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NITROGEN EFFECT ON CATION EXCHANGE CAPACITY OF PLANT ROOTS

by

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of the requirements for the degree

of

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Kamilia Shoukry

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INTRODUCTION

The relationships that exist between soil and plant are very complicated and have aroused man's curiosity for centuries. Many studies have been done in order to understand and clarify this relation. Among these is the hypothesis that plant roots exhibit cation exchange capacity (CEC) and that this is in some way responsible for differential cation uptake. The CEC of the roots was defined by Helmy (1958a) as the total cations which can be exchanged or replaced from the root surface under a given set of conditions and is usually expressed as milliequivalents per 100 grams (me/100 g) of dry roots. The CEC hypothesis of cation uptake proposes that the uptake of cations from soil by plants is in some extent controlled by the CEC of the plant roots and the valence of the cations. The CEC may therefore account for the differences between species in taking up different amounts of nutrients from the same soil.

The presence of a CEC is likely due to some type of "adsorption" compound or compounds in plant roots. As early as 1921 Howe reported that in plant roots there is a gelatinous material of the nature of pectic acid which is found in the outer layer of all roots. It is now known that colloids like cellulose, arabic acid, peptides, polyphosphates and especially pectins in the roots cause electrical charges which give the roots the ability to adsorb ions (Haniuk, 1959, and Miller, 1962). Most of these compounds exhibit negative charges and might be responsible for the cation adsorption.

Because of this interest in CEC many investigations have been conducted during the last ten years in an attempt to study the factors which may cause difference in CEC between different species or within a given species.

Evidence has been presented to show that there is a correlation between the CEC and nutrient treatment. Smith and Wallace (1956) stated that nitrogen fertilization increased the CEC of at least some plant species. This was supported by the work of McLean (1956) who reported that as nitrogen supply was increased not only did the percentage of nitrogen in the plant increase but this was accompanied by an increase in the CEC of the plant roots. Helmy (1958b) found that the nitrogen status of a plant influenced the CEC of the roots. Dunham et al. (1956) suggested that the nutrient treatment effected the CEC of plant roots only in solution with low ionic activity. Asher (1961) concluded from his work that the differences in CEC appeared to be a real characteristic of the plant and not greatly affected by the level of nitrogen.

These different studies, however, are open to question as to what was the real effect of the nutrient treatments and especially the effect of nitrogen on CEC.

This investigation was made to study the effect of different sources and levels of nitrogen on the CEC of roots from different plant species.

REVIEW OF LITERATURE

The fact that plant roots possess a CEC was first mentioned by Deveaux in 1916. Jenny and Overstreet (1939) showed that roots possess cation exchange properties. No appreciable work, however, had been done until the last decade when Williams and Coleman (1951) reported that plant root surfaces possess cation exchange capacities which may be measured by the adsorption and release of various cations. They added that the CEC was the same on live and ether-killed roots which indicated that the CEC on the surface of the root is metabolically inactive.

Effect of plant age on CEC

The age of the plant was found to influence the CEC values (Graham, 1951; Helmy, 1958; and Haniuk, 1959). This may be explained on the change of the chemical composition of plant cell walls with age (Bonner, 1950). He reports that pectic substances constitute about 50 percent of the cell wall material in young tissues, but decreases to only 0.5 to 1.5 percent as the tissue matures. Cellulose, lignin, pentosans, and similar material increased accordingly. These materials seem to be inactive with respect to cation exchange properties.

Effect of the root segments on CEC

Mattson et al. (1949) found that the root surface and especially the growing tip possess a very high content of active acidoids. Smith and Wallace (1956) found that the large roots had about half the CEC of the small roots from the same plant species when expressed on a weight basis.

The root length or segments also affect the CEC. Some of the workers used the whole roots (Drake, 1951) while others (Smith, 1955, and Bell, 1957) used segments that were a certain length from the root tip. Haniuk (1959) found a great difference between the CEC values of the first five cm, the second five cm, and the third five cm. The CEC was highest closest to the root tip.

Effect of the plant species on the CEC

Drake et al. (1951) stated that CEC of the roots of many of the dicotyledonous plants was roughly double the values obtained from roots of monocotyledonous plants. He further reported that differences in the ability of plants to take up cations from the soil are largely controlled by the CEC of the plant roots and the valence of the cation. That study emphasized the work done by Elgabaly (1949) and Graham (1951).

Effect of plant nutrition on CEC

It was found by Smith and Wallace (1956) and McLean (1956) that nitrogen treatment increased the CEC of roots of some plant species. Helmy (1958a) suggested that the influence of nitrogen salt on CEC may be related to the formation of energy-rich phosphorylated nitrogen compounds at the outer surface.

Crooke and Knight (1962) made an evaluation of the data of different workers. They drew on inference that the CEC is positively correlated with the content of the tops of (a) total cations, (b) the ash, (c) the excess base, and (d) the total trace elements.

Methods and procedures for determining CEC

As different methods have been used for determining root CEC it is somewhat difficult to compare the absolute results obtained by different workers. The general method has been to saturate the roots with a given cation and then replace this cation with another. The CEC is expressed as the millequivalent of exchanged cation (Helmy, 1958a).

Drake et al. (1950), Smith (1955), Bell (1957), and Haniuk (1959) saturated the roots with H^+ by electrodialysis. Hydrogen saturated roots were then placed in a concentrated solution of KCl in which the K^+ replaced the H^+. The H^+ was titrated to the original solution pH with KOH. Another method which is related to this one was used by Williams and Coleman (1950) in which they used Ba^{++} or NH_4^+ instead of H^+ as the saturating ion. Then they determined the Ba^{++} or NH_4^+ after replacing it. Huffaker and Wallace (1959) used zinc radioisotope and estimated the CEC by direct counting of the Zn^{65} which was absorbed and not removed by washing.

