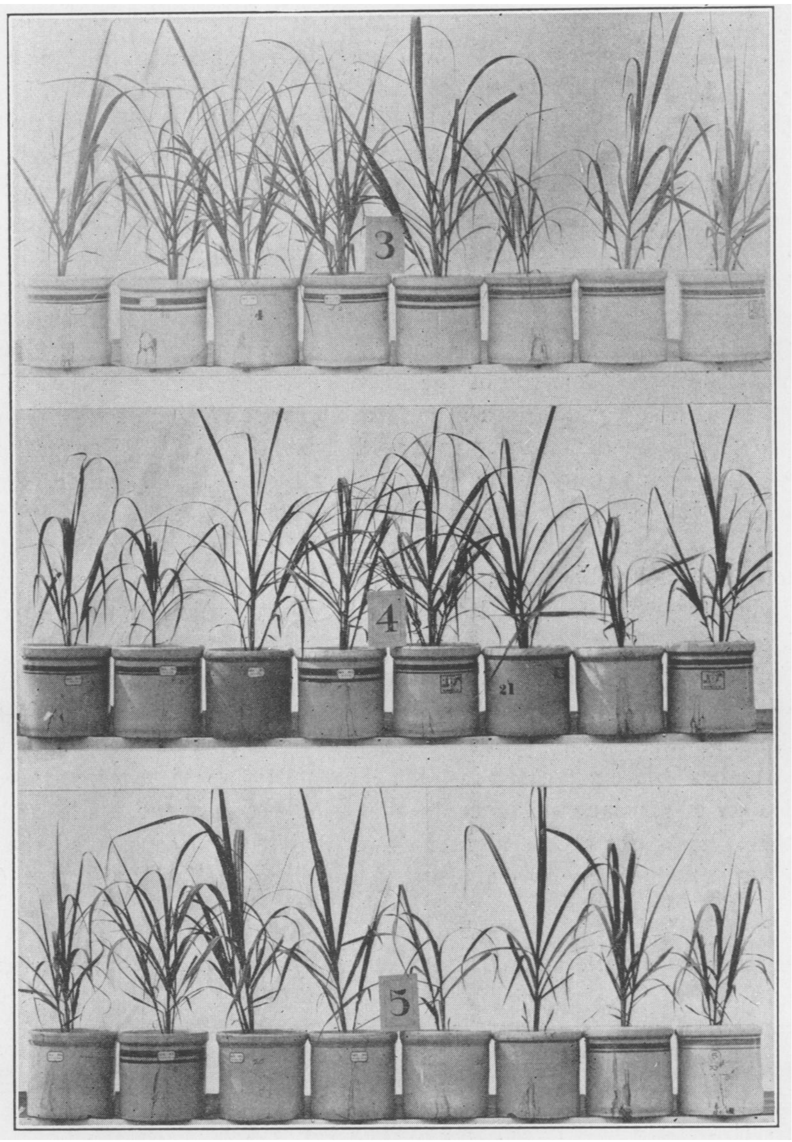
MEASUREMENTS OF PLANTS TAKEN OCTOBER 7, 1931, THREE WEEKS AFTER WATERING WITH NUTRIENT SOLUTIONS WAS BEGUN

SERIES	AVERAGE GROWTH IN LENGTH OF MAIN SHOOTS, SEPT. 23 TO OCT. 7	AVERAGE TOTAL LENGTH OF TILLERS, OCT. 7	AVERAGE TOTAL GROWTH IN LENGTH	AVERAGE NUMBER OF TILLERS
	cm.	*cm.*	*cm.*	
1	32.06	61.1	93.16	2.37
2	37.02	63.9	100.92	2.25
3	28.6	53.18	81.78	2.5
4	25.4	44.7	70.1	2.25
5	25.4	38.0	63.4	2.0

not so conspicuous in series 3 as in 4 and 5; they never developed in series 1, and occurred only slightly in series 2 toward the end of the experiment. By October 23, the plants of series 3, 4, and 5 showed definite symptoms, including decreased growth, discoloration, and dieback. Figures 2 to 6 show the plants on October 27, six weeks after starting them in the nutrient solutions. A definite gradation in size will be noted, as will also the similarity of the plants of series 4 and 5.



FIGS. 2 and 3. Series 1 (controls), on October 27, 1931, six weeks after starting them in the nutrient solutions. Series 2 on October 27, 1931.



Figs. 4–6. Series 3 (above) on October 27, 1931. Series 4 (middle) on October 27, 1931. Series 5 (below) on October 27, 1931.

The plate shows the typical colors of the plants. The sketches were made by a Station artist November 5 and 6, 1931, in the greenhouse from the living leaves. *A* shows a typical leaf from a control plant. It will be noted that there are some very small light green flecks on the lamina. Whether these are due to insect injury or are a similar condition (only less developed) to the red spots on the plants deficient in potassium was not ascertained. Histological studies by WELLER of this Station showed no mycelium. *B, C,* and *D* show the typical colors of the plants deficient in potassium; light, yellow-green laminae, yellow-brown edges, red midribs, red flecks in the laminae, and dieback. *B* shows the color of a midrib soon after it has become red, while *C* shows the darkening of the discoloration as the leaf ages. More will be said later regarding which of these may be considered primary and which secondary symptoms of potassium deficiency.

Symptoms of potassium deficiency under field conditions are the same as those already described. Similar symptoms also developed in the former investigation (**28**), with the exception of the red midribs. The yellow discoloration between the veins of the upper leaves occurring in the Chicago studies was probably due to a slight development of Pahala blight rather than to potassium deficiency. It would seem now that the symptoms of potassium deficiency in sugar cane are well established, comprising decreased growth of the entire plant, dieback of the leaf tips, and the discolorations of the blades as shown in the color plate. The brown edges and tips of the blades and yellowish green color of the laminae are primary symptoms while, as will be shown later, the red discoloration of the midribs is considered secondary.

The first harvest, consisting of two plants from each series, was conducted November 20, *i.e.*, about nine weeks after watering with the nutrient solutions was started. Averages of the measurements of the plants taken on November 19 are presented in table III. "Dewlap" is a term commonly applied in sugar cane parlance to the joint between the blade and the sheath. The height of the highest emerged dewlap is considered the best measurement of the growth of cane. According to VAN DEVENTER (**69**),

TABLE III

MEASUREMENTS TAKEN NOVEMBER 19, NINE WEEKS AFTER STARTING THE PLANTS IN THE NUTRIENT SOLUTIONS, IN AVERAGES

SERIES	LENGTH OF MAIN SHOOTS	TOTAL LENGTH OF TILLERS	HIGHEST DEWLAP	BREADTH OF LONGEST LEAF	NO. OF TILLERS	NO. OF RED MIDRIBS
	cm.	*cm.*	*cm.*	*cm.*		
1	189.4	566.7	38.6	4.1	12.0	0.0
2	192.6	787.7	36.7	3.9	13.0	6.7
3	163.9	332.9	25.5	3.1	2.7	17.0
4	140.2	181.0	20.1	2.7	2.2	10.5
5	145.1	243.7	20.3	2.7	2.5	19.7

the highest leaf joint is about 30 cm. above the real vegetative point because the sheath of that leaf is fully grown, or nearly so. Breadth of leaf is a measurement taken at the broadest part of the longest leaf; this is generally about the middle of the leaf. The average growth of the plants for the period November 3 to 19 is given in table IV. Fresh weights of blades, sheaths, and stems, and air-dry weights of roots of the plants collected November 20 are given in table V. Tables III to V show that nine weeks after starting the plants in the nutrient solutions, the plants of series 1 and 2 were considerably larger in every measurement than the plants starved for potassium, series 3 to 5.

TABLE IV

AVERAGE GROWTH, NOVEMBER 3 TO 19

SERIES	LENGTH OF MAIN SHOOTS	HIGHEST DEWLAP	LENGTH OF TILLERS	NO. OF TILLERS
	cm.	*cm.*	*cm.*	
1	15.4	7.7	262.6	5.5
2	17.5	5.0	464.2	5.0
3	14.9	2.1	73.8	Decreased in number
4	4.9	0.0	0.0	"
5	12.7	0.2	55.7	"

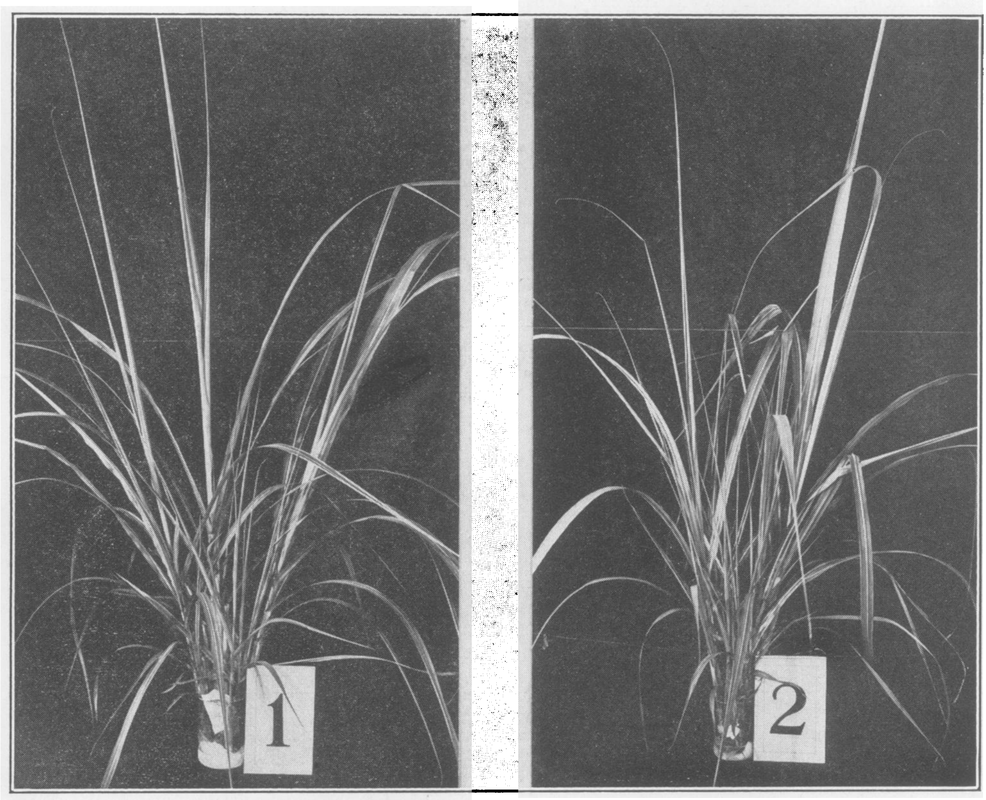
TABLE V

AVERAGE WEIGHTS OF PLANTS, NOVEMBER 20

SERIES	FRESH WEIGHT				AIR-DRY WEIGHT
	BLADES	SHEATHS	STEMS	TOTAL TOPS	ROOTS
	gm.	*gm.*	*gm.*	*gm.*	*gm.*
1	256.0	188.0	81.0	526.0	23.7
2	269.2	196.0	86.2	551.0	28.7
3	130.0	71.2	24.0	225.2	11.2
4	68.0	30.0	9.2	107.7	5.8
5	78.7	35.0	14.0	128.2	6.0

In most measurements the plants of series 2 averaged larger than those of series 1. Attention is drawn to the close similarity between the plants of series 4 and 5; where there is a difference between them it is in favor of series 5. Evidently sodium does not replace potassium in the growth of sugar cane. Figures 7 to 11 show the plants at the time of harvesting, November 20, 1931.

Besides the colors, which are shown in the plate, several other differences should be mentioned. There was a gradation in the development of wax on the stems correlated with the supply of potassium. The roots showed a gradation in size and condition, those of series 1 and 2 being large, firm, and white and those of the plants deficient in potash being small, poorly developed, and discolored yellow and brown.



Figs. 7 and 8. Typical plant (left) of series 1 (control) on November 20, 1931, nine weeks after starting the plants in the nutrient solutions. Typical plant (right) of series 2 on November 20, 1931.

The second harvest was conducted December 4, eleven weeks after starting the plants in the nutrient solutions. At this time two plants from each of series 1 and 3 were collected. Table VI gives the average measurements of all the plants taken December 3. Table VII gives the weights of the tops and roots of the plants harvested December 4, 1931.

