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DISTRIBUTION OF DIFFERENT FORMS OF NITROGEN

IN SOME DESERT SOILS

H. NISHITA AND R. M. HAUG

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Author Name and Affiliation:

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Table 1

Weight percentage of different forms of nitrogen in a desert soil (Profile A)*.

Soil Depth cm.	Inorganic N					Organic N $10^{-2}\%$	Total N $10^{-2}\%$	pH 1:1 Suspension
	Fixed NH_4^+-N $10^{-2}\%$	Extractable						
		NH_4^+-N $10^{-2}\%$	NO_2^--N $10^{-2}\%$	NO_3^--N $10^{-2}\%$	Total $10^{-2}\%$			
0.0 - 7.6	0.53	0.02	N	0.29	0.31	4.9	5.7	8.30
7.6 - 15.2	0.56	0.01	N	0.11	0.12	2.5	3.2	8.25
15.2 - 22.9	0.59	0.01	N	0.08	0.09	1.7	2.4	8.19
22.9 - 30.5	0.54	0.02	N	0.08	0.10	1.3	1.9	8.02
30.5 - 38.1	0.61	0.04	N	0.09	0.13	1.0	1.6	7.88
38.1 - 45.7	0.61	0.02	N	0.06	0.08	1.1	1.8	7.79
45.7 - 53.3	0.58	0.01	N	0.04	0.05	1.1	1.7	8.05
53.3 - 61.0	0.55	0.01	N	0.04	0.05	1.1	1.7	8.03
61.0 - 68.6	0.49	0.01	N	0.03	0.04	0.4	0.9	8.16
68.6 - 76.2	0.57	0.01	N	0.11	0.12	0.4	1.1	7.81
76.2 - 83.8	0.64	0.01	N	0.19	0.20	0.5	1.3	7.55
83.8 - 91.4	0.55	0.02	N	0.26	0.28	0.9	1.7	7.70

*Profile collected under isolated A. canescens in an area in which the dominant plant association was Atriplex-Sphaeralcea-Oryzopsis vegetation. Approximate dimension of plant canopy = 81 cm wide x 64 cm deep x 48 cm high. Plant leaf N content = 3.56 per cent. Plant litter N content = 0.91 per cent. Mean annual temperature (1970) = 56.96° C. Mean annual rainfall (1970) = 0.66 cm.

N = not detectable.

Table 2

Weight percentage of different forms of nitrogen in a desert soil (Profile B)*.

Soil Depth cm	Inorganic N					Organic N 10 ⁻² %	Total N 10 ⁻² %	pH 1:1 Suspension
	Fixed	Extractable						
	NH ₄ ⁺ -N 10 ⁻² %	NH ₄ ⁺ -N 10 ⁻² %	NO ₂ ⁻ -N 10 ⁻² %	NO ₃ ⁻ -N 10 ⁻² %	Total 10 ⁻² %			
0.0 - 7.6	0.67	0.01	N	0.12	0.13	2.7	3.5	7.86
7.6 - 15.2	0.79	0.01	N	0.03	0.04	0.8	1.6	7.87
15.2 - 22.9	0.79	0.01	N	0.02	0.03	0.9	1.7	7.76
22.9 - 30.5	0.77	0.003	T	0.02	0.02	0.8	1.7	7.78
30.5 - 38.1	0.76	0.02	N	0.02	0.04	0.4	1.2	7.76
38.1 - 45.7	0.73	0.01	T	0.01	0.02	0.5	1.2	8.03
45.7 - 53.3	0.65	0.01	T	T	0.01	0.8	1.5	8.06
53.3 - 61.0	0.63	0.004	T	N	0.004	0.8	1.4	8.06
61.0 - 68.6	0.62	0.01	T	N	0.01	0.3	0.9	8.12
68.6 - 76.2	0.64	0.01	T	N	0.01	0.5	1.1	8.11
76.2 - 83.8	0.57	0.01	T	T	0.01	0.6	1.1	8.13
83.8 - 91.4	0.56	0.01	T	N	0.01	0.3	0.9	8.26

*Profile collected under isolated A. canescens in an area in which the dominant plant association was Larrea - Franseria vegetation. Approximate dimension of plant canopy = 71 cm wide x 66 cm deep x 51 cm high. Plant leaf N content = 2.94 per cent. Plant litter N content = 0.64 per cent.

N = not detectable; T = trace amount.

