GROWTH, NUTRIENT UPTAKE AND ACCUMULATION, TOTAL SUGAR CONTENTS AND DISTRIBUTION OF NITROGEN FRACTIONS IN PEA PLANTS CULTIVATED AT DIFFERENT LEVELS OF K AND CA IN THE NUTRITIVE MEDIA

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SUMMARY

1. The effect of K and Ca levels in the nutritive media of pea plants on the interrelationships among nutrient ions in the tissue and on some physiological processes such as growth, uptake of nutrients, sugar formation and distribution of nitrogen fractions in roots and tops were studied.

2. K or Ca uptake and accumulation by pea plants, in presence of an increasing concentration of one of them and keeping the concentration of the other constant in the nutritive media, were found dependent on their concentrations in the media.

3. Increasing K level in the nutritive medium reduced the absorption of Ca to the extent that Ca deficiency symptoms appeared. The same happened with K when the level of Ca was increased in the nutritive medium. K interferred with Ca absorption greater than Ca did with K absorption. Also Ca or K antagonised Mg and Na uptake.

4. Reciprocal relationships were found between the accumulation of K and Na, K and Ca, and Ca and Mg; but positive relation between that of Mg and P, and P and N occurred in pea plants.

5. In presence of excess K, Ca became limiting to growth, sugar formation and nitrogen metabolism while with increments of Ca, K became limiting to them. Under K or Ca deficiency, growth was inhibited and was related to uptake and translocation of nutrients. The majority of the absorbed ions were translocated to plant tops. Nitrate was assimilated in roots as well as in shoots and was utilised mainly in protein synthesis. Simultaneous with nitrate assimilation, asparagine and amino acid levels were increased.

6. Under K deficiency, the total sugar content was reduced and this was accompanied by simultaneous reduction in the uptake and accumulation of K, P and N. However, under Ca-deficiency, total sugar content together with uptake and accumulation of K were increased while those of P and N were decreased. Although with deficiency of K or Ca, asparagine, amino acids and mainly proteins were reduced due to reduction in nitrate assimilation, yet the accumulation of amides plus amino acids was greater than that of proteins under K - deficiency while the reverse was true in control and Ca - deficient plants.

7. Interrelationships among nutrient ions as they occurred in roots of plants cultivated in different culture media were similar to those occurring in corresponding tops. Although the total - N contents of the tops were much higher than those of the roots, yet asparagine and protein contents when calculated as percent of the total - N were found equal in roots and tops of plants receiving excess K or Ca in presence of a constant supply of the other ion indicating similar courses of synthesis in roots and tops.

INTRODUCTION

The growth and development of plants depend to a great extent on the nature of metabolism. Through changes of the prevailing conditions around the plant, especially the nutritive media, variations in metabolism can be obtained. Thus the role of the nutritive media on the vital activity of plants can be studied.

The effects of different ratios between K and Ca on growth and metabolism of plants is one of the most important problems of the mineral nutrition of plants. Arnon and Johnson (1942), Olsen (1942), Sideris and Young (1950), Edgerton (1948), Hanson and Kahn (1957) and Cooil and Slattery (1948) showed that growth and metabolism of different plants varied differently to changing Ca/K ratio in the nutritive media.

A complicating factor of unknown significance in the K accumulation of plants is the promoting effect of Ca and other di - and tri - valent ions on the uptake of K and associated anions (Viets, 1944). Studies of Viets effect have been made with barley (Overstreet et al., 1952), Mung beans (Tanada, 1955) and more recently with corn and barley roots (Hodges and Elzam, 1967). Hanson and Kahn (1957), however, found a typical Viets effect with corn but not with soybean roots where minute amounts of Ca depressed K uptake and accumulation by the latters. Cooil (1948) and Shear et al. (1946) demonstrated that the total amount of cations absorbed by a plant from different media tends to approach a constant but that the relative accumulation of K and Ca is dependent upon the ratios of these

ions in the nutrient media. High concentration of K will tend to depress the accumulation of Ca, and vice-versa. Similarly Overstreet et al. (1952) demonstrated that a given concentration of Ca exerts both a depressing and stimulatory effect on the absorption of K by barley roots and that the effects are related to the concentration of K in the external media. Moreover Hodges and Elzam (1967) found Ca inhibition to K uptake by corn roots during the initial phases of transport. As the absorption periods were lengthened, the effect of Ca gradually changes from an inhibition to a typical promotion. Identical experiments with barley and oats led them to illustrate the hazards involved in applying results obtained with one (or even several) plant species to all species.

As regards, accumulation and distribution of nutrients in plants under variable conditions, the reader is referred to the work of Williams (1948), Wadleigh and Bower (1950), Smith and Wallace (1956) and more recently by Nosseir and Spiridinov (1965b). However the relations between total sugar contents and uptake of nutrients have been studied by Humphries (1951, 1952 and 1956) using barley and pea plants.

Because of the complexities involved in the study of ionic interrelationships, much of the recent work has been done with excised roots and radioactive tracers in an effort to elucidate the individual aspects of the overall problem. However, interactions between inorganic solutes are probably expressed during the total processes of absorption throughout intact plants since recent evidence by Smith and Spstein (1964) suggests that active absorption by leaf tissue is similar to the process that occurs in roots.

Nosseir and Spiridinov (1965b) studied the effect of K/Ca ratios in the nutritive media on the uptake and translocation of isotopic P and S by phaseolus plants. In that study, the total molar concentrations of K + Ca in the different media were either above or below that present in normal Hoagland solution and constant levels of K or Ca were not tried. In the present study, constant molarities of K or Ca as those present in the normal Hoagland solution are used. In the same time progressive increases in concentration of one ion in presence of a constant supply of the other ion and keeping the other nutrients constant are tried. Under these conditions the total molar concentrations of K + Ca are always higher than that of the normal Hoagland solution. The purpose of the present study was to determine the effects of K and Ca levels in the nutritive media of pea plants under the conditions mentioned above on some of the interrelationships among nutrient ions as they occur in tissues. Also this study was extended to include responses of some physiological processes such as growth, uptake of nutrients, sugar formation and distribution of nitrogen fractions not only in roots but also in shoots. Consequently, the physiological activity of the

roots could be compared with those of shoots. Pea plants were selected for such a study because of my previous experience with their mode of cultivation and with the analytical techniques suitable for them (Nosseir and Spiridinov, 1965a).

MATERIAL, METHODS AND EXPERIMENTS

Pisum sativum, variety « Little Marvel » seeds were germinated in the same way as shown in a previous work by Nosseir (1968). The seeds were firstly soaked in water for 4 hours , then distributed singly on moist filter paper in loosely covered petri-dishes, and finally incubated at 25 C. After they produced radicles of 2.5 - 3 cm. long each, the young seedlings were supported in the culture vessels with their radicles immersed in water as shown in plate (1). The seedlings were transferred to nutrient solutions after 20 days. Screened deep glass vessels, 1 L capacity each were used to contain water or nutrient solutions. Four plants were supported within holes in a paraffined wooden cover and put in each vessel so that the plants could be transferred to other cultures and the roots could be examined periodically. Plants were grown on a Hoagland solution containing 5 mM KNO_3; 5 mM Ca $(NO_3)_2$; 2 mM $MgSO_4.7H_2O$ and 1 mM KH_2PO_4 together with the microelements of Shive and Robbins (Nosseir, 1968). Variable levels of Ca and K in the culture media and hence in plants were obtained by additions of KCl or $CaCl_2$ at different concentrations according to the following scheme :

Normal Hoagland solution, designated as K_4Ca_4.