FIG. 9. Typical plant of series 3 on November 20, 1931.

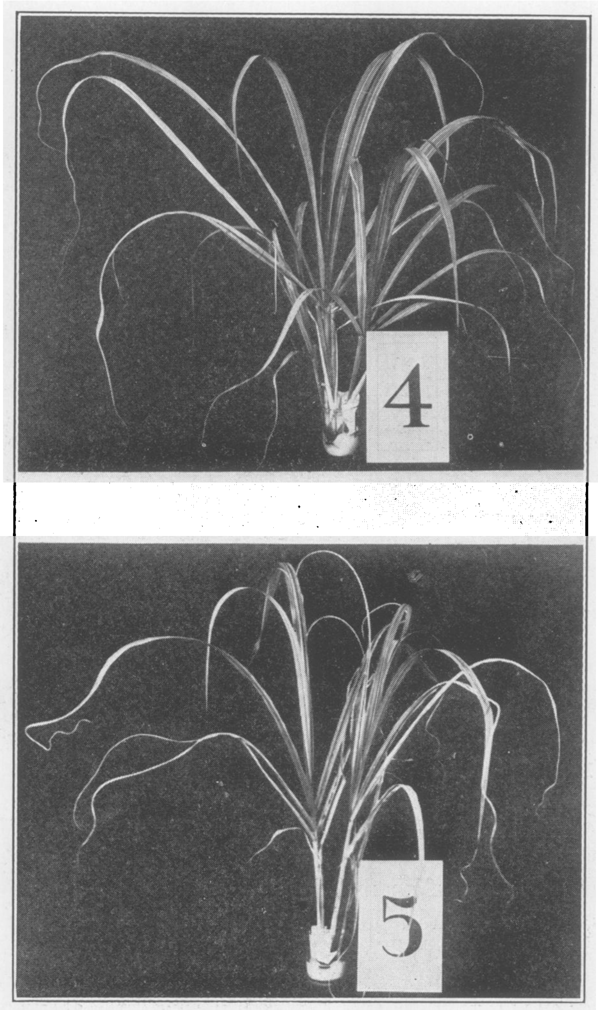
Figures 12 and 13 illustrate the plants just after they were removed from the crocks.

On January 13, about four months after starting the plants in the nutrient solutions, two of the most poorly developed plants of series 4 and 5 were

TABLE VI

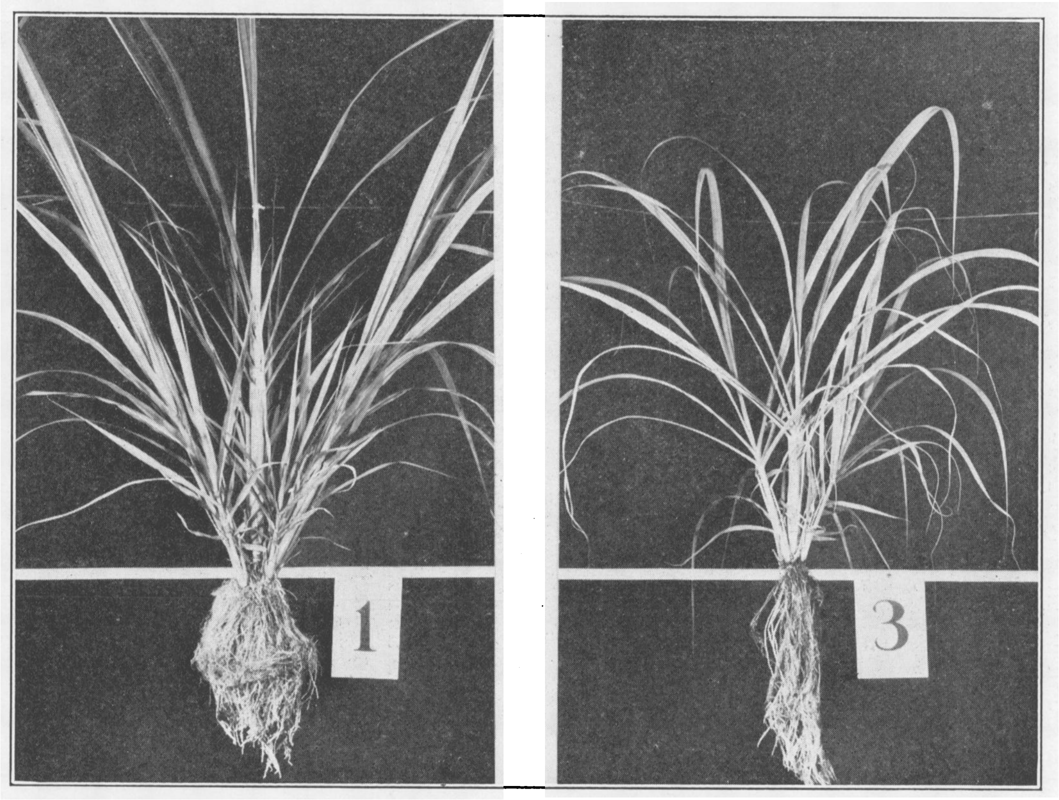
AVERAGE SIZE OF PLANTS, DECEMBER 3, ELEVEN WEEKS AFTER STARTING SOLUTIONS

SERIES	LENGTH OF MAIN SHOOTS	BREADTH OF LONGEST LEAF	HIGHEST DEWLAP	NO. OF TILLERS
	cm.	*cm.*	*cm.*	
1	196.1	4.5	47.2	11.5
2	198.9	4.2	42.5	12.5
3	165.0	3.0	25.8	4.5
4	143.5	2.5	21.3	3.0
5	150.1	2.7	22.3	2.5



FIGS. 10 and 11. Typical plant (above) of series 4 on November 20, 1931. Typical plant (below) of series 5 on November 20, 1931.

given solution 1, this treatment being continued to the end of the experiment. Their appearance on January 13, before starting the new treatment, is shown in figure 14. Thereafter these were called series 6 and 7 respectively. They immediately started to grow. The stems which were already formed became more rigid, straightened up, lengthened, and increased in circumference. Adventitious roots developed at the base of the stem, which acted like prop roots in supporting the rapidly developing stems. Buds also developed at the bases of the stems, and quickly formed new shoots.



FIGS. 12 and 13. Typical plant (left) of series 1 on December 4, 1931. Typical plant (right) of series 3 on December 4, 1931.

The old leaves, which exhibited the symptoms of potash deficiency, dried up, died and fell down; the newly developed leaves were as green and nearly as large as those of the plants of series 1. The increased growth of the stems is shown graphically in figure 15. By the latter part of February, these plants had overtaken and surpassed the plants of series 3 in development. It is interesting that series 7 showed a greater capacity for recovery than did series 6. Their measurements at the time of the final harvest, April 27, are given in tables VIII and IX; their appearance at that time is shown in figures 21, 22, 28, and 29.

TABLE VII

WEIGHTS OF TOPS AND ROOTS, DECEMBER 4

PLANT	TOPS	ROOTS
	gm.	*gm.*
1 G	800.0	448.0
1 H	885.0	354.9
3 G	222.0	201.0
3 H	265.5	246.0

The final harvest of all the plants was conducted April 27, seven and one-half months after starting the plants in the nutrient solutions. Size measurements taken on April 25 are presented in table VIII. The fresh weights of the tops collected April 27 and the air-dry weights of the roots are given in table IX. Figures 16–22 show all the plants on April 25.

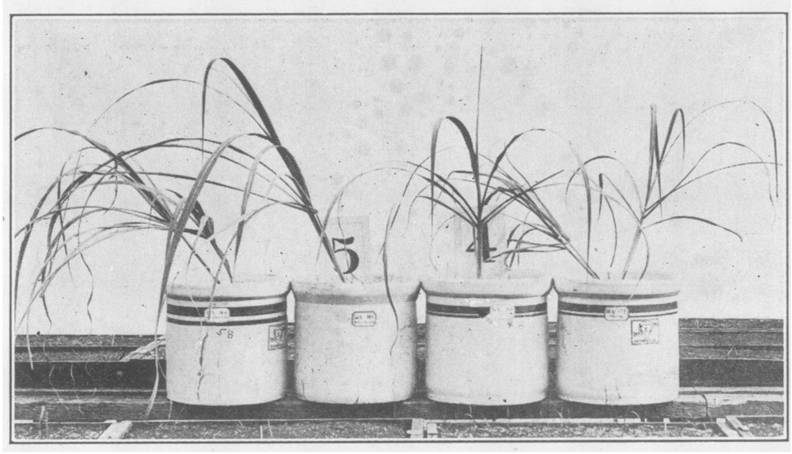


FIG. 14. Appearance of series 4 and 5 on January 13, 1932, just before changing to solution 1. Thereafter these plants were called series 6 and 7 respectively.

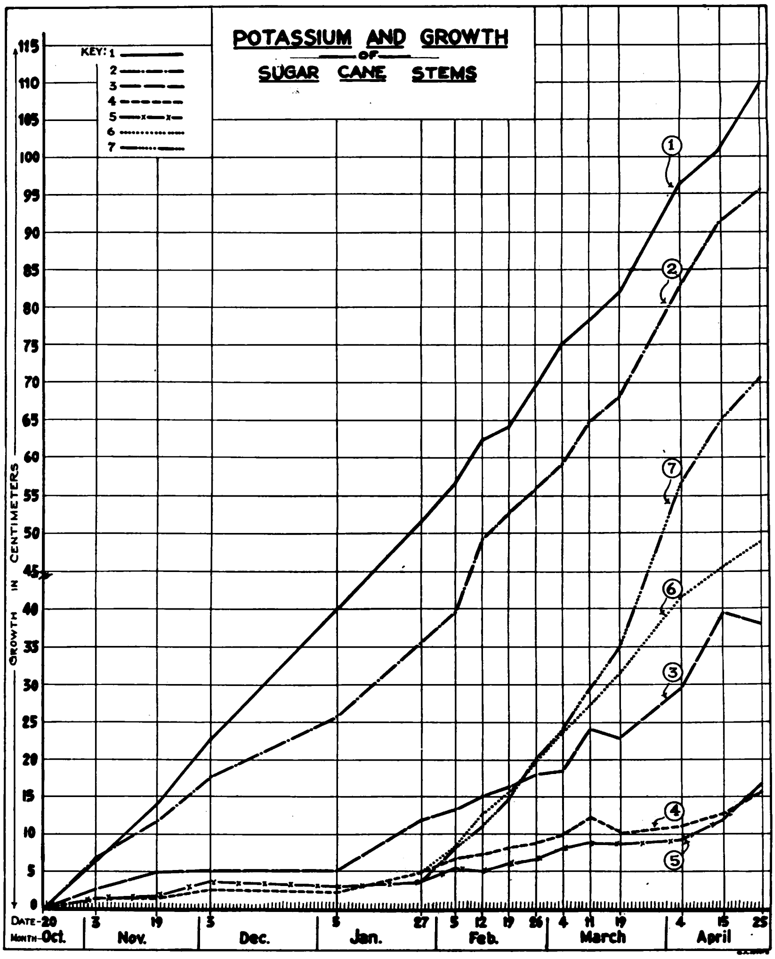
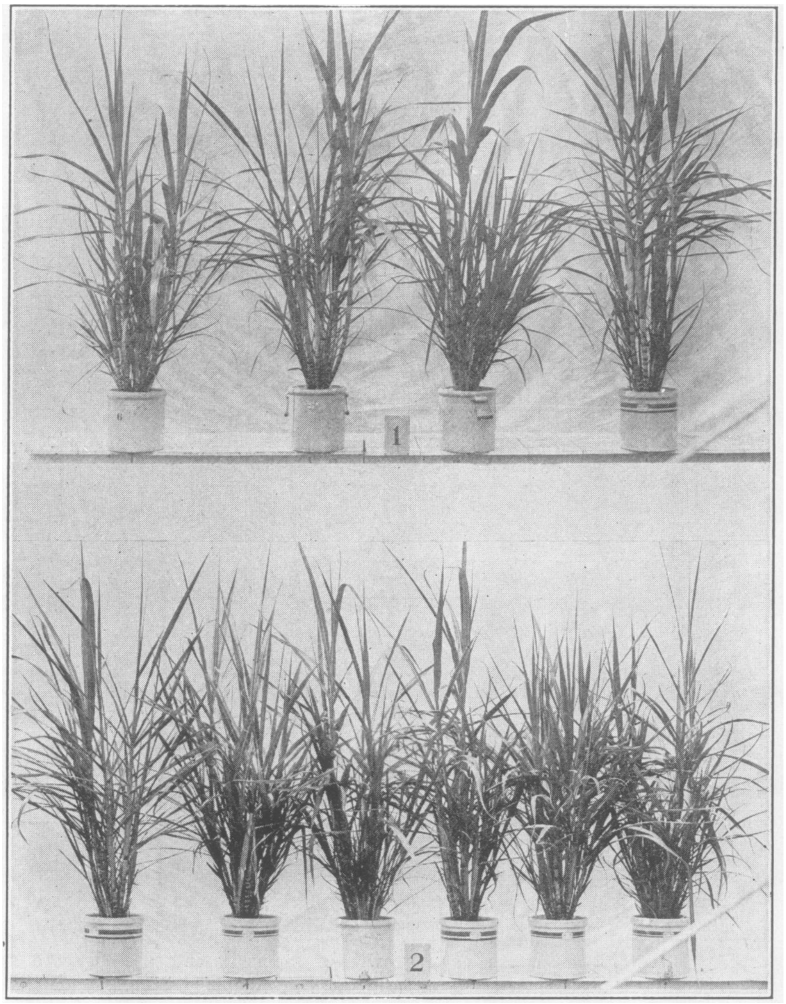


FIG. 15. Effect of potassium upon growth of stems as indicated by the average height of the highest emerged "dewlap" (juncture of blade and sheath).

