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# Transformation of Fertilizer and Organic Nitrogen in Soil as Affected by Soil Factors

A. Hadas, J. Letey,Jr., S. Feigenbaum, A. Feigin,
D. Levanon, W.M. Jarrell, W.T. Frankenberger, Jr.

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# TRANSFORMATION OF FERTILIZER AND ORGANIC NITROGEN IN SOIL AS AFFECTED BY SOIL FACTORS

Name of Investigators:

Principal Investigator: Aviva Hadas

Cooperating Investigator(s): Sala Feigenbaum, A. Feigin, D. Levanon, J. Letey, Jr., W.M. Jarrell, W.T.Frankenberger, Jr.

Name and Address of Affiliated Institutions:

Principal Institution: Agricultural Research Organization, Bet Dagan, 50-250, Israel.

Cooperating Institution(s): The Regents of the University of California, University of California, Riverside, Riverside, Ca. 92521, U.S.A.

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Signatures:

Principal Investigator

Aviva Hadas

Institution's Authorizing Official

Yuval Eshdat

Dr. YUVAL ESHDAT
Head, Div. for Research Projects and Budgets
Agricultural Research Organization

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## A. Abstract

Nitrogen transformations were studied in different soil types, depths and agricultural management practices. Soil N mineralization and $NH_4$ nitrification rates were determined in incubation experiments and the distribution of $NH_4$ and $NO_3$ were determined under various fertilization and irrigation practices. Mineralization rate decreased with soil depth , more than did organic N content, however, about 30% of N mineralized in soil profiles was contributed by soil layers deeper than 60 cm. This was verified under field conditions in undisturbed soil profiles. Potentially mineralizable N ($N_o$), obtained from one-parameter-rate equations, was highly correlated with various soil N forms (which were all significantly correlated with soil total N). The best chemical and biological estimates of $N_o$ were amino acids in soil acid hydrolyzate and $CO_2$ production rate at the 1st week of incubation respectively, both decreasing with soil depth more than total N. Nitrification rate was well-correlated with the growth rate of the nitrifying bacteria. The maximal rate and the delay period of nitrification were greatly affected by soil depth, soil pH or $HCO_3^-$ content and by previous agricultural management of the soils. Increased salinity decreased nitrification and promoted ammonia volatilization, the effect depending on soil type and on the amount and type of salts and N source added. Application of urea ammonium nitrate to a sandy loam by drip irrigation produced a remarkable drop in soil pH in the vicinity of the emitter. Coating $(NH_4)_2SO_4$ with Terrazole inhibited nitrification under field conditions, retaining more $NH_4$ in the soil profile and decreasing movement and denitrification even at high irrigation rates.

## B. Objectives of the research

The general objective of the research was to study nitrogen transformation rates in soil, mainly ammonium nitrification and organic N mineralization, as affected by soil types, soil depths and different agricultural management practices. Soil types were expressed in terms of general soil properties such as texture, pH, electrical conductivity, organic N content, and specific properties, like soil nitrogen forms and microbial activity, which affect or reflect soil N transformations. Agricultural management included different irrigation practices, salinity induced by added salts, fertilizer management and the effect of previous management of the field on N transformation rates.

The specific objectives, corresponding to the different parts of the research, were as follows:

1. To study the distribution of soil organic N forms in profiles of different soil types. To find relations between the various N forms tested, in order to ultimately choose a suitable index for predicting the potentially mineralizable nitrogen or N mineralization rate.
2. To determine soil N mineralization rate in different soil types and depths, and to evaluate the contribution of deeper soil layers to N mineralized in soil profiles. To fit rate equations and to relate the obtained rate parameters to N availability indices or N fractions in soil.
3. To verify, under field conditions, the N mineralization rate in soil profiles and the contribution of deeper soil layers as obtained by incubation experiments.
4. To determine the rate of nitrification of added ammonium in soil profiles of differently managed soil types. To relate the rate constants

to soil properties and soil depth. To determine immobilization of added N and mineralization when ammonium fertilizer is added to soils.

5. To investigate the effect of soil type and soil depth on the growth rate and potential activity of the nitrifying bacteria. To study the composition and activity of the mineralizing microflora in profiles of differently managed soil types.
6. To study the effect of soil salinity, induced by chloride and sulfate salts, on ammonification of urea, nitrification and ammonia volatilization.
7. To follow the fate of nitrogen from surface and subsurface applied liquid urea-ammonium nitrate (UAN) added to soil through a drip system and to determine the influence of UAN on soil pH.
8. To study N transformations and movement in soil as influenced by water application rate and Terrazole nitrification inhibitor.

C. Research Report

# I. DISTRIBUTION OF NITROGEN FORMS AN AVAILABILITY INDICES IN IN PROFILES OF DIFFERENTLY MANAGED SOIL TYPES

Aviva Hadas, Sala Feigenbaum, A. Feigin and Rita Portnoy

ABSTRACT

Various chemical methods have been used to predict the nitrogen mineralization potential of soils, but studies were mostly restricted to surface soil layers to which N mineralization is mainly attributed. In this study the distribution of N forms, extracted from soil by different chemical methods, and the relationship between them was determined within the profiles of several soil types. All N parameters tested were significantly correlated with total N. The fractions of several N parameters of total N changed with soil depth: oxidative release of $NH_4$ by acid $KMnO_4$, N extracted by $NaHCO_3$ and $NH_4$ and hexasamine in soil acid hydrolyzate increased, whereas amino acids and amidase activity decreased with soil depth. Soil type also influenced some N parameters: acid $KMnO_4$ extracted relatively more $NH_4$ from calcareous than noncalcareous soils; a smaller fraction of total N was acid hydrolyzable in soils with a greater surface area.

Amino acids in the hydrolyzate and amidase activity seem more promising for the prediction of mineralizable N, when considering the whole soil profile, than the other N

parameters, because of their greatest decrease with soil depth.

## INTRODUCTION

The rate of nitrogen mineralization in soils can be directly measured by incubating soil samples in controlled environmental conditions. However, incubation techniques are time consuming and therefore often not practical for predicting mineral N contribution from soil organic N and fertilization planning. Consequently, several chemcial extraction methods have been suggested to either predict the quantity of mineral N that the soil will release for a growing crop (Selmer-Oslen et al., 1981; Fox & Piekielek, 1978a), or to predict the potentially mineralizable nitrogen of soils (Stanford & Smith, 1976; Stanford & Smith, 1978). The different empirical methods extract certain fractions of soil organic N and their effectiveness varies probably with soil type and mainly with soil pH. Much better defined fractions of soil organic N can be obtained by acid hydrolysis and chemical fractionation of the hydrolyzate (Bremner, 1965). These fractions could provide a comparative basis for evaluating the empirical extractions in various soil types or soils from fields with a different history.

The quantity of decomposable organic nitrogen, which determines the rate of mineralization, also affects the

potential enzyme activity in soil. Correlations have been found between the activity of several enzymes and extractable organic N (Spalding & Duxbury, 1977) or mineralization rate (Abdelmagid, 1982).

The contribution of mineral N from organic sources is usually attributed to the surface soil only, since microbial activity in deeper soil layers is much smaller. Therefore very little information has been collected on the various chemical indices, as well as enzyme activities, in whole soil profiles. However, plant roots live, die and decompose in soil layers as deep as 1 m and more, and indeed some evidence on N-mineralization in soil profiles has been reported (Cassman & Munns, 1980; Powers, 1980).

The objectives of the present work were: (a) to clarify the distribution of N extracted from soil by means of different chemical methods within soil profiles and in different soil types; (b) to study the relations between organic N forms, N extracted by chemical methods and amidase activity in soils and (c) to choose a suitable index for predicting the potentially mineralizable N (Stanford & Smith, 1972) or N mineralization rate.

## MATERIALS AND METHODS

Soils were sampled from various locations in Israel, representing different climatic conditions, soil parent materials and cropping management. The definition of soil

types and some of the sampling places were determined by the aid of the soil survey of Israel soils (Dan & Koyumdjisky, 1979; Dan et al., 1981; Dan & Singer, 1973). General information about the soils is summarized in Table 1. The Alumim soil profile was uncultivated and sampled according to its pedological horizons. Bet Dagan samples were taken from a 22 year-old "permanent plot" experiment, testing the response of field crops to N,P,K levels and manure. During the last 4 years the field was cropped with cotton. Samples were taken from the control, unfertilized treatment and from the highest N, P, K treatment with manure very 7 years (2 years prior to sampling). The Gilat soil profile was taken from an uncultivated field (for at least the last 20 years) near a 20 year-old "permanent plots" experiment testing the effect of N fertilization in combination with manuring on vegetable crops; Two top soil layers were sampled from that experiment 1 year later, one from an unfertilized control plot and the other from a high N and manure treatment. The Kedma profile was sampled at a clay quarry (formerly a cultivated field) according to its pedological horizons. All the soil samples were air-dried, crushed, sieved to pass a 2-mm screen and stored at room temperature for at least two months prior to chemical analyses.

Oxidative release of $NH_4$-N by acid permanganate was determined in 0.05N and in 0.1N $KMnO_4$ after a preliminary

extraction with acid, according to Stanford and Smith (1978).

Ammnonium-N released from soils was determined after heating soil samples with 2N KCL in an oven at 80°C for 20 h according to Oien and Selmer-Olsen (1980).

Nitrogen extraction with $NaHCO_3$ as suggested by McLean (1964) to estimate N supplying capability of soils, and the UV absorption of this extract (Fox & Piekielek, 1978), were slightly modified in this work. In a preliminary test correlations between organic N content and optical density at 260 u of $NaHCO_3$ extracts were better when the $NaHCO_3$ concentrations were 0.03 N or 0.1 N rather than the one suggested by McLean (1964) (0.01 N). Furthermore, the extraction duration of 1/2 hour was preferred over 1/4 hour due to more consistent and and less time dependent results.

Organic forms of N in the soil profiles were analyzed in acid hydrolyzate (Bremner, 1965).

Amidase activity in the soils was determined by the method suggested by Frankenberger & Tabatabai (1980) using formamide as the substrate. The incubation temperature was 35 $\pm$ 0.2°C and $NH_4$-N was determined in soil extracts after centrifugation and not in soil suspensions.

All extracts were performed in duplicates and ammonium N was determined by steam distillation.

General soil propeties were also determined: pH in a saturated soil paste; EC and $HCO_3^-$ concentration in saturation extract; saturation and air dry gravimetric moisture content; $CaCO_3$ content by the volumetric calcimeter method (Black et al., 1965); cation exchange capacity by sodium saturation (Black et al., 1965); organic carbon by the Schollenberg method (Black et al., 1965); total nitrogen by semimicro-Kjeldahl (Black et al., 1965).

## RESULTS AND DISCUSSION

Several general properties of the soils are shown in Table 2. The C/N ratio was generally between 9 and 11 with only a few exceptions, mainly in Gilat, and with no systematic trend with depth. The CEC and air dry moisture content were highly correlated (Table 5). Both parameters were used to calculate the specific surface area (S) according to regression equations found by Banin and Amiel (1969/70), and the results were very similar. Therefore only S obtained from the air dry moisture content ($W_{ad}$) by the equation

$$W_{ad} = 0.025\ S + 0.488$$

was presented in Table 2.

The results of the nitrogen analyses are presented in Table 3. The total level N was relatively high in the top layer of the uncultivated Alumim soil, in the Golan 37 soil, which was under very extensive use and in Eden soil. It

decreased with depth in all soils though not to the same extent.

The amounts of N extracted from soil by different extracts were all significantly correlated with total N in soil (Table 4) and were therefore presented in Table 3 as the fraction of total N rather than in terms of absolute content in soil. This made it easier to compare between soil types and soil layer.

The level of oxidative release of $NH_4$-N by acid $KMnO_4$ was in the range of 6 to 10% of total N in the top soil layers (Table 3). This coincided generally with Stanford & Smith (1978), who found that about half of the potentially mineralizable N (No), (which was in most of their soils 10-20% of total N) was extracted by this method. The 0.05N $KMnO_4$ extracted slightly less $NH_4$-N but they were highly correlated with each other (Fig. 1, Table 4). More N was extracted by this method from soils with high $CaCO_3$ content and pH above 8, like Eden, Gilat, Alumim and Kedma, than from the noncalcareous soils. The permanganate extractable $NH_4$-N decreased with soil depth but its fraction of total N (Table 3) was larger in deep soil layers. However, Stanford et al. (1974) found that the ratio of potentially mineralizable N to total N dropped in soil layers below 30 cm, therefore the acid permanganate extract does not seem to

be a good estimate of No when dealing with whole soil profiles.

A very small fraction of total N appeared as hot KCl extractable $NH_4$-N (Table 3), only about twice as much as exchangeable $NH_4$. It did not show a consistent trend to change with soil depth, indicating that its absolute values decreased with depth, parallel to total N. Gilat soil had a relatively higher content of hot KCl extractable $NH_4$ than all other soils, which were mostly in the range of 1.5 to 3% of total N. This percentage was greater than in the soils tested by Oien and Selmer-Olsen (1980), which were richer in organic matter content. Compared with the acid permangate extract, the hot KCl extracted a very small proportion of the No of our soils. It probably is more suitable to predict available N in soils of cold climate with a high organic matter content (Selmer-Olsen et al., 1981), and a relatively low mineralization rate.

The amount of total N extracted by $NaHCO_3$ was less than the $NH_4$-N released by acid permanganate. The N extracted by 0.03N $NaHCO_3$ from the top soil layers was about 4% of total N in soil (Table 3) but its proportion increased below the depth of 60 cm. A smaller fraction of N was $NaHCO_3$ extractable in the highly calcareous Eden soil. The highest fraction was found in Gilat which has also a fairly high $CaCO_3$ content. The optical density of the 0.03N $NaHCO_3$

extract at 260 um was in the range of 0.06 to 0.4 and was highly correlated with the extractable N (Table 4). Alumim top-soil layer (0-5 cm) had a much higher O.D., which deviated considerably from the regression lines of O.D as a function of extractable N. The same was true for the 0.1N $NaHCO_3$ extract, though the correlation was slightly lower than the former (Table 4), mainly because of the data of Alumim 0-5 cm which were beyond the range of precise O.D. readings (Fig. 2). The correlation between N extracted by both $NaHCO_3$ concentrations was very high, the 0.1 N extracting only slightly more than the 0.03N $NaHCO_3$ (Table 4). A significant correlation was found between the O.D. of the extracts and soil organic carbon content (Table 5), Similar to what Michrina et al. (1982) had shown, though it was smaller than the correlation with organic N in the extracts.

The acid hydrolyzable N represented a fairly constant fraction of total N within the soil profiles (Table 3) in spite of the decrease of organic N content with depth. However, the fractions varied considerably among soils: less than 50% of total N in Eden and in the Golan soils, between 45 and 65% in Akko and Bet Dagan soils (both cultivated clay soils) about 75% in the uncultivated Alumim and Kedma soils (differing in texture but initiated from similar parent material) and up to 95% in the uncultivated Gilat soil. The

two cultivated soil samples from Gilat were closer in their relative hydrolyzable N content to the cultivated Bet Dagan soil.

The hydrolyzable N fraction was negatively correlated with air dry moisture content (or surface area) of the soils (Fig. 3, Table 5), namely a longer time would be required to hydrolyze the same percentage of total N from soils with a larger specific surface area. The data scattering in Fig. 3 shows that the Golan and Eden soils deviated below the line. This may be explained by the clay mineral composition of these soils: mainly kaolinite in the Golan soils and a high $CaCO_3$ content in Eden. The relation between surface area and moisture content (Banin and Amiel, 1969/70) is mainly based on montmorillonite soils, which have a higher moisture absorbing capacity relative to their surface area. The deviation of Golan and Eden could also be partially explained by their high N content and the significant negative relation found between total N and the hydrolyzable N fraction (Table 5). This however does not fit the constant fraction obtained along the soil profiles where total N decreased considerably.

The concentrations of the different forms of N in the hydrolyzate were within the ranges reported in the literature (Bremner, 1967; Meints and Peterson, 1977; Smith et al., 1980). The relative concentration of amino acids

decreased with soil depth while all other N forms either increased or did not change relative to soil total N (Table 3). Of all chemical forms of N measured amino acids in the hydrolyzate was the only one that decreased with depth more than total N, indicat ing a decrease in the availability of organic N to microorganisms with soil depth. There were considerable differences in the amino acid fraction of total N among soils. This was partly a result of the relative amount of total hydrolized nitrogen that was, as can be seen in the significant correlation between total N and amino acid N in the hydrolyzate (Table 5). But even relative to total hydrolyzable N, the level of amino acids in the top soil layers of Alumim, Gilat and Kedma (all in the southern part of the country or lately uncultivated soils) was a half or more of total hydrolizable N, whereas in all other soils it was only about 30-40% of it. This probably indicates some differences in the composition of the organic N in the soils. A small decrease in the relative concentration of amino acids in cultivated compared with un-cultivated soils was reported by Meints and Peterson (1977) and by Keeney and Bremner (1964), but the main influence of cultivation or of manuring (Smith et al., 1980) was on the absolute content of the different N forms as well as total N. A comparison between Gilat's permanent plot samples and the uncultivated Gilat soil profile revealed a strong influence of intensive

cropping on the composition of organic N, while fertilizer additions, as shown by the two Bet Dagan and the two Gilat appropriate samples, had almost no influence.

Amidase activity in the top soil layers ranged between 45 and 325 mg $kg^{-1}$ (Table 3). Values above 250 were obtained in soils which were either rich in total N or had a large specific surface area. Both parameters were significantly correlated with amidase activity (Table 5). Amidase activity decreased with soil depth more than total N, indicating a relation not only to total organic matter but also to its composition or its mineralizability. There was however no correlation between amidase activity and the relative amount of amino acids or $NH_4$-N in the hydrolyzate, which could be considered as indices of the composition of organic N. A significant correlation was found between amidase activity and amino acids in the acid hydrolyzate (Table 5), but there was a very evident separation of the soil to two groups: 1. Eden, Bet Dagan and Akko; 2. All the rest (Fig. 4). Separate calculations for each group resulted in two very different regression equations with much higher correlation coefficients. There are several common characteristics in each group, although none explains the difference completely: a. Specific surface area was relatively high in group 1 and was indeed positively correlated with amidase activity and negatively with

hydrolyzable N or amino acids. b. Group 1 consisted of cultivated soils, a situation that could enhance amidase activity. c. Group 2 included all the southern soils, which were formed under semi-arid conditions, while group 1 was formed under more humid conditions (Eden was formed under local hydromorphic conditions) and this could affect the composition of organic matter (such as a higher protein content). On the other hand, there were a few exceptions, indicating that not all the soils obeyed the above-mentioned orders: 1. Kedma had a low amidase activity, although its surface area was large. 2. Gilat control and NM samples and Golan soil were cultivated and their amidase activity was relatively low. 3. The Golan soils represent humid climatic conditions, yet they belonged to the arid soil group. The characteristics mentioned above could be the reasons for the grouping of the soils and the exceptions could result from local effects (e.g. microclimate).

Conclusions

All the N parameters tested were significantly correlated with total N in soils, which leaves it as a rough universal indicator of any form of N in soil. Consequently, all N forms measured were also correlated with each other. But additionally to total N other soil properties also affected the amount of N extracted by the different methods: a large specific surface area reduced the efficiency of acid

hydrolyzate; a high $CaCO_3$ content in soil increased the relative amount of N extracted by acid $KMnO_4$; soil depth increased the proportion of N extracted by $KMnO_4$, by $NaHCO_3$ and the $NH_4$ and hexosamine in acid hydrolyzate, while the proportion of amino acids and the amidase activity decreased, indicating changes in the composition of organic matter with depth. The agronomic history and soil formation had probably also some effect on the organic matter composition.

The level of amino acids in soil hydrolyzate and amidase activity seem more promising than the other N parameters for the prediction of mineralizable N, when considering the soil profiles, because they reflect the decrease in the availability of organic or total N with depth. The correlation of these soil properties with total N was smaller (though significant) than that of other N parameters and this could be an advantage indicating that they might provide a more refined index of mineralizable N.