Table 3

Ranges of the amounts of different forms of nitrogen in the desert soil profiles collected under Atriplex canescens.*

Soil Depth cm	Inorganic N					Organic-N	Total-N	pH 1:1 Suspension
	Fixed NH_4^+ -N Total-N %	Extractable N				Total-N		
		NH_4^+ -N Total-N %	NO_2^- -N Total-N %	NO_3^- -N Total-N %	Total Ext.N Total-N %	%	10^{-2} %	
0.0 - 7.6	3.4 - 19.1	0.11 - 0.49	N	0.71 - 7.24	0.93 - 7.41	77.1 - 94.4	3.5 - 16.1	7.47 - 8.30
7.6 - 15.2	4.3 - 49.4	0.22 - 0.63	N-T	0.22 - 6.07	0.54 - 6.48	50.0 - 93.9	1.6 - 11.5	7.65 - 8.25
15.2 - 22.9	5.6 - 46.5	0.27 - 0.76	N-T	0.88 - 3.13	1.64 - 3.46	53.9 - 93.1	1.7 - 8.7	7.57 - 8.23
22.9 - 30.5	5.8 - 48.1	0.19 - 0.79	N-T	0.30 - 4.05	0.67 - 4.84	50.0 - 93.2	1.6 - 7.4	7.62 - 8.11
30.5 - 38.1	7.1 - 63.3	0.15 - 2.31	N-T	0.24 - 5.31	0.76 - 7.63	33.3 - 92.3	1.2 - 6.5	7.31 - 8.23
38.1 - 45.7	5.0 - 61.8	0.19 - 1.00	N-T	0.36 - 7.68	0.70 - 4.28	41.7 - 94.1	1.2 - 6.8	7.17 - 8.03
45.7 - 53.3	4.3 - 43.3	0.14 - 0.65	N-T	N - 5.86	0.33 - 7.89	53.3 - 94.7	1.5 - 7.5	7.21 - 8.06
53.3 - 61.0	4.3 - 45.0	0.20 - 0.79	N-T	N - 3.20	0.29 - 3.46	57.1 - 94.6	1.4 - 7.5	7.09 - 8.03
Overall range	3.4 - 63.3	0.11 - 2.31	N-T	N - 7.68	0.33 - 7.89	41.7 - 94.7	1.2 - 16.1	7.09 - 8.30

*Ranges for soil profiles collected under A. canescens in 5 widely dispersed areas with different dominant plant association. Plant leaf and litter N concentration ranges were 2.50 - 3.56 and 0.64 - 1.25 per cent, respectively. Mean annual temperature (1970) range = 44.2 - 60.6° C. Mean annual rainfall (1970) range = 0.66 - 1.72 cm. N = not detectable; T = trace amount.

Table 4

Ranges of total-N and native fixed NH_4^+ -N in soils examined by several investigators.

Number of Soil Profiles Examined	Total N %	Fixed NH_4^+ -N me./100 g.	Fixed NH_4^+ -N	Reference
			$\frac{\text{Total-N}}{\%}$	
5	0.22 - 0.428	0.01 - 0.34		Nömmik, 1957
9	0.012 - 0.290	0.68 - 1.34	3.5 - 81.7	Stevenson, 1959
17	-	<0.05 ->1.5	-	Stevenson and Dharwal, 1959
21	0.016 - 0.562	0.18 - 1.17	1.3 - 39.9	Walsh and Murdock, 1960
17	0.16 - 0.496	0.09 - 0.77	0.7 - 41.7	Young, 1962
4	-	0.89 - 1.88	-	Shreven, 1963

Table 5

Nitrogen concentration of the soil under Krameria parvifolia and in the profile of the bare soil one meter away from it.*

Soil Depth cm	Fixed $\text{NH}_4^+ \text{--N}$		Extractable Inorganic-N		Organic-N		Total-N	
	I	II	I	II	I	II	I	II
	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$
0.0 - 7.6	0.51	0.76	0.18	0.03	13.7	1.4	14.4	2.2
7.6 - 15.2	0.50	0.58	0.04	0.01	3.8	1.5	4.3	2.1
15.2 - 22.9	0.47	0.56	0.04	0.01	3.4	1.1	3.9	1.7
22.9 - 30.5	0.46	0.56	0.03	0.01	4.0	1.4	4.5	2.0
30.5 - 38.1	0.46	0.59	0.02	0.01	4.3	1.4	4.8	2.0
38.1 - 45.7	0.50	0.60	0.02	0.02	2.2	1.7	2.7	2.3
45.7 - 53.3	0.53	0.72	0.02	0.01	2.6	1.4	3.1	2.1
53.5 - 61.0	0.55	-	0.01	-	2.4	-	3.0	-
61.0 - 68.6	0.61	-	0.01	-	1.7	-	2.3	-

*N content expressed as percentage of oven dry soil.