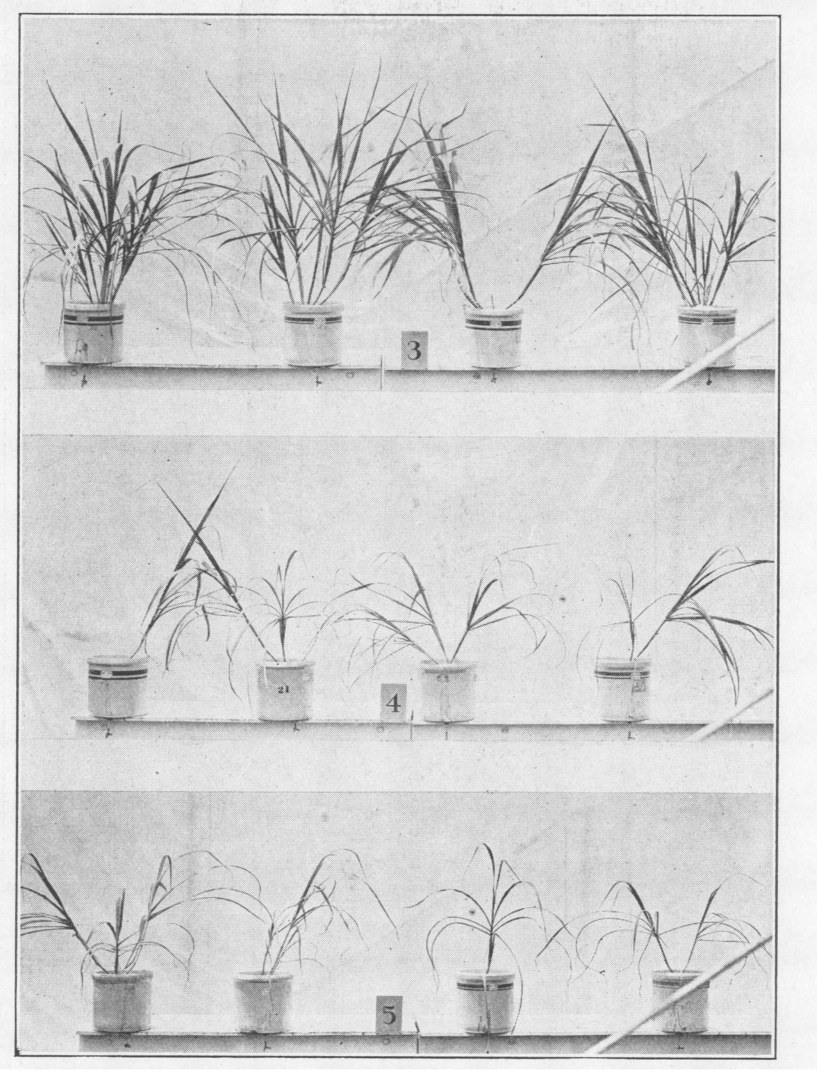
Photographs of representative plants taken at the final harvest are shown in figures 23–29. The colors of the plants were practically the same as before, except that some of the leaves of the plants of series 1 and 2 were burned, owing to the high temperature in the greenhouse. The plants showed very little Pahala blight, these symptoms being confined chiefly to the old leaves of the secondary shoots. Most of the plants deficient in potassium had red midribs. The plants of series 6 and 7 had the best developed individual roots, because they were not yet potbound. Some of the longer roots showed plainly where they had begun to increase growth



FIGS. 16 and 17. Series 1 (above) on April 25, 1932, 7½ months after starting them in the nutrient solutions. Series 2 (below) on April 25, 1932.

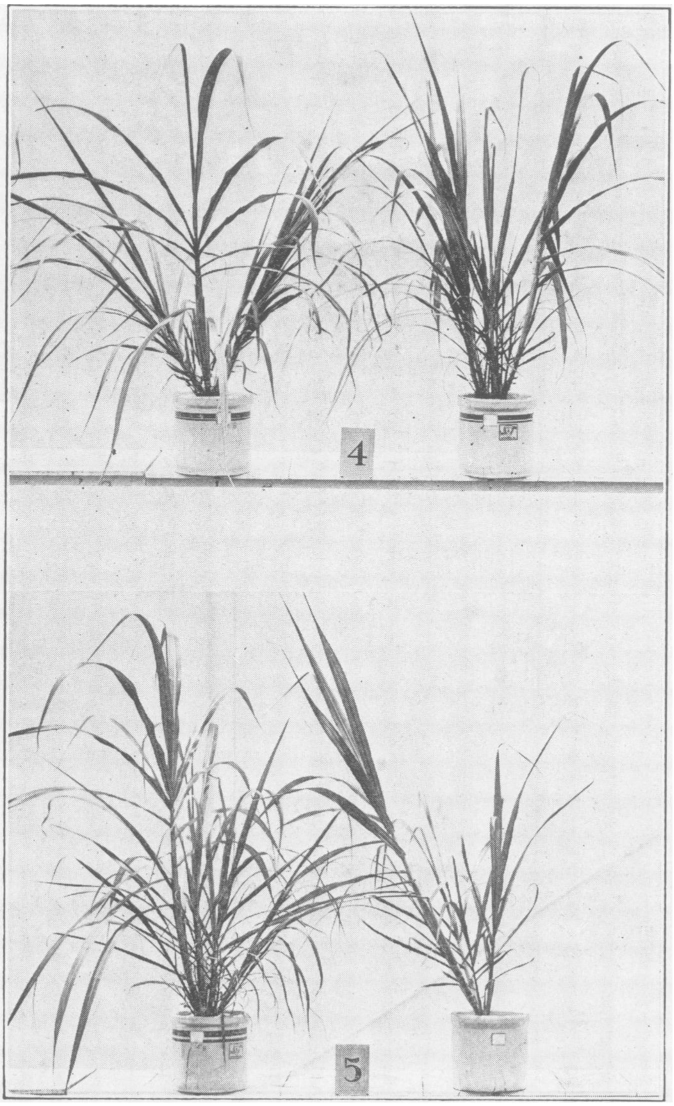
at the time of the first addition of potassium. The plants of series 1 and 2 had very large and interwoven masses of roots.

Graphs of the increase in height of the highest emerged dewlap are given in figure 15. It will be noted that the growth of the stems is markedly affected by the amount of potassium supplied. After the first week or so the plants of series 1 maintained a steady growth, always greater than that of any of the others. The speedy recovery of the plants of series 6 and 7 after the addition of potassium in January is conspicuous. The increase in growth of series 3, 4, and 5 beginning in January may be due in part to the increased light in the spring, but is probably due also to the fact that manganese was added to the solutions for the first time on January 4.



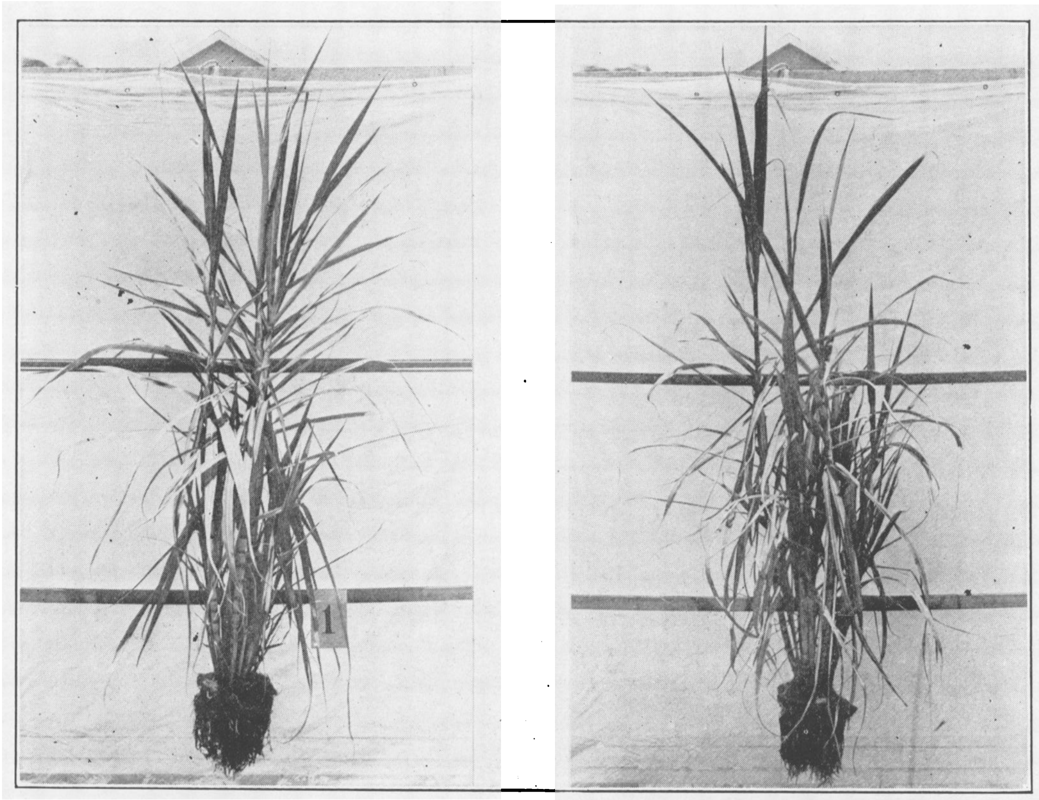
Figs. 18–20. Series 3 (above) on April 25, 1932. Series 4 (middle) on April 25, 1932. Series 5 (below) on April 25, 1932.

That manganese is essential for the growth of sugar cane has been shown by Davis (**15**) and Martin (unpublished work). The development of Pahala blight in the absence of manganese has been studied by Lee and McHargue (**45**) and by Martin (**48**).