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Table 1: Classification and general description of the soils

| Soil location | Classification | Average yearly rainfall mm | Parent material | Texture | Previous management |
|---|---|---|---|---|---|
| Alumim | Calcic Mollic Haploxeralf | 370 | Aeolian loess | Sandy to silty loam | Uncultivated |
| Bet Dágan | Typic Chromoxerert | 560 | Alluvial clay | Clay | Field crop rotation followed by 4 years irrigated cotton |
| Gilat | Typic Haplargid | 240 | Aeolian loess | Sandy to silty loam | Experimental sation; uncultivated area |
| Akko | Typic Chromoxerert | 580 | Alluvial clay | Clay | Cultivated, irrigated |
| Eden | Typic Camborthid | 340 | Lisan marle | Clay | Cultivated, irrigated |
| Qedma | Typic Chromoxerert | 440 | Aeolian clay | Clay | Uncultivated several years |
| Golan 70 | Rhodoxeralf | 850 | Tuff | Silty loam - clay | Cultivated |
| Golan 37 | Rhodoxeralf | 950 | Basalt | Silty loam - silty clay | Cropped with wheat, unfertilized, unirrigated |

Table 2: General soil properties

| Soil | Layer | Organic C g/100g | C/N | Moisture content air dry g/100g | Moisture content SP g/100g | pH | EC dSm | $HCO_3^-$ mol $m^{-3}$ | CEC mole($Na^+$)$kg^{-1}$ | Total $CaCO_3$ g/100g | Specific surface area* $m^2\ g^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alumim | 0 - 5 | 1.26 | 9.5 | 2.79 | 56 | 7.82 | 0.67 | 3.80 | 0.17 | 10 | 90 |
| | 5 - 20 | 0.87 | 9.8 | 3.09 | 55 | 8.13 | 0.33 | 2.05 | 0.16 | 12 | 105 |
| | 20 - 50 | 0.34 | 9.6 | 3.41 | 55 | 8.29 | 0.33 | 1.80 | 0.16 | 15 | 115 |
| | 50 - 85 | 0.24 | 10.1 | 3.62 | 56 | 8.29 | 0.33 | 1.56 | 0.16 | 20 | 125 |
| | 85 - 125 | 0.22 | 10.3 | 3.72 | 57 | 8.35 | 0.25 | 1.65 | 0.17 | 23 | 130 |
| | 125 - 165 | 0.17 | 10.0 | 3.82 | 61 | 8.53 | 0.41 | 2.15 | 0.20 | 16 | 135 |
| BD Control (Bet Dagan) | 0 - 20 | 0.76 | 11.0 | 7.25 | 84 | 7.98 | 0.83 | 2.50 | 0.49 | 7 | 270 |
| | 20 - 40 | 0.72 | 10.8 | 7.25 | 88 | 7.96 | 0.58 | 1.84 | | 7 | 270 |
| BD NPKM | 0 - 20 | 0.83 | 10.3 | 7.30 | 83 | 7.83 | 1.58 | 2.45 | 0.49 | 7 | 270 |
| | 20 - 40 | 0.81 | 10.7 | 7.32 | 85 | 7.87 | 1.22 | 1.85 | | 7 | 275 |
| | 40 - 60 | 0.66 | 10.6 | 7.41 | 85 | 7.91 | 1.16 | 1.35 | | 7 | 275 |
| | 60 - 90 | 0.58 | 12.1 | 7.60 | 87 | 7.96 | 1.08 | 1.30 | | 9 | 285 |
| | 90 - 120 | 0.55 | 12.0 | 7.56 | 85 | 7.96 | 1.25 | 1.10 | | 8 | 285 |
| Gilat | 0 - 20 | 0.62 | 13.1 | 2.35 | 47 | 7.87 | 1.03 | 3.58 | 0.12 | 16 | 75 |
| | 20 - 40 | 0.52 | 11.7 | 2.31 | 47 | 8.09 | 0.83 | 2.48 | 0.11 | 16 | 75 |
| | 40 - 60 | 0.24 | 7.5 | 2.50 | 48 | 8.23 | 0.83 | 2.29 | | 20 | 80 |
| | 60 - 80 | 0.19 | 10.3 | 2.93 | 60 | 8.39 | 0.70 | 2.08 | | 26 | 100 |
| | 80 - 100 | 0.14 | 9.3 | 2.88 | 61 | 8.28 | 1.50 | 2.08 | | 24 | 95 |
| | 100 - 120 | 0.20 | 14.6 | 3.18 | 62 | 8.33 | 2.08 | 1.95 | | 22 | 110 |
| | 120 - 150 | 0.13 | 8.4 | 3.47 | 63 | 8.61 | 0.75 | 3.37 | | 20 | 120 |
| Akko | 0 - 20 | 0.76 | 10.0 | 9.47 | 99 | 7.70 | 0.62 | 1.44 | 0.56 | 1 | 360 |
| | 20 - 40 | 0.66 | 11.2 | 10.14 | 95 | 7.71 | 0.50 | 1.25 | 0.54 | 1 | 390 |
| | 40 - 60 | 0.51 | 10.8 | 10.74 | 96 | 7.75 | 0.58 | 1.24 | 0.54 | 1 | 410 |
| Eden | 0 - 20 | 1.54 | 11.0 | 6.22 | 78 | 8.07 | 1.25 | 2.42 | 0.27 | 39 | 230 |
| | 20 - 40 | 1.12 | 11.0 | 6.08 | 77 | 8.16 | 0.92 | 2.28 | 0.30 | 39 | 220 |
| | 40 - 60 | 0.77 | 11.6 | 6.32 | 77 | 8.24 | 0.92 | 2.25 | 0.36 | 41 | 230 |
| Qedma | 0 - 9 | 0.68 | 10.1 | 5.57 | 72 | 7.97 | 0.75 | 2.66 | 0.28 | 17 | 205 |
| | 9 - 25 | 0.57 | 9.3 | 6.10 | 76 | 8.08 | 0.67 | 1.94 | 0.28 | 14 | 225 |
| | 25 - 58 | 0.40 | 8.7 | 6.56 | 77 | 8.17 | 1.16 | 1.62 | 0.33 | 17 | 240 |
| | 58 - 86 | 0.34 | 11.0 | 6.72 | 80 | 8.37 | 0.83 | 2.32 | 0.41 | 19 | 250 |
| | 86 - 160 | 0.30 | 11.1 | 6.43 | 93 | 8.60 | 0.83 | 2.30 | 0.34 | 18 | 240 |
| Golan 70 | 0 - 20 | 0.78 | 10.3 | 4.96 | 57 | 6.60 | 0.16 | 0.60 | 0.27 | 0 | 180 |
| | 20 - 40 | 0.56 | 9.1 | 5.76 | 59 | 6.70 | 0.16 | 0.55 | 0.27 | 0 | 210 |
| | 40 - 60 | 0.39 | 8.1 | 5.36 | 73 | 6.88 | 0.16 | 0.55 | 0.32 | 0 | 195 |
| Golan 37 | 0 - 20 | 1.13 | 9.3 | 4.2 | 55 | 5.99 | 0.16 | 0.60 | 0.22 | 0 | 150 |
| | 20 - 40 | 0.74 | 8.4 | 5.0 | 59 | 5.64 | 0.13 | 0.44 | 0.24 | 0 | 180 |

*Calculated from the air dry moisture content (Banin and Amiel, 1969/70)

Table 3: Nitrogen forms in soil profiles - relative to total N

| Soil | Layer | Total N | $NH_4$-N in $KMnO_4$ 0.1N | $NH_4$-N in Hot KCl | $NaHCO_3$ 0.03N | | Acid hydrolyzable N | | | | | Amidase activity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | total N | optical density | total | $NH_4$ | Hexos-amine | Serine Treonine | α amino acids | |
| | cm | mg $kg^{-1}$ | -------g/100 g total N in soil-------- | | | | --------g/100g total N in soil---------- | | | | | mg $kg^{-1}2h^{-1}$ |
| Alumim | 0 - 5 | 1320 | 6.0 | 1.43 | 3.9 | 0.76 | 74 | 10.4 | 7.2 | 5.8 | 39 | 281 |
| | 5 - 20 | 890 | 6.9 | 1.05 | 3.7 | 0.30 | 74 | 11.3 | 7.8 | 5.8 | 40 | 198 |
| | 20 - 50 | 360 | 11.3 | 2.12 | 5.7 | 0.09 | 86 | 16.0 | 10.1 | 6.0 | 38 | 72 |
| | 50 - 85 | 240 | 12.4 | 2.47 | 6.9 | 0.06 | 73 | 19.4 | 7.0 | 6.6 | 33 | 33 |
| | 85 - 125 | 210 | 12.6 | 2.16 | | | 76 | 19.4 | 9.6 | 6.5 | 31 | 30 |
| | 125 - 165 | 170 | 14.6 | 1.88 | | | 73 | 20.6 | 10.3 | 6.2 | 30 | 11 |
| BD Control (Bet Dagan) | 0 - 20 | 670 | 8.6 | 1.93 | 4.0 | 0.16 | 63 | 14.5 | 4.5 | 5.7 | 24 | 277 |
| | 20 - 40 | 660 | 8.2 | 1.39 | 3.2 | 0.13 | 63 | 14.5 | 4.7 | 5.6 | 23 | 266 |
| BD NPKM | 0 - 20 | 810 | 8.7 | 1.47 | 3.9 | 0.17 | 64 | 16.3 | 3.8 | 5.8 | 24 | 327 |
| | 20-- 40 | 760 | 7.6 | 2.13 | 3.8 | 0.14 | 66 | 14.1 | 5.4 | 5.3 | 21 | 312 |
| | 40 - 60 | 620 | 8.8 | 2.02 | 3.8 | 0.11 | 63 | 12.9 | 6.1 | 5.4 | 13 | 221 |
| | 60 - 90 | 480 | 10.2 | 1.97 | 4.5 | 0.09 | 62 | 12.8 | 7.5 | 4.8 | 13 | 158 |
| | 90 - 120 | 460 | 10.0 | 2.60 | 4.5 | 0.07 | 56 | 11.6 | 8.1 | 4.6 | 13 | 145 |
| Gilat | 0 - 20 | 470 | 9.8 | 5.79 | 7.3 | 0.41 | 95 | 18.1 | 6.9 | 9.6 | 48 | 146 |
| | 20 - 40 | 440 | 8.9 | 2.84 | 6.3 | 0.24 | 93 | 15.8 | 8.4 | 8.0 | 48 | 124 |
| | 40 - 60 | 310 | 10.9 | 2.33 | 7.2 | 0.15 | 85 | 20.9 | 6.1 | 9.0 | 44 | 75 |
| | 60 - 80 | 180 | 15.5 | 3.35 | 9.7 | 0.08 | 78 | 27.8 | 1.9 | 9.8 | 40 | 46 |
| | 80 - 100 | 150 | 16.6 | 7.34 | 12.1 | 0.06 | 87 | 24.5 | 6.0 | 7.6 | 41 | 27 |
| | 100 - 120 | 140 | 18.1 | 4.50 | 13.0 | 0.05 | 85 | 25.0 | 10.4 | 8.9 | 34 | 20 |
| | 120 - 150 | 155 | 14.4 | 3.71 | 11.4 | 0.05 | 68 | 21.0 | 5.8 | 8.1 | 21 | 32 |
| Gilat control | 0 - 20 | 480 | | | | | 71 | 18.8 | 3.3 | 10.7 | 23 | 44 |
| Gilat NM | 0 - 20 | 600 | | | | | 63 | 17.3 | 4.7 | 9.4 | 24 | 72 |
| Akko | 0 - 20 | 760 | 8.3 | 2.91 | 4.7 | 0.14 | 58 | 12.2 | 7.4 | 5.6 | 16 | 257 |
| | 20 - 40 | 580 | 8.6 | 2.99 | 4.7 | 0.10 | 62 | 13.5 | 9.6 | 4.7 | 16 | 229 |
| | 40 - 60 | 470 | 8.1 | 2.43 | 4.4 | 0.08 | 55 | 12.8 | 7.7 | 4.4 | 15 | 154 |
| Eden | 0 - 20 | 1410 | 9.2 | 1.44 | 2.7 | 0.40 | 44 | 9.1 | 4.4 | 3.5 | 19 | 325 |
| | 20 - 40 | 1030 | 11.3 | 1.47 | 3.1 | 0.31 | 48 | 11.1 | 5.6 | 4.1 | 22 | 283 |
| | 40 - 60 | 660 | 12.2 | 2.64 | 3.3 | 0.15 | 50 | 12.6 | 6.1 | 4.1 | 20 | 180 |
| Qedma | 0 - 9 | 670 | 10.7 | 2.56 | 5.3 | 0.30 | 75 | 14.1 | 4.9 | 6.5 | 42 | 148 |
| | 9 - 25 | 610 | 9.4 | 1.67 | 4.8 | 0.16 | 74 | 13.0 | 5.7 | 5.8 | 37 | 119 |
| | 25 - 58 | 470 | 11.2 | 1.74 | 5.3 | 0.10 | 74 | 15.4 | 7.5 | 5.5 | 34 | 149 |
| | 58 - 86 | 310 | 13.5 | 2.09 | 6.8 | 0.08 | 77 | 17.3 | 8.4 | 6.0 | 36 | 72 |
| | 86 - 160 | 270 | 13.1 | 2.34 | 7.3 | 0.08 | 73 | 16.7 | 8.7 | 4.4 | 31 | 37 |
| Golan 70 | 0 - 20 | 750 | 7.2 | 2.06 | 4.4 | 0.18 | 49 | 11.2 | 7.6 | 4.1 | 20 | 93 |
| | 20 - 40 | 620 | 6.9 | 2.11 | 4.1 | 0.12 | 47 | 9.3 | 9.6 | 4.5 | 15 | 67 |
| | 40 - 60 | 480 | 6.4 | 2.28 | 3.9 | 0.12 | 47 | 10.6 | 8.6 | 4.2 | 12 | 60 |
| Golan 37 | 0 - 20 | 1220 | 6.5 | 1.43 | 3.6 | 0.42 | 50 | 7.5 | 7.9 | 4.7 | 19 | 171 |
| | 20 - 40 | 880 | 6.9 | 1.31 | 4.3 | 0.36 | 43 | 7.6 | 7.6 | 5.6 | 16 | 85 |

Table 4: Linear relations between soil parameters

| Variables* y | Variables* x | Number of observations | Regression equation y = bx + a | Correlation coefficient | Comments |
|---|---|---|---|---|---|
| KMN1 | TOTN | 36 | y = 0.065x + 14.8 | 0.892 | |
| KMN1 | KMNO5 | 38 | y = 1.62x - 15.6 | 0.975 | |
| HOTKC1 | TOTN | 36 | y = 0.010x + 6.4 | 0.659 | |
| BICNO3 | TOTN | 34 | y = 0.023x + 13.5 | 0.868 | |
| ODO3 | BICNO3 | 72 | y = 0.016x - 0.25 | 0.897 | Alumim 0-5 deviated considerably |
| OD1 | BICN1 | 76 | y = 0.018x - 0.31 | 0.825 | |
| ODO3 | BICNO3 | 70 | y = 0.013x - 0.18 | 0.873 | Without Alumino-5 |
| OD1 | BICN1 | 74 | y = 0.011x - 0.15 | 0.866 | |
| BICN1 | BICNO3 | 36 | y = 1.18x - 2.35 | 0.962 | |
| HTOTN | TOTN | 38 | y = 0.50x + 75 | 0.898 | |
| AMINO | TOTN | 38 | y = 0.22 + 17.9 | 0.742 | |

* KMN1 = $KMnO_4$ 0.1N extractable $NH_4$-N, mg $kg^{-1}$; TOTN = Total N mg $kg^{-1}$;
KMNO5 = $KMnO_4$ 0.05N extractable $NH_4$-N;, mg $kg^{-1}$; HOTKC1 = Hot KCl extractable $NH_4$-N, mg $kg^{-1}$;
BICNO3 = $NaHCO_3$ 0.03N extractable N, mg $kg^{-1}$; ODO3 = Optical density of $NaHCO_3$ 0.03N extract.
BICN1 and OD1 = The same as the former but with $NaHCO_3$ 0.1N; HTOTN = Acid hydrololyzable total N, mg $kg^{-1}$;
AMINO = Amino acid in acid hydrolyzate, mg $kg^{-1}$.

Table 5: Correlations between soil parameters

| Variables* | No. of observations | Correlation coefficient | Comments+ |
|---|---|---|---|
| CEC x HYG | 26 | 0.962 | |
| HOTKCl x KMNl | 36 | 0.619 | |
| BICNl x KMNl | 38 | 0.700 | Eden - very high KMNl |
| BICNO3 x HOTKCl | 34 | 0.699 | |
| ODO3 x C | 36 | 0.744 | |
| ODl x C | 38 | 0.699 | |
| PHTOTN x HYG | 36 | -0.545 | |
| PHTOTN x TOTN | 38 | -0.558 | |
| HTOTN x KMNl | 36 | 0.751 | |
| HTOTN x BICNO3 | 34 | 0.897 | |
| PAMINO x PHTOTN | 38 | 0.569 | |
| AMINO x KMNl | 36 | 0.630 | |
| AMINO x BICNO3 | 34 | 0.824 | |
| AMIDAS x TOTN | 38 | 0.758 | |
| AMIDAS x S | 36 | 0.497 | |
| AMIDAS x AMINO | 38 | 0.543 | |
| AMIDAS x AMINO | 13 | 0.856 | Bet Dagan, Acco, Eden |
| AMIDAS x AMINO | 25 | 0.961 | All the rest |
| AMIDAS x KMNl | 36 | 0.770 | |
| AMIDAS x BICNO3 | 34 | 0.558 | |

* In addition to variables described in Table 4: CEC = cation exchange capacity; HYG = Air dry moisture content; C = Total organic carbon; PHTOTN = Acid hydrolyzable N, percentage of total N; PAMIN = Amino acid in hydrolyzate, percent of total N; AMIDAS = Amidase activity; S = Specific surface area.

\+ All correlations were significant at a level of 0.01.

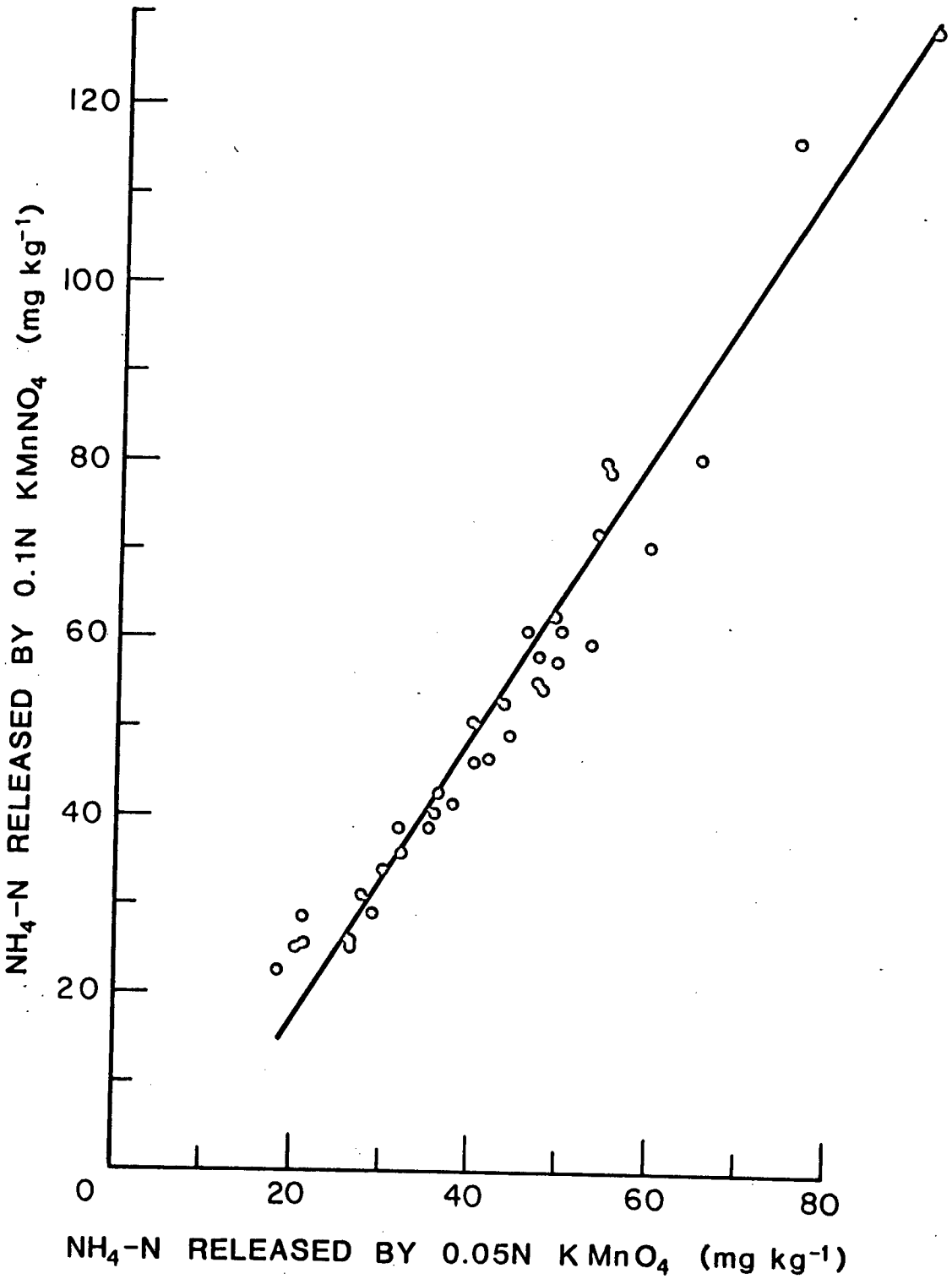


Figure 1: Relation between oxidative release of $NH_4$-N from soil by 0.1N and 0.05N $KMnO_4$ in acid. The line is the calculated linear regression.

