TIME FACTOR IN UTILIZATION OF MINERAL NUTRIENTS BY HEMP

SISTER MARY ETIENNE TIBEAU

(WITH NINE FIGURES)

Introduction

Certain recent studies in mineral nutrition of plants have shown that the time of fertilizer application, in relation to the plant's ability to use nutrients, is as important as the balance among the nutrients themselves. Since it is also known that the physiology of the staminate and pistillate plants is in sharp contrast, especially in dioecious plants, the writer has undertaken to determine the physiological changes in hemp (*Cannabis sativa* L.) by varying the composition of various nutrient solutions, and the time of growth in these cultures, in order to test the effect of the treatment upon the ultimate sex expression.

Procedure

Hemp (*Cannabis sativa*) was chosen for this investigation because it shows marked sexual dimorphism and grows well under laboratory conditions. Seeds were planted in the greenhouse. When the seedlings were about 2 inches tall, they were removed from the soil and their roots were washed in distilled water. They were then transferred to 2-gallon jars containing white quartz sand which had been washed free from all solutes. Eight seedlings were planted in each of twenty-seven pots, on May 27, after being watered with distilled water. Four days later the pots were marked off in sets of three, and to each pot of each set there was added 500 cc. of a specially prepared nutrient solution. The plants were grown under continuous light for 12 days to stimulate vegetative development. As soon as they had attained sufficient growth, 6 plants of uniform size were selected from each set for observation.

All pots were kept constant in weight by the addition of distilled water, and 500 cc. of the nutrient solution was given as needed until 6 liters had been used.

The vegetative growth of the plants was rapid due to the length of the photoperiod. When the first photographs were taken on June 25, the plants being then 29 days old, very striking contrasts in growth and general appearance were apparent.

Knop's four-salt solution was used as the basic solution for supplying nutrients to the control plants. Three types of experiments, in which the basic nutrient solution was modified, were performed: (1) a high content series in which the plants were supplied with a high content of the essential elements K, Mg, Ca, and N, respectively, added to a complete (Knop's) nutrient solution (table I); (2) a deficiency series in which the plants were supplied with a nutrient solution in which K, Mg, Ca, and N, respectively, were omitted from the complete nutrient solution (table II); and (3) a series in which the plants after first undergoing periods of starvation of a single element, were then supplied with a nutrient solution having a high content of this element.

TABLE I

COMPOSITION OF KNOP'S AND HIGH-CONTENT CULTURE SOLUTIONS GIVING WEIGHT IN GRAMS OF EACH SALT IN 14 LITERS OF SOLUTION

SALTS	CULTURE				
	KNOP'S	8K	8MG	8CA	8N
	gm.	*gm.*	*gm.*	*gm.*	*gm.*
KNO_3	2.00	4.00	2.00	2.00	2.00
KH_2PO_4	2.00	4.00	2.00	2.00	2.00
$MgSO_4$	2.00	2.00	8.00	2.00	4.00
$Ca(NO_3)_2$	8.00	8.00	8.00	32.00	8.00
K_2SO_4	....	9.10	....	....	....
KCl	....	5.74	....	....	....
$MgCl_2$	....	....	6.34	....	....
$CaCl_2$	....	....	....	21.64	....
NH_4NO_3	....	....	....	....	32.80

TABLE II

COMPOSITION OF DEFICIENCY CULTURE SOLUTIONS GIVING WEIGHT IN GRAMS OF EACH SALT IN 14 LITERS OF SOLUTION

SALTS	CULTURE			
	–K	–MG	–CA	–N
	gm.	*gm.*	*gm.*	*gm.*
KNO_3	....	2.00	2.00	....
KH_2PO_4	....	2.00	2.00	2.00
$MgSO_4$	2.00	....	2.00	4.00
KCl	....	....	....	1.48
$CaCl_2$	....	....	....	5.50
$Ca(NO_3)_2$	8.00	8.00	....	....
$NaNO_3$	1.68	....	8.32	....
Na_2SO_4	....	2.38	....	....
NaH_2PO_4	1.8	....	....	....