EXPERIMENTAL METHODS

The two species used in this study, corn (Zea mays) and beans (Phaseolus vulgaris), are representative of the monocotyledonous and dicotyledonous plants. They were chosen over others because much work has been reported on the CEC of these two plants.

The corn was germinated by placing the seed on cheese cloth covering a perforated plate; only one seed was placed in every pore. The plate was in a four-liter enameled vassel which was two-thirds filled with distilled water. To this water 1 ml of saturated $CaSO_4$ solution was added to each gallon of water to enhance germination. After eight days from starting germination, the plants were about 5 cm high and were transplanted to gallon jars.

The beans were germinated in the same way as the corn except it took only six days before the plants were about 5 cm and could be transplanted. This method of germination was used to avoid serious damage of the roots at transferring.

In transplanting only similar plants in size, color, and shape were chosen. The plants were arranged in an aerated one-gallon jar supplied with standard nutrient solution used by Weissman (1950). The solution had the same amount of nitrogen but varying in the ratio between ammonium and nitrate. There were two levels, one-fifth level and complete level. Each level contained three treatments, viz., 0 NH_4:100 NO_3, 50 NH_4:50 NO_3, and 100 NH_4:0 NO_3. This made six treatment combinations. The experiment was conducted in a completely randomized design with four replications. There were four plants in every jar and each jar was

Table 1. Composition of nutrient solutions

Full strength		
NH_4 NH_4Cl % of 0.01 M	NO_3 KNO_3 % of 0.01 M	$NH_4:NO_3$ ratio
0	100	0:100
50	50	50:50
100	0	100:0

All solutions contained:

KH_2PO_4	0.0025 M		K_2SO_4	0.004 M	
$CaCl_2 \cdot 2H_2O$	0.004 M		$MgCl_26H_2O$	0.002 M	
Fe	2.75	ppm	Mn	0.50	ppm
B	0.2	ppm	Mo	0.02	ppm
Zn	0.1	ppm	Cu	0.01	ppm

In case of one-fifth strength, these compositions were diluted 1:5.

considered as a replicate. The nutrient solution in the gallon jars was changed every three days and the pH was adjusted every day to 5.5 to 6.0 by addition of KOH or H_2SO_4. In order to maintain a constant culture solution, 2.75 ppm of iron in a chelated form was supplied daily. The plants were grown in the Utah State University greenhouses under a semi-controlled environment. Temperature was around 85 F at day time and about 75 F at night. Humidity was about 54 percent. The day length was 15 hours.

The plants' roots were sampled when they reached the required length. For the corn it was a week from transplanting and in the case of the beans it was six days. The corn and bean roots were sampled every two days for the first five samples. Then the last three samples were taken every four days. For sampling the plants were removed from the nutrient solution and placed in a large pan of distilled water. Only the white and healthy roots without lateral roots were chosen. The size also was considered in that an attempt was made to obtain roots of uniform size. From each root two successive portions of 5 cm length were cut after discarding the first cm from the tip. The root tip was discarded because of the high meristamatic activity which was felt would yield a misleading CEC for the first segment (Haniuk, 1959, and Bell, 1957). The same 5-cm portions of the root were put together in a bundle so that there were about 10 root segments per each bundle for dialyzing.

The samples were placed in a Bradfield-type electrodialysis cell for 90 minutes and a few drops of concentrated HCl were added in the center cell (with the roots) in order to hasten the dialysis. The voltage of the dialysis cell was at 120 volts; the current was from 50 to 100 milliamperes. Whenever the temperature of the end cells reached

30 C the water was flushed and the end cells were refilled with distilled water. This was because the effect of the high temperature during dialysis on CEC is not known.

After the dialysis, the root portions were placed on filter paper for 30 seconds in order to remove the excess water. The roots were then placed in a 400 ml beaker containing 50 ml 1.0 N KCl at pH 7. In preparing that KCl solution, the pH was adjusted to 7 daily with 0.01 N KOH or 0.01 N HCl. The pH was adjusted very carefully again before placing the roots in the solution. That was because the pH changes were taken as an index for the CEC so any change in the initial pH value would cause an error in the CEC obtained. The root portions in KCl were titrated with 0.01 N KOH using a microburet. The pH was followed by using a Beckman zeromatic pH meter over a 5-minute interval. The roots were washed with distilled water and dried at 65 C for two days. The CEC was calculated as me/100 g dried material.

RESULTS AND DISCUSSION

Corn

The first sample was taken from the corn seven days after transplanting or 15 days from the day they were put to germinate. There were apparent differences in the growth of the plants due to the treatments. The treatment made up of 50 NH_4:50 NO_3 (full strength) had the most growth, while the treatment consisting of 100 NH_4:0 NO_3 (full strength) had the least growth, although no appearance of chlorosis was observed until the twentieth day from transplanting.

The pH of the nutrient solution in which corn plants were growing decreased as much as 1 to 1.5 pH units towards the acid side when only ammonium nitrogen was present and increased about 1 pH unit when only nitrate nitrogen was present. The pH of the treatment containing equal amounts of ammonium and nitrate nitrogen did change slightly but in no consistent manner. Also, it was observed that pH in the dilute solution was less changeable than in the full strength solution for the same treatment. As was mentioned before, the pH of the nutrient solution was adjusted every day to pH 5.5 to 6.

In selecting the roots for sampling, it was noticed that the roots of the treatment 100 NH_4:0 NO_3 were somewhat short and stubby and never gave CEC values higher than 3 me/100 g of dry weight. By the time the plants became chlorotic (20 days from transplanting) no further samples were taken. The effect of this treatment on the behavior of the CEC of corn roots was unexpected because it was assumed that corn can utilize ammonium salt as readily as nitrate (Miller, 1938).