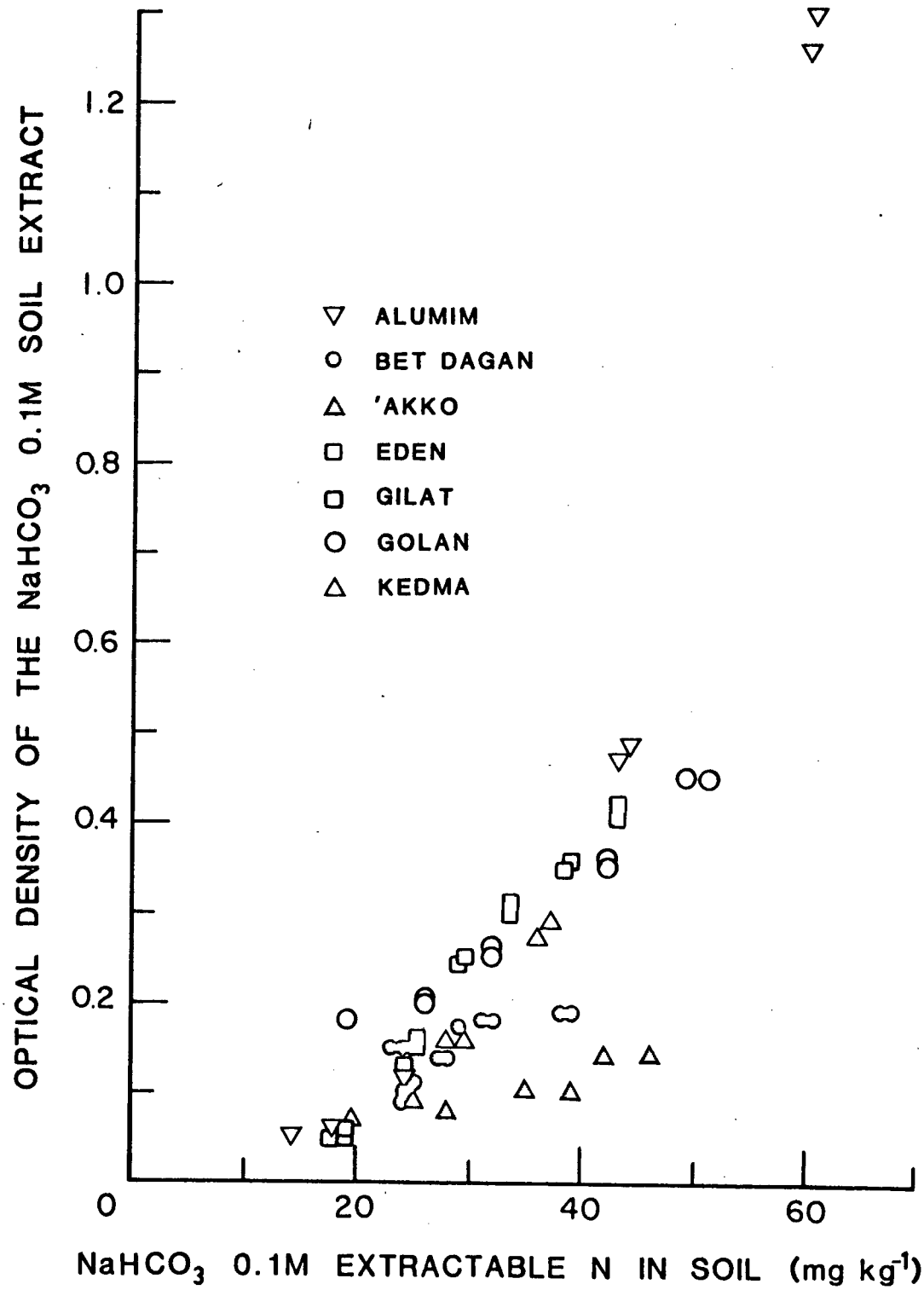


Figure 2: Relation between optical density and N content of $NaHCO_3$ 0.1 M soil extracts.

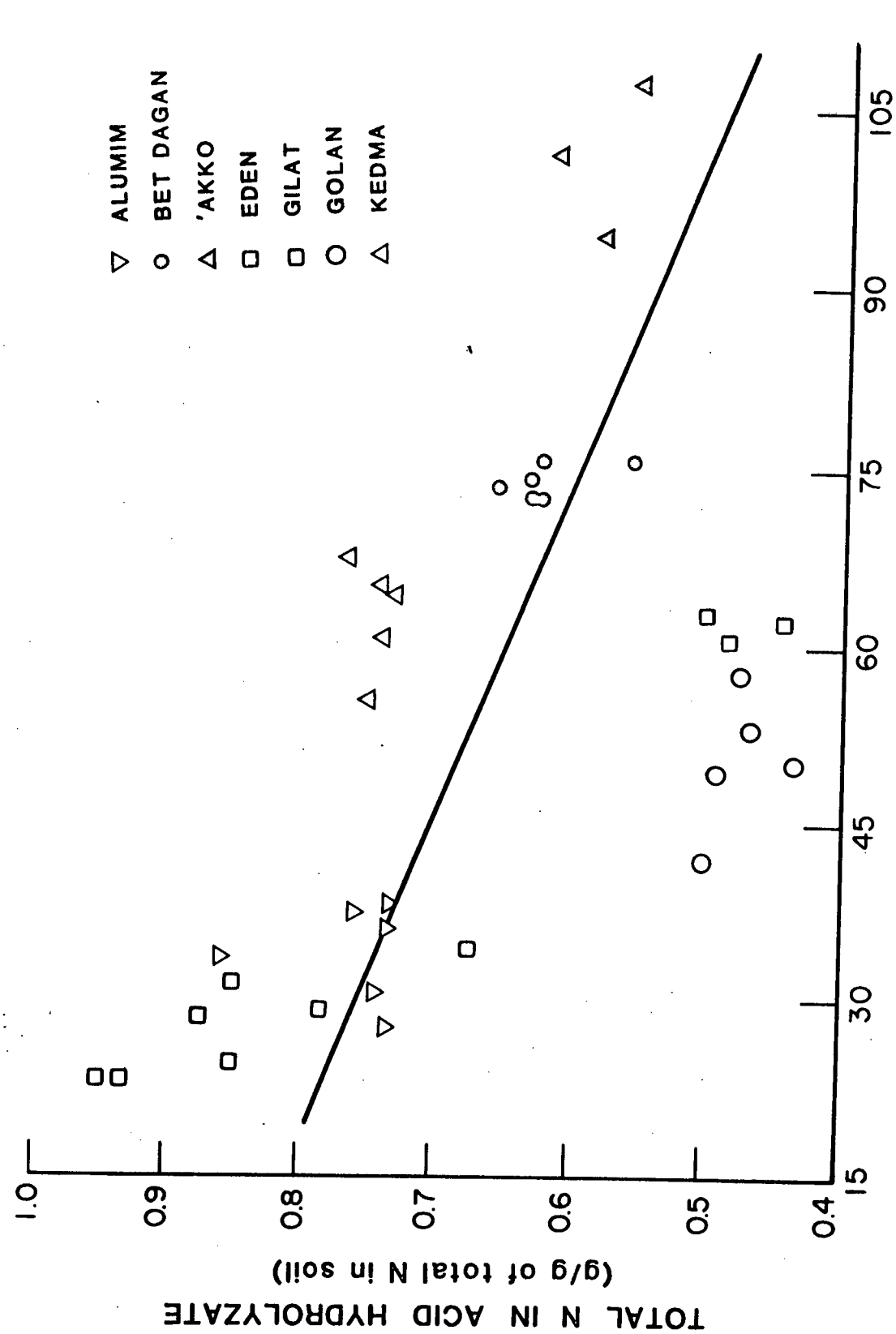


Figure 3: Relation between acid hydrolyzable N fraction of total soil N and the hygroscopic moisture content of the soils. The line is the calculated linear regression.

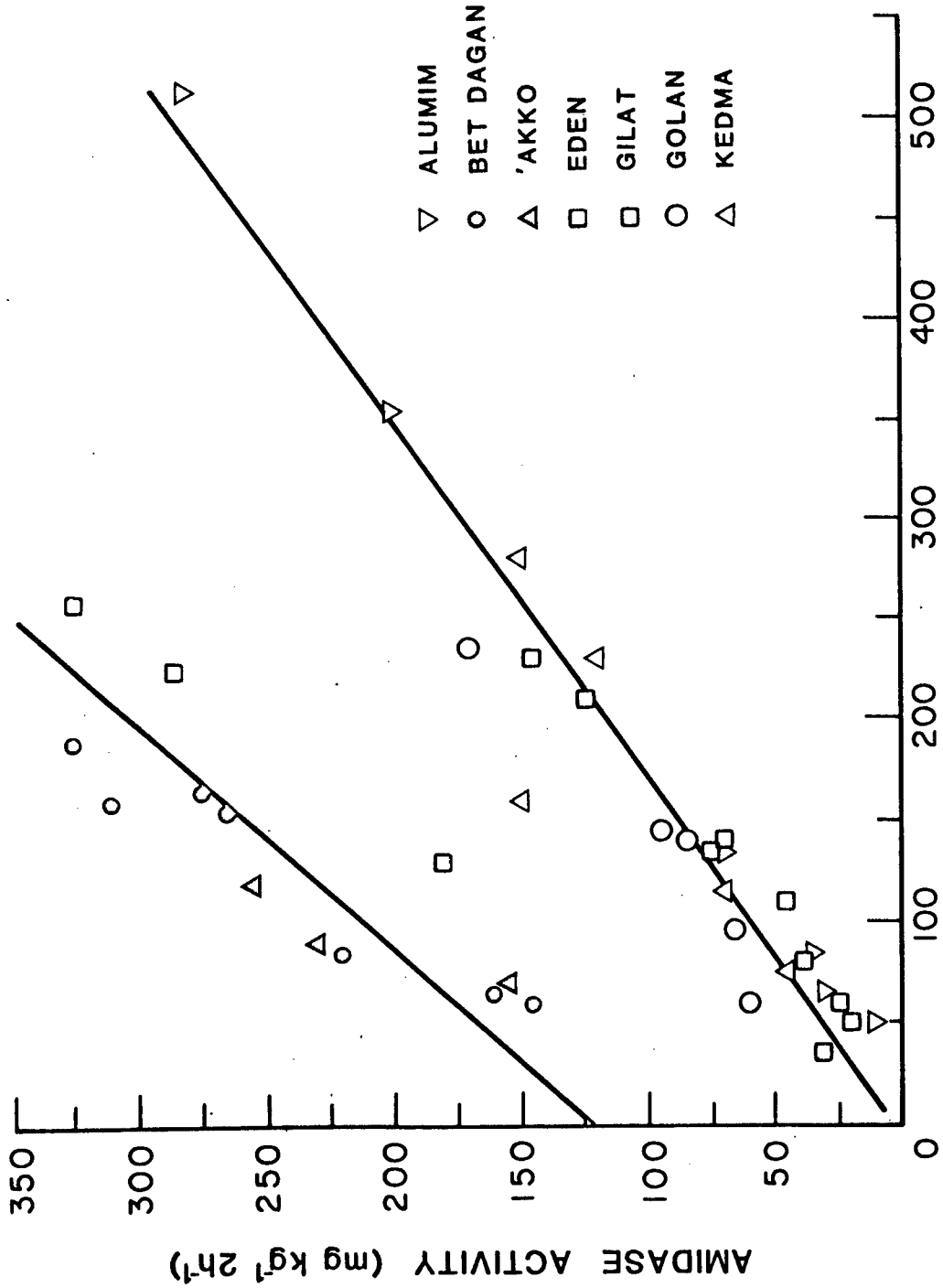


Figure 4: Relation between amidase activity and amino acids in soil acid hydrolyzate. The lines are calculated linear regressions for two soil groups.

# II. NITROGEN MINERALIZATION RATES IN PROFILES OF DIFFERENTLY MANAGED SOIL TYPES

Aviva Hadas, Sala Feigenbaum, A. Feigin and Rita Portnoy

## Abstract

Nitrogen mineralization kinetics and relations between potentially mineralizable N and chemical availabililty indices have been mainly studied in surface soils. In this study the rate of mineralization was measured, by incubation techniques, in various soil types and soil depths, in order to evaluate the contribution of various soil layers to mineral N of the whole root zone and to relate the rate parameters obtained to any soil N fraction. Soil layers of 60 to 120 or 160 cm contributed about 30% of the N mineralized in the whole soil profile. Ammonium accumulated and its nitrification was delayed in deeper soil layers of several profiles. Several rate equations were fitted to the experimental data. The first order rate constant varied from 0.02 to 0.10 $week^{-1}$, without any consistent trend. Similar random variations of rate parameters were observed in other models with two or more parameters. The potentially mineralizable N (No) of one parameter models was highly and better correlated with the amount actually minealized in 32 weeks of incubation and with various N forms in soil than No obtained from two or more parameter models. Hydrolyzable N and amino acid N concentrations in soil were the best

estimates of No. The percentage of these two N forms of total soil N increased slightly in soils after 32 weeks of incubation but their variation among soils were similar to those before incubation indicating a possible relation between soil type and organic N composition.

## INTRODUCTION

The mineralization of soil organic N is of considerable significance in supplying available nitrogen to crops. Being a time-dependent process, the rate of N mineralization, or mineral N supply by the soil as a function of time, should be considered for N fertilization requirements. From long term incubation experiments with many surface soils, Stanford and Smith (1972) concluded that the rate of N mineralization follows a first order reaction and that the rate constant (k) was similar in all soils tested. The similar k was explained by the similarity in the composition of organic N in soils. The differences among soils were mainly in the quantity of the potentially mineralizable nitrogen (No). The effect of temperature and moisture on the mineralization rate has been extensively studied and defined quantitatively (Stanford et al., 1973; Stanford and Epstein, 1974). Thus the only missing parameter to predict the time course of mineral N accumulation in a soil is its No. For practical purposes a chemical index or a fraction of organic N correlated with No should be found rather than determining the value of No from incubation experiments.

In subsequent studies that expressed soil N mineralization by the same exponential rate equation, but used different methods to calculate the rate parameters (a nonlinear procedure based on the least sum of squres of deviations), different and usually larger values of rate constants were obtained (Smith et al. 1980). Furthermore, El-Haris et al (1983) found that values of k obtained for

soils sampled in the spring were about 3 times larger than for samples from the same fields sampled in the Autumn, indicating a possible dependence of k on organic matter composition. Considering the possibility of different rate constants corresponding to different decomposable nitrogen compounds, Molina et al. (1980) suggested a mineralization model consisting of a sum of at least two exponential equations, representing a rapid and a slow reaction rate. The value of k may also depend on soil depth where the decomposability of organic nitrogen decreases.

Meager information exists regarding the rate of mineralization as a function of soil depth. Yet, recent data (Cassman and Munns, 1980; Powers, 1980) indicate that although the top soil is responsible for a considerable part of mineral N release, deeper soil layers cannot be ignored. More information on the rate of the process and the variations of rate parameters with depth could improve the prediction of N mineralization in the whole root zone.

The objectives of this study were to obain rate parameters of N mineralization in different soil types and soil depths from incubation experiments, to relate the rate parameters to chemical indices or any nitrogen fraction in soil and to evaluate the contribution of deeper soil layers to the pool of available N in the root zone.

## Materials and Methods

Soil profiles were sampled from various places in Israel, representing different climates, parent materials and managements. The

soils and their general properties have been fully described in the previous chapter(Chap. C.I. tables 1, 2, 3). All soils were air-dried ground to pass through a 2mm sieve and stored at room temperature for at least 3 months.

The mineralization rate of organic N in 38 different soil samples was determined in an incubation experiment during 32 weeks at a constant temperature of 35°C and a moisture content of water-holding capacity. The water-holding capacity of the different soils was determined by measuring the moisture held by the top 40g of soil, 24 hours after wetting about 3/4 of 200g soil, placed in a 200 $cm^3$ incubation flask and covered to prevent drying. For the incubation of 40g (dry matter basis) subsamples of each soil, corresponding predetermined amounts of water were placed in 200 $cm^3$ flasks and the air-dry soils were evenly poured into the water(a technique recommended by Bremner, 1965a). The flasks were then tightly covered with thin polyethylene (0.01 mm) to minimize drying and enable aeration. Separate duplicate samples for each period of time (0, 1, 2, 4, 6, 8, 12, 16, 24, 32 weeks) were placed in an incubator with a high humidity created by free water at the bottom.

Several samples were weighed every 4 weeks and water was added when the average water loss exceeded 1 ml (7-20% of total water content). After different periods of time, whole incubated samples were extracted with 100 ml of KCl 2N and $NH_4$ and $NO_3$ were determined in the extract by steam distillation.

Several soil samples which were incubated for 32 weeks were leached after the extraction with additional 25 ml KCl solution and 25 ml of water and then freeze-dried. These soils were analyzed for total N and for organic forms of nitrogen in acid hydrolyzate (Bremner, 1965b).

Rate equations of N mineralization in the various soils were calculated from the data of mineral N accumulation ($[NH_4 + NO_3]_t - [NH_4 + NO_3]_o$) with time using the nonlinear procedure of SAS (Helwig and Council, 1979).

## Results and Discussion

### Effect of soil depth on mineral N accumulation

Mineral N accumulated in all soil samples,though to a much smaller extent in deep soil layers. (All the crude data of $NH_4$ and $NO_3$ concentrations in the soils are given in appendix II). The contribution of each soil layer in the different profiles after 16 weeks of incubation (a period in which many agricultural crops complete their N uptake) is presented in Fig. 1. From 23 to 34% of the N mineralized in the soil profiles of Alumim, Gilat, Kedma, and Bet Dagan accumulated below 60 cm. This is certainly not negligible. Within the 0-60 cm layer, the relative contribution of the top 20 cm was from 45% in Acco to 75% in Alumim, with an average of 57% (S.D. = 11). The ratio of the N contribution of the 0-20 cm layer to that of the 20-40 cm layer was in the range of 1.1 in Bet Dagan control to 5 in Alumim with an average of 2.3 (S.D. = 1.3). The decrease of N

mineralization with depth in Alumim was more pronounced than in all other soils because it was a virgin soil, while the other soils were either cultivated or at least disturbed by traffic. Eliminating Alumim, the proportion of N the mineralized at the top 20 cm out of the 0-60cm layer decreased to an average of 54% (S.D. = 8.5) and the average ratio of the 0-20 cm to the 20-40 cm decreased to 1.9 (S.D. = 0.8). These results were in very good agreement with incubation measurements in two Californian soil profiles (Cassman and Munns, 1980; Powers, 1980) where 57-58% of the N mineralized in the 0-60 cm layer was from the top 20 cm and the ratio of N mineralization between 0-20 cm to 20-40 cm was 2.1-2.2.

The soil layer depth affected the nitrification of ammonium to nitrate in several soil profiles. Ammonium concentrations decreased to traces in all the top soil layers within one week of incubation, whereas in deeper layes ammonium remained in the soil for 2 and up to 12 weeks, depending on the soil and the depth (Fig. 2). This phenomenon could explain why in short term incubation tests, when only nitrate is determined (Bremner, 1965a), no mineralization is detected in deeper soil layers.

Rate of N mineralization

The rate of N mineralization generally decreased with time, but in many samples the rate of N accumulation was still considerable after 24 weeks of incubation (Fig. 3 ). The data fitted very well (small standard deviations, or roots of residual mean squares) the first order equation used by Stanford and Smith (1972), namely

$N_t = N_o (1 - e^{-kt})$, where $N_t$ is the mineral N (mg $kg^{-1}$) accumulated at time t (weeks), $N_o$ is the potentially mineralizable N (mg $kg^{-1}$) and k is the rate constant ($week^{-1}$). The curves in Fig. 3 are calculated curves, using the above mentioned equation, and the calculated constants ($N_o$ and k) and standard deviations of the data from the calculated curves are shown in Table 1. The values of k were in the range of 0.004 to 0.145 $week^{-1}$ (with an average of 0.062 and a standard deviation of 0.036) and in the top soil layers k ranged from 0.011 to 0.11. The value of $N_o$ was close to - and in some cases less than - the level of nitrogen mineralized after 32 weeks ($N_{32}$) when k was greater than 0.1 $week^{-1}$, and twice or more than the level of $N_{32}$ when k was less than 0.02 $w^{-1}$ (which corresponds to a half-life of 32 weeks). No consistent trend could be observed in the values of k; it was not constant in the surface soil layers and it did not decrease with soil depth, although biological activity is expected to decrease and organic matter to be less decomposable with depth. The data obtained during the first two weeks of incubation often deviated considerably from the calculated curve, a fact also indicated by Stanford and Smith (1972). Consequently these data were eliminated in an attempt to improve the estimation of k. This correction resulted in a slight decrease of k in 20 curves, where the data were above the curve, and an increase in 11 curves, where the data deviated below the curve.Yet the changes were very small and did not really alter the general

variation of the rate parameters, and they could not be explained by soil type or previous soil management.