I. N concentrations under K. parvifolia.

II. N concentrations in the profile of bare soil one meter away from the base of the above plant.

Table 6

Nitrogen concentration of the soil under Larrea divaricata and in the profile of the bare soil one meter away from it.*

Soil Depth cm	Fixed NH_4^+ -N		Extractable Inorganic-N		Organic-N		Total-N	
	I	II	I	II	I	II	I	II
	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$	$10^{-2}\%$
0.0 - 7.6	0.63	0.66	0.63	0.03	11.72	1.70	12.98	2.39
7.6 - 15.2	0.64	0.66	0.15	0.03	5.17	1.74	5.96	2.43
15.2 - 22.9	0.64	0.64	0.03	0.02	3.13	1.98	3.80	2.64
22.9 - 30.5	0.56	0.59	0.04	0.04	2.98	1.89	3.58	2.52
30.5 - 38.1	0.49	0.55	0.05	0.02	2.78	1.88	3.32	2.45
38.1 - 45.7	0.56	0.65	0.07	0.03	3.10	2.32	3.73	3.00
45.7 - 53.3	0.58	0.61	0.09	0.04	2.73	2.49	3.40	3.14
53.3 - 61.0	0.64	0.62	0.07	0.03	3.18	2.32	3.89	2.97

*N content expressed as percentage of oven dry soil.

I. N concentrations under L. divaricata.

II. N concentration in the profile of bare soil one meter away from the base of the above plant.

Table 7

Exchangeable and nonexchangeable K^+ in the soil profiles under Krameria parvifolia and Larrea divaricata and in the profiles of the bare soil one meter away from them.

Soil Depth cm	<u>K. parvifolia</u>						<u>L. divaricata</u>					
	Under Plant			Under Bare Soil			Under Plant			Under Bare Plant		
	A* me/ 100g	B* me/ 100g	$\frac{A}{B}$ Ratio	A* me/ 100g	B* me/ 100g	$\frac{A}{B}$ Ratio	A* me/ 100g	B* me/ 100g	$\frac{A}{B}$ Ratio	A* me/ 100g	B* me/ 100g	$\frac{A}{B}$ Ratio
0.0 - 7.6	3.72	11.49	0.32	1.71	12.06	0.14	3.08	11.89	0.26	1.39	11.88	0.12
7.6 - 15.2	4.61	11.38	0.41	1.49	10.41	0.14	3.11	12.06	0.26	1.69	12.90	0.13
15.2 - 22.9	4.38	10.86	0.40	1.29	9.71	0.13	3.33	11.98	0.28	1.70	11.95	0.14
22.9 - 30.5	4.15	10.84	0.38	1.28	9.40	0.14	3.29	11.64	0.28	1.65	12.35	0.13
30.5 - 38.1	3.82	10.93	0.35	1.35	9.96	0.14	2.28	11.01	0.21	1.30	11.86	0.11
38.1 - 45.7	3.95	10.78	0.37	1.39	10.62	0.13	2.75	12.01	0.23	1.61	13.32	0.12
45.7 - 53.3	4.35	11.86	0.37	1.52	12.57	0.12	2.32	11.95	0.19	1.64	12.19	0.14
53.3 - 61.0	4.29	12.56	0.34	-	-	-	2.33	14.11	0.17	1.45	11.22	0.13

*A = exchangeable K^+ ; B = nonexchangeable K^+ .

Footnotes:

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ABSTRACT

The distribution of different forms of N in the profiles of desert soils collected in different areas of the Nevada Test Site was examined. Among the soil profiles examined, the order of the amount of the different forms of N in the surface layer (0.0 - 7.6 cm) was always NO_2^- -N (not detectable) < extractable NH_4^+ -N < NO_3^+ -N < fixed NH_4^+ -N < organic-N. This order may be changed in the sublayers. The extractable NH_4^+ -N may be greater than NO_3^- -N with the presence of trace amount of NO_2^- -N and/or the fixed NH_4^+ -N may be greater than organic-N. The amount of total-N was the greatest in the surface layer and usually decreased very sharply in the second layer (7.6 - 15.2 cm). Below the second layer, the total-N contents generally varied slightly. In the surface layers, the total-N was always accounted for primarily by organic-N. The amount of fixed NH_4^+ -N varied somewhat with different soils, but within any given soil profile, it generally varied slightly. The average absolute amount of it in the profiles collected in different areas and under different plant species ranged from 0.0031 to 0.0068 per cent by weight of oven dry soil. Expressed as percentage of total-N, the range was 3.4 - 63.3. The extractable inorganic-N ranged from 0.33 - 7.89 per cent of total-N depending on the soil and the profile layer. Exchangeable K concentration under the plant was 41 to 240 per cent greater than in the bare soil. This plus the higher organic matter content decreased the relative NH_4^+ -N fixation under the plant compared to its fixation in the bare soil.