Normal Hoagland solution, + 2 mM $CaCl_2$, designated as K_4Ca_7

Normal Hoagland solution, + 4 mM $CaCl_2$, disignated as K_4Ca_9

Normal Hoagland solution, + 2 mM KCl , designated as K_7Ca_4

Normal Hoagland solution, + 4 mM KCl , designated as $K_{10}Ca_4$

Normal Hoagland solution, -- 5 mM KNO_3 + 5 mM $NaNO_3$, designated as K_1Ca_4

Normal Hoagland solution, -- 4 mM Ca $(NO_3)_2$ + 8 mM $NaNO_3$, designated as K_4Ca_1.

Ten culture replicates were used for every treatment to make a total of 70 experimental vessels. The pH of the nutrient solutions was maintained at 5.6 - 5.8 throughout the whole experimental period by periodic additions of traces of NaOH or H_2SO_4. The medium was renewed once a week and forced aeration was provided for each culture vessel daily. The plants were cultivated in the different culture media under controlled conditions of

temperature (25 -- 27°C) and continuous light (3200 foot candle) in a specially designed cultivation chamber.

At the end of the experimental period which lasted for 5 weeks, the corresponding plant organs (roots or tops) of every treatment were collected together and mixed well. The roots were washed thoroughly with distilled water and dried gently between blotting paper. The plant organs of every treatment were then divided into two batches. One batch after being weighed in a covered plastic box, was cut into small pieces and immediately killed in boiling water. After extraction with water, protein was coagulated by acetic acid and chilling treatments and then separated by filtration through hard filter paper (Whatman No. 54). The filtrate after being completed to a known volume was used for the determination of the soluble nitrogen fractions. However, the residue was dried, powdered and used for protein - N determination. The methods used for nitrogen fraction determinations are those adopted by El-Shishiny (1955) except that for the determination of the amino acids which was carried out using the ninhydrin method (Nosseir, 1968).

The second batch of the same treatment after being weighed, was cut into small pieces and then dried at 105°C until a constant weight. After the dry weight determination was done, the dry matter was ground to a fine powder using a procelain morter, dried again in the oven and then samples were taken for the determination of total sugars and amino acids or mineral contents.

Extraction, separation and determination of sugars and amino acids were done using the methods adopted by Nosseir (1968). A known weight of the dry powder together with a convenient volume of water-alcohol mixture were transferred into a conical flask fitted with an air condenser. The flask was then immersed in a boiling water bath for 30 minutes. After cooling, the flask was agitated for 15 minutes using a shaker. The suspension is then filtered and the filtrate was evaporated till about 10 ml. The sugars are then separated from amino acids in the filtrate using the ion exchange resin column (KY -2 brought from Moscow). The flow containing sugars was received and evaporated to dryness at room temperature. The amino acids were eluted by 10% ammonia and the eluate was received and evaporated. Total sugar content was determined colorimetrically using the anthrone method while amino acid content was determined using the ninhydrin method, Nosseir (1968).

As regards mineral analysis, a known weight of the dry powder was ashed at 550°C for a convenient time until a perfect clean white ash was obtained. P ashing was carried out in presence of $Mg (NO_3)_2.6H_2O$ using another sample from the dry powdered matter (Jackson, 1960). The ash

was then dissolved in 10 ml. O. 5N HCl and then diluted to 100 ml. (Sideris & Young, 1950). Aliquots from the dissolved ash were taken and used for determinations of Ca and Mg by titration against trilon, P colorimetrically and K and Na by flame photometer, Nosseir (1968).

During the experimental period, the development and some growth characters of plants including morphology and size of roots and shoots and external symptoms of nutrient deficiency were recorded. The untreated plants were harvested after culturing in distilled water for 20 days.

At the time of changing the nutrient solutions, aliquot samples were taken from the old solutions before discarding and of the new ones before transferring the plants thereto, and measurements were made for NH_4, NO_3, PO_4, Na, K, Ca and Mg using the previously mentioned methods except nitrate which was determined colorimetrically using disulphophenolic acid (Nosseir, 1968). Also volume measurements of the nutrient solutions at the beginning and end of intervals of change (one week) were made and adjusted to the original volume for correction of the residual concentrations of the different nutrients. The cumulative absorption of these nutrients throughout the 5 weeks of the experiment were quite consistent with the uptakes determined by substracting the total contents of the untreated plants from the corresponding total contents of the treated ones at the end of experiment, and are presented in figure (2).

RESULTS AND DISCUSSION

Growth and Development of plants at various levels or K and Ca :

The results in figure (1) show that K or Ca, when supplied at equimolar concentrations to pea plants at levels above or below those present in the normal Hoagland solution, expressed depressive effects on growth and development of plants. Such depression was further enhanced by further additions of equimolar concentrations of K or Ca. These results indicate that maximum growth is obtained with optimum concentration of K or Ca but not with maximum or minimum concentrations of these elements, the uptakes of which were dependent on their concentrations in the nutritive media. Sideris and Young (1950) reached to the same conclusion with pine apple plants cultivated at different levels of K and Ca in the nutritive media.

However, plants seem to respond differently to nutrient solutions having different K and Ca levels. Arnon and Johnson (1942) found that growth of lettuce plants was progressively improved as the Ca concentration added to the nutrient solution was increased from 20 to 280 mgm./L whereas
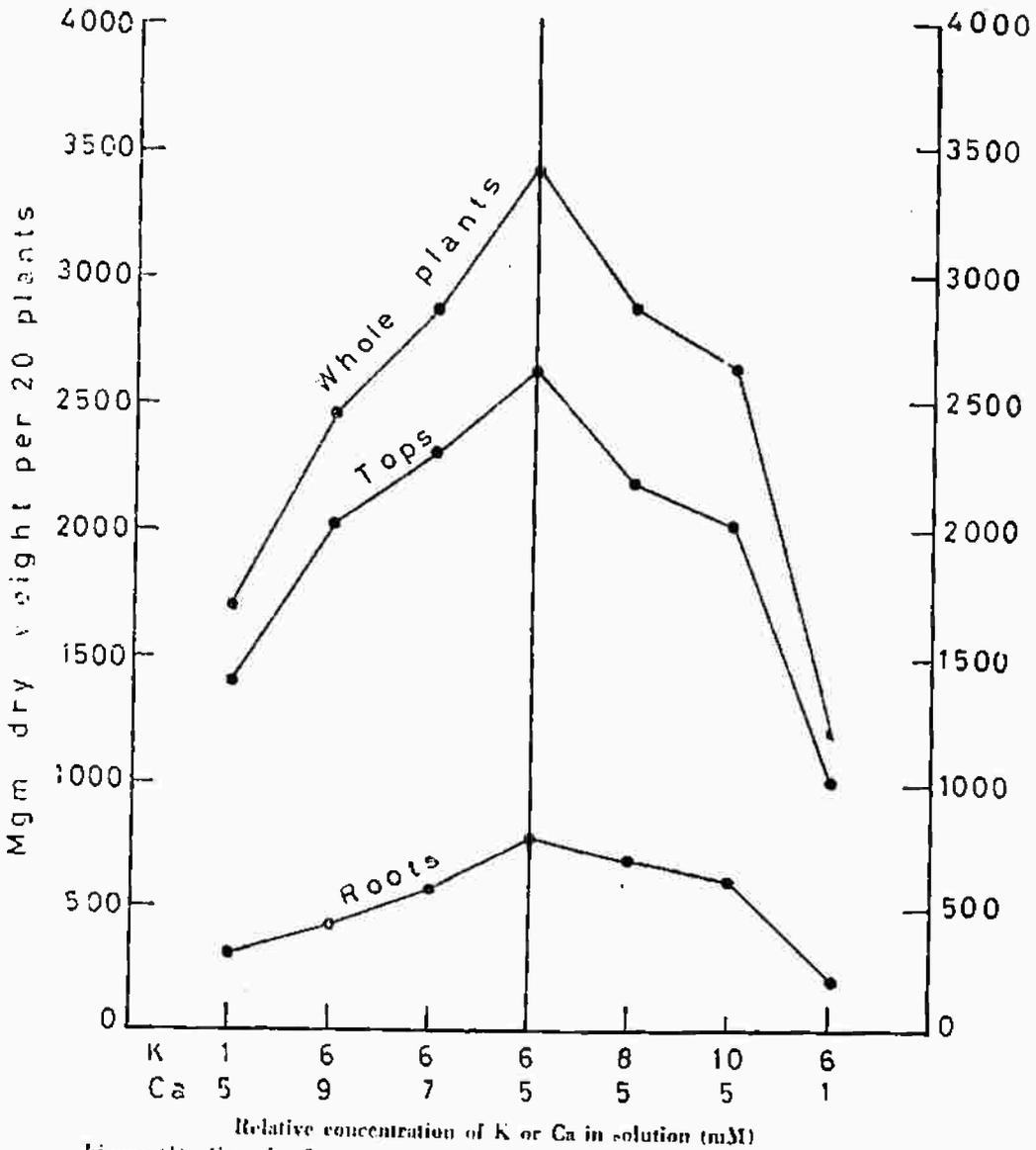
Figure (1)   Growth of roots, tops and whole pea plants grown in various levels of K and Ca in the nutritive media for 5 weeks