Another attempt was done to improve the estimation of $N_o$ by emphasizing the exponential or late stage of the mineralization process. Most of the curves were almost linear during the first 8 weeks (Fig. 3), therefore only the data form 12 to 32 weeks were used to calculate $N_o$. Molina et al. (1980) also indicated that the exponential model applies only for incubation periods longer than 12 weeks. These $N_o$ values, $N_o$ (12), were then used as constants in the rate equations, and the corresponding rate constants (k) were calculated using all data of 1-32 weeks of incubation. The $N_o$ values obtained from the 12-32 weeks' data (Table 1) were in many cases different from those obtained from the 1-32 weeks. They generally decreased where k was very small, like in the upper soil layers of Alumim and Gilat, and increased where k was large, like in the deeper layers of Bet Dagan and Eden soils. The resulting values of k were less extreme than before with an average of 0.059 and a standard deviation of 0.027. The standard deviations of the mineralization data from the curves hardly changed, although they were calculated by a one parameter (k) equation. Yet the range of k values was still too large to allow k to be considered as constant, and the variations of k with soil depth or soil type could not be explained.

Two other models have been suggested for treating N mineralization in soil. Stanford and Smith (1972) showed that the amount of N mineralized was linearly related to the square root of

time. Molina et al. (1980) indicated that the potentially mineralizable N, $N_o$ , of the exponential rate equation (with a rate constant of 0.054 $w^{-1}$) could be used as the constant of the parabolic (square root) model when multiplied by a coefficient a, which is approximately 1/7 for incubation periods longer than 16 weeks, in the following way: $N_t = N_o a \sqrt{t}$. Using this equation, curves were obtained with a standard deviation slightly higher than that of the exponential curves (Table 1). In most of the soils the experimental values were smaller than those obtained by the calculated curve at the short incubation periods and greater at periods longer than 16 weeks, as if this model did not really fit the mineralization process. However, Eden soil and Bet Dagan soil layers deeper than 40 cm fitted this model very well. The $N_o$ values obtained from the parabolic equation, $N_o(\sqrt{t})$, decreased with soil depth and were fairly well related to the amount of N mineralized. They varied from those obtained by the exponential equation according to the values of k, which is obvious from the assumption that a = 1/7 when k = 0.054 $w^{-1}$.

In order to better compare the suitability of the parabolic with that of the exponential equation to the experimental results, the same assumption of a constant k = 0.054 $week^{-1}$ was used to calculate another series of exponential curves and corresponding $N_o$ values, $N_o(k)$ (Table 1). The standard deviations of these curves were greater than those obtained when k was not predetermined, and the average SD was similar to that of the parabolic equation. The $N_o$ values corresponded very well with the parabolic $N_o$, being slightly higher,

because a = 1/7 corresponded to an average k value of 0.058 $week^{-1}$. It seems that both models, when only $N_o$ varied from soil to soil, were equally suitable to describe the rate of mineralization.

Another equation, that was used by Stanford and Smith (1972) in its linear transformation for the first approximation of $N_o$, can be used directly to calculate simultaneously the potentially mineralizable N ($N_o$) and the time required for half of $N_o$ to mineralize ($t_{1/2}$) as shown by Juma et al. (1984): $N_t = N_o t/(t_{1/2} + t)$. Curves calculated by this equation (Table 1) had standard deviations very similar to those of the exponential euation when k was not a predetermined constant. The $N_o$ values of this equation, $N_o$(Jum), were larger than those obtained by the exponential equation and unreasonable in three soil samples (larger than total N content). Simialrly, the half lives, $t_{1/2}$, were longer than the half lives of the exponential model ($t_{1/2} = \ln 2/k$) and did not show any consistent change with soil depth or with soil type.

The large variability of the rate constants or the half life of the potentially mineralizable nitrogen certainly did not indicate that the composition of mineralizable N was similar in all soils. Therefore the suggestion of Molina et al. (1980), who assumed that two groups of compounds decompose at two different rates, was also tested:

$$N_t = S\ N_o\ [1-\exp(-k_1 t)] + (1-S)\ N_o\ [1-\exp(-k_2 t)].$$

S and (1-S) are the fractions of $N_o$ which decompose at the specific rates of $k_1$ and $k_2$ respectively. The $N_o$ values obtained by this model, $N_o$(Mol), (Table 1) were generally larger than those obtained by one exponential equation, especially in the deeper soil layers. The fraction S, the rapidly decomposable N, varied quite randomly among the different soil samples and did not show any consistent pattern among soils or within soil profiles. The fit of this model to the experimental data was not better than the single exponential equation as shown by the standard deviations.

All the two or more parameters' models fitted the data equally well (Table 1), while the standard deviations from the one parameter models were generally greater. However, the possible counterbalance between two or more parameters resulted in variations among the calculated parameters which were difficult to relate to soil properties. Indeed, the correlations between the $N_o$ parameters, calculated using different equations, and the amount acutally mineralized after 32 weeks of incubation ($N_{32}$) were greatest in the one parameter equation (Table 2), namely $N_o(k)$ and $N_o(\sqrt{t})$. These two parameters were very highly correlated with each other and so were $N_o(12)$ and $N_o$(Jum). Correlations of $N_o$ with various nitrogen forms and related soil tests, which were presented previously (Hadas et al., 1985) were all significant at a level of 0.01. $N_o(k)$ and No($\sqrt{t}$) were better correlated with N forms in soil, namely total N, N in $NaHCO_3$ extract, total and amino acid N in acid hydrolyzate, than $N_o(12)$ and $N_o$(Jum), whereas the latter were very highly correlated

with the optical density of the $NaHCO_3$ extracts. This was probably due to the outstanding values for Alumim 0-5cm soil layer, which was also characterized by a very high OD. The $N_{32}$ data were best correlated with the acid hydrolyzate and with the $NaHCO_3$ extract. Amidase activity showed a low correlation with mineralization parameters relative to amino acids. When the soils were divided into two groups, clay soils with high amidase activity and relative low amino acid concentration and the rest of the soils, with a relatively lower amidase activity (see previous chapter), the correlation coefficients within each group greatly increased.

Linear regressions of $N_o$ on various soil parameters are presented in Table 3. The standard deviations of the experimental data from the calculated linear regression were much greater for $N_o(12)$ than for $N_o(k)$ or $N_o(\sqrt{t})$, even when the corresponding correlation coefficients were larger, therefore only the regressions of the latter were presented. The differences between values of the two $N_o$ parameters were very small and among the soil parameters the hydrolyzable N or amino acids seemed to be the best estimates of these $N_o$ values, due to their smallest SD and largest correlation coefficients. Amidase activity in the second groups of soils was even a better estimate according to these criteria, but since the definition of the groups was empirical it could not be recommended for use. Practically, the $NaHCO_3$ 0.03N extract and the determination of total N in soil are much easier to perform than the analysis of acid hydrolyzate, and for routine prediction of mineralization they might be preferential.

N forms in incubated soils

The decline in total N in soils incubated for 32 weeks corresponded quite well to the amount of N mineralized. There was, however, no consistent change in the concentrations of acid hydrolyzable N and amino acids in the hydrolyzate after the long incubation period (Table 4). The variations, relative to the concentrations in the soils before the incubation, were in the range of about ± 30%. Gilat soil was very outstanding in the decrease of hydrolyzable amino acids, which was partly due to its very high initial concentrations of hydrolyzable N forms (Table 3, previous chapter). The concentrations of hydrolyzable N in Alumim soil was also relatively high before incubation and decreased considerably afterwards. Total hydrolyzable N percentage of total soil N increased slightly in all soils, except in the two samples from the Gilat profile (Table 4 compared with Table 3 in the previous chapter). The same was generally true for the amino acids percentage. The differences among soils remained, however, almost the same as before the incubation, namely Eden, Golan and then Akko soils containing relatively less hydrolyzable N than Bet Dagan, Alumim and Gilat soils. This finding indicates that the composition of organic N is probably related to soil type. The increase of acid hydrolyzable N percentage in the incubated soils, not coinciding with the findings of Isirimah and Keeney (1973), does not necessarily mean that the nonhydrolyzable N fraction, which decreased during incubation, was most susceptible to mineralization. Only in the Gilat profile the mineralization could be

directly attributed to the decrease in amino acid concentration, which was initially very high. Presumably, a turnover of nitrogen forms took place during incubation, maintaining a composition typical to the soil type. The N turnover could possibly explain why the correlations of N mineralization with different organic N fractions were not much better than with soil total N.

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Table 1: Estimates of potentially mineralizable N ($N_o$) and rate constants (K) or half lives ($t_{1/2}$) obtained by using several models.

| Soil | Layer | N mineral-izod in 32w | $N_t = N_o(1-\exp(-kt))$ | | | | | | | | $N_t = (N_o/7)\sqrt{t}$ | | $N_t = \frac{N_o t}{t_{1/2}+t}$ | | | $N_t = S N_o(1-\exp(-k1\,t)) + (1-S)N_o(1-\exp(-k2\,t))$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $0 < t \leq 32$ | | | $t \geq 12w$ | $0 < t \leq 32$ | | $k = 0.054$ | | | | | | | | | | | |
| | | $N_{32}$ | $N_o$(ex) | K | SD | $N_o$(12) | K | SD | $N_o$(k) | SD | $N_o(\sqrt{t})$ | SD | $N_o$(Jum) | $t_{1/2}$ | SD | $N_o$(Mol) | S | k1 | k2 | SD |
| | cm | mm kg$^{-1}$ | mg kg$^{-1}$ | w$^{-1}$ | | mg kg$^{-1}$ | w$^{-1}$ | | ---------- mg kg$^{-1}$ ---------- | | | | w | | mg kg$^{-1}$ | - w$^{-1}$ ----- | | | mg kg$^{-1}$ | |
| Alumim | 0-5 | 236 | 789 | 0.0106 | 12 | 590 | 0.015 | 12 | 236 | 20 | 220 | 31 | 1446 | 172 | 12 | 727 | 1.00 | 0.0112 | 0.108 | 12.6 |
| | 5-20 | 71 | 102 | 0.037 | 2.4 | 93 | 0.043 | 2.8 | 82 | 3.4 | 79 | 6.4 | 160 | 40 | 2.9 | 115 | 0.02 | $10^{14}$ | 0.029 | 2.6 |
| | 20-50 | 18 | 19 | 0.076 | 1.4 | 21 | 0.062 | 1.4 | 22 | 1.5 | 22 | 1.1 | 26 | 16 | 1.3 | 24 | 0.10 | $10^{15}$ | 0.040 | 1.0 |
| | 50-85 | 12 | 14 | 0.072 | 1.4 | 14 | 0.069 | 1.4 | 16 | 1.4 | 15 | 1.4 | 19 | 18 | 1.4 | 45 | 0.31 | 0.072 | 0.0000 | 1.5 |
| | 85-125 | 11 | 17 | 0.033 | 1.1 | 16 | 0.036 | 1.1 | 13 | 1.1 | 13 | 1.4 | 28 | 48 | 1.1 | 36 | 0.39 | 0.037 | 0.0019 | 1.2 |
| | 125-165 | 8 | 10 | 0.058 | 1.5 | 10 | 0.060 | 1.5 | 11 | 1.5 | 11 | 1.5 | 15 | 24 | 1.5 | 48 | 0.21 | 0.058 | 0.0000 | 1.6 |
| Bet Dagan control | 0-20 | 59 | 66 | 0.069 | 2.8 | 63 | 0.076 | 2.8 | 75 | 3.2 | 72 | 5.6 | 97 | 20 | 3.1 | 109 | 0.61 | 0.069 | 0.0000 | 2.9 |
| | 20-40 | 49 | 54 | 0.088 | 3.6 | 50 | 0.102 | 3.7 | 68 | 4.7 | 65 | 5.5 | 76 | 14 | 4.0 | 97 | 0.55 | 0.088 | 0.0000 | 3.7 |
| Bet Dagan | 0-20 | 81 | 88 | 0.061 | 4.9 | 116 | 0.038 | 5.6 | 93 | 4.8 | 91 | 3.7 | 123 | 20 | 4.3 | 132 | 0.10 | $10^{15}$ | 0.026 | 2.8 |
| | 20-40 | 48 | 55 | 0.050 | 2.8 | 71 | 0.034 | 3.1 | 53 | 2.8 | 51 | 4.1 | 82 | 27 | 2.7 | | no convergence | | | |
| NPK | 40-60 | 34 | 34 | 0.106 | 2.1 | 37 | 0.087 | 2.2 | 45 | 3.4 | 44 | 1.8 | 44 | 10 | 1.8 | 36 | 0.10 | $10^{14}$ | 0.076 | 1.6 |
| | 60-90 | 20 | 19 | 0.118 | 1.8 | 23 | 0.078 | 2.0 | 26 | 2.5 | 26 | 1.1 | 24 | 8 | 1.5 | 23 | 0.18 | 3462 | 0.053 | 0.9 |
| | 90-120 | 18 | 16 | 0.106 | 2.2 | 25 | 0.040 | 2.5 | 20 | 2.3 | 20 | 1.8 | 20 | 10 | 2.0 | 70 | 0.08 | 0.390 | 0.0054 | 1.8 |
| Gilat | 0-20 | 91 | 144 | 0.031 | 4.7 | 122 | 0.039 | 4.8 | 102 | 5.9 | 97 | 11 | 241 | 53 | 4.8 | 134 | 1.00 | 0.034 | 0.034 | 4.8 |
| | 20-40 | 75 | 177 | 0.018 | 3.3 | 117 | 0.030 | 3.7 | 81 | 5.9 | 77 | 10 | 322 | 103 | 3.3 | 176 | 0.00 | 0.033 | 0.018 | 3.5 |
| | 40-60 | 29 | 62 | 0.019 | 1.4 | 58 | 0.020 | 1.4 | 30 | 2.2 | 29 | 3.3 | 108 | 92 | 1.4 | 85 | 0.01 | $10^{14}$ | 0.012 | 1.4 |
| | 60-80 | 10 | 12 | 0.051 | 2.4 | 9 | 0.086 | 2.4 | 12 | 2.3 | 11 | 2.8 | 20 | 32 | 2.4 | 50 | 0.25 | 0.051 | 0.000 | 2.5 |
| | 80-100 | 12 | 57 | 0.0075 | 1.1 | 25 | 0.020 | 1.1 | 12 | 1.5 | 12 | 2.1 | 112 | 263 | 1.1 | 68 | 0.36 | 0.010 | 0.004 | 1.2 |
| | 100-120 | 8 | 9 | 0.055 | 1.5 | 9 | 0.059 | 1.5 | 9 | 1.5 | 8 | 1.5 | 13 | 24 | 1.5 | 44 | 0.05 | 0.224 | 0.004 | 1.6 |
| | 120-150 | 13 | 15 | 0.069 | 1.3 | 14 | 0.079 | 1.3 | 17 | 1.3 | 17 | 1.3 | 21 | 19 | 1.3 | 59 | 0.26 | 0.069 | 0.000 | 1.3 |
| Gilat contr. | 0-20 | 50 | 67 | 0.043 | 1.7 | 65 | 0.045 | 1.7 | 59 | 2.0 | 56 | 5.3 | 108 | 36 | 1.8 | 91 | 0.74 | 0.043 | 0.000 | 1.8 |
| Gilat NM | 0-20 | 57 | 63 | 0.069 | 1.8 | 65 | 0.065 | 1.8 | 71 | 2.3 | 69 | 4.1 | 91 | 19 | 1.8 | 101 | 0.40 | 0.096 | 0.001 | 1.9 |
| Akko | 0-20 | 77 | 96 | 0.055 | 4.1 | 92 | 0.059 | 4.0 | 97 | 3.9 | 92 | 7.7 | 145 | 26 | 4.2 | 96 | 0.87 | 0.056 | 0.049 | 4.3 |
| | 20-40 | 60 | 64 | 0.102 | 3.2 | 62 | 0.107 | 3.2 | 84 | 5.9 | 82 | 4.8 | 85 | 11 | 3.4 | 105 | 0.60 | 0.102 | 0.0000 | 3.3 |
| | 40-60 | 28 | 29 | 0.098 | 2.8 | 33 | 0.074 | 2.9 | 37 | 3.3 | 37 | 1.8 | 37 | 10 | 2.5 | 37 | 0.15 | 219 | 0.043 | 1.8 |
| Eden | 0-20 | 161 | 168 | 0.088 | 7.7 | 184 | 0.072 | 8.3 | 210 | 11 | 204 | 4.7 | 225 | 13 | 6.2 | 189 | 0.09 | $10^{16}$ | 0.058 | 4.0 |
| | 20-40 | 84 | 80 | 0.108 | 5.8 | 92 | 0.080 | 6.5 | 108 | 8.5 | 106 | 2.2 | 101 | 9 | 4.6 | 97 | 0.16 | $10^{4}$ | 0.053 | 2.0 |
| | 40-60 | 36 | 31 | 0.145 | 3.5 | 36 | 0.104 | 3.7 | 46 | 5.2 | 45 | 2.8 | 38 | 6 | 2.9 | 84 | 0.17 | 0.597 | 0.0109 | 2.5 |
| Qedma | 0-9* | 64* | 72 | 0.131 | 2.4 | | | | 120 | 5.6 | 108 | 4.5 | 104 | 10 | 2.2 | 185 | 0.19 | 0.240 | 0.014 | 2.5 |
| | 9-25 | 54 | 56 | 0.086 | 2.6 | | | | 70 | 3.8 | 68 | 2.6 | 76 | 14 | 2.4 | 61 | 0.08 | 1.73 | 0.063 | 2.1 |
| | 25-58* | 14* | 11 | 0.695 | 2.4 | | | | 27 | 4.1 | 26 | 2.5 | 12 | 1 | 2.1 | 90 | 0.07 | $10^{16}$ | 0.005 | 1.7 |
| | 58-86 | 23 | 20 | 0.344 | 2.5 | | | | 34 | 5.9 | 34 | 3.9 | 23 | 2 | 1.9 | 23 | 0.42 | 1.80 | 0.090 | 1.5 |
| | 86-160* | 4* | 26 | 0.010 | 1.6 | | | | 5.7 | 1.6 | 4 | 1.9 | $10^{11}$ | $10^{12}$ | 1.5 | 83 | 0.00 | 0.003 | 0.003 | 1.6 |
| Golan 70 | 0-20 | 69 | 67 | 0.115 | 3.5 | 75 | 0.091 | 4.2 | 93 | 7.1 | 90 | 4.5 | 87 | 9 | 2.9 | 115 | 0.30 | 0.245 | 0.017 | 2.8 |
| | 20-40 | 27 | 51 | 0.022 | 1.7 | 59 | 0.018 | 1.7 | 28 | 2.2 | 27 | 2.1 | 88 | 77 | 1.7 | 164 | 0.02 | 0.136 | 0.005 | 1.8 |
| | 40-60 | 24 | 181 | 0.0043 | 2.7 | no convergence | | | 24 | 3.3 | 22 | 4.2 | 1177 | 1570 | 2.7 | 181 | 0.00 | $10^{10}$ | 0.004 | 2.8 |
| Golan 37 | 0-20 | 64 | 136 | 0.020 | 2.2 | 121 | 0.023 | 2.2 | 69 | 4.4 | 65 | 8.0 | 243 | 90 | 2.2 | 136 | 1.00 | 0.020 | 0.024 | 2.4 |
| | 20-40 | 21 | 24 | 0.069 | 2.9 | 24 | 0.068 | 2.8 | 27 | 2.8 | 26 | 2.0 | 35 | 20 | 2.9 | 69 | 0.34 | 0.069 | 0.000 | 3.0 |

* Incubations for 16 weeks

Table 2: Correlation coefficients between potentially mineralizable N from different models and various nitrogen indices in soils (data from the previous chapter).

| N index[x] | $N_t = N_o(1-e^{-kt})$ $N_o(12)$ | $N_o(k)$ | $N_t=(N_o/\bar{y})\sqrt{t}$ $N_o(\sqrt{t})$ | $N_t = \frac{N_o\ t}{t_{1/2}+t}$ $N_o(Jum)$ | N mineralized $N_{32}$ |
|---|---|---|---|---|---|
| $N_o$ ($t \geq 12$) | -- | 0.848 | 0.835 | 0.978 | 0.923 |
| $N_o$ ($k=0.054$) | 0.848 | -- | 1.000 | 0.740 | 0.985 |
| $N_o(\sqrt{t})$ | 0.835 | 1.000 | -- | -- | 0.980 |
| $N_o$(Jum) | 0.978 | 0.740 | -- | -- | 0.838 |
| TOTN | 0.647 | 0.812 | 0.814 | 0.519 | 0.787 |
| KMN1 | 0.469 | 0.758 | 0.769 | ns | 0.693 |
| BICNO3 | 0.756 | 0.804 | 0.798 | 0.767 | 0.821 |
| ODO3 | 0.855 | 0.802 | 0.792 | 0.818 | 0.855 |
| OD1 | 0.944 | 0.802 | 0.788 | 0.923 | 0.875 |
| HTOTN | 0.817 | 0.866 | 0.862 | 0.724 | 0.885 |
| AMINO | 0.862 | 0.832 | 0.825 | 0.796 | 0.874 |
| AMIDAS | 0.463 | 0.691 | 0.698 | ns | 0.648 |
| AMIDAS[+] | 0.802 | 0.716 | 0.712 | 0.798 | 0.754 |
| AMIDAS[++] | 0.834 | 0.888 | 0.888 | 0.786 | 0.888 |

x TOTN = total N; KMN1 = $NH_4$-N extractable by Acid $KMnO_4$ 1N; BICNO3 = N extractable in $NaHCO_3$ 0.03N; OD1 = Optical density of that extract at 260 µm; OD1 = Optical density of $NaHCO_3$ 0.01N extract; HTOTN = Total N in acid hydrolyzate; AMINO = amino acid in hydrolyzate; AMIDAS = amidase activity

\+ Only in Bet Dagan, Eden and Akko soils (13 samples).