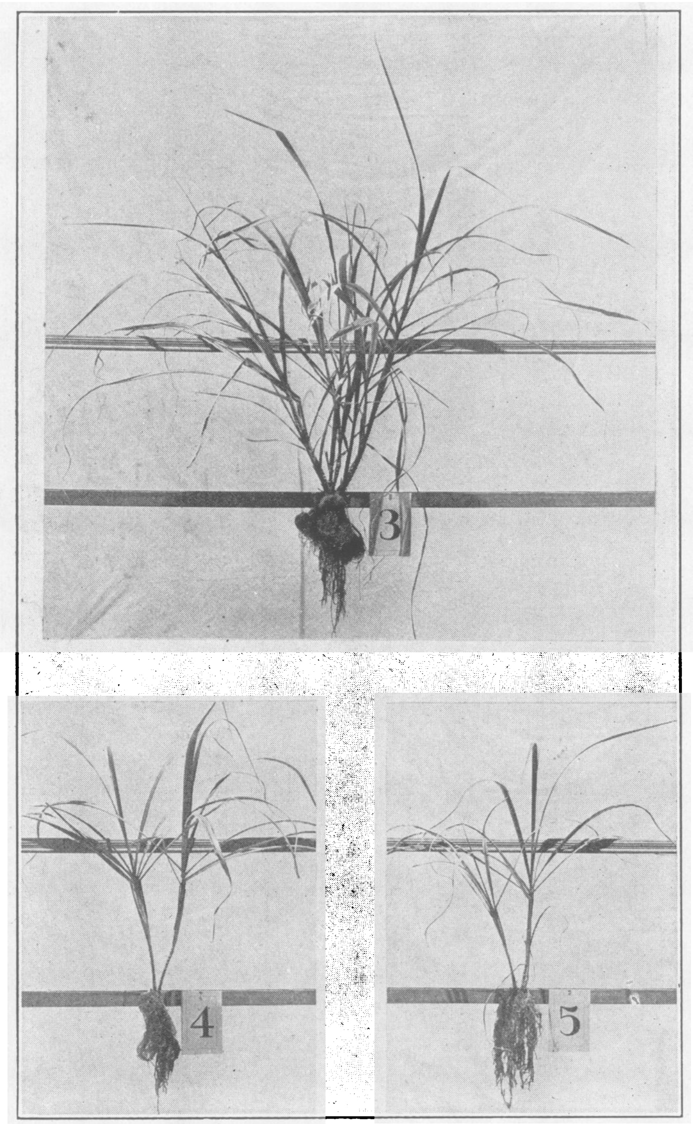


FIGS. 21 and 22. Series 6 (above) on April 25, 1932. Until January 13, these plants received solution 4; after that time, solution 1. Series 7 (below) on April 25, 1932. Until January 13, these plants received solution 5; after that time, solution 1.

Mention has already been made of the development of red midribs on the leaves of plants deficient in potassium. The average numbers of red midribs per plant are shown in table X. These counts were discontinued after November 22. No red midribs developed in the plants of series 1. In

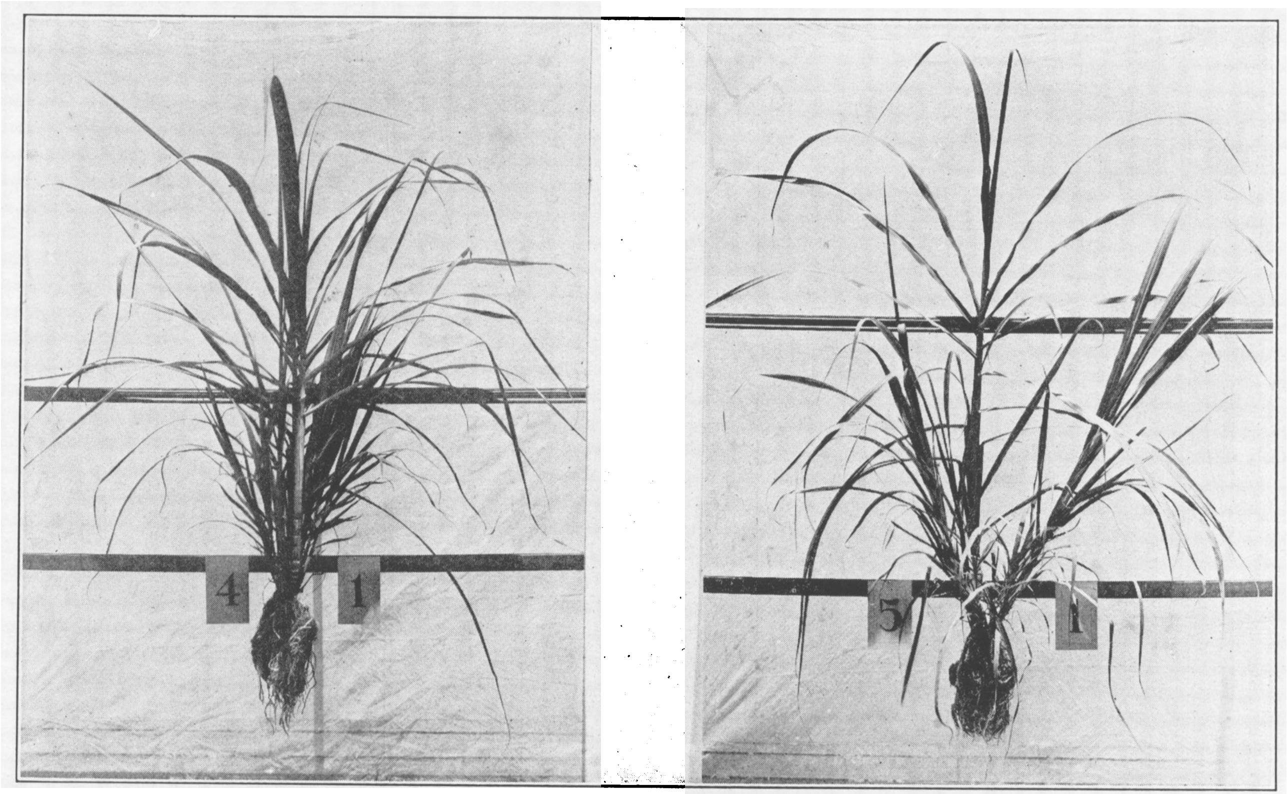


FIGS. 23 and 24. Typical plant (left) of series 1 at the final harvest, April 27, 1932. Typical plant (right) of series 2 on April 27, 1932.



Figs. 25–27. Typical plant (above) of series 3 on April 27, 1932. Typical plant (below, left) of series 4 on April 27, 1932. Typical plant (below, right) of series 5 on April 27, 1932.

general, they occurred on most of the plants of series 3, 4, and 5 up to the end of the experiment. It will be seen that their occurrence is correlated with a deficiency in potash. The question arose as to whether this discoloration is a specific symptom of potash deficiency in cane or a secondary reaction.



Figs. 28 and 29. Typical plant (left) of series 6 on April 27, 1932. Typical plant (right) of series 7 on April 27, 1932.

TABLE VIII

Average size of plants at final harvest, April 25, 7½ months after starting in the nutrient solutions

Series	Highest dewlap of main stalks	Breadth of leaf at middle of longest leaf of main stalk	Circumference of main stalks
	cm.	*cm.*	*cm.*
1	130.9	5.5	9.3
2	116.4	4.4	8.4
3	57.9	3.9	5.5
4	34.3	2.6	3.8
5	36.0	2.6	3.7
6	69.0	4.9	7.7
7	94.3	5.6	9.3

Red midribs frequently occur on cane grown in the field resulting from infection by the red rot fungus, *Colletotrichum falcatum.* This fungus gains entrance through mechanical injuries or following leafhopper injury. The plants of the present investigation were examined by the pathologists and entomologists of this Station and no leafhopper punctures were found. As reported by MARTIN (**47**), samples studied histologically by WELLER of this Station showed no mycelium. Attempts made by MARTIN to isolate an

TABLE IX

Average weights of plants collected April 27, expressed in grams

Series	Fresh weight				Air-dry roots
	Blades	Stems	Sheaths	Total tops	
	gm.	*gm.*	*gm.*	*gm.*	*gm.*
1	955.88	2185.10	1009.75	4150.73	108.5
2	1035.30	1639.50	993.60	3668.40	106.8
3	277.70	176.95	172.92	627.57	27.8
4	62.02	25.20	28.30	115.52	8.2
5	63.70	28.05	31.87	123.62	11.3
6	569.75	358.25	443.00	1371.00	47.6
7	472.50	415.25	337.00	1224.75	40.5

TABLE X

AVERAGE NUMBER OF RED MIDRIBS

	SERIES				
	1	2	3	4	5
October 15	0	0	1.5	2.3	1.5
October 20	0	0	4.8	4.7	5.6
November 4	0	0.6	12.7	12.6	11.8
November 22	0	6.7	17.0	10.5	19.7

organism from red-midrib tissue were negative. Hypodermic injections of 0.25 per cent. acetic acid into the midribs of other cane plants did not result in the development of any red discoloration. It was concluded that the red midribs were not caused by an organism or by acidity alone.

Microscopic studies showed that the red color of the midribs was a discoloration of the lignified cell walls. The cuticle and epidermis were not affected. The walls of the subepidermal plates were red, also the sheaths of the large vascular bundles, the xylem, and the lignified regions between the bundles and the lower epidermis. The color of the walls was the same as that which develops in the microchemical test for lignin, *viz.*, staining with phloroglucin-hydrochloric acid. The course of the discoloration seemed to be as follows: first the protoplasm of the parenchyma became slightly brown, then the parenchyma walls next to the lignin became faint red, finally the lignified walls reddened. Thus the disturbance seemed to originate in the parenchyma.

STEUERWALD (**67**) isolated saccharetin from cane fiber and stated that it belongs to the phlobaphenes and may be considered the aromatic compound in lignin. It is very soluble in alcohol. On treatment with phloroglucin-hydrochloric acid, saccharetin becomes intensely red.

Because of these characteristics of saccharetin and because of the resemblance of the discolored walls to the ordinary lignin test, it was thought that phloroglucin might be present in the cells of the potassium-deficient leaves, and thus explain their discoloration. Phloroglucin occurs in some plants as a hydrolytic product of certain tannic acids (**23**).

Evidence of the presence of phloroglucin was obtained as follows. Heating sections of the discolored midribs in alcohol partially removed the red color. When a partially decolorized section was treated with concentrated hydrochloric acid, with no addition of phloroglucin, the reddish color deepened. Subsequently heating caused a decided reddening of the walls. When sections of the control leaves were heated with hydrochloric acid no suggestion of red occurred, although decisive tests for lignin were obtained using phloroglucin-hydrochloric acid. It would seem that the plants of series 1 contained no phloroglucin, while the potassium-deficient plants did.

The need for an acid as well as phloroglucin for the red coloration of saccharetin was realized. The presence of enough hydrochloric acid within the plants was doubted, since the nutrient solutions contained no chlorides. The attempt was made to produce a similar color using tannic acid instead of hydrochloric, but without success. Sulphuric acid, however, gave a red color very similar to that formed when hydrochloric acid was used, and closely resembling the discolored midribs, both in shade and location. The first red midribs to develop were noticed on October 10, just three days after the first application of ferrous sulphate in the nutrient solutions. It would appear that this offers an explanation of the red midribs of the potassium-deficient plants.

To sum up, it seems possible that potassium deficiency causes a decomposition of tannic acids, resulting in the formation of phloroglucin. This in the presence of an excess of sulphuric acid may cause the reddening of saccharetin. The development of red midribs is thus a secondary rather than a primary symptom of potassium deficiency, and will occur only in the presence of an excess of sulphates or possibly chlorides.

Since the above was written, confirmatory evidence of the importance of sulphates in the development of red midribs has been supplied by W. W. G. Moir, of American Factors, Honolulu, who states that at Olaa Sugar Company red midribs developed within a month after the application of two tons of sulphur per acre to land deficient in potassium. The midribs of other plants became red after the application of copper sulphate.

In this connection it is interesting to note that it is characteristic of sugar cane to become reddened when diseased or injured, whatever the causal agent. Although other factors are probably involved also, the possibility is suggested that wherever a red color develops in the cell walls, following disease or injury, it may be due to the action of sulphates or chlorides and phloroglucin upon saccharetin. Sugar cane soils are often high in sulphates, and it seems possible that many diseases might lead to the decomposition of tannic acids and thus the formation of phloroglucin.

Van Den Honert (70) recently described symptoms of potassium deficiency obtained with variety P. O. J. 2878, which in general agree with those described here. The main difference between the Java results and ours lies in the location of the discoloration of the midribs. Van Den Honert gives figures of cross sections of the discolored midribs and states that in potassium deficiency the discoloration is confined to the upper surface; whereas all the lignified regions of the midribs of the potassium-deficient plants appeared red in places in the investigation herein reported, when examined microscopically. It is interesting to note that VAN DEN HONERT used sulphuric acid in his nutrient solutions, because of the importance of sulphates in the production of red midribs brought out in this study. The gumming of the epidermal walls of the midribs considered a symptom of potassium starvation by VAN DEN HONERT was not observed in the present study.