Investigation

Experiments I and II

The plants supplied with a high-potassium (8K) solution showed an increase in growth compared with those supplied with Knop's solution, while the plants supplied with a potassium-deficient (−K) solution exhibited a retarded development (fig. 1). These differences in height, however, were

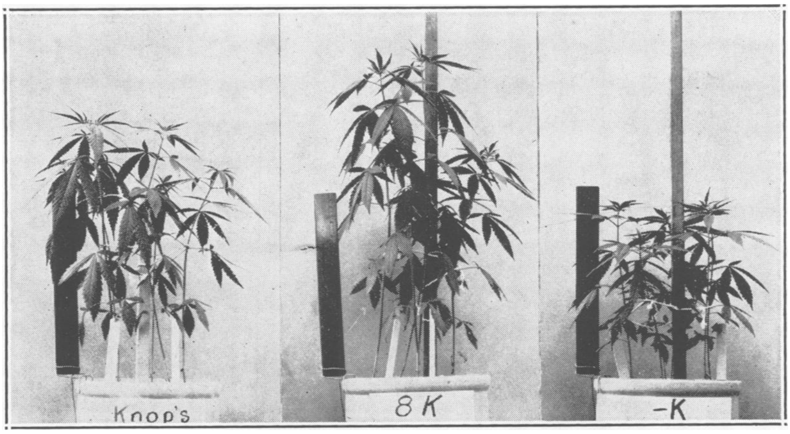

Fig. 1. Comparative growth of vegetative hemp in sand cultures variously treated with potassium. Age 29 days.

not maintained. At the end of 47 days, although the plants supplied with high-potassium (8K) solution were somewhat taller, plants supplied with Knop's solution had attained almost the same height; and the plants supplied with a potassium-deficient (−K) solution were lagging far behind,

Fig. 2. Comparative growth of vegetative hemp in sand cultures variously treated with magnesium. Age 29 days.

owing to the fact that potassium is abundantly utilized by the plant in the early stages of its growth (**2, 4**).

The plants supplied with a high-magnesium (8Mg) solution, at this time, were taller than those supplied with a magnesium-deficient solution (fig. 2), but the most striking contrast was in the color, the latter showing chlorosis (**9**).

The plants supplied with a high-calcium (8Ca) solution were shorter than any of the high-content series so far considered, yet they were dark green in color and looked healthy. The plants supplied with a calcium-deficient (– Ca) solution were stunted in growth, the eleventh node scarcely reaching the eighth node of the plants grown in a high-calcium (8Ca) solution (fig. 3).

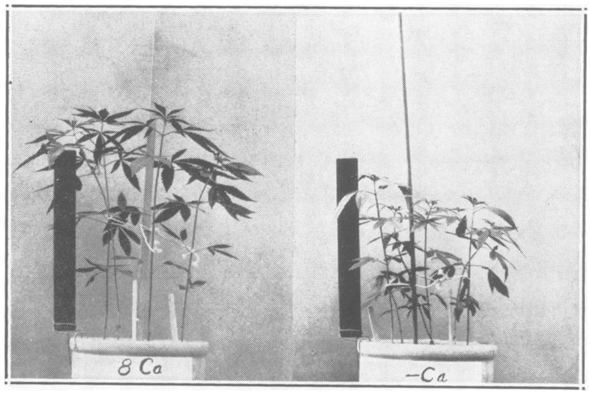

FIG. 3. Comparative growth of vegetative hemp in sand cultures variously treated with calcium. Age 29 days.

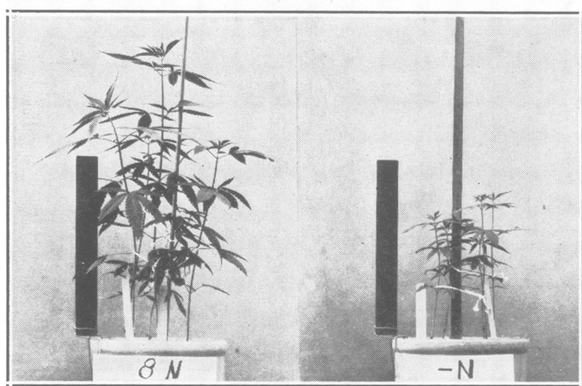

FIG. 4. Comparative growth of vegetative hemp in sand cultures variously treated with nitrogen. Age 29 days.