There was some correlation between the growth of the plant and root CEC. The treatment consisting of 50 NH_4:50 NO_3 (full strength) had the highest CEC and the most growth. The CEC for the first sample was 14 me/100 g of dried root and for the last sample (27 days) was 12 me/100 g (Figure 1 and Table 1). The individual values are presented in the appendix. Between these two values the CEC of the roots rose to a high value of 20 me/100 g at 11 days. This highest value agreed with the CEC value obtained for corn by Drake et al. (1951) where they got 22 me/100 g at 10 days. Also the value was very close to the values obtained by Bell (1957) for corn reported to be 14 days old where he got 23 me/100 g. McLean (1957) also got 25 me/100 g for corn at 15 days old. That may indicate that the plants having suitable nutrient status give a maximum definite value of CEC. The CEC for treatment 0 NH_4:100 NO_3 started at 11 me/100 g and rose to 14 me at 9 days, then went gradually to 9 me at the end of sampling. That showed the tendency of the corn to possess higher CEC with NO_3 as its source of nitrogen than with NH_4^+. The highest values, however, were obtained when NH_4 and NO_3 were combined.

When the nutrient concentration was reduced to one-fifth full strength, the differences between the three treatments decreased. The ammonium to nitrate ratio was reduced (Table 1 and Figure 2). But it was clear that the 50 NH_4:50 NO_3 was better than the 100 NH_4:0 NO_3 and 0 NH_4:100 NO_3. All the CEC values in this reduced nutrient level were less than those obtained in the full strength nutrients except for the treatment 100 NH_4:0 NO_3. In case of the 100 percent NH_4 treatment (one-fifth strength) the effect of ammonium nitrogen source and/or the inability to maintain a constant control of the acidity of the solution (Wander and Site, 1956) were less than that in the full strength

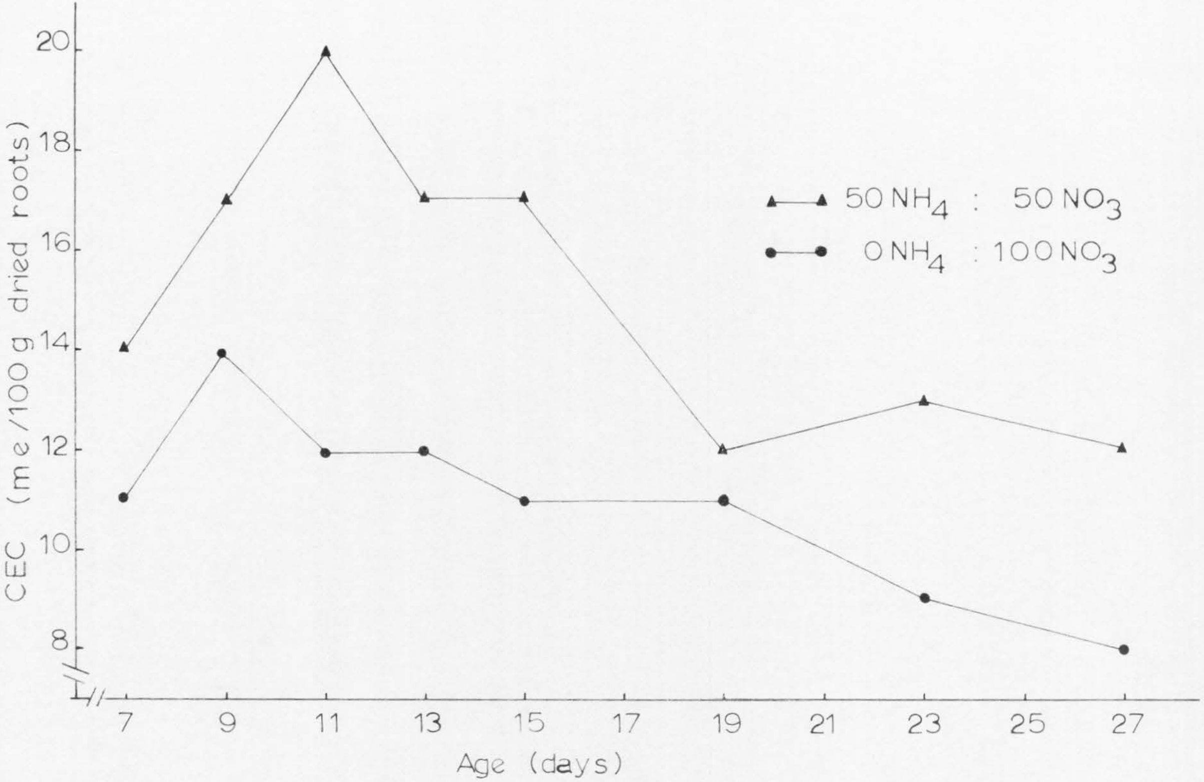

Figure 1. The CEC values of the first 5 cm segments of corn roots grown in full strength nutrient solution.