B. ABSORPTION OF POTASSIUM.—Three experiments were conducted dealing with the absorption of potassium. On October 16, composite samples of the drainage of the plants in series 1 to 3 were collected. Each plant had received 1.5 liters of solution four days previously. Analyses for potassium were performed by the Chemistry Department of this Station and the results are given in table XI. The control solution prepared that week contained 92 p.p.m. potassium, by analysis. Analyses of the other solutions were not made, the calculated parts-per-million being used to obtain the amount of potassium absorbed by the plants of series 2 and 3. It will be noted that the plants of series 1 and 2 absorbed potassium at the same rate that week.

TABLE XI

POTASSIUM ANALYSES OF DRAINAGE COLLECTED OCTOBER 16, 1931

SERIES	K IN DRAINAGE	K ABSORBED IN 4 DAYS
	p.p.m.	*p.p.m.*
1	62.0	30.0
2	9.4	30.0
3	2.1	1.8

Several investigators have found evidence of a relationship between the absorption and utilization of potassium and light, which will be mentioned more completely in the discussion. To determine whether the amount of potassium absorbed during the day differs from that taken up by night, the following test was performed. On November 13 and 14, drainage samples were collected from the plants of series 1 and 2 at 6 A. M. and 6 P. M. Fresh solutions were added each time. The samples were analyzed for potassium by the Chemistry Department of this Station. Sunrise occurred at 6:11 and sunset at 5:20, according to the Weather Bureau. It was therefore possible to determine the amount of potassium absorbed during approximately 12 hours of darkness and 12 hours of daylight. The results are reported in table XII, which shows that both sets of plants absorbed the same amount of potassium during the night and the day.

TABLE XII

DAY AND NIGHT ABSORPTION OF POTASSIUM

SERIES	WATERED 6 P. M. FRIDAY AND 6 A. M. SATURDAY	CONTAINED 6 A. M. SATURDAY	CONTAINED 6 P. M. SATURDAY	ABSORBED IN 12 HOURS' DARKNESS	ABSORBED IN 12 HOURS' DAYLIGHT
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	93.6	4.7	5.2	89.9	88.4
2	43.1	3.0	3.5	40.1	39.6

The object of the third experiment dealing with absorption was to determine whether or not cane plants can absorb potassium through their leaves. It is well known that iron can be absorbed that way. Evidence has been presented by SHAW (**63**) showing that cane leaves may absorb large quantities of water during rains. DOMONTOVICH and ZHELEZNOV (**17**) have shown that painting leaves with salts of potassium and magnesium leads tc the absorption of these elements.

On March 18, several leaves of the plants of series 5 were washed with a 5 per cent. solution of potassium dihydrogen phosphate. No sign of recoloration was observed. The results of this test are inconclusive, since it is possible that potassium might be absorbed without causing the leaves to become green. On the other hand, it may be that they were already beyond recovery.

C. HYDROGEN ION CONCENTRATION OF DRAINAGE.—Colorimetric determinations of the hydrogen ion concentration of the drainage were made at intervals. The reaction of the nutrient solutions was pH 6.4 and the object of these tests was to ascertain how well this reaction was maintained. The results are presented in table XIII. The high acidity was probably due to

TABLE XIII

pH OF DRAINAGE

SERIES	COMPOSITE DRAINAGE					INDIVIDUAL	
	OCT. 23	OCT. 26	OCT. 30	NOV. 2	NOV. 6	NOV. 9	NOV. 11
1	3.4	3.3	3.9	3.9	4.4	6.5–7	5.9–7.1
2	3.6	3.7	4.6	6.1	5.6	7	6.9
3	3.6	4.2	4.3	4.1	4.7	3.9–6.1	......
4	3.7	2.8	3.7	3.9	4.3	3.5–6.1	......
5	3.5	2.8	3.5	3.7	4.0	3.6–5.9	......

the use of ferrous sulphate as the source of iron. Because of the acidity, the solutions were changed more frequently. An important fact is that there was as much variation in reaction between the individuals of one series as there was between the different series, indicating that the differences in growth and external appearance of the plants were not caused by differences in the reaction of the medium. There was no correlation within a series between hydrogen ion concentration and general appearance, length of leaf, height of dewlap, number of red midribs, or amount of die-back. McGeorge (**51**) found that a hydrogen ion concentration as acid as pH 4.0 was without effect upon the growth of cane. An important conclusion to be drawn from these tests is that cane can grow in quartz sand cultures at a reaction varying from about pH 3.5 to 7 without any apparent external differences. In the field the range is probably less than that, since under field conditions changes in hydrogen ion concentration would cause more or less aluminum to go into solution, which would have a decided effect upon growth, as mentioned by Moir at the 52d annual meeting of the Hawaiian Sugar Planters' Association, December, 1932.

D. Pahala blight.—The symptoms of Pahala blight which began to develop the latter part of December, 1931, were alternating stripes of green and white in the blades, small elongated red spots in the white stripes, longitudinal splitting of the blades, and cessation of growth of the secondary stems. These symptoms are the same as those described by Lee and McHargue (**45**). They were confined to the plants of series 1 and 2.

The addition of 0.1 p.p.m. manganese as manganous sulphate to the nutrient solutions, begun January 4, resulted in a diminution of the symptoms of the blight. The secondary shoots started growing again. Because of a recurrence of the symptoms, the amount of manganese in solutions 1 and 2 was doubled twice in March.

Washing the leaves with 1 and 3 per cent. solutions of ferrous sulphate and manganous sulphate on March 4 and 19 resulted in no recoloration of the leaves. On March 21, plant 1 E was dusted with a mixture composed of equal quantities of manganous sulphate and sulphur. In two days this plant looked better. Thereafter all the plants of series 1 and 2 were dusted once a week. By the time of the final harvest the symptoms of Pahala blight had practically disappeared.

E. Silicon and titanium.—As mentioned earlier, silicon was added to the solutions beginning March 22, 1932. This was deemed necessary because of the rotting of the sheaths. On March 28 it was noted that the sheaths, particularly those of the potassium-deficient plants, were stronger, stiffer, greener, and less inclined to rot. Early in April it was noted that none of the plants had as many dead leaves as before the use of silicon. Although the addition of silicon was not a controlled experiment, the evidence presented here seems to indicate that it is essential for the best growth of cane.

There was no evidence that the addition of titanium nitrate to the solutions produced any effect upon the growth or appearance of the plants.

2. MICROCHEMICAL OBSERVATIONS

The stems of the potassium-deficient plants were found to contain iron at the nodes when given the HOFFER test (**33**), while the stems of the controls showed very little accumulation of iron. A dark discoloration of the bundles of the stems of the plants deficient in potassium was noted before staining. The sieve tubes and companion cells of some of the bundles of the midribs of the plants of series 5 were found to be very dark brown, when examined October 29, 1931. These discolorations were not found in the control plants.

3. ANALYTICAL DATA

The results of the moisture determinations are found in table XIV. In general, the plants supplied with potassium had a higher percentage of water than the potassium-deficient plants.

TABLE XIV

MOISTURE PERCENTAGES IN CANE

SERIES	NOVEMBER HARVEST		APRIL HARVEST	
	BLADES	STEMS	BLADES	STEMS
	%	%	%	%
1	74.1 ± 0.071	83.4 ± 0.047	79.1 ± 0.333	86.35 ± 0.071
2	74.9	85.6 ± 0.023	74.65 ± 0.071	83.65 ± 0.548
3	72.1 ± 0.238	81.0 ± 0.381	75.3 ± 1.09	79.7 ± 0.095
4	....	....	76.85 ± 0.071	80.75 ± 0.071
5	....	....	76.85 ± 0.548	76.75 ± 0.023
6	....	....	78.15 ± 0.023	....
7	....	....	77.65 ± 0.071	....

The results of the ash analyses, which were performed by the Chemistry Department of this Station, are given in tables XV and XVI, in which they are expressed on the percentage basis. The percentage of potassium within the plants was directly proportional to the amount supplied in the nutrient solution. In November the percentage of total ash was higher in the plants deficient in potassium than in the controls, in both blades and roots, whereas in April the blades of the control plants had the highest percentage of ash, the amount in the roots remaining (as before) greater in the potassium-deficient plants. In November the blades of the plants deprived of potash had the highest percentages of phosphorus, calcium, and magnesium; in the roots, phosphorus was greater in the potassium-deficient plants, but calcium and magnesium did not vary greatly. Silicon varied inversely with the amount of potassium in the blades, while in the roots the percentage of silicon varied irregularly, in the November material. While the high percentages of silicon in the roots in both the November and April material might suggest the possibility of contamination with minute particles of quartz sand, yet every precaution was taken to prevent such contamination and the chemist stated that no grains of sand were found in the ash.

In April the percentage of potassium in the blades, stems, dead leaves, and roots varied directly with the amount supplied. It is interesting that the plants of series 7 contained a higher percentage of potassium in the blades, stems, and roots than the controls. The percentage of potassium in series 6 also surpassed that in series 1 in stems and roots. Evidently the plants which received the first application of potassium in January absorbed it at a high rate.

TABLE XV

ASH ANALYSIS OF PLANTS HARVESTED NOVEMBER 20, 1931

PERCENTAGES EXPRESSED ON MOISTURE-FREE BASIS

SERIES	ASH	SI	K	P	CA	MG
	%	%	%	%	%	%
Blades						
1	5.139	0.0659	1.78	0.359	0.279	0.170
2	4.222	0.0617	0.955	0.396	0.411	0.384
3	4.666	0.0892	0.540	0.668	0.502	0.540
4	5.636	0.121	0.424	0.882	0.503	0.645
5	5.917	0.100	0.458	0.983	0.557	0.521
Roots						
1	24.96	8.008	1.78	0.598	0.532	0.308
2	17.42	4.555	0.741	0.450	0.765	0.471
3	28.56	9.395	0.388	0.747	0.515	0.274
4	31.74	11.42	0.294	0.721	0.550	0.237
5	33.82	10.99	0.329	0.856	0.616	0.268

In April phosphorus was again found to be higher in the potassium-deficient plants, in general. The percentage of silicon was inversely proportional to the potassium content in the roots, in the April material. Calcium, which was higher in the potassium-deficient plants in November, showed the opposite relationship in the blades in April but no striking differences in the other organs. Magnesium was higher in the blades and stems of the potassium-deficient plants than in those of the controls.

The plants receiving sodium contained more of that element than the other plants, but except in the stems the percentage of sodium in the plant was not proportional to the amount supplied in the nutrient solutions. In general the percentages of sodium decreased from the roots to the stems to the blades, whereas the percentages of potassium increased. All the blades and the stems contained higher percentages of potassium than sodium, even those supplied with more sodium than potassium. With the exception of the plants of series 3 and 5 the same condition existed in the roots.