The plants supplied with a high-nitrogen (8N) solution and those supplied with a nitrogen-deficient (– N) solution showed by far the most striking contrasts (fig. 4). At this stage of growth, the best plant of the set supplied with a high-nitrogen (8N) solution was equal in development to the plants supplied with a high-potassium (8K) solution (fig. 1) and had produced an abundance of dark green foliage; but shortly after the plants were photographed brown spots covered the leaves, and they developed brown-rimmed shot-hole markings. In a short time the leaves rolled laterally and the whole plant showed signs of wilting. The marginal rolling up of the leaves may have been a means by which the plant checked excessive transpiration, since the weather was unusually hot. The plants supplied with a nitrogen-deficient solution were very small and of a pale yellowish-green color.

The height of hemp plants grown in high-content series of nutrient solution was in the order: 8K > 8Mg > 8Ca > 8N; and the height of those plants grown in the deficiency series of solutions was in the order: – Mg > – Ca > – K > – N.

Observations on the hemp plants were recorded weekly during the period of vegetative growth and the early reproductive stage (table III). In general appearance the plants supplied with the high-potassium (8K), Knop's, and high-calcium (8Ca) solutions were healthy looking and dark green, while the plants supplied with a high-magnesium (8Mg) solution were tall, and had long internodes, but were pale green. An excess of nitrogen produced a green leafy plant, but the nitrogen proved to be toxic.

The leaves of the plants supplied with a high-magnesium (8Mg) solution showed brown spot, shot hole with brown rim, and tip scorch; those supplied with a high-nitrogen (8N) solution, brown spot and shot hole with a brown leaf margin; while those plants supplied with potassium-deficient (– K) and the calcium-deficient (– Ca) solutions showed only brown spot, which JAMES (**8**) has designated as "coppering," and defined as a characteristic spot deficiency of potassium.

The plants supplied with a high-potassium (8K) solution produced the largest leaves. They had approximately fourteen times more leaf surface than the plants supplied with a nitrogen-deficient (– N) solution. The leaves of the latter plants were the smallest produced.

The most striking contrast of these two experiments was between the plants supplied with a high-nitrogen (8N) solution and those supplied with a nitrogen-deficient (– N) solution. The plants of the former series (8N) produced an abundance of dark green foliage, and all plants had begun to differentiate into females before they wilted and died; the latter series (– N) had small, pale green leaves, and all plants were males. Sex ratios

TABLE III

Comparative observations on hemp planted May 27, 1934, and recorded July 18, 1934. X, small amount; XX, slightly more; XXX, moderate amount; XXXX, abundant

Solution	General appearance	Leaves	Protein distribution in stem	Starch distribution in plant stem		Av. height of plants		Sex ratios	Stem texture
				Male	Female	♂	♀		
						cm.	cm.	%	
Knop	Healthy Dark green	Leaflet 12.5 × 2.2 cm.	Xylem—XX	Xylem—XX Pith—X Phloem—X	Xylem—XXX Pith—X Phloem—X	77.2	81.7	♀ 65 ♂ 35	Solid, herbaceous, fluted edge
8K	Healthy Dark green	Leaflet 13.6 × 2.5 cm. White pin-point spots on leaves	Xylem—XX	No male plant available	Xylem—XXX Phloem—X	86.5	78.6	♀ 73 ♂ 27	Hollow pith, woody, fluted edge
− K	Apical meristems pale Paler than 8K	Leaflet 9.2 × 1.6 cm. Brown spot on leaves Bleaching in vein islets	♂ Xylem—XX ♀ Xylem—XXXX	Xylem—XXX Phloem—XX Pith—X	Xylem—X Phloem—XX Pith—XXX	68.0	62.3	♀ 53 ♂ 47	Less woody, fluted edge, ♂ hollow, ♀ solid
8Mg	Plants tall with long internodes Pale green	Leaflet 10.2 × 1.4 cm. Brown spot on older leaves; white to yellow vein islets; tip scorch; shot hole with brown rim	♀ Xylem—XXX ♀ Cortex—XX ♂ Xylem—XX	Xylem—XXX Phloem—XX	Phloem—XX Xylem—XXX	108.5	95.4	♀ 40 ♂ 60	Fibrous, hollow pith, woody, fluted edge
− Mg	Stems grow smaller at top Chlorosis evident	Leaflet 11.5 × 1.7 cm. Yellow vein islets; white pin-point spots on leaves	♂ Xylem—XX ♀ Xylem—X	Xylem—XXXX Phloem—XX Pith—X	Xylem—XXXX Phloem—XXX Pith—X	79.6	74.0	♀ 53 ♂ 47	Hollow pith, ♀ herbaceous, fluted edge, ♂ woody
8Ca	Healthy Dark green	Leaflet 13 × 1.8 cm. Less abundant foliage Bleaching in vein islets	♂ Xylem—XX ♀ Xylem—X	Xylem—XXX Phloem—XX	Xylem—X Pith—X	101.9	86.3	♀ 33 ♂ 67	Fibrous, woody, hollow pith, fluted edge