DISTRIBUTION OF DIFFERENT FORMS OF NITROGEN IN SOME DESERT SOILS

H. Nishita and R. M. Haug

It is well known that in natural ecosystems the N content of soils approaches an equilibrium value. The magnitude of this value depends on a number of factors such as climate, nature of terrain, chemical and physical characteristics of the soil, type of vegetation, and the activities of the microflora and microfauna. A change of any one of these factors will lead immediately to a new equilibrium value. An excellent review of soil N is given in a monograph edited by Bartholomew and Clark (1965).

The objectives of this investigation were to determine the contents and the distributions of the different forms of N in the soils of different areas (areas of different plant associations) of Nevada Test Site, which is located in a region that straddles the boundary between the Mojave and the Great Basin Deserts (Shreve, 1942).

MATERIAL AND METHODS

In obtaining the soil samples, a trench was dug and then the samples were collected from the side of the cut from the top to the bottom in 7.6 cm (3 inch) increments. Wherever possible, the soil profile samples were collected to a depth of 94.4 cm (36 inches). Several profiles had indurated caliche layer in the 45-60 cm depth zone. The profiles without caliche layers generally appeared to be well drained. As each soil increment was taken, the lower increment was protected from the soil that may fall from above with a 3-sided (15 x 15 cm), telescopic, stainless

steel sleeve, which was open toward the trench. As soon as each soil increment was collected (into a plastic bag), it was placed in an ice box containing blocks of dry ice (solid CO_2) and kept there until the analyses for different forms of N were completed. This procedure was followed to minimize the activity of the microorganisms that may be involved in N transformations during the period of sample transport and storage. This precaution was taken because some of the subsoil samples collected were relatively high in moisture. The moisture contents of samples collected during the hot, dry season varied from 1.10 to 7.20 per cent depending on the site of collection and the depth in the soil profile. All results presented are on the basis of oven dry soil. The profile samples were collected under the canopy of isolated plants (Atriplex canescens (Pursh) Nutt., Krameria parvifolia Benth., and Larrea divaricata Cav.) and in the bare soil near it. The soil profiles collected under the plants were always within 15 cm distance from the plant base. The profiles collected in the bare soil were 100 cm from the plant base.

Aside from the soil samples, the new growth leaves of the plant and the litter under it were collected for total-N analyses. The total-N was determined with a Coleman Model 29A Analyzer II on 0.1 g aliquots of pulverized plant material. The total-N contents of the soils were determined by one g aliquots, using the apparatus operating parameters essentially as prescribed by Keeney and Bremner (1967). The NO_3^- , NO_2^- , and exchangeable NH_4^+ were determined by micro-Kjeldahl procedures using MgO and Devarda alloy. These procedures were essentially as presented by Bremner (1965) with a slight modification, i.e., the determination of NH_4^+ was done on the steam distillate by means of Nesslerization and

photometry. The NO_3^- , NO_2^- , and extractable NH_4^+ were extracted for analysis from the soils with 2 N KCl. The nonexchangeable (fixed) NH_4^+ was determined also by a method presented by Bremner (1965). In this method, NH_4^+ was determined on the soils treated with 5N HF-1N HCl solution. The soils were pretreated with KBr-KOH solution to remove the organic-N compounds and with 0.5 N KCl to remove the extractable NH_4^+ before their treatment with 5N HF-1N HCl solution. The organic-N was calculated by subtracting the sum of the inorganic-N from the total-N. The exchangeable and the nonexchangeable K were determined by Haylock's method (1956). All analyses were done on soil samples that were passed through a 2-mm sieve, except the nonexchangeable NH_4^+ and the total-N analyses. The latter two analyses were done on samples that were passed through the 2-mm sieve and then ground to pass through a 100-mesh (149 micron) screen.