Table 2. The CEC of the first 5 cm of corn roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

	Days from transplanting							
$NH_4:NO_3$	7	9	11	13	15	19	23	27
				Full strength				
50:50	14	17	20	17	17	12	13	12
0:100	11	14	12	12	11	11	9	8
				One-fifth strength				
100:0	9	7	7	8	6	5	5	-
50:50	8	9	10	11	10	8	6	7
0:100	10	10	8	8	8	6	6	6

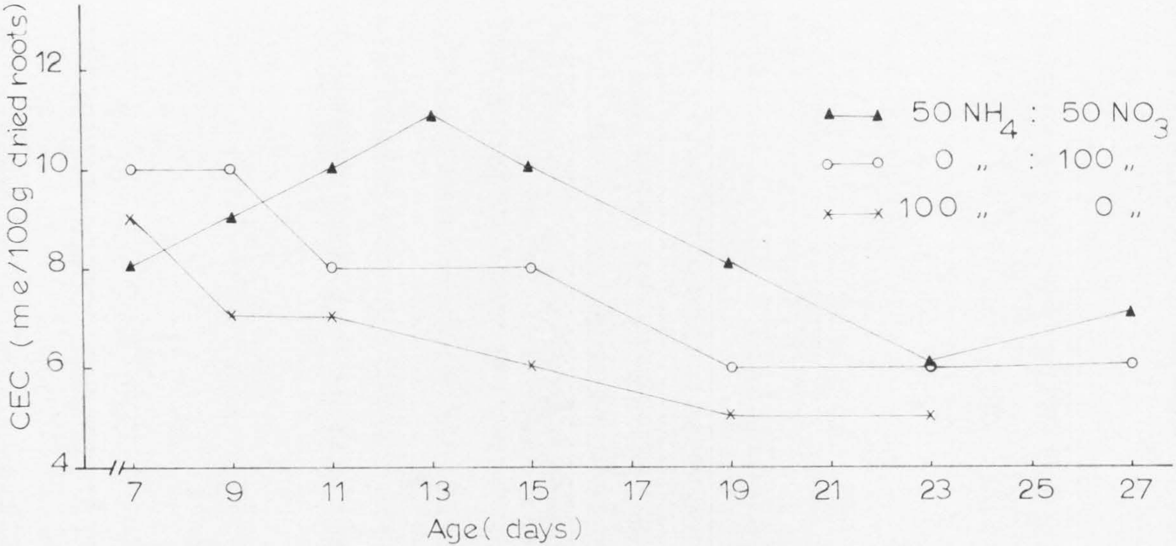

Figure 2. The CEC values of the first 5 cm segments of corn roots grown in one-fifth strength nutrient solution.

solution.

It can be seen from Figures 1 and 2 that most of the treatments did not yield the highest CEC values for the first sampling. This may have occurred as a result of some disturbance in the composition of the plant during transplanting, although Haniuk (1959) observed the same phenomena. Following these highest values the CEC decreased again which may be due to the effect of the age. As the plants become old the chemicals in the root composition which affect the CEC apparently decrease (Bonner, 1950).

The second segment sampled (5 cm) had lower values than the first segment although they had the same pattern (Table 3 and Figure 3). Haniuk (1959) also reported that the 1 to 6-cm root sections had higher CEC values than the 6 to 11-cm sections.

The CEC value for 50 NH_4:50 NO_3 treatment rose to 12 me/100 g at the age of 11 days and went down to 7 me/100 g at 23 days. The 0 NH_4: 100 NO_3 came next. It started at a high value of 11 me/100 g and ended at 6 me/100 g. Thus the CEC values for the second root segment sampled followed the same pattern as was found for the first 5-cm segment.

Concerning the second segments in one-fifth strength solution, the values of CEC were close but lower than that in full strength. This is the same pattern as was found with the first segments. Treatment 50 NH_4:50 NO_3 had 8 me at 11 days, while the same segment in full strength solution had 12 me at the same age. Figure 4 presents graphically the data for second segments in one-fifth strength solution.

Beans

The pH changes that had been noted for corn plants growing in the different nutrient solutions were also noted for beans. The bean plants

Table 3. The CEC of the second 5 cm of corn roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

$NH_4:NO_3$	Days from transplanting 7	9	11	13	15	19	23	27
				Full strength				
50:50	8	10	12	10	9	8	7	7
0:100	11	8	7	8	8	7	7	6
				One-fifth strength				
100:0	7	7	5	6	6	5	4	-
50:50	6	7	8	7	6	5	7	5
0:100	7	7	5	5	6	4	4	3

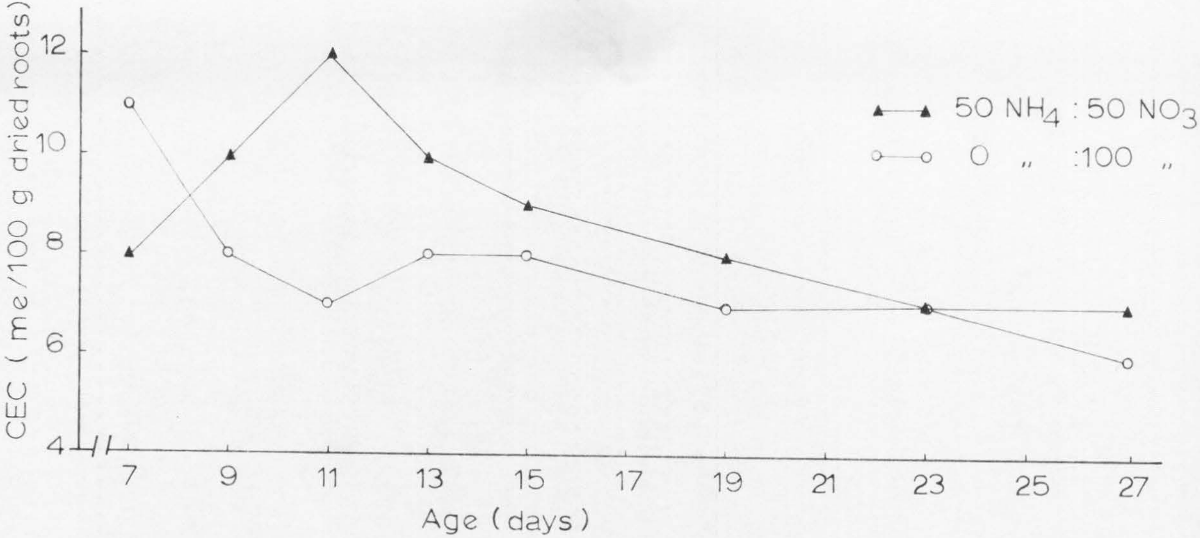

Figure 3. The CEC values of the second 5 cm segments of corn roots grown in full strength nutrient solution.