TABLE III—(*Continued*)

SOLUTION	GENERAL APPEARANCE	LEAVES	PROTEIN DISTRIBUTION IN STEM	STARCH DISTRIBUTION IN PLANT STEM		AV. HEIGHT OF PLANT		SEX RATIOS	STEM TEXTURE
				MALE	FEMALE	♂	♀		
						cm.	*cm.*	%	
– Ca	Plants shorter than Knop's Pale green	Leaflet 10.1 × 1.7 cm. Brown spot and white pin-point spots on leaves	♀ Xylem—XXX ♂ Xylem—XX	Phloem—X	Phloem—X	73.1	76.1	♀ 57 ♂ 43	Fibrous, woody, hollow pith, fluted edge
8N	Abundant foliage	Leaflet 11.5 × 2 cm. Leaves rolled laterally; shot hole with brown rim; brown spot general	♀ Xylem—XXX Cortex—XX		Xylem—X Phloem—X		78.7	♀ 100	Herbaceous hollow pith, fluted edge
– N	Plants short and abnormal looking Pale to yellowish-green; red stems and petioles	Leaflet 6.3 × .9 cm. White pin-point spots general	♂ Xylem—XX	Xylem—XXX Phloem—X		98.3		♂ 100	Woody, hollow pith, fluted edge

(table III) in the other cultures ranged from 100 per cent. male plants in those that were supplied with a nitrogen-deficient (–N) solution to 100 per cent. female plants in those that were supplied with a high-nitrogen (8N) solution.

A group of plants grown in distilled water had the same characteristics as those supplied with a nitrogen-deficient solution: *viz.*, pale green, stunted growth, red stems, and a preponderance of males. It seems that in the absence of nitrogen the other essential nutrients are not utilized. Furthermore, the fact that the flowers of hemp (*Cannabis*) are sometimes perfect suggests that both sex potentialities are present, but only one is normally expressed. The sex of the plant would, then, seem to depend, in large measure, upon the presence or absence of certain nutritional factors (**10**). In the groups under consideration, the plants supplied with high-content and nitrogen-deficient solutions, the presence of nitrogen apparently was the factor which determined the female sex of the plants supplied with a high-nitrogen (8N) solution; and the absence of nitrogen may have been the factor which determined the male sex of the plants supplied with the nitrogen-deficient (–N) solution.

Experiment III

Experiment III was performed to determine the feeding capacity of the hemp plant: that is, to learn how long an essential element might be withheld from a plant without permanent injury; to what extent it would recover; and how rapidly such recovery would take place after a more or less prolonged period of starvation.

For this experiment four set of plants were used. The first set was designated as $-K_1$, $-Mg_1$, $-Ca_1$, and $-N_1$ and each pot was first supplied with two liters of a solution lacking the element indicated. The plants were grown in this solution 27 days. Following this each pot was supplied with a solution containing a high content of the same element. For example, in the case of the –K deficiency series, 2 liters of the –K solution were followed by 6 liters of 8K solution.