++ The remaining 25 soil samples

ns Not significant

Table 3: Linear relations between $N_o$, estimated by using the exponential equation with $k = 0.054\ w^{-1}$ and the square root equation, and several soil N indices.

| N index $^{x}$ X | Dependent variable Y (SD*) $N_o(k=0.054\ w^{-1})$ mg $kg^{-1}$ | $N_o(\sqrt{t})$ |
|---|---|---|
| TOTN (mg $kg^{-1}$) | Y = 0.127X-15 (30) | Y = 0.121X-13 (29) |
| KMN1 " | Y = 1.61X -24 (36) | Y = 1.55X -24 (34) |
| $BICNO_3$ " | Y = 4.98X -73 (32) | Y = 4.70X -68 (31) |
| OD03 | Y = 276X -11 (32) | Y = 260X -12 (31) |
| OD1 | Y = 183X +22 (34) | Y = 171X +22 (33) |
| HTOTN (mg $kg^{-1}$) | Y = 0.247-31 (29) | Y = 0.234X -28 (28) |
| AMINO " | Y = 0.436-3 (29) | Y = 0.411X-2 (28) |
| $AMIDAS^{+}$ (mg $kg^{-1}2h^{-1}$) | Y = 0.541X-56 (36) | Y = 0.521X -54 (35) |
| $AMIDAS^{++}$ " " | Y = 0.690X-8 (24) | Y = 0.647X-7 (23) |

x,+,++ : See footnotes of Table 2

* Root mean square error

Table 4: Acid hydrolyzable N in soils after 32 weeks of incubation.

| Soil | Depth | Total hydrolyz. N | α amino acid-N | Total hydrolyz. N | Amino acid-N |
|---|---|---|---|---|---|
| | cm | g/100g total N | | relative to initial content | |
| Alumim | 0 - 5 | 79 | 36 | 0.82 | 0.71 |
| | 5 -20 | 82 | 36 | 0.98 | 0.79 |
| Bet Dagan | 0 -20 | 82 | 32 | 1.32 | 1.35 |
| NPK | 20 -40 | 79 | 29 | 1.28 | 1.26 |
| Gilat | 0 -20 | 80 | 17 | 0.81 | 0.33 |
| | 20 -40 | 79 | 18 | 0.76 | 0.33 |
| Gilat cont. | 0 -20 | 80 | 31 | 1.01 | 1.27 |
| Gilat NM | 0 -20 | 75 | 28 | 1.04 | 1.05 |
| Akko | 0 -20 | 64 | 20 | 0.98 | 1.13 |
| | 20 -40 | 67 | 18 | 1.05 | 1.12 |
| Eden | 0 -20 | 54 | 23 | 1.02 | 1.00 |
| | 20 -40 | 52 | 23 | 1.00 | 0.98 |
| | 40 -60 | 49 | 19 | 0.91 | 0.88 |
| Golan 37 | 0 -20 | 63 | 21 | 1.20 | 1.10 |
| Golan 70 | 0 -20 | 56 | 24 | 1.09 | 1.21 |

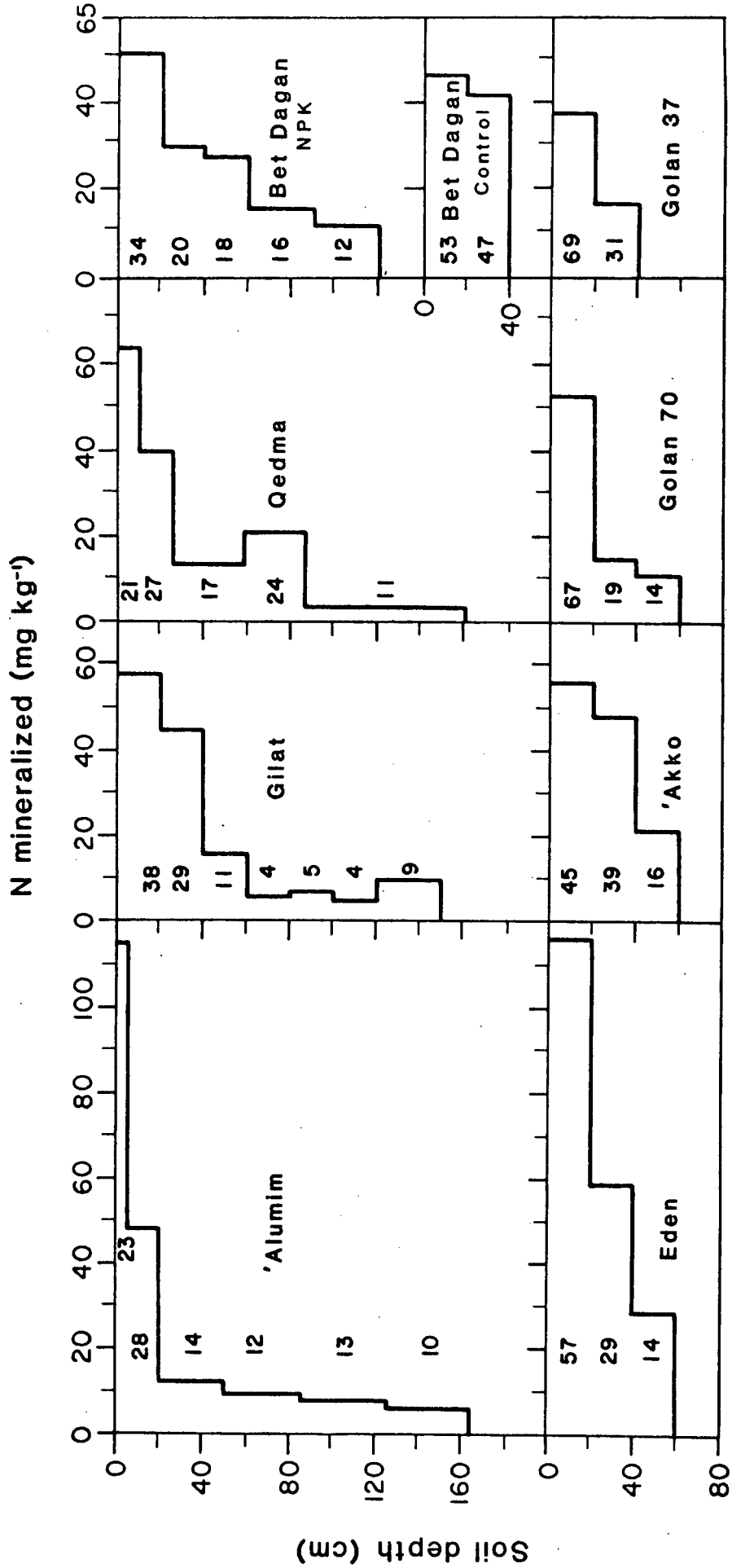


Figure 1: Mineral N accumulated in soil profiles after 16 weeks of incubation at 35°C. The numbers in each diagram indicate the relative contribution of each soil layer in percent of total N mineralized in the whole profile.

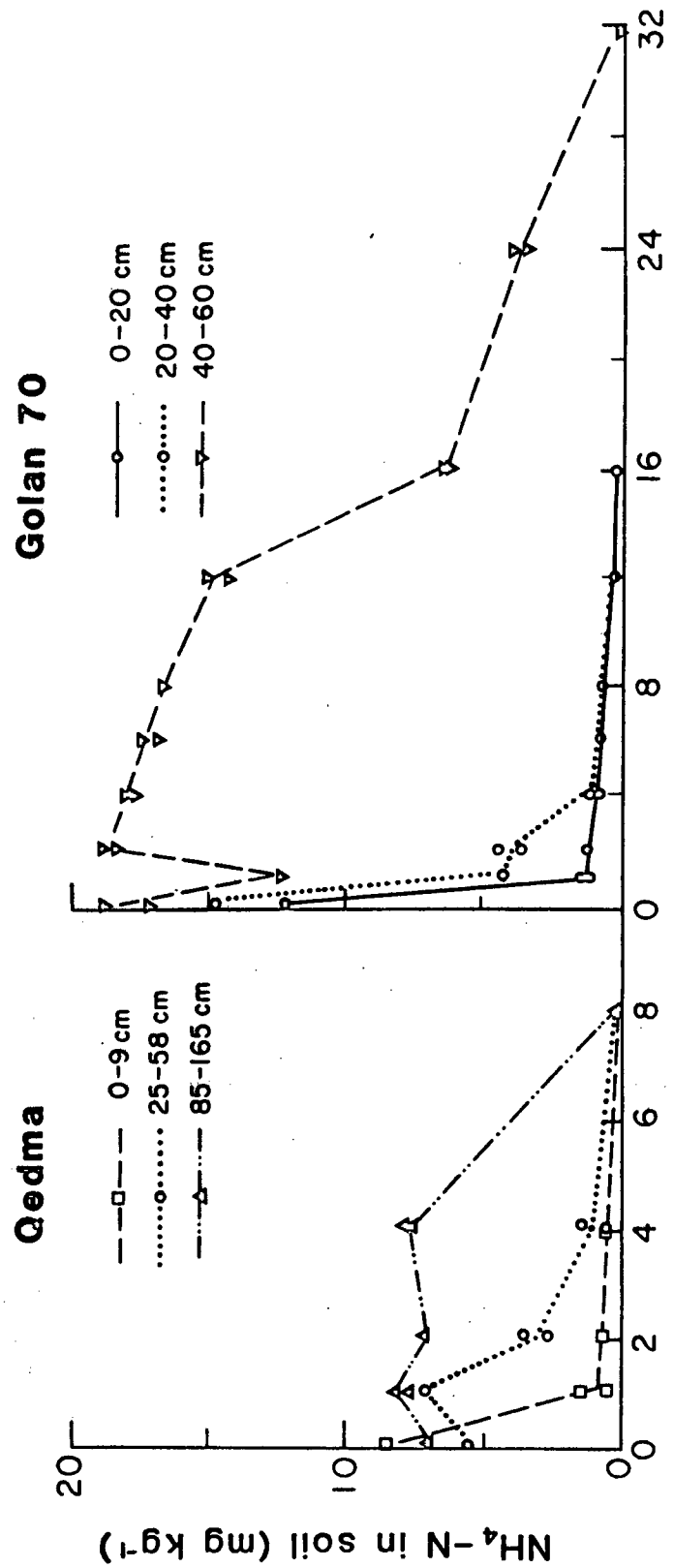


Figure 2: Concentrations of $NH_4$-N in various layers of Qedma and Golan 70 soils during incubation.

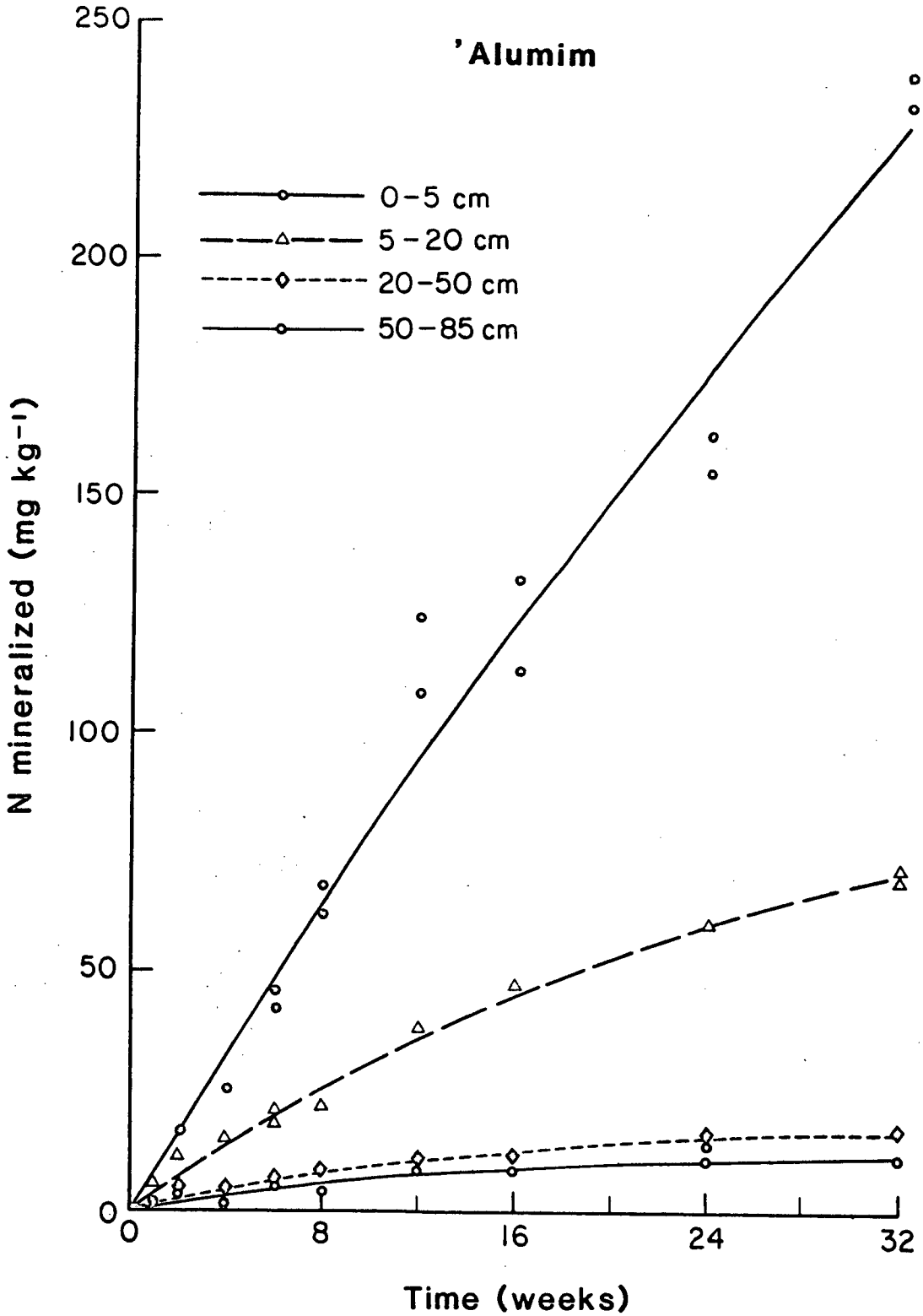


Figure 3: Nitrogen mineralization in soil profiles incubated for 32 weeks at 35°C. The symbols represent the experimental data and the curves are calculated, using the exponential equation.

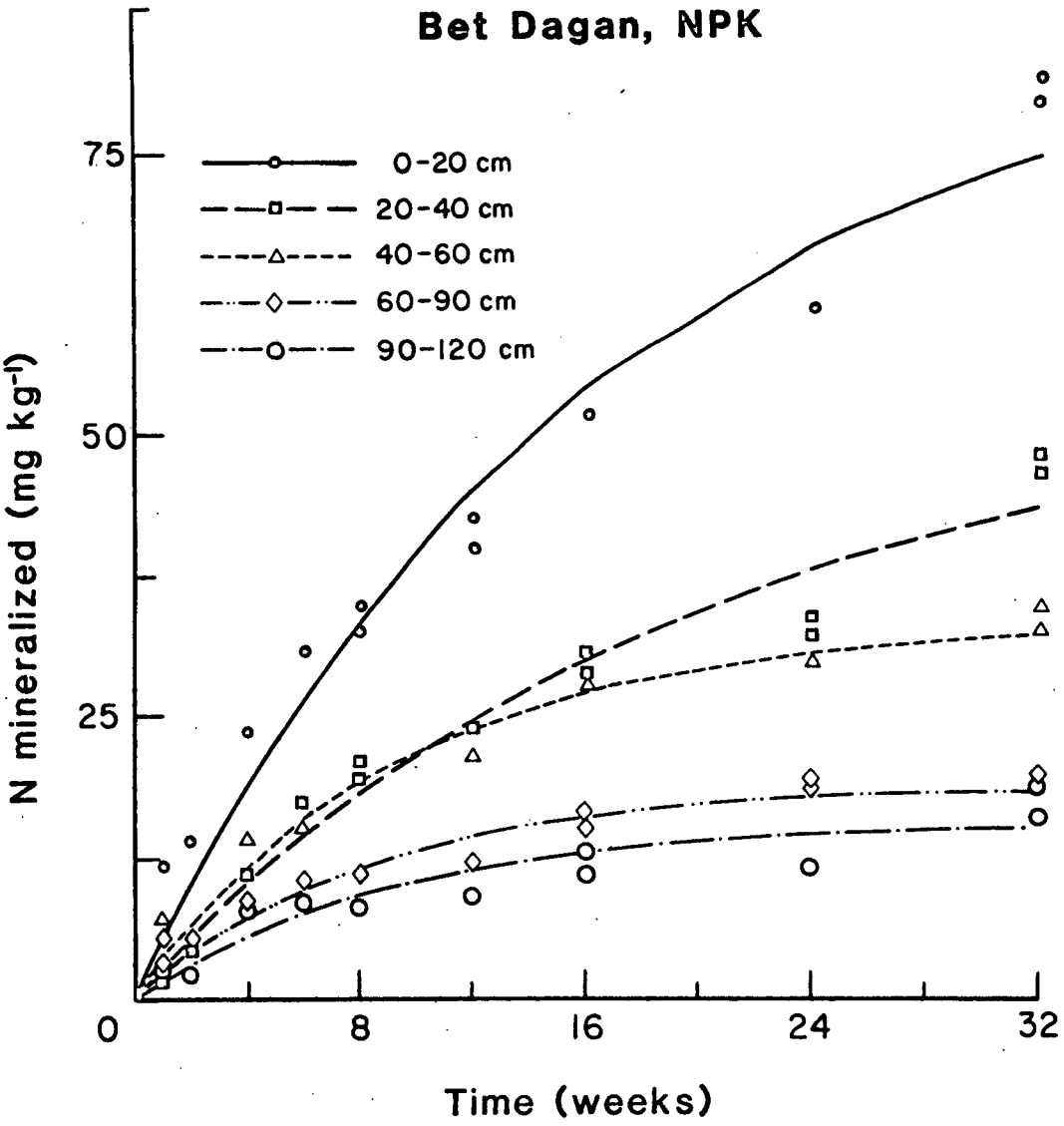
Bet Dagan, NPK
0-20 cm
20-40 cm
40-60 cm
60-90 cm
90-120 cm
N mineralized (mg kg⁻¹)
75
50
25
0
8
16
24
32
Time (weeks)

Fig. 3.