growth of tomato plants showed a marked increase upon increasing the Ca content of the media from 20 to 80 mgm./L and a further increase to 280 mgm./L was not associated with further increase in growth. With pea plants under the present study, increasing the Ca content of the nutritive media from 40 to 200 mgm./L. caused a marked increase in growth, and development but at concentrations above 200 mgm./L. growth and development were progressively decreased.

On the other hand, Edgerton (1948) studied the response of 2 varieties of young apple trees to nutrient solutions having K concentrations of 25, 50, 100, 200 and 400 mgm./L. He found that growth increased with increasing concentration of K up to 200 mgm./L with McIntosh variety of the trees and only up to 100 mgm./L with Delicious variety. His results also indicated that K is freely absorbed by apple trees beyond the point at which maximum growth occurs. With pea plants under study, increasing the K content of the nutritive media from 39 to 234 mgm./L caused a marked increase in growth of plants, but with concentrations above 234 mgm./L, growth was progressively decreased where K was freely absorbed irrespective of growth.

Also figure (1) shows that dry weights of tops of pea plants cultivated in the various nutrient solutions were very much higher than the weights of corresponding roots. This fits good with the results depicted in tables (1), (2) and (4) where higher fractions of mineral elements, sugar contents and nitrogen freactions mainly proteins were recorded in tops than in roots of the same plants. According to Withrow (1951), the mineral elements enter into synthesis with carbohydrate derived material and form the metabolic and structural components of plants. Also elements may accumulate in the vacuole and so provide the necessary concentration of solutes for producing the osmotic pressure exerted by the cell.

It was interesting to find that pea plants cultivated in nutrient solutions having increasing Ca concentrations exhibit symptoms of K deficiency both visually and metabolically (as will be shown later) while plants grown in media having increments of K show symptoms of Ca deficiency although the levels of Mg, N and P were very much reduced in plants receiving excess Ca or K. These results are supported by plants grown from the beginning of the experiment in nutritive media deficient in K or Ca which show the same corresponding symptoms. Under such conditions antagonestic effects of K and Ca on the uptake of each other did occur reducing the concentration of the other element to the deficiency level in the tissues with the resultant external and metabolic symptoms.

K or Ca deficiency symptoms began to appear externally on plant organs during the last week of the experiment. The external symptoms of

Table 1.—Distribution of the absorbed nutrients within roots and tops of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media (mgm. nutrient element/20 plants).

Treatment	Accumulated in roots						Translocated to tops					
	Na	K	Ca	Mg	P	N	Na	K	Ca	Mg	P	N
K1Ca5	5.8	0.2	6.4	1.8	7.7	3.9	39.5	31.5	25.6	2.1	10.8	36.9
K6Ca9	1.0	10.1	17.0	1.4	20.0	11.5	15.6	63.5	73.6	12.1	38.5	72.7
K6Ca7	5.2	22.9	15.0	1.2	35.5	20.3	22.4	82.0	69.6	22.1	96.7	116.9
K6Ca5	6.8	48.2	15.6	71.0	63.1	37.6	33.5	106.7	65.5	31.8	175.2	177.0
K8Ca5	4.8	56.9	8.7	6.2	51.9	28.9	17.8	113.9	42.9	19.1	148.3	120.1
K10Ca5	2.6	64.8	5.2	5.7	37.9	19.6	12.4	178.7	29.7	12.5	130.1	103.5
K6Ca1	9.6	6.6	2.4	1.2	1.7	1.9	56.1	32.3	7.9	13.6	4.0	23.4

Table 2.—Total sugar contents in roots and tops of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media. The data are presented as mgms/gm. dry weight or 100 gm. fresh weight of tissues. The data are also given as percent of that of the control in K6Ca5 solution.

Treatment	Roots**		Tops**		Roots*		Tops*	
	mgm.	percent	mgm.	percent	mgm.	percent	mgm.	percent
Water for 20 days	10.1	9	15.1	13	32.3	5	120.8	11
K1Ca5	20.1	18	18.4	17	80.4	13	165.6	16
K6Ca9	69.6	54	62.8	55	250.6	40	565.2	53
K6Ca7	84.3	75	85.8	77	421.5	68	789.9	74
K6Ca5	112.2	100	113.0	100	618.2	100	1062.2	100
K8Ca5	124.8	111	130.2	115	648.9	105	1171.8	110
K10Ca5	140.6	125	136.6	120	703.0	114.	1256.7	118
K6Ca1	180.1	160	180.4	160	720.4	117	1623.6	153

*Mgm./100 gm. fresh weight   **Mgm./gm. dry weight

K deficiency included mottled chlorosis followed by the development of necrotic yellowish areas at the tip and margin of the leaves. Because of the high mobility of K, these symptoms first appeared on the more mature leaves and then extends upwards by elapse of time. Also there was a tendency of some leaves to curl downwards as in French bean and potato plants (Hewitt, 1963). On the other hand, Ca deficiency caused malformation of the younger leaves and hooking of the leaf tip appearing first in the younger leaves and the growing apices as a consequence of the less mobility of Ca. Also the roots of Ca - deficient plants were short and brown as in Ca - deficient tomato plants (Kabra, 1956). Moreover pea plants deficient in Ca or K as the result of disturbing the balance between them were shorter and more stunted than the plants grown in the normal Hoagland solution, plate (1).
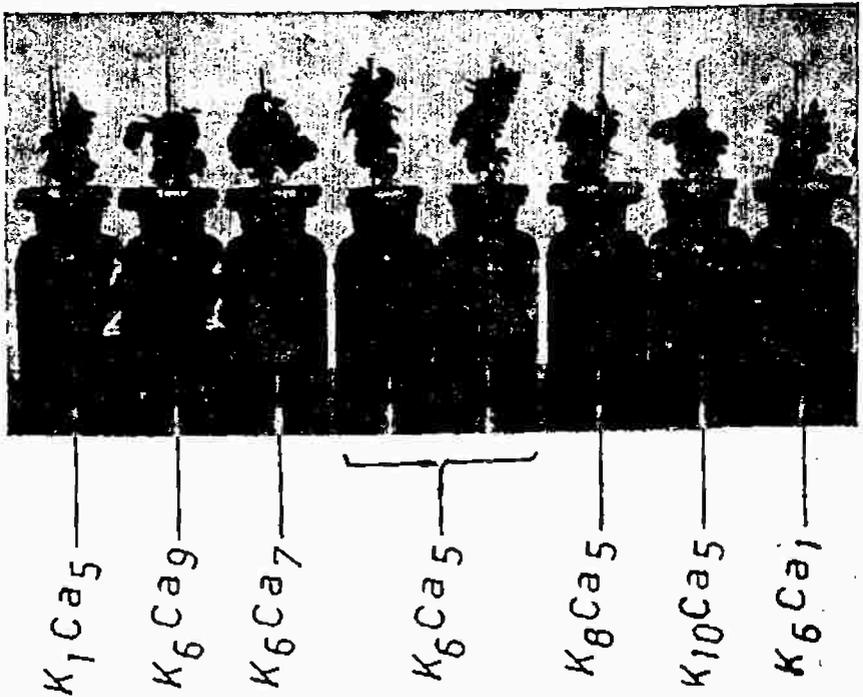
K_1Ca_5 K_6Ca_9 K_6Ca_7 K_6Ca_5 K_8Ca_5 $K_{10}Ca_5$ K_6Ca_1