The plants of the second set were designated as $-K_2$, $-Mg_2$, $-Ca_2$, and $-N_2$, and each pot of the set was first supplied with 4 liters of a solution lacking the element indicated. The plants were grown in this culture for 44 days. Following this they were supplied with 4 liters of a solution containing a high content of the same element.

The plants of the third set were designated as $-K_3$, $-Mg_3$, $-Ca_3$, and $-N_3$, and each pot of the set was supplied with 6 liters of a solution lacking the element indicated. The plants were grown in this culture for 57 days. Following this the plants were then supplied with two liters of a solution containing a high content of the same element.

The plants of the fourth set were designated as $-K_4$, $-Mg_4$, $-Ca_4$, and $-N_4$, and each pot of the set was supplied with 8 liters of the solution lacking the element indicated.

On July 18, at the age of 27 days, as previously stated, the deficiency culture solutions were replaced by high content solutions of the essential elements previously lacking.

Two weeks later (fig. 5) there was a marked improvement in the appearance of the plants supplied with the 8 K solution. There was an increase

FIG. 5. Recovery of 6-weeks-old hemp plants after a 27-day potassium starvation period. $-K_4$ plants without potassium for 6 weeks; $-K_1$ plants without potassium until 27 days old; 8K plants supplied with potassium for 6 weeks.

in height, in size of the leaves, and in vigor of growth. The hemp was growing rapidly at this time owing to the length of the photoperiod (Mazda lights, 1000 watts per square yard 1 foot above the tops of plants were used daily from 6:00 P.M. to 11:00 P.M.). In two weeks the average height of the plants of the $-K_1$ group increased from 11.4 to 35.2 cm., while the plants of the $-K_4$ group, grown in a solution lacking potassium, increased from 13.5 to 30.2 cm. This shows a growth difference of 7.1 cm. or a daily increase of 0.5 cm. more for the plants of the $-K_1$ group than for those grown in the potassium-deficient ($-K$) solution.

In the magnesium groups the difference in height was not so significant, all of the plants having attained a growth almost equivalent to that of the control. Chlorosis, however, was evident in the plants grown in the magnesium-free solution. Recovery here was slow but at the end of 2 weeks the new growth at the apical meristem was darker green, and 4 days later the lower leaves showed the same recovery.

Recovery in the calcium groups was apparent in the leaves, which became darker green, and in the disappearance of white stripings which had been quite general.

A very striking recovery was made by the plants of the nitrogen-deficient ($-N_1$) group (fig. 6). After 27 days of nitrogen starvation, these plants,

FIG. 6. Recovery of 6-weeks-old hemp plants after a 27-day nitrogen starvation period. $-N_4$ plants without nitrogen for 6 weeks; $-N_1$ plants without nitrogen until 27 days old; 8 N plants, with nitrogen for 6 weeks.

on receiving a high-nitrogen nutrient solution, were able to make rapid growth, increasing daily 1.1 cm. more in height than plants growing in a nitrogen-deficient solution. Recovery was also apparent in the leaves which, in the new growth, were much larger and dark green. The lower leaves recovered slightly but the new growth remained quite distinct from the old. The stems increased in diameter throughout their entire length and the red color was either masked by the chlorophyll or disappeared. This rapid recovery may have been due to the fact that the nitrogen-free solution used in this experiment contained potassium chloride and monopotassium phosphate (table II). Since, in the absence of nitrogen, potassium is not absorbed, it seems reasonable that as soon as the high-nitrogen (8N) nutrient was applied an abundance of potassium became available to the plant and it was utilized quickly.

After 44 days of potassium shortage, the nutrient solution of the $-K_2$ group was changed to a high potassium (8K) solution. In the 2 weeks which followed, the daily increase in growth was 1.27 cm. more than that of the plants grown in the potassium-free solution (fig. 7). At the same time a marked improvement was apparent in the appearance of the foliage and in the color of the plants. Likewise the plants of the $-K_3$ group were supplied with a high-potassium nutrient after a starvation period of 58 days, after which they increased in height 0.6 cm. more daily than the plants grown in the potassium-free solution.