There were greater percentages of iron in the blades, stems, and roots of the plants deficient in potassium than in the controls. The amount of

TABLE XVI

ASH ANALYSIS OF PLANTS HARVESTED APRIL 27, 1932
PERCENTAGES EXPRESSED ON MOISTURE-FREE BASIS

SERIES	ASH	SI	K	P	CA	MG	NA	FE
	%	%	%	%	%	%	%	%
Blades								
1	7.34	0.118	2.175	0.5102	0.544	0.4301	0.014	0.002
2	7.88	0.094	1.801	0.5341	0.842	0.5621	0.037	0.017
3	5.61	0.103	0.724	0.6529	0.278	0.5163	0.030	0.054
4	6.46	0.130	0.355	0.8007	0.215	0.6379	0.033	0.031
5	6.41	0.174	0.501	0.7893	0.241	0.5412	0.026	0.052
6	6.47	0.151	1.765	0.5269	0.279	0.2717	0.025	0.031
7	6.87	0.164	2.475	0.4964	0.264	0.2590	0.025	0.064
Stems								
1	4.53	0.119	1.504	0.4242	0.116	0.1828	0.020	0.020
2	3.18	0.158	0.437	0.3593	0.191	0.2710	0.129	0.016
3	2.98	0.102	0.335	0.4227	0.149	0.2547	0.143	0.063
4	3.77	0.134	0.292	0.5262	0.167	0.2391	0.237	0.254
5	4.22	0.153	0.278	0.5572	0.168	0.2941	*	*
6	6.21	0.261	1.934	0.5215	0.131	0.4119	0.015	0.025
7	5.99	0.057	2.206	0.5050	0.106	0.3376	0.019	0.019
Dead leaves								
1	8.23	0.102	1.270	0.6335	0.632	0.6115	0.025	0.047
2	8.78	0.111	0.213	0.7048	1.395	0.4881	0.205	0.059
3	7.58	0.123	0.160	0.9481	0.179	0.6236	0.041	0.031
4	7.81	0.140	0.205	0.9565	0.287	0.7248	*	0.041
5	8.53	0.117	0.132	0.1429	0.112	0.5588	0.027	0.027
6	8.54	0.145	1.262	0.8530	0.527	0.6050	*	*
7	8.61	0.175	1.154	0.8725	0.426	0.5630	*	*
Roots								
1	12.14	1.904	0.901	0.7817	0.991	0.2135	0.082	0.233
2	14.88	2.975	0.353	0.8123	1.254	0.2851	0.296	0.273
3	15.90	3.567	0.183	0.8808	1.018	0.1595	0.376	0.625
4	23.67	7.075	0.161	0.9972	0.911	0.0781	0.301	1.210
5	21.21	5.854	0.183	0.9816	0.945	0.1581	0.017	0.686
6	15.34	2.855	1.303	0.8881	0.938	0.4478	0.041	0.330
7	23.51	6.897	1.454	0.8579	0.622	0.3002	0.058	0.299

* Omitted because of insufficient material.

iron in all the plants was greater in the roots than in the stems and the blades. The percentages of iron in the roots of series 4 and 5 were greater than in 6 and 7.

The results of the ash analyses, recalculated to show the total amounts per plant in grams, are presented in tables XVII and XVIII. Table XVII shows that the blades of series 1 and 2 were nearly the same in dry weight per plant; that series 1 had a higher total ash content than series 2 chiefly because of the higher amount of potassium in series 1 than in 2; that silicon was very nearly equal in the two series; and that phosphorus, calcium, and magnesium were all present in greater amounts in series 2 than in series 1. Even series 3, the blades of which had half the dry weight of series 1, contained more phosphorus and magnesium and nearly the same amount of calcium as series 1. The roots of series 2 contained more calcium and magnesium than those of series 1, but the roots of series 3 were lower in all the ash constituents studied.

TABLE XVII

Average total amount of ash constituents in plants harvested November 20, expressed in grams; recalculated from table XV

Series	Average total dry weight (oven dry)	Ash	Si	K	P	Ca	Mg
Blades	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	66.3	3.41	0.044	1.180	0.238	0.185	0.113
2	66.6	2.81	0.041	0.636	0.264	0.274	0.256
3	36.3	1.69	0.032	0.196	0.242	0.182	0.196
Roots (air dry)							
1	23.7	5.915	1.898	0.421	0.142	0.126	0.073
2	28.7	5.000	1.307	0.213	0.129	0.219	0.135
3	11.2	3.199	1.052	0.043	0.084	0.058	0.031
4	5.8	1.840	0.662	0.017	0.042	0.032	0.014
5	6.0	2.029	0.659	0.020	0.051	0.037	0.016

Table XVIII shows that at the age of seven and one-half months the total amounts of ash constituents in the plants depended more upon the size of the plant than upon the percentage of potassium. Both the stems and roots of series 2 weighed less than those of series 1, but the stems of series 2 had more silicon, calcium, magnesium, and sodium than series 1; and the roots of series 2 had more ash, silicon, phosphorus, calcium, magnesium, sodium, and iron than in series 1. It was therefore by no means general that the plants deficient in potassium contained greater total amounts of ash constituents per plant than the controls, probably because the former

TABLE XVIII

Average total amounts of ash constituents in plants harvested April 27, expressed in grams; recalculated from table XVI

Series	Average total dry weight	Ash	Si	K	P	Ca	Mg	Na	Fe
Blades (oven dry)	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	199.8	14.7	0.235	4.345	1.019	1.090	0.859	0.028	0.044
2	263.0	20.7	0.247	4.737	1.405	2.214	1.478	0.097	0.045
3	68.6	3.9	0.071	0.497	0.448	0.191	0.354	0.021	0.037
4	14.4	0.9	0.019	0.051	0.115	0.031	0.092	0.005	0.004
5	14.9	1.0	0.026	0.074	0.118	0.036	0.081	0.004	0.008
6	124.8	8.1	0.188	2.203	0.658	0.348	0.339	0.031	0.039
7	105.8	7.3	0.017	2.618	0.525	0.279	0.274	0.026	0.067
Stems (oven dry)									
1	299.4	13.47	0.357	4.50	1.27	0.347	0.547	0.059	0.059
2	268.9	8.55	0.425	1.17	0.97	0.513	0.729	0.347	0.043
3	35.9	1.07	0.037	0.12	0.15	0.053	0.091	0.051	0.023
4	4.9	0.18	0.006	0.01	0.03	0.008	0.012	0.012	0.012
5	6.5	0.27	0.009	0.02	0.04	0.010	0.019	....	....
Roots (air dry)									
1	108.5	13.17	2.06	0.977	0.848	1.075	0.232	0.089	0.253
2	106.8	15.89	3.18	0.377	0.867	1.339	0.304	0.316	0.291
3	27.8	4.42	0.99	0.051	0.245	0.283	0.044	0.104	0.174
4	8.2	1.94	0.58	0.013	0.082	0.075	0.006	0.025	0.099
5	11.2	2.40	0.66	0.021	0.111	0.106	0.018	0.002	0.077
6	47.6	7.30	1.36	0.620	0.423	0.446	0.213	0.019	0.157
7	40.5	9.52	2.79	0.589	0.347	0.252	0.121	0.023	0.121

were generally smaller. However, the fact that they did contain more in the places just mentioned increases the importance of the differences in percentage and leads to the conclusion that the absorption of potassium tends to decrease the absorption of such elements as phosphorus, calcium, magnesium, and iron.

Discussion

The economic importance of physiological studies of potassium deficiency in sugar cane lies in the effects upon the growth, resistance to diseases, and quality of the juices exerted by potassium. A survey of the literature dealing with sugar cane shows that there is no real agreement regarding the value of potash fertilization, inasmuch as the results of some experiments indicate a response while others do not. No attempt will be made to cite all the pertinent references, but a few representative ones will be mentioned as illustrations. The importance of potassium in increasing growth and yield of cane has been discussed by Stewart and Verret (**68**) and by Moir (**53**), who stress its necessity in the early growth of cane.

Naquin (**54**) has found that there is a greater response to potash fertilization in hollows than on knolls or in thin soil. Ayres (**8**) found that cane in some crops used well over 800 lb. K_2O per acre, illustrating the tremendous demand made by cane for potash. McGeorge (**50**), on the other hand, states that the majority of Hawaiian soils do not respond to potash fertilization.

Among those reporting gains in juice quality resulting from the application of potassium, the following may be mentioned: Agee (**1**), Alexander (**3, 4**), Harrison (**27**), and Pratt (**61**). Ferris (**19**) found no increase in yield due to the addition of potassium. Verret (**71**) reported that there was no effect whatever on the quality ratio from the use or omission of phosphoric acid or potash or both. According to Geerligs (**21, 22**), generally a juice of low purity is highest in potassium, while juices rich in sucrose contain less potassium, and those varieties which make the most sugar generally have the least potassium. Geerligs concluded that many other factors have a greater effect upon quality than potash. That this condition of non-conformity of results of potash studies still exists is shown by a recent report by Agee (**2**), in which the results of several experiments are summarized. When one considers the sources of error in field experiments as at present conducted, there is no wonder that the results are not always in agreement. Of course the response from applications of potash depends upon the amount of potassium already in the soil and many other factors. Moir (**53**) stresses the balance as important, stating that the application of plant foods aids crop quality when the element lacking is supplied, and continues to do so until some other element becomes limiting or until one is added in too large amount.

The importance of potassium in increasing resistance to disease in plants is well known. Sugar cane is no exception. Lee (**43**) and Lee and Martin (**44**) report that potassium aids in increasing resistance toward eye spot. Moir (**53**) suggests that the increase in cutin due to potassium found by Hartt (**28**) points to the effect of potassium in lessening damage due to cane diseases such as eye spot and brown stripe. He also states that the large cavities in the cortex of the roots and the poor root hairs in the potassium-deficient plants reported by Hartt may suggest one possible cause of the root failure complex or Lahaina disease. The evidence is inconclusive regarding a relationship between a lack of potassium and brown stripe disease. Hance (**26**) by spectroscopic analysis found that cane plants susceptible to brown stripe were deficient in barium, potassium, magnesium (or copper), and cadmium (or zinc). Shepardson (**64**), however, found no apparent correlation between brown stripe and potassium, but suggested further studies concerning silicon and that disease. In general there is need for more investigation of the relation between potassium and disease resistance in sugar cane.

The preceding brief review illustrates the need for more fundamental physiological studies of potassium in sugar cane.

Although similar in plan and purpose, the present studies are not absolutely comparable with those carried on in Chicago (**28**), for several reasons. In the Chicago experiment the variety used was Louisiana Purple (Cheribon), while H 109 was used in the Honolulu studies. The growing conditions also differed considerably. In the former investigation the plants were grown during the winter and spring in Chicago and during much of the time the light conditions were poor, although supplemented by electricity. In Honolulu the length of day and amount of light were more nearly uniform and better adapted for the growth of cane. The temperature also differed, the Chicago greenhouse being kept around 90° F., whereas in Honolulu the temperature at times reached 110° F. Because of the differences in light and temperature, the growth rate of the plants in the present investigation was considerably greater than that of the first study. The nutrient solutions used in Honolulu were less concentrated than those used in Chicago but were renewed more frequently. Also silicon, manganese, and titanium were used in these studies and not in the former. Iron was added as ferric phosphate in the former, whereas ferrous sulphate was used in the latter investigation. Undoubtedly there were other differences in the growing conditions of the two experiments. Secondary growth was purposely discouraged in the Chicago experiment, whereas in Honolulu the secondary shoots were allowed to develop. The writer thus agrees with the criticism of VAN DEN HONERT (**70**) that the plants in Chicago were grown under unfavorable light conditions. Notwithstanding these differences in variety, light, temperature, growth rate, and nutrient solutions, similar symptoms of potassium deficiency occurred in both and it is felt that broad comparisons are justified between the two investigations.

Evidence of the difference in the growth rates of the plants grown in Chicago and Honolulu is given in table XIX. This shows that in one month the main stalks of the plants grown in Honolulu were nearly as tall as those in Chicago in about five months, when the lengths of the longest leaves are compared. The first symptoms of potassium starvation developed in Honolulu within one month after watering with the nutrient solutions was begun, while four months elapsed in Chicago before deficiency symptoms appeared. While other factors no doubt contributed to these differences in growth and development of symptoms, yet it is felt that one of the most important causes was the amount of light. In this connection mention should be made of an unpublished study conducted by Miss MARJORIE

Bodwell in 1931, at that time a student with the writer at Connecticut College. Miss Bodwell grew buckwheat and soy bean plants with and without potassium under several intensities of light. The plants in the most intense light were the first to exhibit symptoms of potassium starvation, the others following in the order of decreasing intensities of light.