RESULTS AND DISCUSSION

The soil profiles examined showed various distribution patterns of N forms. One distribution pattern is shown in Table 1 (profile A collected under an isolated A. canescens). The order of the amount of the different N forms in the surface layer (0.0 - 7.6 cm) was NO_2^- -N (not detectable) < extractable NH_4^+ -N < NO_3^- -N < fixed NH_4^+ -N < organic-N. This order was maintained to a depth of 61 cm. In the 61-84 cm depth zone, the fixed NH_4^+ -N was greater than the organic-N. This occurred because the organic-N decreased to a relatively low level in this depth zone while the fixed NH_4^+ -N varied only to a small extent from the top to the bottom layer of the profile. Both the total-N and the organic-N occurred in the greatest concentration in the surface layer (0.0 - 7.6 cm) and decreased sharply in the second layer (7.6 - 15.2 cm). Below

the second layer, the amount of the organic-N and the total-N varied relatively only a small extent throughout the profile. Because of the lower total-N in the sublayers, the proportion of the total-N in the form of fixed NH_4^+ -N was considerably greater than in the surface layer. For example, expressed as percentage of total-N, the amount of fixed NH_4^+ -N in the surface layer was 9.3 whereas that in the sublayers ranged from 17.5 to 54.4. The point to note here is that the absolute amount of fixed NH_4^+ -N varied only a small extent throughout the profile. The total extractable inorganic-N varied from 0.0009 to 0.0031 per cent (3.75 to 16.47 per cent of the total-N) depending on the profile layer. The extractable inorganic-N was primarily in the form of NO_3^+ -N.

The texture of the surface layers of soil profile A was quite loose down to about 25 cm depth. In the 25-30 cm depth zone the soil was somewhat compacted, but below this zone, it was relatively loose. Most of the A. canescens plant roots were distributed above the compacted zone. In view of the root distribution and the N distribution, the N in the plant probably was absorbed primarily from the surface layers of the soil profile.

Table 2 shows another pattern of distribution (profile B). Note that the surface layer exhibited the same order shown above, i.e., NO_2^- -N (not detectable) < extractable NH_4^+ -N < NO_3^- -N < fixed NH_4^+ -N < organic-N. Again the amount of fixed NH_4^+ -N is shown to vary only a small extent throughout the profile. This profile differed from profile A in that most sublayers of this soil contained trace amounts of NO_2^- -N. Also, the amount of extractable NH_4^+ -N was consistently greater than that of NO_3^- -N below the

45.7 cm depth. This and the presence of trace amounts of NO_2^- suggest that the oxidation of the reduced form of N to a more oxidized state was inhibited to some extent. Part of this effect may have been caused by the compacted zone of the soil profile. The soil of this profile was of loose texture to a depth of 15 cm and was somewhat compacted in the 15-43 cm zone. The strongest compaction occurred in the 23-31 cm zone. Below the 43 cm depth, the soil was loose. Perhaps, the compacted zone restricted the oxygen concentration. The NO_3^- accumulation is dependent upon adequate aeration. The N autotrophs are obligate aerobes, and except for Clostridium butyricum, all the known heterotrophs involved in nitrification are aerobic (Alexander, 1965). The absence of oxygen is invariably associated with the absence or immediate loss of oxidized form of N. The optimum percentage of oxygen for rapid NO_3^- production in soil is similar to that found in air (Amer and Bartholomew, 1951; Grechin and Ch'eng, 1960).

The distribution of the plant roots in the soil of profile B was primarily within the 30 cm with a few in the 61-91 cm depth zone. This again indicates that the N in the plant was absorbed mostly from the surface layers of the profile.

Profiles A and B give two examples of the distribution of the different N forms in the soils found in different areas of Nevada Test Site. In order to minimize tabular data, the data obtained for the profiles that were collected at different places are reduced to ranges of values in Table 3. These data serve to give the reasonable values which might be expected under A. canescens growing in the soils of several areas having different plant associations. In order to include all profiles collected under

A. canescens, the data only to a depth of 61 cm are given. Several profiles were not sampled below this depth because of the hard caliche layer. Note that the soils were all on the alkaline range of the pH scale. The most favorable reaction in soil for NH_4^+ oxidizers is above neutrality, while that for the NO_2^- oxidizers is close to the neutral point (Morill and Dawson, 1962). Nitrification proceeds only slowly in acid soils (Alexander, 1965).