The daily increases in the height of the plants owing to the addition of K to the nutrient after various periods of shortage were as follows:

After 27 days of shortage	0.50 cm.
" 44 " " "	1.27 "
" 58 " " "	0.60 "

It is evident from these data that, for hemp, approximately 44 days of initial shortage gives optimum increase in vegetative growth. However, the final data show that while some of the plants in each initially deficient group were able to recover from the deficiency and attain a height equal to that of plants continuously supplied with potassium, yet the average height of the plants was considerably less.

Final observations on these plants showed that the plants grown in a high-potassium (8K) solution (fig. 7) were tall and had large leaves, but

FIG. 7. Recovery of 64-day-old hemp plants from K starvation. 8K plants supplied with high-potassium nutrient 64 days; $-K_1$ plants supplied with K-deficient nutrient 27 days and high-potassium 37 days; $-K_2$ plants supplied with potassium-free solution 44 days and high potassium 20 days; $-K_3$ plants supplied with potassium-free nutrient 58 days and high potassium 6 days; $-K_4$ plants without potassium.

meristematic activity had ceased. The plants of the $-K_1$ and the $-K_2$ groups were equally tall, in some cases even taller, and were still growing. The plants of the $-K_3$ group showed some improvement in growth but the leaves were still small and the color was notably paler green than those of the plants already described. The plants of the $-K_4$ group were stunted and the leaves were generally covered with brown spot.

Apparently potassium is necesary in the early life of the plant; and hence it seems reasonable to the writer that the greater the requirement for potassium, at least to a limited extent, the more rapidly it will be absorbed and utilized (**6**). The extreme heat and the lateness of the season prevented the continuation of the experiment to a point where potassium starvation would result in permanent injury and the plant would be unable to utilize any potassium.

Recovery of the plants in the magnesium groups was somewhat different from the others. In the $-Mg_1$ group of plants, from which magnesium had first been withheld for 27 days, no increase in growth attributable to magnesium was observed until 2 weeks after the high-magnesium (8Mg) nutrient solution had been supplied. The plants of the $-Mg_2$ group recovered more rapidly than those of the $-Mg_1$ group, but the plants of the $-Mg_3$ group were unable to recover from initial shortage of 58 days. The results of recovery expressed in daily increase in height of the plants owing to the addition of Mg to the nutrient after various periods of shortage are as follows:

After 27 days of shortage	1.93 cm.	(4 wk. av.)
" 44 " " "	1.08 "	(2 wk. av.)
" 58 " " "	....	

Since all of the plants of these groups attained considerable height, even those grown in magnesium-free solutions, it appears that magnesium has more to do with the actual life of the plant than with the vigor of its growth. Recovery in this case involves the production of chlorophyll. In general, the final data showed that the tips of the plants grown in the high-magnesium (8Mg) solution were dead and that there was some growth at the nodes. The leaves of the plants of the $-Mg_1$ group were dark green; the lower leaves of the plants of the $-Mg_2$ group were yellowish-white and dropping off, and the upper parts of the plants were green; while the plants of the $-Mg_3$ and $-Mg_4$ groups died.

Recovery in the calcium group (fig. 8) was more striking than in that of any group previously considered. In contrast with the potassium- and magnesium-deficient series, these plants were not only able to recover from the initial shortage (**3**), but they were able to make a better and a more rapid recovery the longer the calcium was withheld. It was observed in the final data (fig. 8) that both the plants grown in the high calcium (8Ca) and the calcium-deficient (– Ca) solutions were stunted, while the plants of the $-Ca_1$, $-Ca_2$ and $-Ca_3$ groups, from which calcium had been withheld for various periods, were taller and more vigorous.

The daily increases in growth of plants imputable to the addition of calcium after various periods of shortage were as follows:

FIG. 8. Recovery of 64-day-old hemp plants from calcium starvation. 8Ca plants supplied with high calcium nutrient 64 days; $-Ca_1$ plants supplied with calcium-free nutrient 27 days and high calcium solution 37 days; $-Ca_2$ plants supplied with calcium-free nutrient 44 days and high-calcium solution 20 days; $-Ca_3$ plants supplied with calcium-free nutrient 58 days and high calcium solution 6 days; $-Ca_4$ plants without calcium.