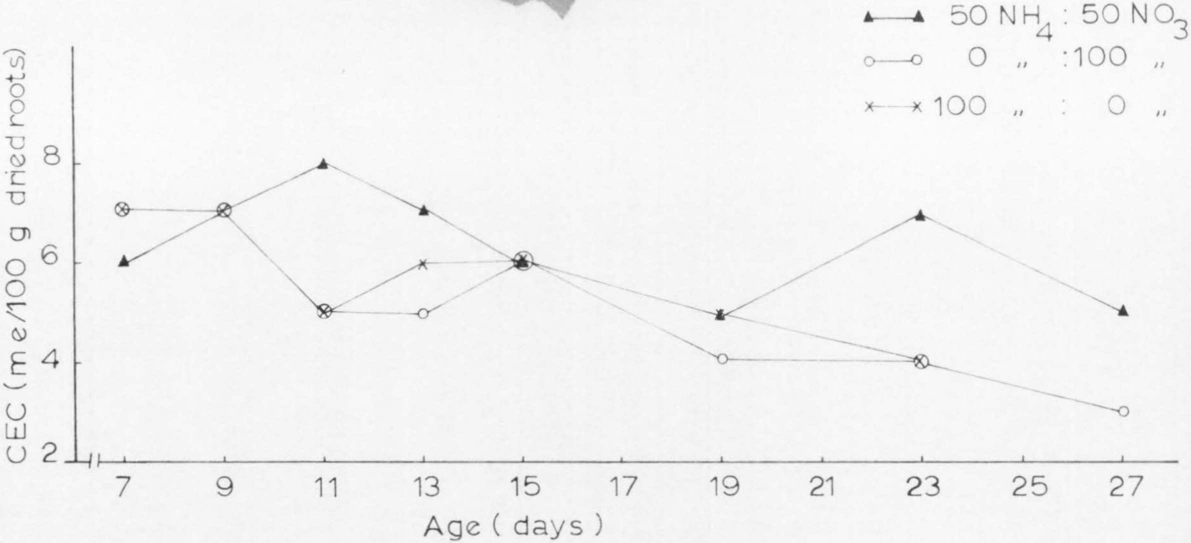

Figure 4. The CEC values of the second 5 cm segments of corn roots grown in one-fifth strength nutrient solution.

were allowed to grow for six days after transplanting before samples of the roots were checked for their CEC.

The growth of the plants was fair. There was no distinguishable difference in appearance between the treatments. In general the CEC values obtained from the bean roots were much higher than those obtained from the corn. This has been found by others. Also it was stated by Drake et al. (1951) that the CEC of roots of dicotyledonous plants in general were roughly double the value for monocotyledonous plants.

In contrast to the values obtained with corn (Figures 1 to 4), the CEC of the bean roots, with one exception, started at the highest value and then decreased with age (Figures 5 to 8 and Tables 4 and 5). The decrease was most in those roots from the plants grown in 100 NH_4:0 NO_3 (full strength). In this treatment the roots were short and unhealthy as had been found with corn.

One other comparison should be made with the values obtained for corn. The CEC for bean roots in the full strength solution (Figure 5) was always highest with the 0 NH_4:100 NO_3. This was also true for the second segment sampled (Figure 7). When the solution concentration was reduced to one-fifth strength (Figures 6 and 8) the treatment of 50 NH_4:50 NO_3 gave initial values that were much higher. In the latter case, however, the CEC values dropped rapidly with age until for the last samplings the CEC values were below those obtained in 0 NH_4:100 NO_3. In the case of beans the treatment of 0 NH_4:100 NO_3 was highest at the initial sampling for three (Figures 5, 6, and 8) out of the four (Figure 5) instances but dropped very soon. At the same time, in the treatment consisting of 50 NH_4:50 NO_3, there was the early rise followed by the decrease in CEC with age noted by Haniuk (1959) for corn.