Plate (1) Growth and development of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media

Uptake, distribution and translocation of elements at various levels of
K and Ca :

In figure (2), the uptakes of nutrients by 20 plants during the experimental period were shown. Control plants cultivated in normal Hoagland solution absorbed nutrients at different rates. Additions of equimolar concentrations of K or Ca to the nutritive media and keeping the other nutrients constant resulted in progressive decreases in uptakes of Mg, P and N. K uptake was also decreased in the increasing Ca - series while Ca uptake increases by its increase in the nutritive media. Also Ca uptake was decreased in the increasing K - series while K uptake increases by increase of its concentration in the media. These results clearly show not only the antagonistic effects of K and Ca on the uptake of each other by pea plants but also show their antagonistic effects on Mg and Na uptakes. The accompanying reduction in absorption of P and N in presence of excess Ca or K in the media is not due to the antagonistic effects of the latters but is no more than an effect of growth dilution as found by Dumbroff and Michel (1967) for pine plants. Ca absorbed progressively by increase of its concentration in the nutrient media might have also interferred with the physiological functioning of the absorbed K, thus reducing the physiological activity of pea tissues. This suggestion is supported by Spiridinov (1963) who found that Ca reduces the physiological activity of phaseolus and corn tissues. Moreover Ca might have reduced energy dependent K transport by decreasing membrane permeability which is indeed one of the classical suggested effects of divalent cations, Collander (1959).

In literature, there is a good deal of work concerning the antagonistic effects of K and Ca on the uptake of each other by various plants and that such phenomenon depends on the concentration of both ions in the culture media. Thus Viets (1944) working with barley, Tanada (1955) with mung beans, Jacoby (1961) with citrus plants, Hodges and Elzam (1967) with corn and Pierre and Bower (1943) with corn and other crops showed the antagonistic effect of Ca on K uptake by excised roots as well as intact plants. On the other hand, Smith and Wallace (1956) working with beans, oranges and barley plants and Sideris and Young (1950) with pine apple plants showed antagonistic effects of K on Ca uptake by plants. The latter authors also found that high Ca concentration in the media interferred less with the absorption of K than high K concentrations with Ca. The results in hand agree with those of Sideris and Young since equimolar concentrations of K and Ca depressed the uptake of each other by pea plants and the reduction with Ca on K uptake was less pronounced than with K on Ca uptake.

The depressive effect of Ca or K on Mg uptake by plants are also reported by Smith (1962), Ingestad (1957), Smith et al. (1954), Hodges and Hanson (1965) and Jacoby (1961).
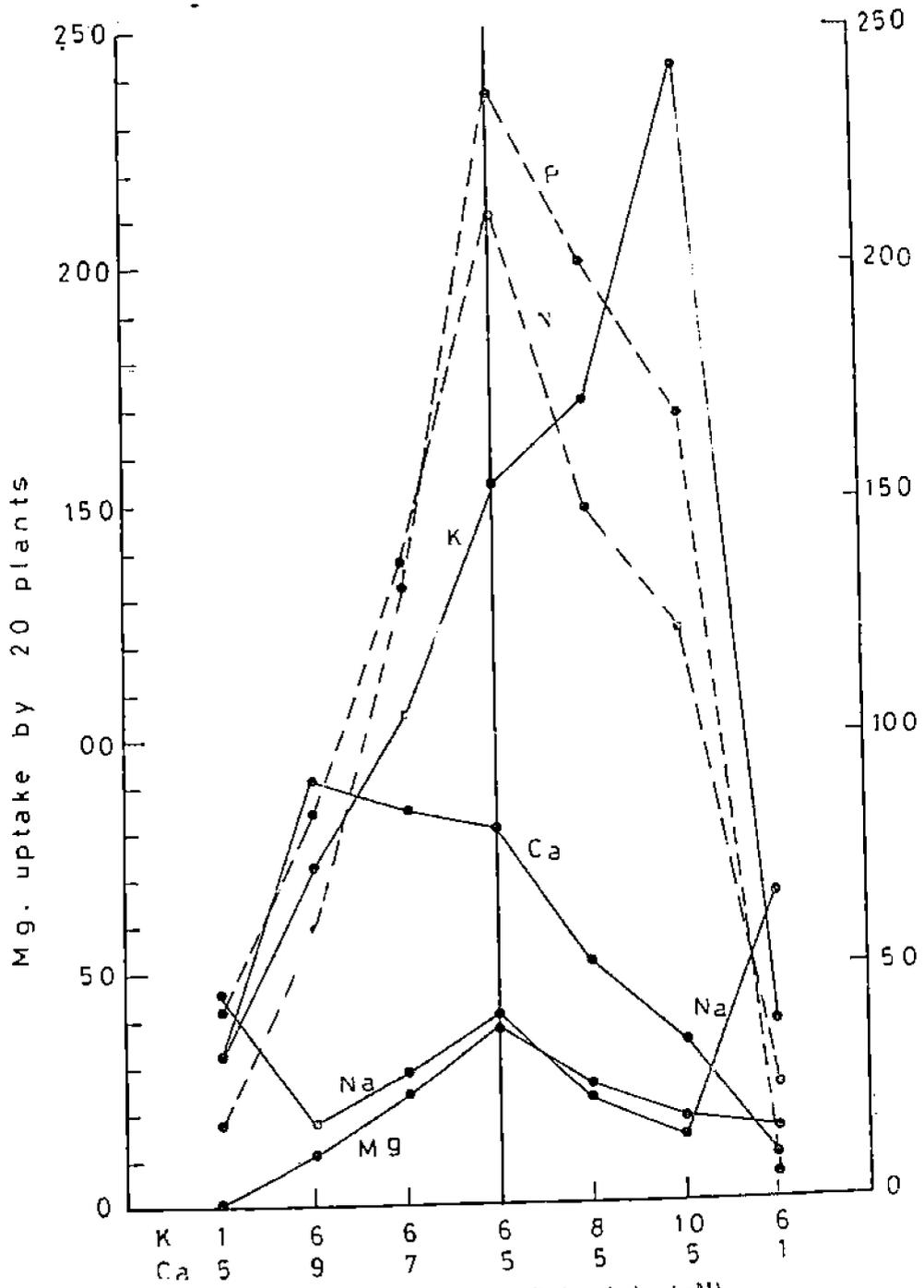
Figure (2) Uptake of nutrients by pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media

However in the excess Na-series in presence of low K or Ca in the nutritive media, the uptake of nutrients was very much reduced below those in excess K- or Ca-series except the uptake of Na which was increased by the increase of its concentration in the nutritive media. Similarly Dumbroff and Michel (1967) working with pine plants and Rains and Epstein (1967a & b) with barley roots found that plant tissues absorb Na as a function of its concentration in the culture media. On the other hand the amounts of Na taken up by pea plants cultivated in the different culture media except $K_1Ca_5Na_3$ and $K_6Ca_7Na_3$ are derived from that amount added as NaOH during the successive adjustment of the pH of the media throughout the whole experimental period. Actually, Na analysis of the media at the start of every solution change was very low (8.5 — 12.2 mgm./L), thus the antagonistic effects of the relatively progressively higher supplies of Ca or K on the uptakes of Na was clear. Similarly, Rains and Epstein (1967a and 1967b) found that K or Ca antagonises Na absorption by barley roots. Also Na absorption is drastically curtailed by Ca as shown by Epstein (1960) and (1961).