Table 3 shows that a considerable amount of NH_4^+ fixation by inorganic soil materials can occur in the desert soils examined. Within the depth of the soil profile shown (down to 61 cm) up to about 63 per cent of total-N occurred in the form of fixed NH_4^+ -N. This is important because the biological activity of fixed NH_4^+ -N is considered to be lower than the exchangeable NH_4^+ -N. Bower (1951), working with the subsoils of two soils with vermiculite as their predominant mineral component, found that after a nitrification period of 28 days, only 13 to 28 per cent of the fixed NH_4^+ -N was nitrified, whereas 78 to 87 per cent of the readily exchangeable NH_4^+ -N was nitrified in the same interval of time. Allison, Doetsch and Roller (1951), working with soils containing predominantly montmorillonite and illite, found that not more than 10 per cent of the fixed NH_4^+ -N was available to nitrifying bacteria during 6 to 16 week periods. The availability of fixed NH_4^+ -N to plants is limited also. Millet grown in an illitic soil assimilated not more than 7 per cent of the fixed NH_4^+ -N when fixation had been brought about by air drying and 12 per cent when fixation was brought about by oven drying (Allison, Doetsch and Roller, 1953b). Working with a vermiculitic soil, Walsh and Murdock (1960) found that only about 15 per cent of the native fixed NH_4^+ -N was

absorbed by corn plants, even under the most advantageous condition.

Table 4 gives a compilation of the total-N and native fixed NH_4^+ -N in soils examined by a number of different investigators. The data represent soils collected in widely different areas of the world. The range of the fixed NH_4^+ -N (expressed as percentage of total-N) in the desert soils (table 3) was more or less similar to those of soils collected in other areas of the world (table 4). The soil components chiefly responsible for the fixation of NH_4^+ -N are vermiculite, illite and montmorillonite (Allison, Doetsch and Roller, 1953a, 1953b; Nömmik, 1957; Stevenson, 1959; Stevenson and Dhariwal, 1959; Walsh and Murdock, 1960).

Examples of the differences of soil N distribution that may occur under a plant and in the bare soil near it are given in tables 5 and 6, which show the soil N contents under K. parvifolia and L. divaricata and the bare soil profiles one meter away from them, respectively. The profile under L. divaricata was about 9 meters away from that under K. parvifolia. The L. divaricata plant was isolated, the nearest plant to it being 3 meters away. The tables show several consistent effects. The absolute concentration of total-N in the soil layers under the plant were consistently greater than in the profile layers of the bare soil. In both cases, the organic-N composed the major fraction of the total-N. Also, its fraction in the soil layers under the plants were consistently greater (0.80 - 0.95) than in the bare soils (0.64 - 0.79, depending on the layer). The total extractable inorganic-N, which consisted primarily of NO_3^- -N, was generally greater under the plant also. The amounts of fixed NH_4^+ -N, however, were greater in the profile of the bare soil than in the soil under the plant.

This difference probably was caused partly by the higher organic matter content of the soil under the plant. Organic molecules are sorbed to a varying extent by expanding lattice aluminosilicate minerals by the replacement of inorganic cations (Ensminger and Gieseking, 1941; Hendricks, 1941; Walker, 1959; Mortland, 1961; Greenland and Quirk, 1962; Greenland, Laby, and Quirk, 1965). The cation movement into the lattice interlayers is considered to be by diffusion along cation exchange sites (Walker, 1959). In order for this to occur, the external solution phase ions must be able to exchange with other ions on the exchange complex. If the adsorption energies of the organic cations are sufficiently large so that the external solution phase ions (NH_4^+ ions, in the present case) cannot displace them, the external ions are in effect blocked. This effect also implies that the number of accessible exchange sites for the fixation of NH_4^+ ions is decreased.

Another factor causing the relatively lower concentration of fixed $\text{NH}_4^+\text{-N}$ in the soil under the plants may be the depressive effect of K^+ on NH_4^+ fixation, which is a well known phenomenon (Stanford and Pierre, 1947; Bower, 1950; Nõmmik, 1957; Jansson, 1958). This may be surmised from the fact that the exchangeable K^+ concentrations in the soil under K. parvifolia was 118 to 240 per cent greater than in the bare soil, depending on the soil depth (table 7). That in the soil under L. divaricata was 41 to 122 per cent greater than in the bare soil. Since the nonexchangeable K^+ in the soils under the plants differed only slightly, if at all, from that in the bare soils, the exchangeable/nonexchangeable K^+ ratios for the former soils were consistently much greater than those for the latter soils. Thus, the K^+ available to compete with NH_4^+ ions was greater in the soils under the plants.