TABLE XIX

Comparison of growth: Chicago and Honolulu

Solution No.	Chicago studies			Honolulu studies			Solution No.
	K	Length of longest leaf				K	
		1 mo. 15 days	5½ mo.	1 mo. 5 days	3½ mo.		
	p.p.m.	*cm.*	*cm.*	*cm.*	*cm.*	*p.p.m.*	
1	703.8	88.9	170.2	140.7	198.6	87.9	1
4	39.0	67.3	143.5	147.1	198.2	39.0	2
3	3.9	68.9	151.1	133.7	160.5	3.9	3
2	0.0	71.7	139.7	125.8	135.9	0.0 (+Na)	4
				120.3	136.9	0.0 (−Na)	5

The effect of light upon the absorption and utilization of potassium by plants has been studied by several workers. Johnston and Hoagland (**39**) have given evidence that plants absorb more potassium during the day than at night and suggested that the energy of light may be an important factor governing the absorption of nutrient ions by plants. Nemec (**56**) grew rye under colored glass bell jars and found that plants under green jars absorbed less potassium than those in full sunlight, while those under violet and red jars contained more potassium than those in sunlight. Nightingale (**57**) refers to Stoklasa who found that sugar beet seedlings in darkness when supplied with potassium and sugar accumulated much more dry matter than plants in the dark lacking potassium but supplied with sugar; while in the light, the amount of sugar absorption was only a little higher in the plants supplied with potassium than in those lacking it. It was therefore suggested that potassium to some extent assumes the rôle of light. A connection between light and potassium seems substantiated. Since in the present studies equal amounts of potassium were absorbed by sugar cane plants during twelve hours of darkness and twelve hours of daylight (table XII), it would seem that light must affect the utilization of potassium by sugar cane rather than its absorption. Whether this may be due to the photoelectric properties of potassium or is merely a matter of limiting factors will be discussed in the second paper of this series.

ABSORPTION OF POTASSIUM

The amount of potassium absorbed probably depends more upon its amount and availability in the soil than upon the rate of its utilization within the plant, since considerable evidence has been given by BARTHOLOMEW and JANSSEN (9) indicating that plants may indulge in a luxury consumption of potash. Undoubtedly the age of the plant is also an important factor influencing the absorption of potassium, particularly when young. Evidence of this is given in table XI, showing that one month after watering with the nutrient solutions was begun, the plants of series 1 and 2 were absorbing potassium at the same rate. The plants were about the same size at that time, no symptoms of potassium deficiency having yet appeared in series 2. As is shown in figure 15, early in November, the plants of series 1 definitely surpassed those of series 2 in growth. It is interesting that on November 13 and 14, series 1 showed the ability of absorbing double the amount of potassium absorbed by series 2, according to table XII. It would seem that when supplied with 39–88 p.p.m. potassium, the amount absorbed during the first month is limited by the size of the plant, probably in particular by the size of the root system; but when there is 3.9 p.p.m. potassium or less, the amount of potassium is the limiting factor, and potash starvation symptoms develop earlier. Inasmuch as the absorption of potassium seems to be limited by the size of the young plant, it is apparent that large applications of potash in the field during the first month may not be economical.

ANDRÉ and DEMOUSSY (**6, 7**) have stressed the importance of the mobility of potassium. The absorption of considerable amounts of potassium may decrease the amounts of certain other elements absorbed, which may offer a partial explanation for the depressing effect of potassium upon the growth and juice quality of cane which has been mentioned by AGEE (**2**). In the present study, little evidence of a depressing effect upon growth was obtained. Three weeks after starting the plants in the nutrient solutions, the plants of series 2 slightly surpassed those of series 1 in growth, as shown in table II. This difference held also in nine weeks for certain measurements (tables III–V), but at that time the average height of the highest dewlap of the plants of series 1 was higher than that of series 2; and from then to the end of the experiment the growth of the plants of series 1 steadily surpassed that of series 2, as shown in figure 15.

Sugar cane plants deficient in potassium were found to absorb more of certain other elements on the percentage basis than did the controls, a condition similar to that studied in other plants by various investigators: ANDERSON *et al.* (**5**), DAVIS (**16**), FONDER (**20**), GINSBURG (**24**), HOAGLAND (**32**), OWEN (**59**), and others. Two months after starting the plants in the nutrient solutions, the potassium-deficient plants were absorbing more silicon, phosphorus, calcium, and magnesium than the controls, as shown by table XV. That this was a real difference in amount is shown by the fact that the plants of series 4 and 5 had the largest percentage of total ash, particularly in the roots, and is also shown by the greater total amounts of ash constituents in the plants deficient in potassium than in the controls, found in some of the series, as shown in tables XVII and XVIII. This difference in absorption did not continue to the end of the experiment, as at the time of final harvest the potassium-deficient plants had the lowest percentage of total ash in the tops, although they still had the highest percentage in the roots. The absorption of phosphorus continued to be greater in the plants starved for potassium to the end of the experiment, which may have an important bearing upon the activity of amylase, as will be mentioned in the second paper in this series. The final percentages of calcium and magnesium varied irregularly in the different parts of the plants, except that calcium was highest in the blades of the plants of series 1 and 2.

Determinations were also made of the amounts of iron and sodium in the plants harvested in April. The percentages of iron in the blades, stems, and roots of the plants deficient in potash were found to be higher than in the controls, showing that a deficiency in potassium leads to the absorption of a greater amount of iron. Sodium was lower in amount than potassium in the blades and the stems of all the plants, even those supplied with more sodium than potassium. These comparisons are taken from table XVI.

The addition of potassium to the potassium-deficient plants resulted in a rapid absorption of that element and a considerable increase in growth. The steps in recovery outlined in the results were similar to those obtained in the field, according to Moir (personal communication). Table XVI shows that in some instances the plants of series 6 and 7 contained higher percentages of potassium than did the controls. To a certain extent this may be due to the fact that the absorption of potassium was more rapid than the resulting growth. The plants of series 7 contained more potassium than did those of series 6 in all organs except the dead leaves. This higher percentage in series 7 led to a considerably greater growth, series 7 surpassing series 6 to a marked degree during the latter part of the experiment. The addition of potassium to the plants of series 6 and 7 also decreased the percentages of phosphorus and magnesium in those plants.

The effect of the addition of potassium upon the distribution of iron within the plant is important. Table XVI shows that the plants of series 6 and 7 had considerably lower percentages of iron in the roots than those of series 4 and 5, indicating that the addition of potassium to the former beginning in January had the important effect of decreasing the percentage of iron in the roots as a part of their recovery from potassium deficiency. Table XVI also shows that the stems of the plants deficient in potassium contained larger percentages of iron than the controls, whereas the plants of series 6 and 7 contained nearly the same amount in the stems as the controls. It is evident that the addition of potassium to the potassium-deficient plants resulted in a decrease in the percentage of iron within the roots and stems. That this was not entirely the effect of a greater distribution of the iron within the larger stems is shown by the relative amounts of iron in the blades and stems of the plants of series 6 and 7. Table XVI shows that the percentages of iron in the blades of series 6 and 7 were nearly double or treble the percentages in the stems of those plants, whereas in series 1–4 the percentages of iron in the blades were equal to or less than the percentages in the stems. It seems that the addition of potassium to the plants starved for that element caused some of the iron which had accumulated in the stems to pass up into the blades. This may be explained by assuming that the addition of potassium increased the turgidity of the leaves and thus increased the speed of the upward movement of the transpiration stream and the mass movement of the iron. That potassium affects turgidity is well known, having been established by COPELAND (**13**) as early as 1897. Evidence that the rate of transpiration is affected by the supply of potassium was obtained in a test using the cobalt chloride paper method, in which equal shades of pink were developed in 55 seconds on a blade of one of the plants of series 1, and in four minutes on a blade of one of the plants of series 3, these blades having similar exposures.

To summarize, several generalizations may be offered regarding the absorption of potassium by the sugar cane plant, from the studies reported in this paper:

1. Since equal amounts of potassium were absorbed by day and by night, the absorption of potassium does not seem to be affected by light.
2. With the exception of the first three or four weeks, the amount of potassium absorbed is directly proportional to the amount supplied, within the limits of this experiment.
3. During the first month the absorption of potassium is limited by the size of the plant.
4. Cane plants deficient in potassium absorb more phosphorus and iron, at least during the first seven months of their growth. They also absorb more calcium, magnesium, and silicon during the first two or three months.
5. The addition of potassium to plants deficient in that element results in a rapid absorption of potassium, a decrease in the intake of phosphorus and magnesium, and causes some of the iron which had accumulated in the stems to pass up into the blades.

MIGRATION OF POTASSIUM

There was a greater percentage of potassium in the blades than in the stems, and the stems in turn were higher in potassium than were the dead leaves (table XVI). In every series the percentage of potassium in the dead leaves collected in April was not only lower than in the blades harvested at the same time but also lower than in the blades of the November material. Therefore the potassium migrated from the dying leaves to the living top of the sugar cane in this experiment, as has also been shown by BONAME (**10**). BARTHOLOMEW and JANSSEN (**9**), JAMES (**36**), JANSSEN and BARTHOLOMEW (**37**), NIGHTINGALE and coworkers (**57**), and others have mentioned this in connection with other plants. This migration is against the diffusion gradient.

If the percentage of potassium in the dead leaves is subtracted from the percentage in the blades (table XVI), a rough estimate of the amount of migrated potassium is obtained. Then if the ratio is taken of the percentage of migrated potassium to the percentage of potassium left in the dead leaves, the results in table XX are obtained. This shows that the relative amounts of migration are in this order: $2 > 3 > 5 > 7 > 4 > 1 > 6$. If this is compared in a similar manner with the percentages of the following in blades: total ash, K, Si, P, Ca, Mg, Fe, Na, and H_2O, it is found that there is no relation between any of the ash constituents studied and the migration of potassium. The moisture content decreased in this order: $1 > 6 > 7 > 4$ and $5 > 3 > 2$. Omitting the plants of series 6 and 7, it is found that the migration of potassium occurred in this order: $2 > 3 > 5 > 4 > 1$. The water content decreased in the order: $1 > 4$ and $5 > 3 > 2$. Possibly the plants of series 6 and 7 should be considered separately inasmuch as their treatment was changed during the course of the experiment. Of the two, series 6 had the greater moisture content and the lower migration of potassium while series 7 had the greater migration of potassium and the lower percentage of water. The conclusion seems inevitable that the greatest migration of potassium occurred in the blades having the lowest water percentage, and that there was no relationship between the amount of migration and the percentage

TABLE XX

RELATIVE AMOUNTS OF MIGRATION OF POTASSIUM

SERIES	% POTASSIUM MIGRATED ÷ % POTASSIUM LEFT IN DEAD LEAVES
1	0.71
2	7.4
3	3.5
4	0.73
5	2.0
6	0.4
7	1.1

of potassium in the plant. In other words, migration did not occur most readily in those plants which needed it most; therefore the translocation of potassium is not an adaptation in potassium-deficient plants, but occurs there more than elsewhere only when those plants at the same time have the lowest moisture content. The suggestion made by Penston (**60**) is pertinent, that migration is possibly related to age rather than to a deficiency in potassium. It is probably an exception in the present study that the plants of series 2 contained less water than those of series 3, 4, or 5, possibly explained by their greater size and the fact that for some undetermined reason it was practically impossible to keep the plants of series 2 adequately supplied with water, as they required even more than series 1. It is probably more generally true that the moisture percentage is directly proportional to the amount of potassium supplied, since several investigators (**11, 28, 35, 38, 72**) have reported lower moisture contents or higher percentages of dry matter in potassium-deficient plants; hence the migration of potassium may in general occur most in the plants which benefit most by that condition. It is felt that statements in the literature regarding such translocations often verge on the teleological, when it is implied or stated that plants deficient in potassium can transfer the little potassium they contain from a place where it is no longer in use to where it is needed. The results herein reported show that this is not an adaptation in potassium-deficient plants, since it occurred most readily in the plants of series 2, which contained considerably more potassium than the plants of series 3, 4, or 5, and occurred equally well for series 1 and 4. Dowding (**18**) also found that a translocation of potassium occurs within the embryonic cone during bud elongation in the spruce, and those plants were not deficient in potash.