The antagonistic effects of Ca or K on the uptake of each other and on uptake of Na or Mg by pea plants can be interpretted as the result of a competition for a metabolically produced binding compound as suggested by Overstreet et al. (1952). Laggett and Epstein (1956), Hodges and Hanson (1965) and Rains and Epstein (1967b).

When the K/Ca ratios of the solutions were plotted against the K/Ca ratios in the plants (roots or tops) as illustrated by figure (3), the relative uptake and hence accumulation of K and Ca in pea tissues appeared to be dependent on the ratios of these ions in the nutritive media. Hanson and Kahn (1957), Cooil (1948) and Sideris and Young (1950) found the same relation with different plants.

Truog et al. (1947) found positive correlations between P and Mg contents of peas under different nutritional conditions, thus supporting the theory that Mg serves as a carrier of P within the plant. This result is emphasized by the present work since Mg uptake and translocation to tops of peas ran parallel to those of P, table (1) and figure (2). In contrast, Dumbroff and Michel (1967) found no relationship between Mg supply and P uptake and accumulation by pine plants.

Also the positive correlation between uptake and accumulation of N and P by pea plants cultivated in the different culture media. figures (2) & (5) clearly show the close connection between uptake and metabolism of N and those of P. Such correlation is repeatedly shown by so many workers, Cole et al. (1963) using corn. Nosseir and Spiridinov (1965b) using phaseolus and Nosseir and Hathout (1970) using sweet potato. Moreover,
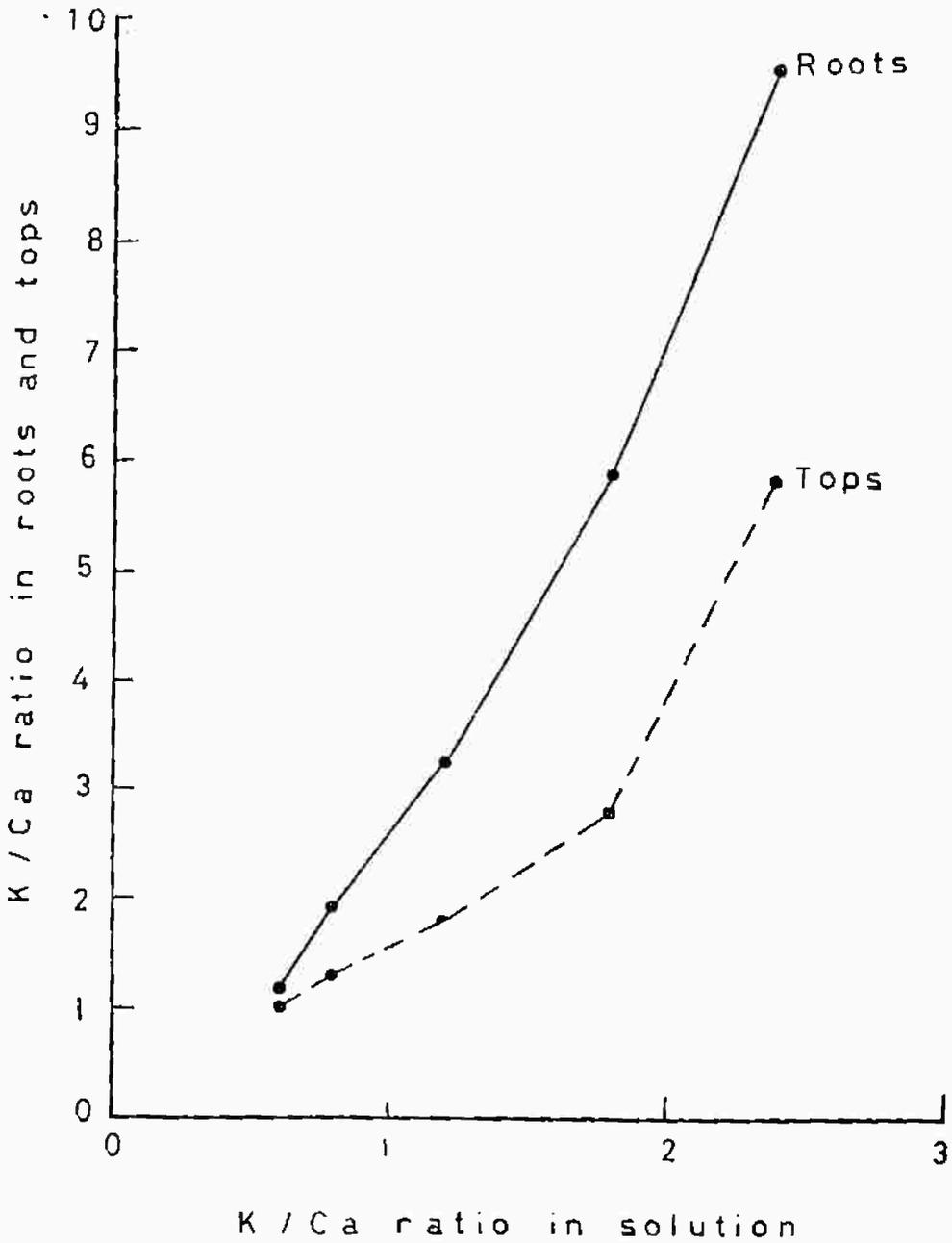
Figure (3)   Variations in the K/Ca ratio in the roots and tops of pea plants are a function of K/Ca ratio in the nutritive media

the relation found in pea plants fits with growth together with metabolic changes within the plant tissues (as will be discussed later) although Cole et al. (1963) found that the stimulation of P uptake together with increasing N levels in corn plants is not related to growth but rather to metabolic changes within the plant tissues.

Humphries (1951, 1952) has shown that the rate of uptake of N, P and K by roots of barley and pea plants, cultivated in solutions deficient in these elements, increase with increasing total sugar contents. A rexamination of his previous results, Humphries (1956) has shown that the positive regression of the nutrient uptake is attributable to the reducing sugar fraction. He concluded that conditions inducing high reducing sugars, also induce high rates of uptake and vice-versa. Since the total sugars determined in the present investigation include glucose, fructose and sucrose collectively it can be safely concluded that there is a fair connection between reducing sugars and sucrose on one hand and uptakes of K, N and P on the other hand by pea plants cultivated in the increasing Ca - solutions where uptakes of K, N and P were progressively depressed associated with progressive decreases in total sugar contents (figure 1). Under such conditions, sugars may be the parent substances for the formation of a chemical compound capable of combining with K, P or N as suggested by Humphries (1952). Also the results in hand show that active protein synthesis is a prerequisite of salt uptake since decreases in protein formation were associated with decreases in K, N and P uptakes by K - deficient plants, table (4) and figure (2).

Data showing uptake and distribution of nutrient ions in pea plants (table 1 and figure 2) revealed the close parallelism between total uptake and distribution of ions within plant parts and that the major fraction of these ions have been translocated to the tops while only a small fraction remained in the roots. Obviously this is due to the fact that shoots of plants are the seats of synthesis from which photosynthates are in part transferred to roots, Lundegardh (1951).