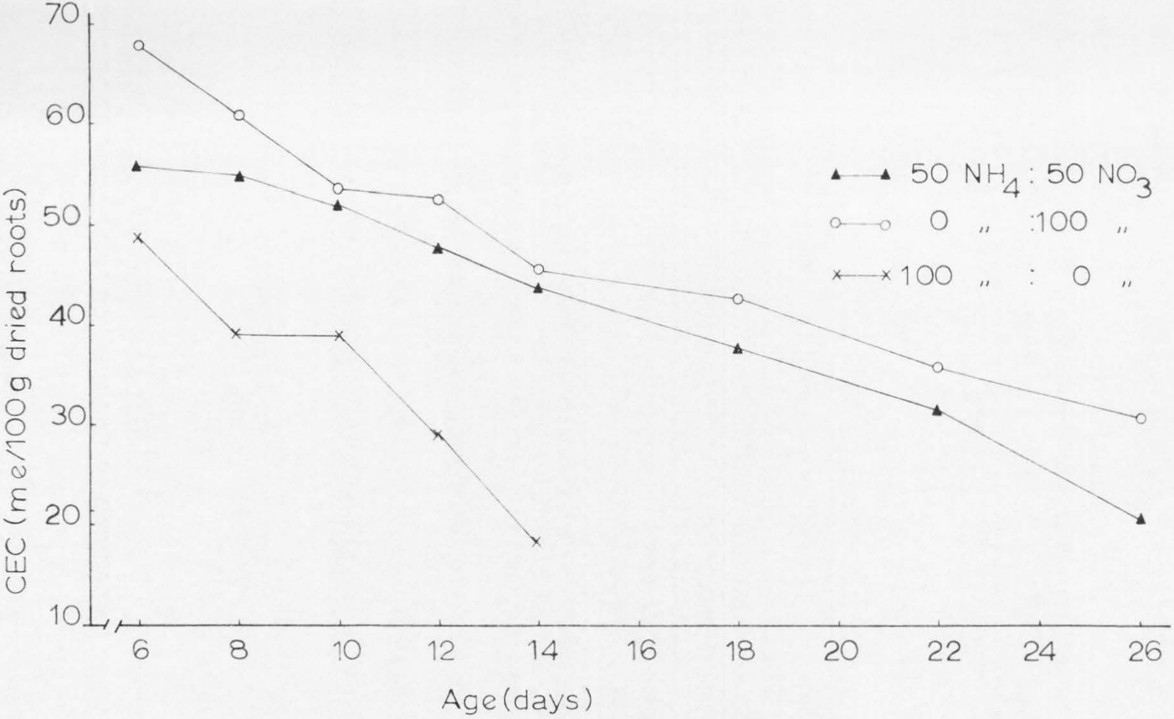

Figure 5. The CEC values of the first 5 cm segments of bean roots grown in full strength nutrient solution.

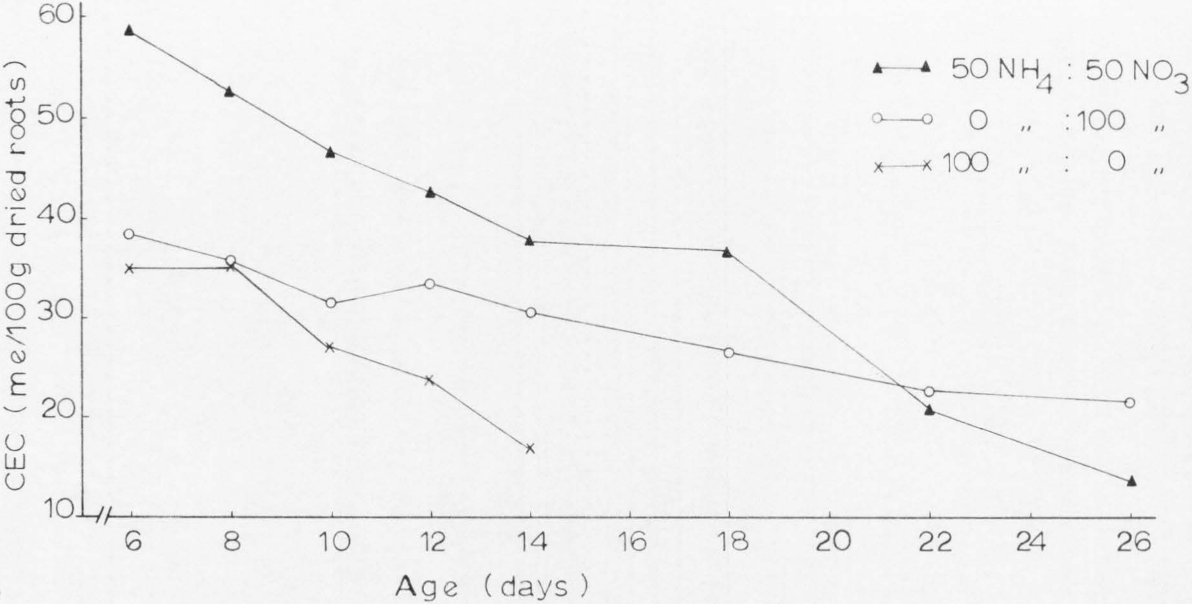

Figure 6. The CEC values of the first 5 cm segments of bean roots grown in one-fifth strength nutrient solution.

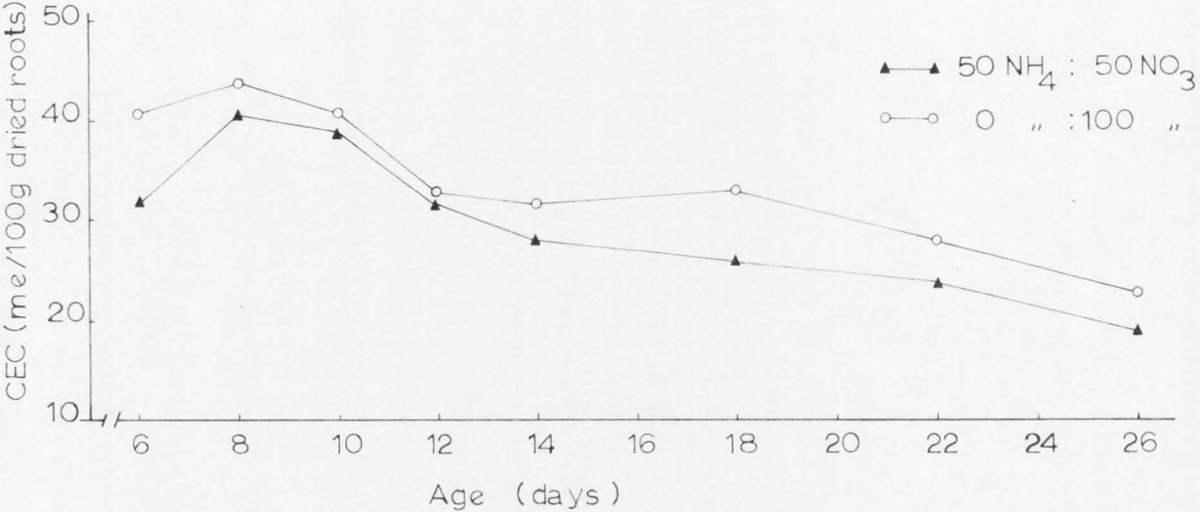

Figure 7. The CEC values of the second 5 cm segments of bean roots grown in full strength nutrient solution.