After 27 days of shortage	0.23 cm.
" 44 " " "	0.43 "
" 58 " " "	2.60 "

Since the plants grown in a calcium-free nutrient had practically ceased meristematic activity when the last data were taken, the results in terms of daily increase in height are as follows:

After 27 days of shortage	1.5 cm.
" 44 " " "	2.2 "
" 58 " " "	2.6 "

These data indicate that the limit for recovery from calcium starvation for this particular group of hemp plants is approximately 60 days, after which there is a cessation of meristematic activity followed by death of the apical meristems.

In the plants of the nitrogen group, those which had been grown in a high-nitrogen (8N) solution died early (7). The plants of the $-N_1$ group made a good recovery, but after receiving a high-nitrogen solution for three weeks they began to show signs of wilting. The plants of the $-N_2$ group had large, dark green leaves on the upper part of the plant and small, pale green leaves on the lower part. Apparently, the application of nitrogen after 44 days of shortage benefited only the new growth. The plants of the $-N_3$ group showed slight improvement in size and color of the upper leaves (1).

The recovery of plants in the nitrogen groups, upon the addition of N after various periods of shortage, is given in centimeters of daily increase in height as follows:

After 27 days of shortage	1.080 cm.
" 44 " " "	1.007 "
" 58 " " "	0.700 "

The above data support the conclusion that the longer nitrogen is withheld, the slower is the recovery that the plant is able to make (5).

As stated before, the plants grown in a high-nitrogen nutrient solution tended to be 100 per cent. female while those deprived of nitrogen were 100 per cent. male. After an initial shortage of 27 days, plants of the $-N_1$ group were able to utilize the available nitrogen and the plants were all females. On the other hand, plants of the $-N_2$ group were apparently unable to use adequately the nitrogen which they received after 44 days of starvation, and male plants resulted. The plants of the $-N_3$ group had already begun to differentiate into males when the high-nitrogen solution was given to them after a shortage of 58 days. At the end of 64 days, plants of the $-N_4$ group were still hardy, growing slowly, and beginning to differentiate into male plants.

An examination of cross-sections of stems and leaves of hemp plants variously treated revealed certain significant differences. The stem tips of both

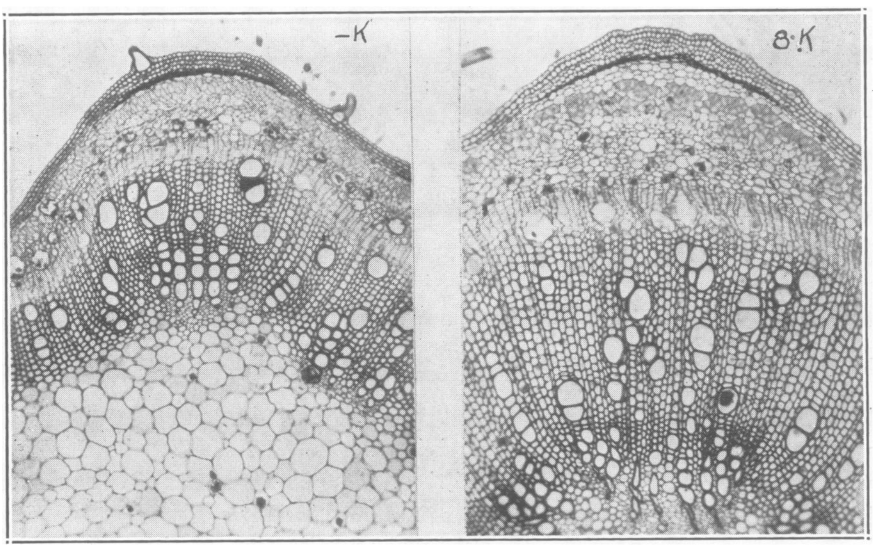

Fig. 9. Cross-sections of stem tips of 54-day-old hemp plants. Right, cross-section of stem of plant grown in high-potassium (8K) nutrient; left, cross-section of stem of plant grown in potassium-deficient (– K) nutrient.