The interrelationships among nutrient ions as they occured in pea organs are illustrated in figure (5). Petrie as cited by Williams (1948) discussed the accumulation and redistribution of nutrients within the plant and he contrasted the behaviour of K to Ca in these respects. Such contrasted behaviour of K to Ca is also shown by pea plants where high accumulation of K was always associated with low accumulation of Ca and vice-versa in both roots and tops. This is true with all treatments except with $K_4Ca_3Na_2$ and $K_4Ca_4Na_4$ treatments probably due to the interference of the
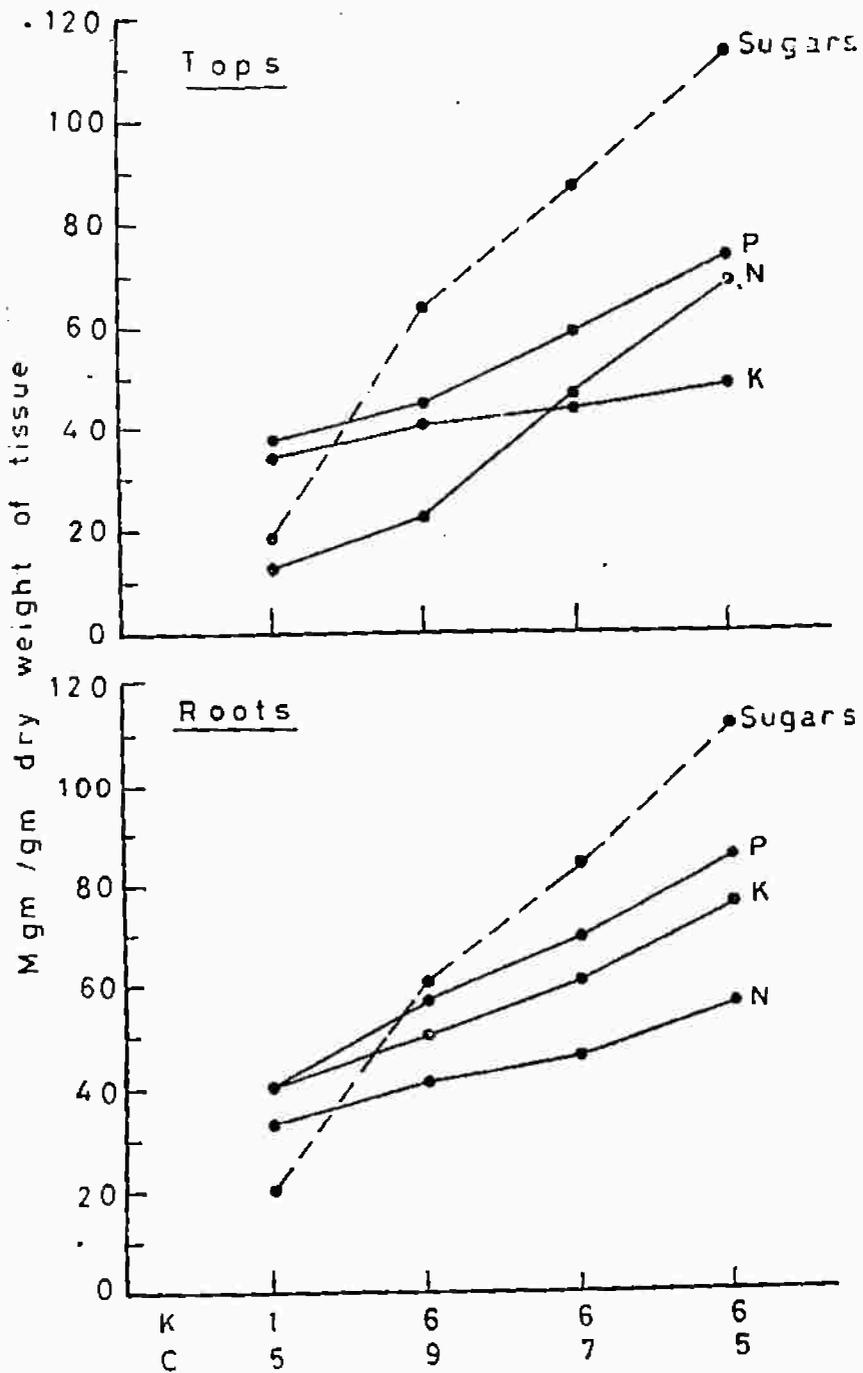
Relative concentration of K or Ca in solution (mM)
Figure (1) K, P, N and total sugar contents of roots and tops of pea plants grown for 5 weeks in various levels of Ca in presence of a constant supply of K and other nutrients in the culture media
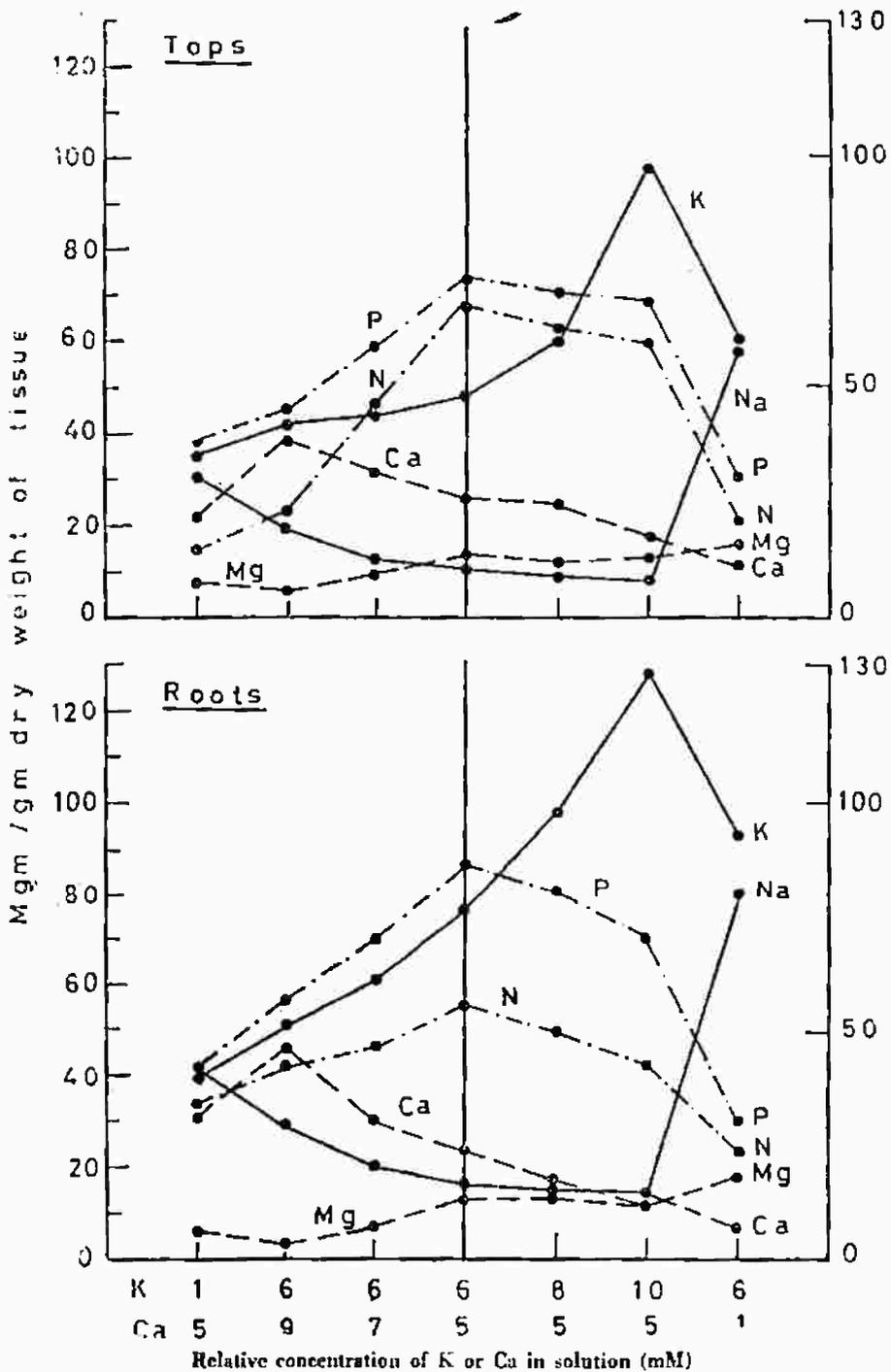
Figure (5)   Accumulation of nutrients by roots and tops of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media