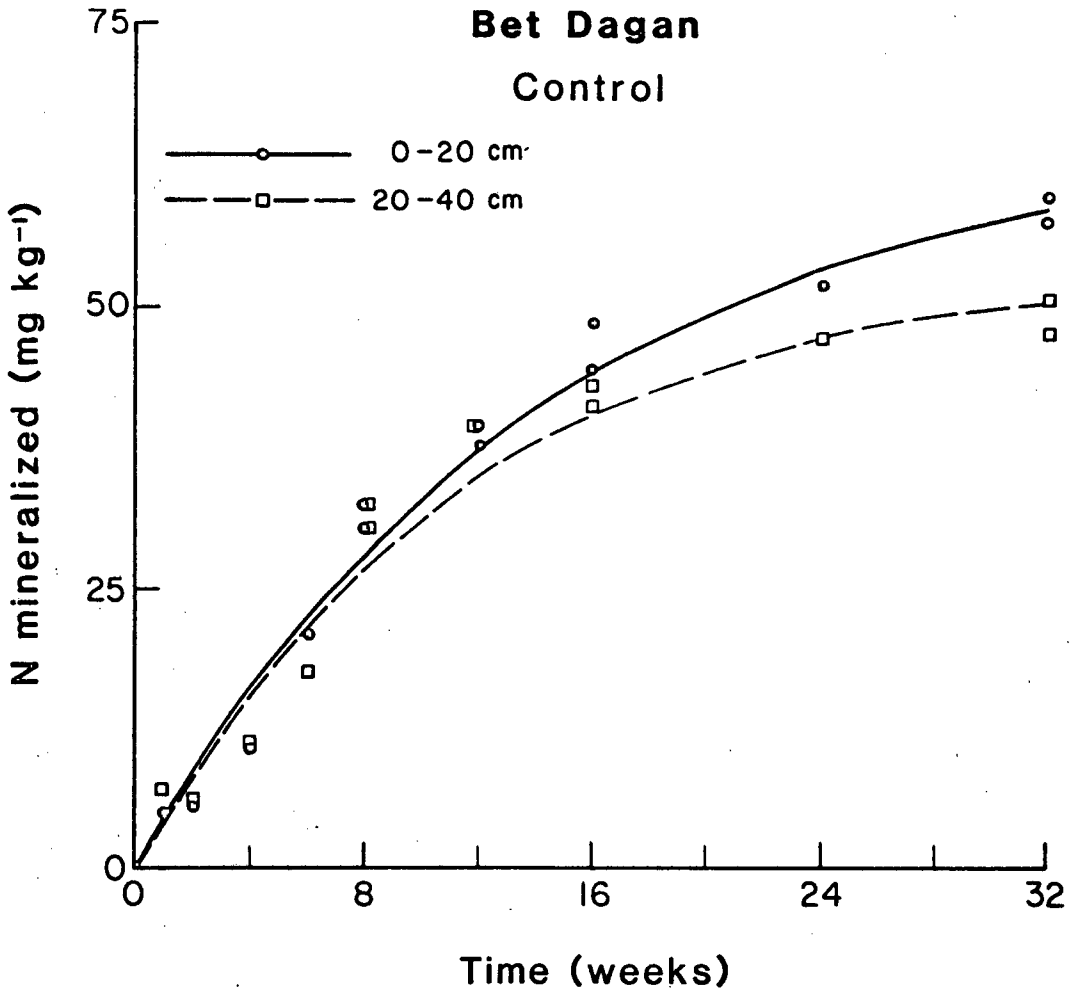
Bet Dagan
Control
0-20 cm
20-40 cm
N mineralized (mg kg⁻¹)
75
50
25
0
0
8
16
24
32
Time (weeks)

Fig. 3

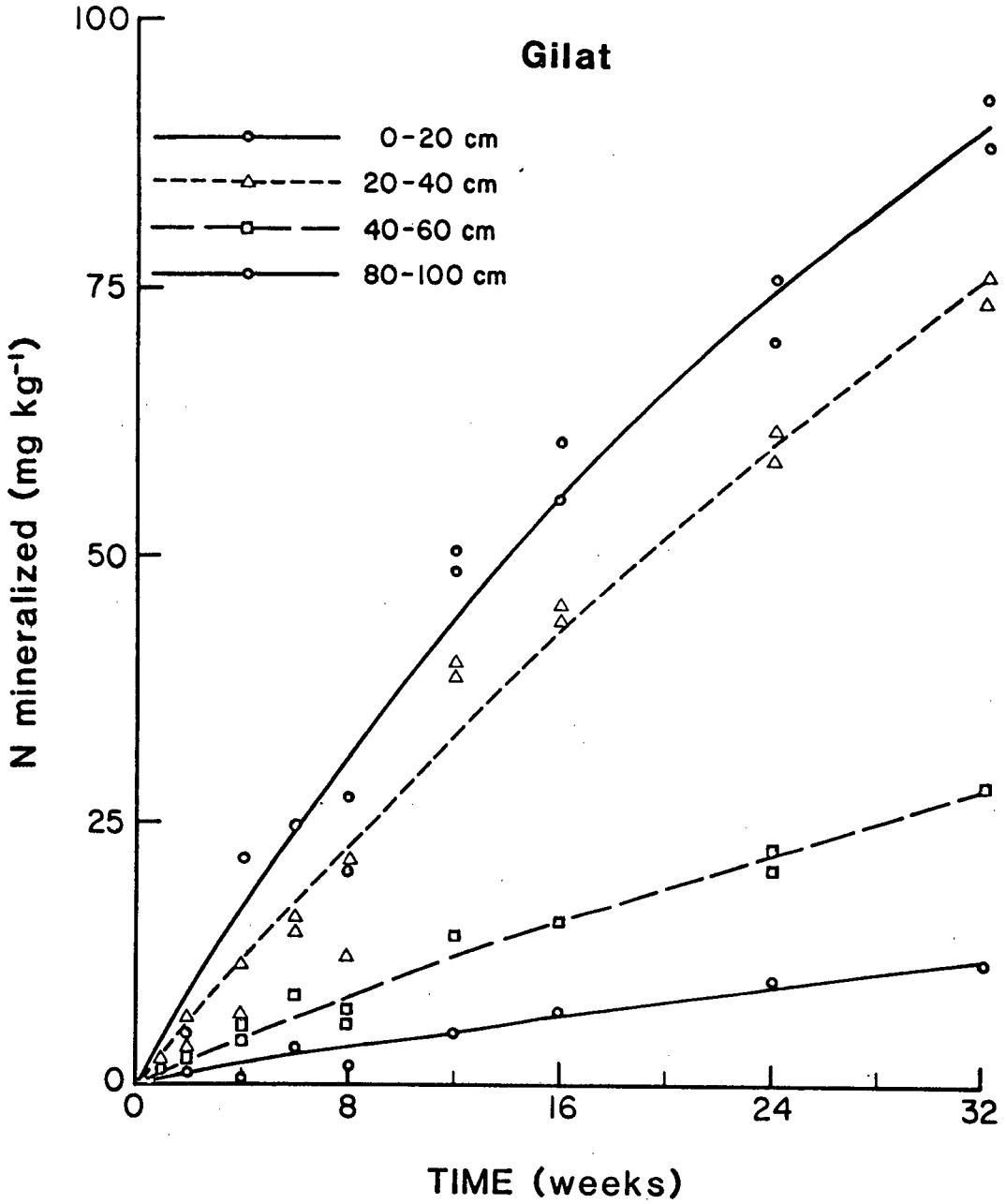
Gilat
0-20 cm
20-40 cm
40-60 cm
80-100 cm
N mineralized (mg kg⁻¹)
TIME (weeks)
0
25
50
75
100
0
8
16
24
32

Fig. 3.

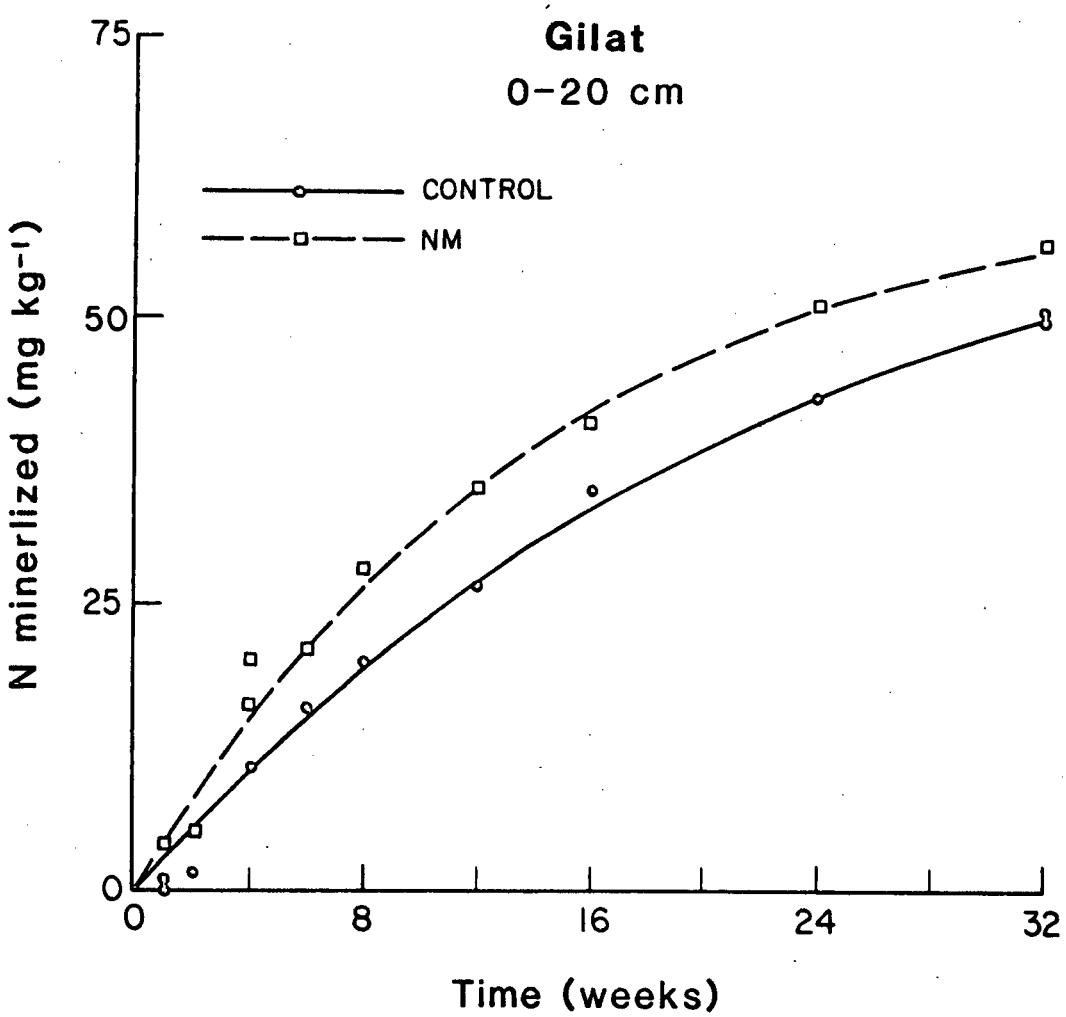
Gilat
0-20 cm
CONTROL
NM
N minerlized (mg kg-1)
75
50
25
0
0
8
16
24
32
Time (weeks)

Fig. 3.

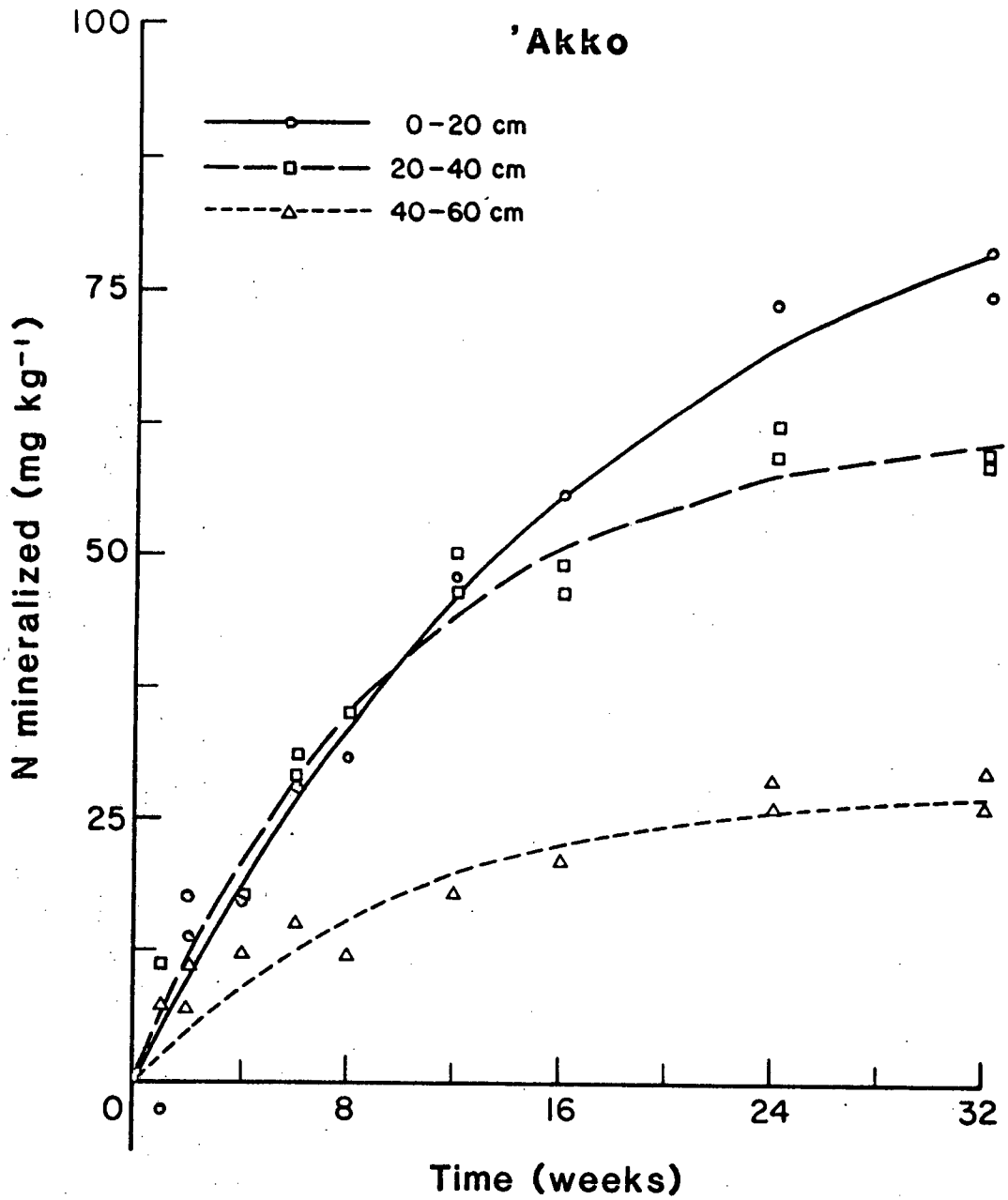
'Akko
0-20 cm
20-40 cm
40-60 cm
N mineralized (mg kg⁻¹)
100
75
50
25
0
8
16
24
32
Time (weeks)

Fig. 3.

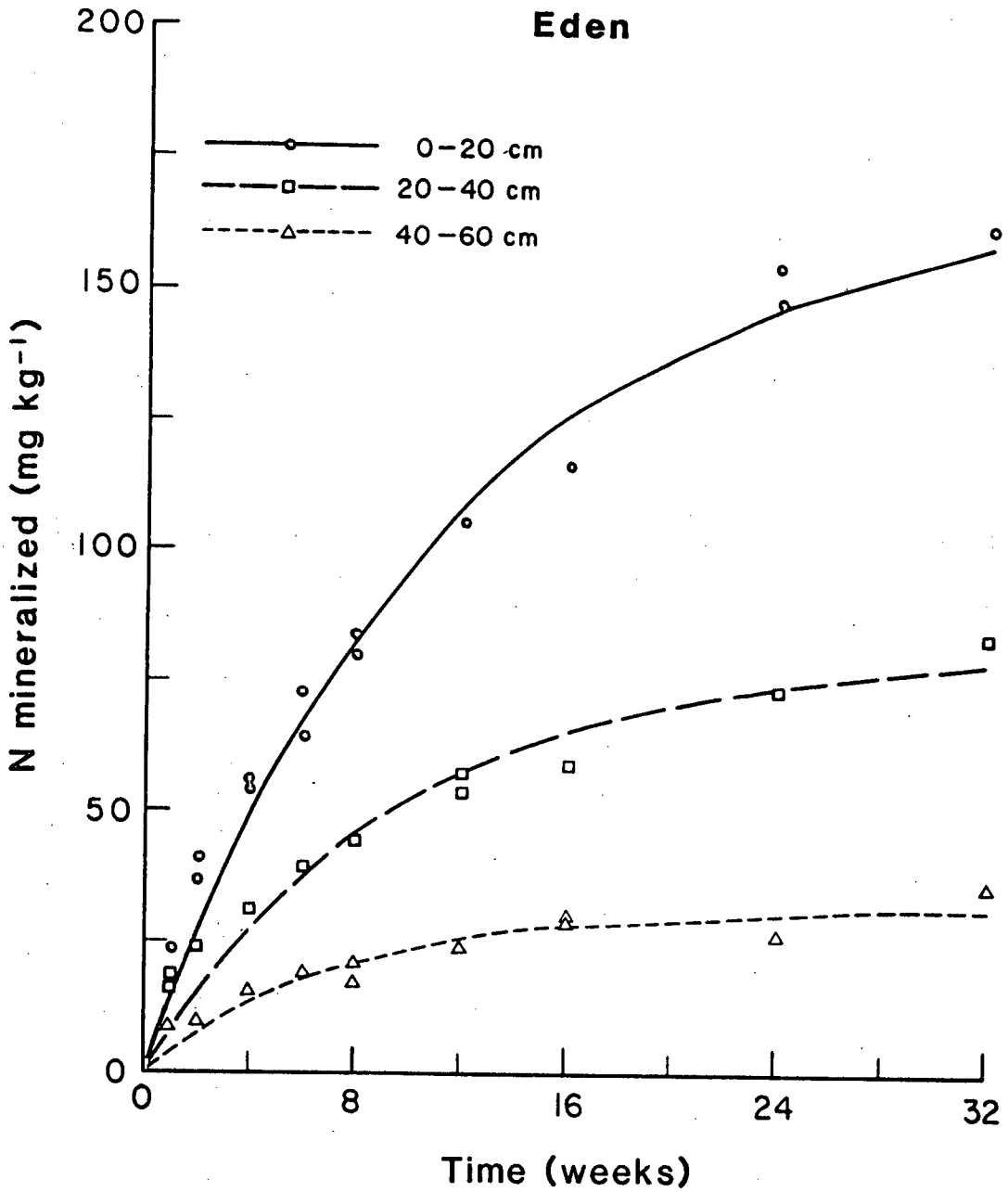
Eden
0–20 cm
20–40 cm
40–60 cm
N mineralized (mg kg⁻¹)
200
150
100
50
0
0
8
16
24
32
Time (weeks)

Fig. 3.

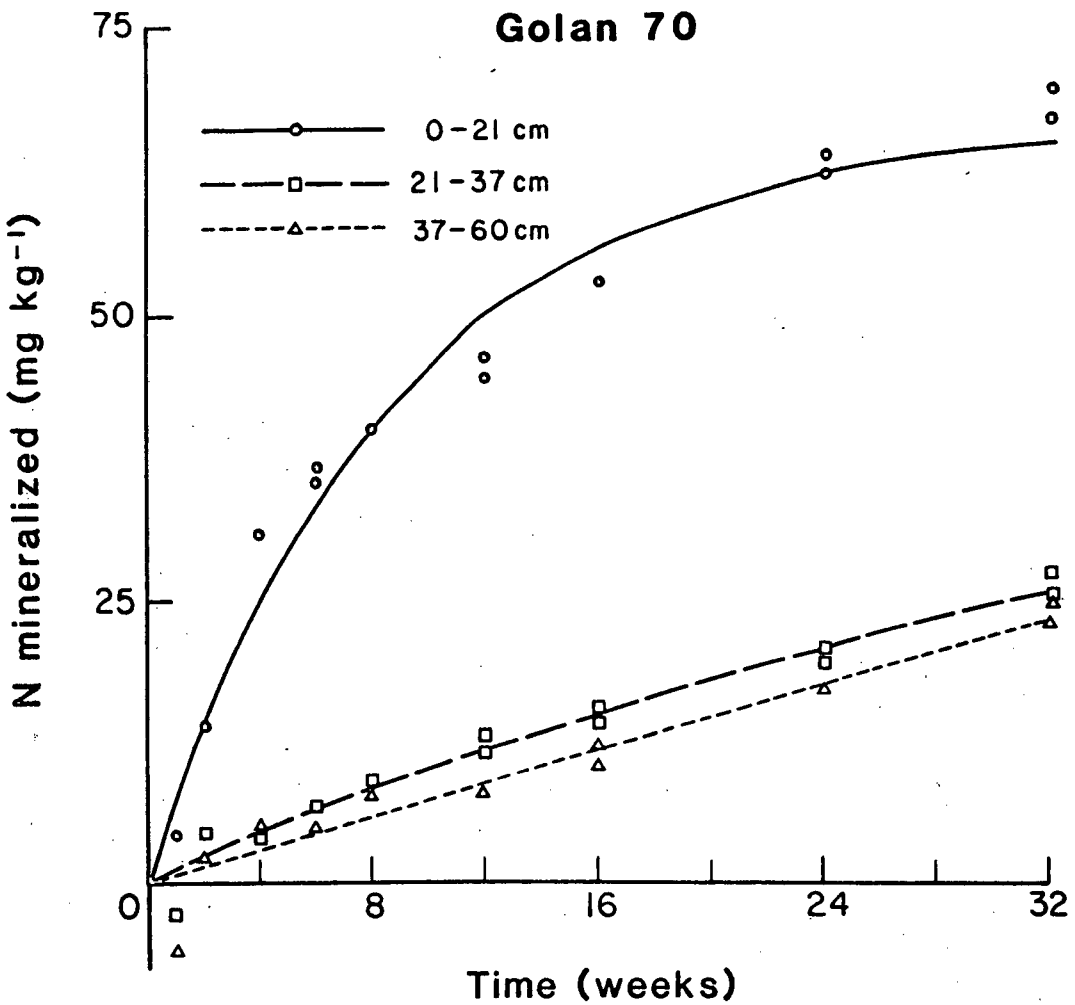
Golan 70
0-21 cm
21-37 cm
37-60 cm
N mineralized (mg kg⁻¹)
75
50
25
0
8
16
24
32
Time (weeks)

Fig. 3.