the plants grown in the high-potassium (8K) and the potassium-deficient (– K) solutions (fig. 9) were fluted, and had mechanical tissue largely in the areas that bulged. Well defined cortex, phloem, cambium, and xylem were in evidence in both, although the stem of the plants grown in the high-potassium (8K) solution was much larger, measuring 1.9 mm. more in diameter at node 6 than that of the plants grown in the potassium-deficient solution (– K). Calcium oxalate crystals were numerous in the stem of the plants grown in the high-potassium (8K) solution but there were few of them in the stem of the plants grown in the potassium-deficient solution. Large inclusions, staining deeply red with haematoxylin, were found in the sieve tubes of both stems but they appeared more granular in the stem tip of the plants grown in the potassium-free (– K) solution. Inclusions of various sorts occurred in the cortex of both stems.

The stem tip of the plants grown in the high-magnesium (8Mg) solution had solid pith in contrast with the hollow pith of those grown in the magnesium-deficient (– Mg) solution, in which calcium oxalate crystals were more numerous. Large brownish inclusions, the resin of hemp, appeared in the phloem of the stem tip of plants grown in the high-magnesium solution and in the xylem of the stem tip of those grown in the magnesium-deficient solution.

The stem tip of the plants grown in the high-calcium (8Ca) solution showed numerous calcium oxalate crystals in the solid pith, which also contained a few calcium carbonate crystals. Mechanical tissue appeared largely in the areas of the stem that bulged. The bast fibers were better developed in the stem tip of plants grown in the high-calcium (8Ca) solution than in those grown in the calcium-deficient (– Ca) solution.

The stem tips of the plants grown both in the high-nitrogen (8N) and in the nitrogen-deficient (– N) solutions had a hollow pith; the former having some calcium oxalate crystals near the vascular tissue, and the latter considerable resin. More mechanical tissue had developed in the absence of nitrogen.

Examination of the vegetative stem tips of male and female plants failed to reveal any consistent outstanding variations, but the vegetative leaf of the female was slightly thicker than that of the male. The flowering stem tip of the male plant was 2.5 mm. in diameter and it had extensive xylem and little phloem. This contrasted with the female stem tip which was 5 mm. in diameter and had phloem as well as xylem well developed. Both had hollow pith with numerous calcium oxalate inclusions.

Summary

1. This investigation was concerned with the physiological effects of various nutrients on the hemp plant and the results of withholding single essential nutrients for varying intervals of time.

2. High-potassium (8K) nutrient (Knop's solution having 8 times the usual amount of potassium) produced the tallest and most vigorous plants which also had the largest and thickest leaves. Potassium-deficient nutrient (complete Knop's solution except for potassium) caused stunting of the growth of the plant and copper mottling on the leaves.

3. After variously prolonged periods of potassium starvation, hemp plants recovered rapidly but failed to attain a growth equal to that of plants which had a continuous supply of potassium.

4. Concentration of magnesium in the nutrient did not affect the growth of the plant, but magnesium deficiency resulted in chlorosis.

5. Recovery from magnesium starvation was slower the longer the magnesium was withheld.

6. Excess of calcium in the nutrient solution retarded growth. Calcium deficiency caused paleness in color, necrotic spots on the leaves, and early cessation of meristematic activity.

7. Recovery from calcium shortage in the hemp plant was more rapid after longer periods of starvation. Recovered plants attained greater height than those grown continuously in high-content solution.

8. High-nitrogen nutrient produced a dark green, leafy plant which did not survive. Plants grown in nitrogen-free solution were stunted and pale green.

9. After a short period of nitrogen starvation, hemp plants made a rapid recovery but died soon after. From longer periods of nitrogen shortage, recovery was slower.

10. An abundance of nitrogen at the time of fruit bud differentiation obviously leads to the production of female flowers, while the absence of nitrogen at that time tends to the production of male flowers.

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Mount Mercy Junior College
Cedar Rapids, Iowa

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