excess Na present in these media. Inspite of the higher concentration of Ca ever K in the media of the Ca - increasing series (figure 5), yet K accumulation was always higher than Ca. Similarly Smith and Wallace (1956) showed that although K^{42} concentration in the solution of different plants was only $1/_3$ the concentration of Ca, there was a great accumulation of K^{42} than there had been for Ca^{45}. Moreover. Wadleigh and Bower (1950) found evidence for a reciprocal relationship in the accumulation of Ca & Mg on one hand and Na and K on the other hand among the tissues of bean plants on variations of Ca supply in the water culture. Such relationships are quite clear (figure 5) in pea plants under investigation not only on variations of Ca supply but also on variations of K supply.

As regards N and P, increasing concentrations of K or Ca in the nutritive media depressed progressively their accumulation in roots and shoots of peas. With the different treatments used. P accumulation within pea tissues was always higher than and positively related to that of N and this fits with Petric's statement (Williams, 1948)that the cell is able to accumulate much larger amounts of inorganic and soluble organic compounds of P than with N.

From the result shown by figure (5), it is clear that interrelationships among nutrient ions as they occur in roots of pea plants cultivated for 5 weeks in different culture media are similar to those occuring in tops. Recent evidence by Smith and Epstein (1964) suggests that active absorption and accumulation of inorganic solutes by leaf tissue are similar to the processes that occur in roots of corn plants.

Assimilation of nitrate and distribution of nitrogen fractions in plants at various levels of K and Ca.

The assimilation of nitrates as measured by the rate of disappearance from pea organs are illustrated in table (3). The available NO_3-N includes the initial nitrate (of untreated tissues)plus the difference between the total-N content of the treated and untreated tissues. It is quite clear that the assimilation of nitrate was very much greater in the tops than in the roots of pea plants cultivated in the different culture media. Similarly Street & coworkers (1946) found that nitrate assimilation was greater in the shoots than in the roots of potato sprouts. This together with the postulations of Burstrom (1945) and the findings of Sideris and Young (1950) that nitrate assimilation takes place in chlorophyllous tissues does not receive evidence from the present work with pea plants since nitrate assimilation goes on in roots as well as in shoots.

Also table (3) shows that pea plants cultivated in control media (K_6Cu_5) contain 30 and 83.2 mgm. NO_3-N/100 gm. fresh weight of tissue in roots and

Table 3.—Assimilation of nitrate - N by roots and tops of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media. Mgm-N/100 gm. fresh weight of tissues.

Treatment	Roots			Tops		
	Available No3 - N	Found No3 - N	Assimilated No3 - N	Available No3 - N	Found No3 - N	Assimilated No3 - N
K1Ca5	60.6	30.1	30.5	241.9	120.1	121.8
K6Ca9	104.7	55.3	49.4	299.9	126.3	173.6
K6Ca7	159.4	42.1	117.3	430.2	105.5	324.7
K6Ca5	236.1	30.0	206.1	587.8	83.2	504.6
K8Ca5	188.2	47.7	140.5	457.0	113.1	343.9
K10Ca5	142.1	82.4	59.7	450.1	155.7	294.4
K6Ca1	48.2	40.7	7.5	168.1	145.7	22.4

shoots respectively. Increasing the levels of Ca or K in presence of a constant supply of either of them and keeping the other nutrients constant in the culture media caused progressive high nitrate contents in roots and shoots. In the same time, K and Ca levels of tissues were increased by the increase in concentration of these elements in the nutritive media. Similar results were reached with in pine apple plants (Sideris & Young, 1945 and 1946) where nitrate contents were greater in the high-K than in the low-K cultures and were related directly to Ca levels in cultures and hence in tissues.

The progressive increased accumulation of nitrate in pea tissues (table, 3) in presence of excess K or Ca in the culture solutions together with the coincident reduction in nitrate availability in the tissues resulted from progressive reductions in nitrate assimilation. The nitrate assimilation was always associated with pronounced increases in proteins and relatively small increases in asparagine and amino acids in either roots or shoots of plants under variable nutritional conditions but are higher in shoots than in roots (table 4). Several investigators reported higher protein synthesis consequent to feeding plants or organs with nitrate and that the rate of synthesis is limited by nitrate assimilation, Steward and Street (1946) Sideris

Table (4)

Changes in the nitrogen fractions of roots and tops of pea plants cultivated for 5 weeks in different levels of K or Ca in the nutritive media as compared with untreated plants. Data are given as mgm. - N/100 gm. fresh weight of tissue.

Treatment	Roots							Tops						
	NH$_4$ N	NO$_3$ N	Aspara-gine N	Gluta-mine N	Amino acid N	Rest N	Protein N	NH$_4$ N	NO$_3$ N	Aspara-gine N	Gluta-mine N	Amino acid N	Rest N	Protein N
Water for (20 days) untreated	0	3.9	29.2	3.7	16.4	13.2	11.5	0	20.6	30.0	14.0	23.8	13.0	22.0
K1Ca5	0	+26.2	+ 8.1	— 1.1	+ 8.7	— 7.2	+ 22.0	0	+ 99.5	+46.7	— 5.4	+39.3	+ 3.2	+ 38.0
K1Ca9	+0.7	+51.4	+11.9	+ 0.1	+14.4	— 8.6	+ 30.9	+1.7	+105.7	+56.4	+ 7.4	+38.0	+ 1.7	+ 68.4
K1Ca7	+0.3	+38.2	+22.6	+ 9.0	+23.6	— 7.9	+ 77.8	+0.8	+ 84.9	+72.4	+ 7.8	+64.0	+ 1.3	+178.4
K6Ca5	+0.3	+26.1	+27.0	— 0.9	+48.8	— 2.7	+133.6	+0.4	+ 62.6	+82.0	+16.6	+66.0	+12.2	+397.4
K8Ca5	+0.2	+43.8	+ 9.3	+ 1.9	+37.6	— 7.0	+ 98.5	+0.6	+ 92.5	+74.8	+14.0	+49.2	+ 3.2	+202.1
K10Ca5	+0.5	+78.5	+12.0	+ 0.7	— 1.3	—11.0	+ 58.5	+1.5	+135.1	+66.8	+13.8	+38.2	+ 5.3	+168.8
K6Ca1	0	+36.8	— 7.8	+ 0.9	— 7.1	— 5.1	+ 26.6	0	+125.1	— 5.0	+ 1.0	—12.7	+ 6.0	+ 33.1

et al. (1937) and (1938) and Said and El-Shishiny (1949). Glutamine, however, showed no significant change in roots of pea plants under the different conditions of the experiment but it becomes somewhat high in tops indicating that glutamine precursor is produced in the chlorophyllous tissues.

Glutamine, however, was tentatively regarded by Steward and Street (1946) as a reactive intermediate in protein synthesis of potato tuber tissues. Since asparagine was dominating in pea plants , it is possible that this amido can act as glutamine acts in potato tissues, being intermediary in protein synthesis of pea plants. Moreover, incorporation rates of various amino acids into the proteins of pea homogenates has been demonstrated by Webster and Varner (1955).