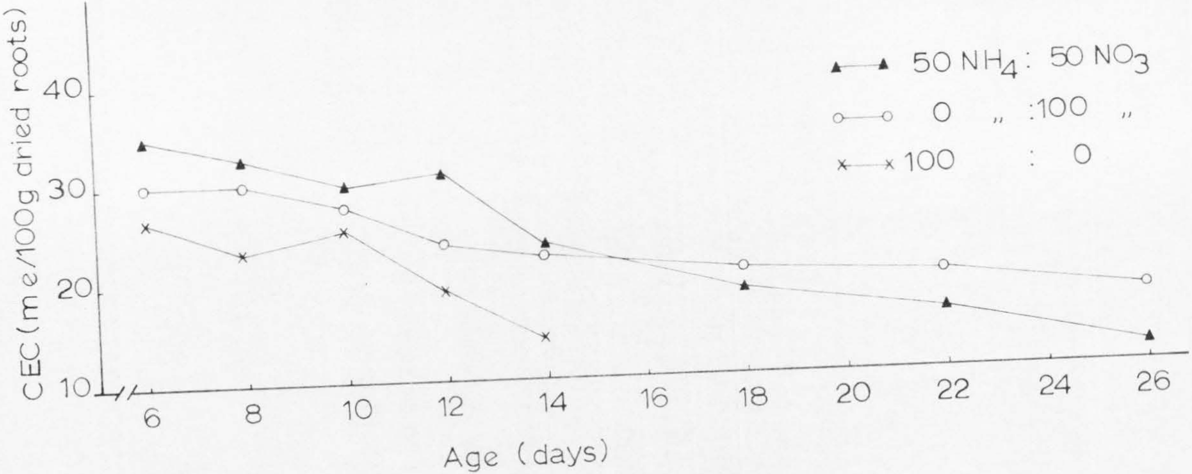

Figure 8. The CEC values of the second 5 cm segments of bean roots grown in one-fifth strength nutrient solution.

Table 4. The CEC of the first 5 cm of bean roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

	Days from transplanting							
NH_4:NO_3	6	8	10	12	14	18	22	26
				Full strength				
100:0	49	39	39	29	18	-	-	-
50:50	56	55	52	48	44	38	32	31
0:100	68	61	54	53	46	43	36	31
				One-fifth strength				
100:0	35	35	27	24	17	-	-	-
50:50	59	53	47	43	38	37	21	14
0:100	39	36	32	34	31	27	23	22

Table 5. The CEC of the second 5 cm of bean roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

	Days from transplanting							
$NH_4:NO_3$	6	8	10	12	14	18	22	26
	Full strength							
50:50	32	41	39	32	28	26	24	19
0:100	41	44	41	33	32	33	28	23
	One-fifth strength							
100:0	27	23	25	19	14	-	-	-
50:50	35	33	30	31	24	19	16	12
0:100	30	30	28	24	23	21	20	18

The CEC values for bean roots at 10 days in the 0 NH_4:100 NO_3 (full strength) and 50 NH_4:50 NO_3 (full strength) were 54 and 52 me/100 g. These were similar to the value obtained by Smith (1955) for beans at the same age when grown in Hoagland's nutrient solution. This also was approximately what Haniuk (1959) reported for beans of this age (Table 6).

The full strength solution should be compared with the dilute solution for beans (Figures 5 and 6). The CEC of the roots followed essentially the same pattern with age for the 50 NH_4:50 NO_3 when the two growth media are compared. In the case of the nutrient solution consisting of 0 NH_4:100 NO_3, however, there was a 43 percent decrease in the CEC for the initial sampling when the solution was dilute. At the end of the sampling the difference had narrowed to only 30 percent. This means that if the nutrient solution contains nitrate and ammonium nitrogen in about equal quantities the CEC of the roots of bean plants will be about the same whether the nutrient concentration is dilute or full strength. If the solution contains the nitrogen in the nitrate form, the root CEC will be much less if the solution is dilute. If the solution contains only ammonium nitrogen the root CEC will be the lowest.

Table 6 shows the CEC values obtained by other studies for the two species corn and beans in comparison with the values obtained from the first segment in this experiment.

Table 6. Cation exchange capacity of corn and bean roots reported by various studies

	Plant species			
	Corn		Beans	
Worker	CEC	Age	CEC	Age
	me/100 g	days	me/100 g	days
Present study (1962)				
Highest value	20	11	68	6
Lowest value	12	27	31	26
Initial value	14	7	68	6
Bell (1957)	46-23	9-14		
Haniuk (1959)	91-26	10-21	30-88	10-42
Drake et al. (1951)	22	10		
McLean et al. (1956)	25	15		
Smith (1955)			53	10

SUMMARY

This experiment was conducted to study the effect of different sources and levels of nitrogen on the CEC of roots for two plant species--corn (Zea mays) and beans (Phaseolus vulgaris).

The CEC of the roots was found by titrating dialyzed roots with standard base and relating to the dry weight.

1. The corn roots showed a tendency to possess higher CEC with NO_3 as its source of nitrogen than with NH_4. The highest values, however, were obtained when NH_4 and NO_3 were combined.

2. The CEC of the corn at full strength was higher than in the dilute solution, though both had the same pattern.

3. The CEC values obtained for bean roots were much higher than those obtained from the corn.

4. The CEC of the bean roots followed essentially the same pattern with age for the 50 NH_4:50 NO_3 when the two growth media are compared. This means that if the nutrient solution contains nitrate and ammonium nitrogen in about equal quantities the CEC of the bean roots will be about the same whether the nutrient concentration is dilute or full strength.