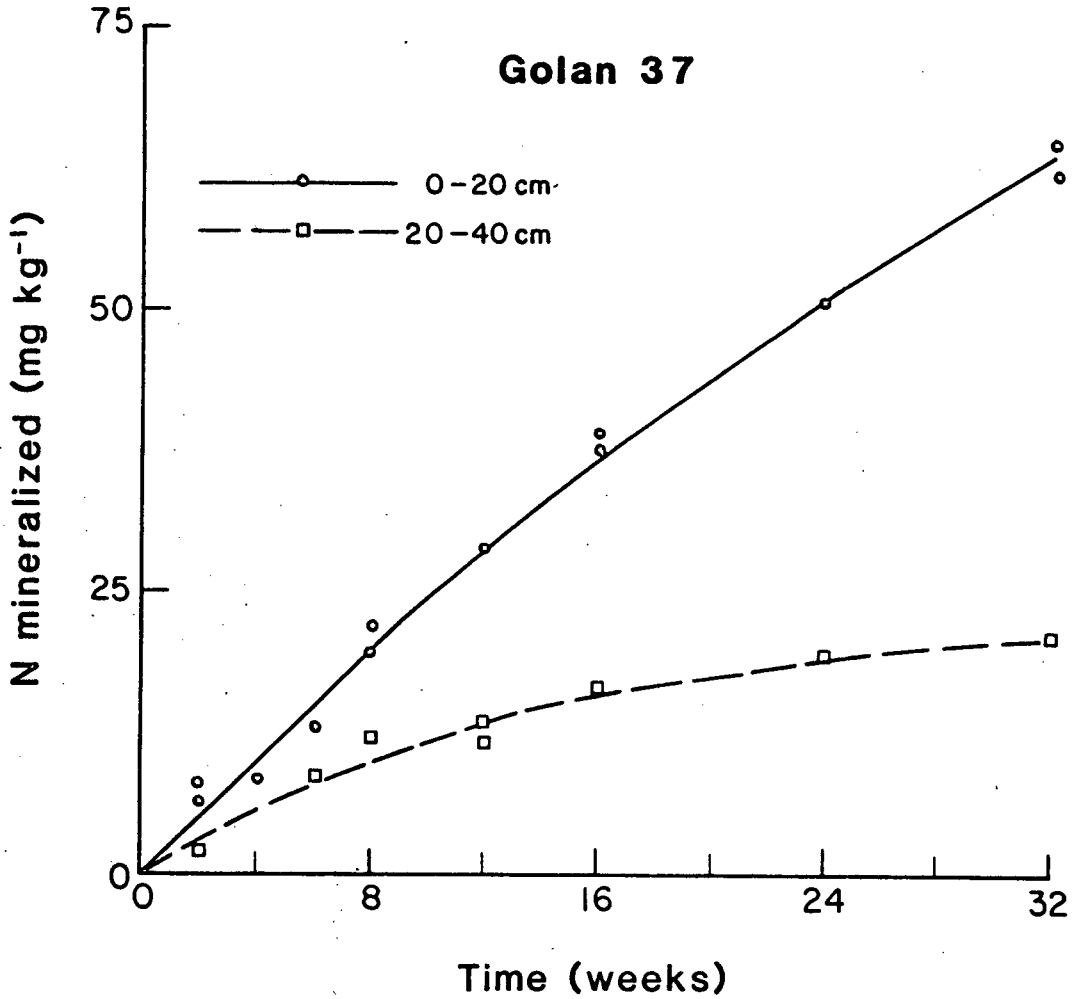
Golan 37
0-20 cm
20-40 cm
N mineralized (mg kg⁻¹)
75
50
25
0
0
8
16
24
32
Time (weeks)

Fig. 3.

Appendix (II).

MINERALIZATION EXPERIMENT : NH4-N AND NO3-N (PPM) AT TIME T (W)

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BET DAGAN CONTROL | | | | ---------- BET DAGAN N P K ---------- | | | | | | | | | |
| | 0-20 | | 20-40 | | 0-20 | | 20-40 | | 40-60 | | 60-90 | | 90-120 | |
| 0 | 4.6 | 5.4 | 3.9 | 3.9 | 8.0 | 39.2 | 10.5 | 40.0 | 6.2 | 24.7 | 6.2 | 15.9 | 6.1 | 15.2 |
| 0 | 4.6 | 5.4 | 3.9 | 3.9 | 8.0 | 39.2 | 10.5 | 39.3 | 5.4 | 25.2 | 6.9 | 16.2 | 6.1 | 15.1 |
| 1 | 1.5 | 13.2 | 0.8 | 14.0 | 0.8 | 57.6 | 1.3 | 50.6 | 1.5 | 36.3 | 2.2 | 25.7 | 4.0 | 20.0 |
| 1 | 1.5 | 13.9 | 0.8 | 14.0 | 0.8 | 58.7 | 1.3 | 50.0 | 1.5 | 36.3 | 2.2 | 25.7 | 3.8 | 19.8 |
| 2 | 1.4 | 14.4 | 1.1 | 12.4 | 1.1 | 60.3 | 0.6 | 53.7 | 0.8 | 36.3 | 0.5 | 27.7 | 0. | 23.0 |
| 2 | 1.1 | 13.9 | 1.2 | 12.6 | 1.0 | 59.5 | 0.8 | 53.2 | 0.8 | 36.0 | 0.5 | 27.4 | 0. | 23.4 |
| 4 | 0.9 | 20.1 | 0.8 | 17.9 | 0.6 | 70.8 | 0.5 | 60.9 | 0.5 | 44.3 | 0.5 | 30.8 | 0.8 | 28.5 |
| 4 | 1.1 | 20.1 | 0.8 | 17.9 | 0.6 | 69.8 | 0.6 | 60.6 | 0.5 | 44.5 | 0.5 | 30.0 | 0.8 | 28.8 |
| 6 | 0.9 | 29.7 | 0.8 | 25.2 | 0.5 | 77.7 | 0.6 | 67.7 | 0.6 | 45.5 | 0.8 | 32.3 | 0.8 | 29.2 |
| 6 | 0.9 | 30.9 | 0.9 | 24.1 | 0.5 | 77.2 | 0.5 | 66.3 | 0.5 | 44.8 | 0.9 | 32.0 | 0.8 | 29.2 |
| 8 | 0.5 | 41.8 | 0.6 | 39.8 | 0.3 | 82.0 | 0.3 | 70.9 | 0.2 | 50.5 | 0.5 | 33.1 | 0.5 | 29.2 |
| 8 | 0.3 | 40.2 | 0.6 | 37.3 | 0.3 | 79.6 | 0.3 | 69.3 | 0.3 | 50.3 | 0.5 | 32.9 | 0.6 | 28.5 |
| 12 | 0.3 | 49.0 | 0.6 | 46.3 | 0.3 | 90.0 | 0.3 | 74.2 | 0.3 | 52.0 | 0.5 | 33.9 | 0.5 | 30.0 |
| 12 | 0.3 | 47.8 | 0.6 | 46.3 | 0.3 | 86.8 | 0.3 | 73.3 | 0.3 | 51.7 | 0.5 | 33.9 | 0.5 | 29.2 |
| 16 | 0.3 | 58.4 | 0.3 | 50.6 | 0.3 | 98.9 | 0.3 | 81.1 | 0.3 | 59.0 | 0.5 | 38.5 | 0.3 | 31.7 |
| 16 | 0.3 | 54.2 | 0.3 | 49.0 | 0.3 | 98.6 | 0.3 | 79.0 | 0.3 | 57.7 | 0.5 | 37.0 | 0.3 | 33.8 |
| 24 | 0.3 | 61.5 | 0.3 | 54.8 | 0.3 | 109. | 0.3 | 83.8 | 0.3 | 61.0 | 0.3 | 41.6 | 0.3 | 32.3 |
| 24 | 0.3 | 61.9 | 0.3 | 54.5 | 0.3 | 108. | 0.3 | 82.4 | 0.3 | 60.1 | 0.3 | 40.0 | 0.3 | 32.9 |
| 32 | 0.3 | 67.5 | 0.3 | 55.2 | 0.3 | 127. | 0.3 | 96.7 | 0.3 | 63.3 | 0.3 | 41.9 | 0.3 | 37.7 |
| 32 | 0.3 | 69.7 | 0.3 | 57.9 | 0.3 | 129. | 0.3 | 98.5 | 0.3 | 65.8 | 0.3 | 42.2 | 0.3 | 40.0 |
| | GOLAN 37 | | | | ------GOLAN 70 ------- | | | | | | GILAT CNT | | GILAT NM | |
| | 0-20 | | 20-40 | | 0-20 | | 20-40 | | 40-60 | | 0-20 | | 0-20 | |
| 0 | 17.7 | 2.9 | 10.9 | 2.2 | 12.2 | 4.5 | 14.8 | 4.5 | 18.9 | 4.8 | 4.4 | 3.0 | 4.1 | 3.3 |
| 0 | 18.4 | 2.2 | 10.9 | 2.2 | 12.4 | 4.2 | 14.8 | 4.0 | 17.2 | 4.8 | 4.1 | 3.1 | 4.3 | 3.0 |
| 1 | 2.2 | 16.7 | 3.2 | 3.9 | 1.2 | 19.7 | 4.2 | 12.1 | 12.2 | 4.4 | 1.5 | 5.8 | 1.5 | 10.1 |
| 1 | 2.2 | 16.7 | 3.6 | 4.6 | 1.5 | 19.4 | 4.4 | 12.1 | 12.4 | 4.8 | 1.8 | 6.7 | 1.5 | 9.8 |
| 2 | 0.7 | 28.1 | 8.0 | 7.0 | 1.4 | 30.0 | 4.5 | 19.1 | 18.8 | 6.5 | 1.5 | 7.7 | 1.0 | 11.1 |
| 2 | 0.7 | 26.4 | 8.8 | 6.4 | 1.2 | 29.1 | 3.7 | 19.6 | 18.4 | 6.0 | 1.3 | 7.4 | 1.0 | 11.8 |
| 4 | 0.7 | 28.7 | . | 9.7 | 0.9 | 46.1 | 1.1 | 21.8 | 17.7 | 10.3 | 0.9 | 17.3 | 0.7 | 26.9 |
| 4 | 0.7 | 28.5 | . | 9.6 | 0.8 | 47.2 | 1.1 | 21.8 | 18.0 | 9.4 | 0.9 | 17.8 | 0.7 | 22.5 |
| 6 | 0.7 | 33.3 | 8.0 | 13.7 | 0.8 | 52.6 | 0.8 | 24.9 | 16.7 | 11.1 | 0.3 | 23.2 | 0.4 | 28.1 |
| 6 | 0.6 | 33.0 | 7.4 | 14.5 | 0.8 | 51.4 | 0.8 | 25.3 | 17.5 | 11.1 | 0.4 | 22.5 | 0.4 | 27.4 |
| 8 | 1.5 | 41.3 | 5.6 | 19.5 | 0.8 | 55.7 | 0.8 | 26.7 | 16.7 | 13.5 | 0.2 | 26.6 | 0.3 | 34.9 |
| 8 | 1.2 | 39.1 | 5.5 | 19.4 | 0.8 | 56.3 | 0.8 | 27.5 | 16.7 | 14.3 | 0.2 | 27.4 | 0.3 | 35.5 |
| 12 | 0.7 | 49.2 | 2.2 | 22.4 | 0.3 | 63.0 | 0.3 | 31.9 | 15.1 | 15.6 | 0.3 | 33.4 | 0.3 | 42.2 |
| 12 | 0.7 | 48.9 | 1.9 | 24.6 | 0.3 | 61.1 | 0.3 | 30.3 | 14.3 | 16.7 | 0.3 | 33.9 | 0.3 | 42.5 |
| 16 | 0.4 | 59.4 | 0.7 | 29.0 | 0.3 | 69.7 | 0.3 | 34.2 | 6.2 | 27.0 | 0.3 | 41.4 | 0.3 | 47.5 |
| 16 | 0.4 | 57.9 | 0.7 | 29.0 | 0.3 | 69.2 | 0.3 | 32.9 | 6.4 | 28.6 | 0.3 | 42.2 | 0.3 | 47.9 |
| 24 | 0.3 | 71.0 | 0.3 | 32.4 | 0.3 | 80.5 | 0.3 | 39.6 | 4.0 | 35.6 | 0.3 | 50.3 | 0.3 | 58.0 |
| 24 | 0.3 | 71.0 | 0.3 | 31.9 | 0.3 | 78.9 | 0.3 | 38.1 | 3.5 | 36.6 | 0.3 | 49.7 | 0.3 | 58.5 |
| 32 | 0.3 | 82.8 | 0.3 | 33.3 | 0.3 | 83.9 | 0.3 | 44.3 | 0.3 | 47.7 | 0.3 | 56.5 | 0.3 | 64.1 |
| 32 | 0.3 | 85.4 | 0.3 | 33.7 | 0.3 | 86.2 | 0.3 | 46.3 | 0.3 | 45.5 | 0.3 | 57.7 | 0.3 | 63.3 |
| | GILAT | | | | | | | | | | | | | |
| | 0-20 | | 20-40 | | 40-60 | | 60-80 | | 80-100 | | 100-120 | | 125-150 | |
| 0 | 3.8 | 2.5 | 5.3 | 2.9 | 1.6 | 2.0 | 2.4 | 0.8 | 1.5 | 1.5 | 1.3 | 1.8 | 1.2 | 0.0 |
| 0 | 4.2 | 3.8 | 3.8 | 1.7 | 0.5 | 1.0 | 1.3 | 0.8 | 2.1 | 2.3 | 0.2 | 1.0 | 1.1 | 0.1 |
| 1 | 1.0 | 6.7 | 0.0 | 8.8 | 0.6 | 3.8 | 0.2 | 0.9 | 1.9 | 1.2 | 1.2 | 1.1 | 2.3 | 1.3 |
| 1 | 0.7 | 6.1 | 0.6 | 9.0 | 1.1 | 2.5 | 1.0 | 0.0 | 1.2 | 0.6 | 1.4 | 1.0 | 2.4 | 0.8 |
| 2 | 0.0 | 11.9 | 0.0 | 13.3 | 0.0 | 5.2 | 2.1 | 1.3 | 2.2 | 2.5 | 1.8 | 1.1 | 1.5 | 2.6 |
| 2 | 0.1 | 12.2 | 0.2 | 9.8 | 0.0 | 5.4 | 1.6 | 0.4 | 1.7 | 3.1 | 2.5 | 2.2 | 2.2 | 2.6 |
| 4 | 0.4 | 28.5 | 0.0 | 18.3 | 0.0 | 8.1 | 2.2 | 0.6 | 2.6 | 1.5 | 1.4 | 1.5 | 0.6 | 3.1 |
| 4 | 0.4 | 28.3 | 0.2 | 13.3 | 0.0 | 6.8 | 2.3 | 0.5 | 2.6 | 1.7 | 1.1 | 1.3 | | |
| 6 | 0.0 | 32.1 | 0.6 | 20.8 | 0.2 | 10.4 | 4.5 | 0.9 | 4.2 | 2.7 | 6.3 | 1.8 | 2.1 | 5.7 |
| 6 | 0.4 | 31.6 | 0.4 | 22.4 | 0.1 | 10.8 | 5.3 | 0.9 | 4.9 | 3.2 | 4.3 | 2.5 | 1.8 | 4.9 |
| 8 | 0.0 | 27.7 | 0.0 | 23.9 | 0.0 | 8.1 | 1.6 | 1.3 | 0.0 | 5.4 | 2.2 | 0.7 | 0.0 | 5.5 |
| 8 | 0.2 | 34.4 | 0.6 | 27.7 | 0.0 | 9.6 | 2.2 | | 0.2 | 5.3 | 2.6 | 1.1 | 0.0 | 5.2 |
| 12 | 1.5 | 54.2 | 0.9 | 44.7 | 0.5 | 16.6 | 0.5 | 12.5 | 1.0 | 8.0 | 2.6 | 4.1 | 1.4 | 8.3 |
| 12 | 1.5 | 56.2 | 1.0 | 45.8 | 0.5 | 16.1 | 0.5 | 12.9 | 1.0 | 7.5 | 3.8 | 3.8 | 1.1 | 8.0 |
| 16 | 1.3 | 61.4 | 0.7 | 50.3 | 0.3 | 17.8 | 0.3 | 8.3 | 0.3 | 10.1 | 0.8 | 6.7 | 0.4 | 12.3 |
| 16 | 1.3 | 66.6 | 0.6 | 51.8 | 0.3 | 17.7 | 0.3 | 8.6 | 0.3 | 10.6 | 0.8 | 6.0 | 0.3 | 11.2 |
| 24 | 0.7 | 76.8 | 0.6 | 68.1 | 0.6 | 22.2 | 0.3 | 11.0 | 0.3 | 13.4 | 0.7 | 6.7 | 0.6 | 13.6 |
| 24 | 0.6 | 82.8 | 0.6 | 65.1 | 0.7 | 24.2 | 0.3 | 10.6 | 0.3 | 13.6 | 0.7 | 6.8 | 0.6 | 13.6 |
| 32 | 0.3 | 95.5 | 0.3 | 80.6 | 0.3 | 30.9 | 0.3 | 11.8 | 0.3 | 15.1 | 0.3 | 9.8 | 0.3 | 13.6 |
| 32 | 0.3 | 99.9 | 0.3 | 83.2 | 0.3 | 30.9 | 0.3 | 11.9 | 0.3 | 15.1 | 0.3 | 9.8 | 0.3 | 13.6 |
| 0 | | | | | | | | | | | | | | |

Appendix (II).