The accumulation of asparagine rather than glutamine in pea plants emphasizes the results already obtained by Nosseir and Spiridinov (1965a) where asparagine was the only amino acid amide that appears on the chromatogram of both roots and shoots of pea plants cultivated in Hoagland solution under different conditions.

Tables (3) and (4) also show than the assimilated nitrate by pea plants cultivated in normal Hoagland solutions were accounted for by increases mainly in proteins, asparagine and amino acids. In roots, these increases account for 64 %, 13 % and 23 % of the assimilated nitrate as proteins, asparagine and amino acids respectively. In the shoots, however, these increases account for 64 %, 16 %, 13 %, 3 %, and 2% as proteins, asparagine amino acids, glutamine and rest-N respectively. Increments of K or Ca in the nutrient media inhibited the formation of these fractions in roots and tops due to reductions in nitrate assimilation.

Although, the quantity of total-N in the shoots of pea plants was much higher than in corresponding roots under any experimental condition, yet asparagine, and protein of the roots as % of total-N are present in the same proportions in shoots of plants cultivated in excess Ca- or K-media in presence of constant supplies of either ions (table 5). Under these conditions, similar courses of asparagine or protein syntheses in both roots and shoots might have occured.

As suggested by Sideris and coworkers (1937 and 1938), because of the low rate of nitrate assimilation in pine apple plants, carbohydrate might have been preserved and kept at relatively higher level, thus promoting protein synthesis. In pea plants under investigation, although nitrate assimilation was lowered by the increase of K or Ca level in the culture media (table 3), yet protein synthesis was also lowered in both cases (table 4) while the total sugar content decreases by the increase of Ca level but

Table (5)

Distribution of the nitrogen fractions in roots and tops of pea plants grown for 5 weeks in various levels of K and Ca in the nutritive media. The data are given as percent of total-N.

Treatment	Roots							Tops						
	NH$_4$	NO$_3$	Asp-	Glut-	Aminoacid	Rest-	Protein	NH$_4$-	NO$_3$-	Asp-	Glut-	Aminoacid	Rest-	Protein
	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Water for 20 days	0	5.2	6.6	4.	21.4	17.1	14.9	0	16.7	24.3	11.3	19.1	10.	17.8
K1Ca5	0	22.5	27.2	1.9	1.	4.5	25.1	0	34.8	22.2	2.3	1.4	4.8	17.5
K6Ca9	0.5	31.1	22.6	2.1	17.3	2.6	23.8	0.6	31.3	21.4	5.4	15.3	3.6	22.4
K6Ca7	.2	18.1	21.8	2.0	17.2	2.3	0.1	19.8	19.2	4.1	16.5	2.7	2.7	37.6
K6Ca5	0.2	9.7	17.8	0.9	21.1	3.4	46.9	0.1	12.1	16.2	4.4	13.0	3.6	50.9
KCa5	0.3	1.3	14.3	2.1	20.6	2.3	32.1	0.1	20.1	18.7	5.0	13.1	2.9	40.1
K10Ca5	0.1	3.3	1.7	2.1	7.0	1.1	32.7	.3	28.1	17.5	5.1	11.2	3.3	34.5
K6Ca1	0	33.6	16.8	3.9	7.8	6.6	31.3	0	53.7	9.2	5.5	4.1	7.1	20.5

increases by increase of K level in the nutrient meedia (table 2) both in roots and shoots.

Since symptoms of K-deficiency were dominating on the shoots of pea plants receiving excess Ca and emphasized by plants cultured from the beginning and throughout the whole experimental period in K-deficient media, it becomes clear that high concentration of Ca antagonising the absorption of K, have reduced the latter to deficiency levels in the tissues with the resultant effects of K deficiency on nitrogen metabolism and sugar formation. The same appears true in case of excess K leading to effects of Ca-deficiency.

Table 6.—Asparagine + gultamine + amino acids/protein ratios in roots and tops and whole pea plants grown at various levels of K and Ca in the nutritivemedia.

Treatment	Roots	Tops	Whole plants
K1Ca5	1.90	2.49	2.27
K6Ca9	1.76	1.37	1.81
K6Ca7	1.08	1.05	1.06
K6Ca5	0.85	0.66	0.72
K8Ca5	0.88	0.91	0.90
K10Ca5	0.84	0.96	0.94
K6Ca1	0.89	0.92	0.90

The main effects of K-deficiency on the N metabolism have been studied by Richards and Templeman (1936), Sideris and Young (1946) and Cooil and Slattery (1948) using various plants and found higher proportions of amides and amino acids to proteins in K-deficient plants. Such relation is clear from table (6) where the ratios of amides and amino acids to proteins increase progressively by progressive decreases in absorption and accumulation of K ; in the same time, total sugar contents as compared with controls in normal Hoagland solution decreased. Similarly, Cooil and Slattery (1948) using guayule and Russell as cited by them using barley plants

reported low total sugar contents in K-deficient plants. The low sugar contents of pea plant deficient in K might be attributed to the low assimilation rate, and high respiration of the tissues since Richards (1932) found that with decrease in the K supply to barley plants, the respiration rate of leaves increases to a maximum when the K supply is one-ninth that of the fully manured plants. Also White (1936) found that Lemna plants show low assimilation rate under K-deficiency. Moreover, shortage of K leads to reduction in photosynthetic activity of plants as stated by Stiles (1936).

The limiting effect of Ca-deficiency on the N-metabolism of pea plants is also clear from figure (5) where total-N runs parallel to the level of Ca in the tissues when K was present in excess over Ca in the nutrient media. Parker and Truog (1929) pointed that in a series of 34 plant species, the total-N content and Ca ran parallel and they saw in this fact evidence of the acid-neutralizing function of Ca. The same connection between N metabolism and Ca is also indicated by the work of Nightingale (1931) who found that tomato plants suffering from Ca-deficiency were unable to absorb or utilize nitrates to any appreciable extent. On the acid-neutralizing theory, this could be explained by supposing that under Ca-deficiency, acids accumulate in the plant and inhibit the normal processes involved in nitrogen metabolism. Here with pea plants (table 3), the availability of nitrates in roots or tops decreased progressively by increase in Ca-deficiency (K- increasing series as compared with controls in normal Hoagland solution). This was accompanied by more pronounced reduction in nitrate assimilation which reached 96 % and 95 % below controls in roots and shoots of plants cultivated in the Ca-deficient media from the beginning and throughout the whole experimental period and this was accompanied by reductions of 81% and 74% in nitrate availability by roots and shoots. In contrast, total sugar contents were increased by the increase of Ca-deficiency and reached 60% higher in K_6Ca_1-treated plants over that of controls. The progressive increase in total sugar contents of Ca-deficient plants was associated with progressive decreases in the level of organic nitrogenous compounds, mainly proteins, table (4). Under these conditions, the carbohydrates which would normally be involved in the synthesis of these organic nitrogen compounds remain unutilized and so the increase in the total sugar contents (table 2).

Although the quantity of the total-N of the Ca-deficient or high K-plants were very much below that of the fully manured ones, yet the ratios of amides + amino acids/proteins are equal in roots and higher in shoots of the Ca-deficient plants than those of the fully manured ones. With all plants, this ratio was always below unity. These results might indicate not only a normal rate of synthesis of these compounds in roots of Ca-deficient

plants, but also protein synthesis going on faster than those of amides and amino acids.

On the other hand, with K-deficient or high Ca-plants, the ratios of amides + amino acids/proteins are always higher than unity indicating a relatively lower rate of protein synthesis. Steward & Preston (1941) Said and El-Shishiny (1949) have found that increasing concentrations of K, increase protein synhesis while increasing that of Ca produces the diverse process is potao & radish root respectively.

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