5. If the solution contains the nitrogen in the nitrate form, the CEC of bean roots will be much less when the solution is diluted.

6. The first 5 cm in both corn and beans had higher CEC than in the second 5 cm.

As was shown by the data presented in this experiment, the different sources of the nutrient element and its level affected the CEC of both corn and beans. This may have an important effect on a number of phases. It is considered that ion absorption process is an exchange process (Overstreet, 1952). So it would depend to a large extent on the CEC values of the roots.

This experiment also emphasizes the effect of the species, age, and segment of the root on the values of the CEC. So, for a proper comparison between two species, these factors should be in mind.

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APPENDIX

Table 7. The individual CEC values of the first 5 cm of corn roots grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

		Days from transplanting							
$NH_4:NO_3$	Rep	7	9	11	13	15	19	23	27
		Full strength							
50:50	1	17	15	20	16	15	16	10	13
	2	12	19	18	17	17	11	17	14
	3	13	13	22	20	20	8	12	10
	4	13	20	20	16	16	12	13	9
0:100	1	9	15	11	11	8	14	11	7
	2	11	12	15	8	11	9	8	10
	3	11	17	8	8	11	10	8	9
	4	13	13	12	19	13	11	8	7
		One-fifth strength							
100:0	1	8	8	7	6	8	5	4	-
	2	7	6	6	8	7	5	6	-
	3	10	7	9	10	5	6	4	-
	4	11	-	6	5	6	5	5	-
50:50	1	8	11	13	9	9	11	6	7
	2	7	10	6	13	10	6	7	6
	3	10	7	9	11	12	8	7	9
	4	9	8	10	11	9	-	6	5
0:100	1	7	7	-	6	4	5	5	1
	2	6	8	6	5	6	4	2	4
	3	8	6	5	6	7	4	4	3
	4	6	6	5	4	-	3	4	5

Table 8. The individual CEC values of the second 5 cm of the corn roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

		Days from transplanting							
NH_4:NO_3	Rep	7	9	11	13	15	19	23	27
		Full strength							
50:50	1	8	9	10	13	10	8	7	7
	2	11	8	17	9	9	9	8	5
	3	7	14	10	9	9	9	6	8
	4	7	11	13	9	8	7	8	7
0:100	1	5	8	8	8	8	6	–	7
	2	16	9	6	7	8	8	7	5
	3	15	9	7	8	10	6	7	7
	4	7	6	7	–	6	9	6	3
		One-fifth strength							
100:0	1	7	7	6	8	6	5	5	–
	2	7	8	5	4	5	4	3	–
	3	6	6	5	5	6	5	3	–
	4	8	–	5	5	5	–	5	–
50:50	1	7	7	8	6	6	6	4	6
	2	7	6	9	7	7	4	5	5
	3	3	9	9	9	5	5	6	4
	4	6	7	6	–	–	–	12	6
0:100	1	7	7	–	6	4	5	5	1
	2	6	8	6	5	6	4	2	4
	3	8	6	5	6	7	4	4	3
	4	6	6	5	4	–	3	4	5

Table 9. The individual CEC values of the first 5 cm of the bean roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

		Days from transplanting							
$NH_4:NO_3$	Rep	6	8	10	12	14	18	22	26
				Full strength					
100:0	1	47	40	45	30	21	-	-	-
	2	50	39	36	28	17	-	-	-
	3	45	36	34	25	19	-	-	-
	4	53	42	40	34	14	-	-	-
50:50	1	55	55	53	48	45	38	29	22
	2	59	53	52	50	44	46	26	21
	3	53	56	46	50	40	39	32	17
	4	56	-	56	46	48	29	40	24
0:100	1	69	57	53	52	49	46	25	28
	2	74	58	50	52	38	47	35	25
	3	67	54	60	51	51	35	44	32
	4	64	74	54	58	46	44	39	39
				One-fifth strength					
100:0	1	40	34	30	24	17	-	-	-
	2	36	36	29	27	18	-	-	-
	3	33	37	27	26	14	-	-	-
	4	32	32	21	19	20	-	-	-
50:50	1	62	57	48	44	38	32	23	-
	2	60	58	43	42	43	27	21	14
	3	65	41	47	40	36	50	17	11
	4	49	57	51	46	34	31	22	17
0:100	1	38	37	38	42	32	32	25	20
	2	39	38	35	35	33	28	24	16
	3	44	32	22	30	28	26	20	22
	4	34	36	31	29	32	23	-	31

Table 10. The individual CEC values of the second 5 cm of bean roots when grown in full strength and one-fifth strength nutrient solution in which the ammonium to nitrate ratio varies (me/100 g)

		Days from transplanting							
$NH_4:NO_3$	Rep	6	8	10	12	14	18	22	26
		Full strength							
50:50	1	35	41	37	27	24	40	26	17
	2	32	38	41	32	29	22	23	18
	3	21	34	34	40	35	24	19	17
	4	39	52	44	30	23	17	27	24
0:100	1	40	44	41	24	30	28	31	23
	2	44	51	45	41	34	42	29	33
	3	32	42	36	34	38	32	27	20
	4	48	40	-	32	28	29	29	21
100:0	1	26	25	23	20	13	-	-	-
	2	29	21	26	16	15	-	-	-
	3	24	20	20	23	18	-	-	-
	4	29	27	31	17	11	-	-	-
50:50	1	42	30	33	30	20	23	18	-
	2	40	38	42	38	31	20	17	14
	3	37	43	18	25	21	18	16	15
	4	20	20	16	-	22	15	11	20
0:100	1	27	28	25	23	21	24	28	20
	2	25	38	26	29	27	20	16	22
	3	31	21	29	25	22	26	20	16
	4	35	33	32	21	-	13	17	13