Probably several factors are involved in the migration of potassium. In leaves it may simply be a balance of forces between the transpiration of the plant as a whole and that of the lower leaf. When the lower leaf contains very little water the pull of transpiration from above readily overcomes the pull of the individual dying leaf, but when the lower leaf contains a considerable amount of water, such is not the case. The failure of the development of the abscission layer in plants in extreme potassium deficiency, found in cane by Naquin (**55**), who stated that in potassium deficiency the dead leaves adhere to the stalk, and reported in the tomato by Lipman (**46**), is another important factor. Without the usual abscission layer the leaf would tend to remain longer on the plant, thus allowing migration. Kostytschew and Eliasberg (**42**) were among the first to find that potassium can be extracted from plant tissues *in toto* by water. Since Janssen and Bartholomew (**37**) and others have also found that most of the potassium in plants is soluble in water, it seems that potassium is present in a readily movable form. Undoubtedly other factors are involved, because the situation is not always so simple. Potassium not only migrates into the upper leaves, but also into fruits and to the meristematic tips of roots as reported by LIPMAN (**46**). If electric currents of mitotic origin similar to those found in wheat plants by COLLA (**12**) are of general occurrence, possibly these might aid in explaining the migrations of potassium to meristematic regions. The suggestion proposed by MCGEORGE (**52**) that bases may be absorbed by lignin and displaced by other bases or by hydrogen, and that this interchange may play a part in ionic movement through plant tissue, may contribute to the explanation of the mechanism of the translocation of potassium. In short, the forces involved in the migration of potassium from the older regions of plants to young developing portions possibly include transpiration, base exchange, and electrokinetic phenomena.

Of the ash constituents studied, potassium was the only one which exhibited the ability to migrate. Table XVI shows that the dead leaves of all the plants had a higher percentage of total ash than had the green blades. The silicon, phosphorus, calcium, magnesium, iron, and sodium varied irregularly in most of the groups, being greater in amount in the dead leaves than in the blades, with occasional exceptions. This is to be expected, since with the exception of sodium the elements mentioned are known to enter into organic compounds, either in wall material or protoplasm; potassium exists for the most part in simple form. Another factor involved is the greater mobility of potassium as compared with the other elements, which has been stressed by ANDRÉ and DEMOUSSY.

IRON TOXICITY

An interesting controversy has occurred in Java as to whether certain symptoms in sugar cane may be attributed to potassium deficiency or to iron toxicity. In the condition known as Kalimati disease (so called from the name of the principal plantation where it occurs), the symptoms are very similar to those of potassium deficiency and the addition of potassium has been found to overcome the trouble. WILBRINK (**73**) thinks that Kalimati disease is caused by potassium deficiency. KONINGSBERGER (**40, 41**), however, is of the opinion that the disease is due to iron toxicity, which occurs particularly with ferrous iron when ammonium nitrogen is used instead of nitrate nitrogen. He thinks that the disease is overcome by the addition of potassium either because potassium counteracts the injurious action of iron or because it may stimulate nitrification. That the Kalimati disease is overcome by the addition of potassium is insufficient ground for calling the disease potassium deficiency, according to KONINGSBERGER, who feels that that is no better than to speak of "quinine deficiency" in the case of malaria.

Whether one agrees with WILBRINK or with KONINGSBERGER, it is interesting that a toxic effect of iron, which can be overcome by the addition of potassium, occurs in both Kalimati disease and potassium deficiency. HOFFER (**34**) reported that the addition of potassium to corn plants having accumulations of iron at the nodes cleared up that condition but the accumulation of aluminum was not affected. HOFFER found the vessels of plants deficient in potassium clogged with iron, and these vessels became clear upon the addition of potassium. He pointed out that this accumulation causes the breakdown, either by precipitation or by coagulation, of the cell contents of certain joint tissues, interfering with translocation. Furthermore, HARVEY (**30**) stated that in maize grown in acid soil there may be a deposit of Fe_2O_3 in the vascular tract sufficient to interfere with translocation, and that firing of the leaves may be observed under such conditions. MCGEORGE (**51**) found that both potassium and phosphorus aid in the distribution of iron and that any growth-retarding factor may induce accumulations of iron and aluminum in the nodes of cane. In the present study iron was found to be higher in the potassium-deficient plants than in the controls, particularly in the roots and stems. Iron occurred especially at the nodes of the plants deficient in potassium but not of the controls.

Either because of this nodal accumulation of iron or on account of an upset in the synthesis of proteins resulting in abnormal protoplasm in the sieve tubes and companion cells, or for both reasons, a necrosis of the phloem occurred in the plants deficient in potassium. The derangement in the formation of proteins will be discussed fully in the second paper of this series. In the previous study (**28**) a little evidence was obtained of derangements of the phloem in the plants deficient in potassium. Reference to the section dealing with microchemical results will show that further evidence of phloem necrosis in the plants deprived of potash has been offered in the present study. The evidence consisted of a dark discoloration of the bundles of the stems and of both sieve tubes and companion cells of the bundles of the midribs. These discolorations were noted as early as the latter part of October. Furthermore, it has recently been found by MARTIN (**49**) that similar discolorations of the bundles in cane stems occur throughout the Hawaiian Islands, and there is some evidence that they are related to potash deficiency. This condition has been termed "internal stalk necrosis."

These accumulations occur more at the nodes than at the internodes, possibly because of the anastomosis of the bundles in the former location. Perhaps another factor involved in the nodal accumulations of iron is the tannin content which, according to HALDEN (**25**), is particularly large in the nodes. It would seem that the insolubility of iron tannate must play a part in the deposition of iron at the nodes, although how the addition of potassium could clear up the iron tannate is difficult to explain. X-ray photographs of nodal accumulations in sugar cane have been published by CRUTCHFIELD (**14**).

Evidence is presented in table XVI showing that the addition of potassium to plants deficient in that element resulted in a considerable decrease in the percentage of iron in the roots and stems and a slight increase in the blades, leading to the conclusion that potassium caused some of the iron to pass up from the stems to the blades. As mentioned before, this was possibly due to an increase in the transpiration rate; hence the upward movement of the transpiration stream following the addition of potassium. The fact that the transpiration stream of potassium-deficient plants is so sluggish as to permit the lodging of sufficient iron and aluminum to clog the vessels and yet strong enough to pull out the remaining potassium in the lower leaves is possibly explained by the differences in the mobilities of these elements. Because of the tendency to use these nodal accumulations of iron as a symptom of potassium deficiency, although they have been found to occur in both calcium and phosphorus deficiency (**52**) as well as increased soil acidity (**30**), the need is felt for further study of this question. Because the plants which contained the largest percentages of iron did not have as much as some of MCGEORGE's (**51**) plants which gave good growth (5.1 per cent. iron in the roots of plants 4 compared with 21.8 per cent. iron in one of MCGEORGE's plants, both on the ash basis), the results of the present study support the view advanced by MCGEORGE that the toxicity of iron in sugar cane is due to its unequal distribution rather than to its total concentration.

One of the conditions which must be taken into account in a consideration of potash starvation therefore is iron toxicity. One of the most important derangements in potassium deficiency to which iron toxicity contributes is the disturbance in the translocation of the sugars and nitrogenous compounds, which will be discussed in the second paper of this series.

CAN SODIUM REPLACE POTASSIUM?

The question of the possibility of the substitution of sodium for potassium in the nutrition of plants, which was settled temporarily by NOBBE, SCHROEDER, and ERDMAN (**58**) in 1871, has been reopened in recent years. Several investigators (**29, 31, 66**) report at least the partial substitution of sodium, whereas others, for example REED and HAAS (**62**), conclude that there is no evidence that sodium can replace potassium.

To study this question with cane, the plants of series 5 were supplied with a nutrient solution lacking both sodium and potassium. Very little difference was found between the plants of series 4 (supplied with sodium) and those of series 5 (deprived of sodium) in either growth or external appearance. Their similarity in appearance is shown in figures 10 and 11, 19 and 20, 26 and 27. Tables II–VI, VIII, and IX show that where there was a difference in size between series 4 and 5, the plants of series 5 were generally the larger, indicating that the sodium may have exerted a somewhat depressing effect. Figure 15 shows that the stems of these plants grew at about the same rate, their curves crossing at several points. The plants of series 5 showed a better ability to recover upon the addition of potassium than series 4, which perhaps was due to the greater supply of calcium in solution 5, possibly leading to a better absorbing system.

The percentages of sodium in the ash of all the plants are given in table XVI, from which it will be seen that the plants receiving sodium in the nutrient solutions contained more than the others; but except in the stems, the percentage of sodium in the plant was not proportional to the amount supplied.

All the blades contained higher percentages of potassium than of sodium, even those supplied with more sodium than potassium. This was true also for the stems and for the roots, except in series 3 and 4. The smaller amounts of potassium in the solutions were evidently absorbed more readily than the larger amounts of sodium. Similar results were reported by André and Demoussy (**6**, **7**), who found that plants supplied with more sodium than potassium absorbed more potassium than sodium, which they explained by the greater mobility of the element potassium.

The results of the present study, therefore, lead to the conclusion that sodium does not even partially replace potassium in the nutrition of sugar cane, but may possibly exert a slightly depressing effect upon growth.

Summary

1. Sugar cane plants, variety H 109, grown in quartz sand cultures, were supplied with varying amounts of potassium as follows: 87.9 p.p.m. K, 39 p.p.m. K, 3.9 p.p.m. K, no K + Na, no K, no Na.

2. This paper deals with the effects of varying amounts of potassium upon the growth of sugar cane and upon the absorption and migration of the constituents of the ash. The following paper reports the results of determinations of the activity of the enzymes invertase, amylase, and ereptase; also analyses of total and amino nitrogen, reducing sugars, and sucrose; and the hydrogen ion concentration, titratable acidity, and titration curves of the juices expressed from the leaves, stems, and roots.

3. Symptoms of potassium starvation began to appear three weeks after watering with the nutrient solutions was begun.

4. The symptoms of potassium deficiency which developed were similar to those which occurred in the previous study (**28**): depressed growth of the plant as a whole, discoloration of the leaves, and dieback of the leaf tips.

5. The development of red midribs, which occurred on the plants deficient in potassium, is shown to be a secondary rather than a primary symptom of potash deficiency, developing when phloroglucin and sufficient sulphate occur simultaneously within the plant. The source of phloroglucin suggested is the decomposition of tannic acids, a possible result of potassium deficiency. The sulphate came from an excess of ferrous sulphate which was used as the source of iron.

6. The growth of the plants was proportional to the amount of potassium supplied.

7. Because the plants totally deprived of both sodium and potassium equaled or surpassed those supplied with sodium but no potassium, the conclusion is drawn that sodium does not even partially replace potassium in the nutrition of sugar cane.

8. The addition of potassium to plants deficient in that element resulted in a rapid absorption of potassium and a considerable increase in growth. The absorption of phosphorus and magnesium was decreased in these plants.

9. Plants previously deprived of both sodium and potassium recovered upon the addition of potassium more rapidly than did those previously deprived of only potassium.

10. During the first month the absorption of potassium was limited by the size of the plant, whereas after the first month the amount of potassium absorbed was directly proportional to the amount supplied.

11. Since equal amounts of potassium were absorbed by day and by night, the absorption of potassium was found not to be affected by light.

12. No evidence was obtained showing that sugar cane can absorb potassium through the leaves.

13. The sugar cane plants deficient in potassium absorbed more phosphorus and iron than the controls, at least during the first seven months of their growth. They also absorbed more calcium, magnesium, and silicon during the first two or three months.

14. The toxicity of iron in sugar cane is due to its unequal distribution rather than to its total concentration, a conclusion agreeing with that reached by McGeorge.

15. Nodal accumulations of iron were found in the plants starved for potassium.

16. The addition of potassium to plants deprived of that element caused some of the iron which had accumulated in the roots and stems to pass up into the blades, possibly due to an increase in turgidity of the leaves and in the upward movement of the transpiration stream.

17. Brown discolorations of the sieve tubes and companion cells in the midribs of the plants deficient in potassium indicated a necrosis of the phloem.

18. The control plants had a higher moisture content in both stems and blades than had the plants deprived of potash.

19. The percentage of potassium within the plants was directly proportional to the amount supplied in the nutrient solutions. A similar relationship held for sodium only in the stems.

20. With the exception of the roots of the plants of series 3 and 4, all the plants contained higher percentages of potassium than sodium in all organs, even those plants supplied with more sodium than potassium.

21. The ash analyses showed that potassium migrated from the dying leaves to the living top of sugar cane, and that no other elements studied did so.

22. The greatest migration of potassium occurred in the blades having the lowest moisture percentage. There was no relationship between the amount of migration and the percentage of potassium. Therefore the translocation of potassium is not an adaptation in potassium-deficient plants but occurs there more than elsewhere only when those plants at the same time have the lowest moisture content.

23. Some evidence is presented indicating that the transpiration of the plants deficient in potassium was less than that of the controls.

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