## MINERALIZATION EXPERIMENT (CONTINUED)

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ALUMIM | | | | | | | | | | | | | |
| | 0-5 | | 5-20 | | 20-50 | | 50-85 | | 85-125 | | 125-165 | | | |
| 0 | 7.2 | 2.4 | 1.8 | 0.3 | 0.0 | 0.4 | 0.4 | 0.8 | 0.8 | 0.1 | 0.9 | 0.4 | | |
| 0 | 4.6 | 1.2 | 1.7 | 0.0 | 0.5 | 0.0 | 0.7 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | | |
| 1 | 0.4 | 9.4 | 0.4 | 8.0 | 3.6 | 0.3 | 1.8 | 2.0 | 1.0 | 0.0 | 2.0 | 0.8 | | |
| 1 | 0.1 | 12.6 | 0.4 | 7.6 | 3.5 | 0.4 | 1.5 | 0.0 | 1.0 | 0.0 | 2.1 | 1.0 | | |
| 2 | 0.3 | 23.1 | 0.4 | 13.6 | 2.2 | 3.3 | 2.6 | 2.3 | 2.0 | 0.4 | 1.7 | 0.8 | | |
| 2 | 0.2 | 24.5 | 0.1 | 13.1 | 3.3 | 2.2 | 1.8 | 2.1 | 2.2 | 0.5 | 2.6 | 1.7 | | |
| 4 | 0.5 | 32.5 | 0.4 | 16.8 | 0.0 | 3.5 | 1.9 | 1.3 | . | . | 1.6 | 0.3 | | |
| 4 | 0.0 | 34.1 | 0.3 | 16.9 | 0.3 | 5.1 | 1.5 | 1.0 | . | . | 1.2 | 0.1 | | |
| 6 | 0.4 | 53.6 | 0.0 | 19.7 | 0.5 | 6.6 | 3.8 | 3.3 | 4.0 | 0.9 | 3.7 | 2.1 | | |
| 6 | 1.3 | 49.0 | 0.7 | 22.1 | 0.6 | 7.0 | 3.6 | 3.5 | 2.6 | 2.5 | 3.9 | 0.8 | | |
| 8 | 0.6 | 75.0 | 0.0 | 24.3 | 0.0 | 10.1 | 0.5 | 5.3 | 0.0 | 2.0 | 1.4 | 1.5 | | |
| 8 | 0.0 | 70.0 | 0.4 | 22.6 | 0.2 | 8.2 | 1.0 | 4.6 | 0.7 | 2.6 | 1.1 | 0.8 | | |
| 12 | 2.0 | 128. | 0.9 | 39.2 | 1.0 | 10.1 | 0.6 | 8.6 | 0.5 | 4.6 | 0.2 | 5.4 | | |
| 12 | 2.0 | 114. | 1.0 | 37.7 | 0.8 | 10.8 | 0.6 | 8.6 | 0.5 | 5.0 | 0.3 | 5.4 | | |
| 16 | 0.8 | 139. | 0.6 | 51.0 | 0.6 | 12.0 | 0.6 | 8.9 | 0.5 | 7.9 | 0.5 | 6.9 | | |
| 16 | 0.9 | 120. | 0.6 | 48.1 | 0.7 | 11.7 | 0.7 | 9.0 | 0.5 | 7.6 | 0.3 | 6.6 | | |
| 24 | 0.6 | 170. | 0.7 | 61.6 | 1.5 | 16.4 | 1.0 | 10.6 | 1.2 | 9.1 | 0.8 | 8.7 | | |
| 24 | 0.7 | 162. | 0.7 | 60.1 | 1.3 | 15.0 | 1.5 | 13.6 | 1.3 | 9.1 | 0.9 | 9.5 | | |
| 32 | 0.3 | 246. | 0.3 | 74.0 | 0.3 | 18.0 | 0.3 | 12.8 | 0.3 | 10.6 | 0.3 | 8.0 | | |
| 32 | 0.3 | 240. | 0.3 | 70.3 | 0.3 | 17.3 | 0.3 | 12.1 | 0.3 | 11.4 | 0.3 | 8.3 | | |
| | ACO (HADAR) | | | | | | NETIVOT | | | | KEDMA | | | |
| | 0-20 | | 20-40 | | 40-60 | | 0-22 | | 105-155 | | 9-25 | | 58-86 | |
| 0 | 6.1 | 11.0 | 5.2 | 2.2 | 3.6 | 1.9 | 8.1 | 2.5 | 0.7 | 2.1 | 2.3 | 2.4 | 1.3 | 6.7 |
| 0 | 5.6 | 9.9 | 4.2 | 2.3 | 2.4 | 1.4 | 7.9 | 1.4 | 1.8 | 2.0 | 2.2 | 2.0 | 0.1 | 6.1 |
| 1 | 0.6 | 24.8 | 0.2 | 7.9 | 1.9 | 8.7 | 2.4 | 29.2 | 2.7 | 1.3 | 0.8 | 10.3 | 6.1 | 9.4 |
| 1 | 0.0 | 25.1 | 0.0 | 11.2 | 2.4 | 10.1 | 3.5 | 25.0 | 1.9 | 1.7 | 0.0 | 11.7 | 7.6 | 9.6 |
| 2 | 0.0 | 40.7 | 0.0 | 25.2 | 0.0 | 14.4 | 0.9 | 36.6 | 2.3 | 3.2 | 0.0 | 18.4 | 7.3 | 10.7 |
| 2 | 0.0 | 37.9 | 0.0 | 24.8 | 0.0 | 12.3 | 0.0 | 34.4 | 3.0 | 4.1 | 0.0 | 18.0 | 8.1 | 12.2 |
| 4 | 0.2 | 54.8 | 0.2 | 21.4 | 0.0 | 19.2 | 0.4 | 47.3 | 2.6 | 3.2 | 0.2 | 21.7 | 7.9 | 13.8 |
| 4 | 0.3 | 52.6 | 0.0 | 28.7 | 0.2 | 14.0 | 3.0 | 53.0 | 2.2 | 3.2 | 0.2 | 18.7 | 7.3 | 12.3 |
| 6 | 0.2 | 38.2 | 0.0 | 20.2 | 0.6 | 20.9 | 0.0 | 60.0 | 6.1 | 4.0 | 0.0 | 27.3 | 8.3 | 16.2 |
| 6 | 0.0 | 51.0 | 0.1 | 25.4 | 0.6 | 21.3 | 3.5 | 68.0 | 5.5 | 3.7 | 0.6 | 27.5 | 8.6 | 12.0 |
| 8 | 0.0 | 35.5 | 0.0 | 34.9 | 0.0 | 20.2 | 0.0 | 80.5 | 3.0 | 4.4 | 0.0 | 27.1 | 7.2 | 17.7 |
| 8 | 0.0 | 64.6 | 0.6 | 27.4 | 0.0 | 23.5 | 0.0 | 73.7 | 2.3 | 3.2 | 0.0 | 32.3 | 5.2 | 17.4 |
| 12 | 0.8 | 88.7 | 0.8 | 40.0 | 0.5 | 25.9 | . | . | . | . | 0.8 | 40.9 | 0.3 | 24.5 |
| 12 | 1.0 | 86.5 | 0.7 | 39.6 | 0.5 | 26.2 | . | . | . | . | 0.9 | 41.9 | 0.3 | 25.6 |
| 16 | 0.5 | 87.8 | 0.7 | 45.4 | 0.3 | 28.6 | 0.7 | 158. | 0.7 | 9.1 | 0.3 | 45.4 | 0.3 | 28.0 |
| 16 | 0.7 | 79.8 | 0.3 | 44.5 | 0.3 | 28.1 | 0.6 | 146. | 0.7 | 8.4 | 0.3 | 43.5 | 0.4 | 28.5 |
| 24 | 0.5 | 111. | 0.5 | 63.0 | 0.8 | 33.9 | 0.3 | 268. | 0.3 | 10.2 | 0.3 | 53.1 | 0.3 | 28.3 |
| 24 | 0.5 | 104. | 0.5 | 61.1 | 0.7 | 31.6 | 0.4 | 260. | 0.4 | 10.2 | 0.3 | 52.4 | 0.4 | 25.6 |
| 32 | 0.3 | 134. | 0.3 | 74.3 | 0.3 | 37.6 | 0.3 | 286. | 0.3 | 10.5 | 0.3 | 58.5 | 0.3 | 29.6 |
| 32 | 0.3 | 134. | 0.3 | 73.5 | 0.3 | 36.5 | 0.3 | 278. | 0.3 | 10.5 | 0.3 | 57.7 | 0.3 | 30.4 |
| | ACCO | | | | | | EDEN | | | | | | | |
| | 0-20 | | 20-40 | | 40-60 | | 0-20 | | 20-40 | | 40-60 | | | |
| 0 | 21.3 | 18.3 | 12.6 | 6.4 | 11.4 | 4.2 | 10.7 | 26.1 | 8.3 | 9.9 | 7.6 | 7.6 | | |
| 0 | 20.8 | 17.6 | 13.1 | 6.7 | 11.8 | 4.2 | 10.3 | 25.6 | 8.3 | 10.1 | 7.6 | 7.1 | | |
| 1 | 1.7 | 34.9 | 2.5 | 28.2 | 2.5 | 20.5 | 1.3 | 58.4 | 0.8 | 36.0 | 0.6 | 22.9 | | |
| 1 | 2.0 | 34.4 | 2.5 | 27.7 | 2.7 | 20.3 | 1.3 | 58.8 | 0.8 | 33.6 | 0.8 | 22.9 | | |
| 2 | 1.2 | 55.4 | 0.8 | 30.2 | 1.7 | 21.0 | 1.3 | 76.2 | 1.1 | 42.3 | 1.4 | 24.0 | | |
| 2 | 1.0 | 52.1 | 0.8 | 29.6 | 1.7 | 21.0 | 1.1 | 72.5 | 1.0 | 40.7 | 1.5 | 23.7 | | |
| 4 | 1.7 | 55.0 | 0.3 | 36.8 | 0.3 | 27.7 | 0.8 | 89.8 | 1.0 | 49.5 | 0.8 | 29.5 | | |
| 4 | 1.7 | 53.8 | 0.3 | 36.6 | 0.3 | 26.9 | 0.8 | 92.2 | 1.0 | 47.9 | 0.9 | 29.9 | | |
| 6 | 1.5 | 66.0 | 0.3 | 50.0 | 0.3 | 31.1 | 0.5 | 109. | 0.8 | 55.8 | 0.3 | 33.5 | | |
| 6 | 1.5 | 65.0 | 0.3 | 47.9 | 0.2 | 30.2 | 0.6 | 100. | 0.8 | 56.7 | 0.4 | 34.0 | | |
| 8 | 0.8 | 68.9 | 0.3 | 53.4 | 0.8 | 27.0 | 0.3 | 116. | 0.5 | 60.7 | 0.3 | 31.3 | | |
| 8 | 0.5 | 70.6 | 0.3 | 54.6 | 0.5 | 27.7 | 0.3 | 120. | 0.5 | 63.1 | 0.4 | 35.3 | | |
| 12 | 0.3 | 86.5 | 0.3 | 69.2 | 0.3 | 33.1 | 0.3 | 142. | 0.3 | 75.1 | 0.3 | 38.2 | | |
| 12 | 0.4 | 86.4 | 0.4 | 65.5 | 0.3 | 33.6 | 0.3 | 140. | 0.3 | 71.4 | 0.3 | 36.6 | | |
| 16 | 0.3 | 94.6 | 0.3 | 68.0 | 0.3 | 36.6 | 0.3 | 151. | 0.3 | 76.7 | 0.3 | 45.0 | | |
| 16 | 0.3 | 94.4 | 0.3 | 65.5 | 0.3 | 36.1 | 0.3 | 153. | 0.3 | 77.5 | 0.3 | 42.7 | | |
| 24 | 0.3 | 112. | 0.3 | 81.5 | 0.3 | 44.5 | 0.3 | 190. | 0.3 | 92.0 | 0.3 | 41.2 | | |
| 24 | 0.3 | 113. | 0.3 | 78.6 | 0.3 | 42.0 | 0.3 | 184. | 0.3 | 91.2 | 0.3 | 41.2 | | |
| 32 | 0.3 | 114. | 0.3 | 79.3 | 0.3 | 45.4 | 0.3 | 197. | 0.3 | 101. | 0.3 | 50.7 | | |
| 32 | 0.3 | 118. | 0.3 | 78.1 | 0.3 | 42.0 | 0.3 | 198. | 0.3 | 102. | 0.3 | 51.1 | | |

# III. NITROGEN MINERALIZATION IN SOIL PROIFLES IN SITU COMPARED WITH INCUBATION TESTS

Aviva Hadas, A. Feigin, Sala Feigenbaum and Rita Portnoy

## ABSTRACT

Nitrogen mineralization of soil organic N has been extensively studied by incubation techniques but only little has been reported on mineralization under field conditions. The purpose of this work was to measure soil N mineralization in undisturbed soil profiles in the field, to evaluate the contribution of different soil layers and compare it with incubation tests.

Measurements were conducted on two plots of a long-term fertilization experiment in microplots covered with thin black polyethylene, to minimize water loss and nitrate translocation. The accumulation of mineral N was determined in different soil depths, within 0 to 120 cm, at different time intervals during 16 weeks. Soil temperature and moisture were also determined. At the same time soil was sampled from the 0-20 cm layer of the same sites and incubated at 35$^{o}$C and the field moisture content.

During 11 weeks 138 and 77 kg ha$^{-1}$ of mineral N accumulated in the 0-120 cm soil profiles, 25% and 45% of which were found below 60 cm, in the high NPK and the control plot respectively. The field data were corrected according to the incubation moisture and temperature conditions. About 30% more mineral N accumulated in the 0-120 cm soil layer under incubation conditions than in the field. The N mineralization in the wet incubated soil samples was even greater, indicating that: (1) drying the soil prior to incubation did not

increase N mineralization in long-term tests and (2) some nitrate was probably lost in the field.

## INTRODUCTION

Mineralization of soil organic nitrogen contributes available N to crops during their growth period and is therefore an important component in the considerations that determine fertilizer requirements. Being a biological time dependent process, many studies on the rate of N mineralization have been conducted by incubation techniques, from which rate equations have been developed and used in models to predict N status in soils (Stanford and Smith, 1972; Stanford, 1982; Hadas et al., 1979). However, only a few studies on soil N mineralization under field conditions have been reported.

Although temperature and moisture vary continuously under field conditions, their effects on the rate of N mineralization can be accounted for quantitatively (Stanford et al., 1973; Stanford et al., 1975; Stanford and Eptstein, 1974). A major difficulty in measuring N mineralization in the field is the translocaton of nitrate, the ultimate product of N mineralization, by water, which is added to the soil. To overcome this difficulty soil samples were removed from the field, homogenized and transferred into polyethylene bags which were buried at the same location (Smith et al., 1977; Westerman and Crothers, 1980). By this technique, which was in good correlation with mineralization predicted from laboratory experiments or other field measurements of N, the soil was disturbed (though not dried, crushed and stored) and then incubated under the varying temperature and aeration conditions of the field.

Nitrogen mineralization, although mainly attributed to surface soils, has been detected in deep soil layers in incubation experiments (Cassman and Munns, 1980; Hadas et al., 1985). Different aeration and soil bulk density in incubated samples compared with in situ conditions in the field might influence the rate of the microbial process.

The objective of this study was to measure soil N mineralizaiton in undisturbed soil profiles in the field, to evaluate the contribution of the various soil layers and to compare it with results of a previous incubation experiment with soil samples taken from the same profiles.

## MATERIALS AND METHODS

Measurements of soil organic N mineralization in the field were carried out in a 25-year-old fertilization experiment at Bet Dagan, on a control unfertilized plot and on a highly fertilized and manured plot. Cotton was grown in the field for the last six years. The (Chromoxerert clay soil has a pH of 7.8 and a field capacity moisture content of about 0.30 g/g. Soil sampled from the same plots two years earlier were used in incubation experiments (Hadas et al., 1985). More detailed information on the soils was given in Chapter 6.I. At the beginning of May, shortly after seedlings' emergence and two days after irrigation, 4 microplots of 2m x 1m were covered with black polyethylene, 30 um thick, in each of the two plots. The high NPK level plot was not fertilized during the last 6 months. Plants were removed from the microplots and from 1 m of the surrounding area. The purpose of the cover was to maintain soil moisture by minimizing

evaporation and to avoid irrigation to prevent nitrate movement in the soil profile. The cover was anchored into the soil around the microplot and it moved lightly up and down with every breeze, indicating that the cover was not airtight.

Soil temperature was measured during the period of the experiment in an extra covered plot, in order to compare the field conditions with the standard conditions of 35°C. Three measuring bulbs, connected to a thermograph with steel capillary tubing filled with mercury, were inserted into the soil at three depths in a vertical direction, to measure the average tempeatures of the 0-20, 20-40 and 40-60 cm soil layers. It was assumed that the temperature below 60 cm did not change with depth.

Soil samples from 0 to 120 cm depth were taken several times from each micro-plot during a period of 16 weeks. Three cores of each soil layer were combined into one sample. Duplicate moist subsamples were analyzed shortly after sampling for moisture content and for $NH_4$ and $NO_3$ in a 1N KCl extract (Bremner, 1965a).

At the beginning of the field experiment, larger soil samples were taken from the 0-20 cm layer near each of the 8 microplots. Each wet soil sample was gently mixed and 1.3 kg soil was placed in a plastic container, covered with polyethylene, 12 um thick, weighed and placed in an incubator at 35°C. Soil moisture content and $NH_4$ and $NO_3$ in 1N KCl extract were determined periodically in samples taken from the containers. The initial moisture content of the sois was maintained during the entire period of incubation by adding the quantity of water missing after each sampling (usually 1-2 ml). This incubation experiment served as an "intermediate" condition between

undisturbed conditions in the field and the standard treatment of drying, crushing, sieving and storing of soils for incubation experiments, which is expected to increase the rate of mineralization (Caskey and Tiedje, 1979).

## RESULTS AND DISCUSSION

### Soil temperature

The recorded soil temperature showed a clear diurnal curve at the 0-20 cm depth, whereas at the 20-40 and 40-60 cm soil layers the daily fluctuations were rather small, less than $\pm$ 1$^{o}$C from the average temperature (Fig. 1). the same pattern was obtained during the entire period of the experiment, except that the temperatures increased gradually during the first 9 weeks, from May to July. Weekly average temperatures (Table 1) were derived graphically from the weekly recordings of the thermographs. The highest average soil temperature was 33$^{o}$C and the maximal daily temperature never exceeded 37$^{o}$C. These temperatures were lower than those recorded in the same soil type mulched with transparent polyethylene (Mahrer et al., 1984).

### Soil moisture content

The soil moisture content, as measured at the sampling dates (Table 2), decreased with soil depth. It also decreased with time, mainly between 11 and 16 weeks, but also between 0 and 2 weeks. The field was irrigated at the 6th, 10th and 13th week after covering the microplots and it could have slightly affected the soil moisture content through lateral movement of soil water. The gradual drying of the soil towards the end of the experiment caused very severe cracking of the soil and an increase in its bulk density, unlike the

surrounding field, that was under drying and wetting cycles, especially at the top soil layer, and only small and shallow cracks could be observed.

Mineral N accumulation in soil under field conditions

the concentration of $NH_4$ in the soil was very small and did not change with time, therefore the accumulation of mineral N is represented by $NO_3$-N concentrations in the soil (Table 3). Nitrate concentrations in soil were greater in the high NPK level plot than in the control plot, where they decreased with soil depth and increased with time. Nitrate was lost from the soil of the control plot after 11 weeks in all soil layers. It could not be explained by dentirfication occurring due to the compaction of the cracked soil, because hardly any N loss could be observed in the high NPK plot. It could, however, be attributed to N uptake by the neighboring plants (1m of the microplots) which might have been more pronounced in the N deficient soil. The variability of the results increased with time, especially after the 4.5 weeks' samples, during the irrigation and rapid growth period of the cotton in the surrounding area.

The total amount of N mineralized in the various soil layers of the two profiles during 11 weeks was 138 and 77 kg ha in the high NPK and the control plots, respectively. The distribution with depth indicated that the relative contribution of the top 40 cm soil layer was 60% and 36% of the N accumulated in the 0-120 cm soil profile in the high NPK and control plots, respectively, while below 60 cm 25% and 45% of total N mineralized could be found in the respective plots. Cropping for 25 years in an unfertilized soil (control plot) resulted

in a more uniform distribution of N mineralization along the soil profile.

Comparison between field and incubation conditions

The rate of N mineralization in the field was compared with that determined previously in an incubation experiment with the same soil profiles (Chapter C.II). The accumulation of $NO_3$ in the field was "corrected" for the same temperature and moisturte conditions that prevailed in the incubator, namely 35°C and optimal water content. The amount of nitrate that accumulated in each time period between sampling dates was determined for each soil layer. These values were multiplied by the ratio of optimal to actual soil moisture content, to correct them for optimal soil moisture conditions, according to Standford and Epstein (1974). The average soil moisture of a given period was equal to the mean moisture content of a sample at the beginning and at the end of the same period (Table 2). The optimal soil water content was 30 g/100g, as determined in the top 20 cm, 2 days after irrigation, and was assumed to be the same in all soil layers, similar to the same hygroscopic moisture content and water holding capacity, as determined previously for the incubation experiment. The "correction" for temperature was calculated using the effect of temperature (T, °C) on the first order mineralization rate constant (k, $day^{-1}$) according to Stanford et al (1973):

$$k(T) = 7.3 \cdot 10^{[6-2758/(273+T)]}$$

If the the amount of N mineralized at a temperature T and a period of time t is (Hadas et al., 1985) $N_T = N_o(1-e^{-k(T)t})$ than the corrected amount for 35°C ($N_{35}$) for the same period of time will be

$$N_{35} = N_T(1-e^{-k(35)t})/(1-e^{-k(T)t})$$

$N_o$ was assumed to be the same for both temperatures for all time periods. The average soil temperatures for each period of time were obtained from Table 1.

The amounts of N mineralized during each period, corrected for optimal temperature and moisture content, were recombined into cumulative mineral N concentrations (Table 4) and compared with the N mineralized in the previous incubation experiment. The mineralization in the incubation experiment was generally greater than in the field, although the ratio between them was not the same in all soil samples. About 10-20% more mineral N accumulated in the top soil layer of the high NPK level plot under incubation conditions than under field conditions. Considering a possibility of nitrate transport within the profiles in the field experiment, the average mineral N accumulation in the whole 0-120 cm profile was also calculated. The quantity of N accumulated $NO_3$ in the whole profile was from 25 to 50% greater in the incubation than in the field experiment, the difference decreasing with time. The quantity of N mineralized in the top soil layer of the control plot in the field was much smaller than under incubation conditions. It was, however, also much smaller than in the high NPK plot in the field, whereas below 40 cm the differences between the plots were not so great. The reason for the greater difference

between field and incubation results in the control compared with high NPK plots is not clear.

Incubation of moist surface soils

Ammonium concentrations in the top soil layer samples, taken near the microplots at the beginning of the field measurements and subsequently incubated, were very low during the entire period of the incubation experiment (similar to the field results). Therefore only $NO_3$ concentrations represent the accumulation of mineral N in the soil (Table 5). The control plot had a lower $NO_3$ content, as well as accumulation than the high NPK plot. The accumulation of nitrate in the incubated soils was greater than in the field after correcting the results to the same temperature and moisture conditions (Table 4). This indicates that the conditions in the incubator (besides temperature and moisture) were more favorable for mineralization than in the field, or that some nitrate losses from the top soil layer occurred in the field.

The N mineralization measured in the wet soil samples from the control plot was very similar to that found in the previous incubation experiment with dried and stored soils (Table 5); it was, however, considerably greater in the high NPK level plot. Possible exlanations for the difference are that the N mineralization potential of high NPK soil changed during 2 years or that the high initial $NO_3$ content of the dried soil inhibited the process.

It seems that drying and storing the soil increased the rate of minralization only in the period of 2 weeks, which is commonly used to evalute available N by incubation (Bremner, 1965b), but not in long-term incubations.

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Table 1: Average weekly soil temperatures in a covered microplot.

| Time after covering | Soil layer (cm) 0 - 20 | 20 - 40 | 40 - 60 |
|---|---|---|---|
| Weeks | | °C | |
| 1 | 22 | 21 | 20 |
| 2 | 24 | 23 | 22 |
| 3 | 27 | 25 | 24 |
| 4 | 28 | 26 | 25 |
| 5 | 29 | 27 | 26 |
| 6 | 30 | 29 | 27 |
| 7 | 30 | 28 | 28 |
| 8 | 31 | 29 | 28 |
| 9 | 32 | 30 | 29 |
| 10 | 31 | 30 | 30 |
| 11 | 32 | 30 | 29 |
| 12 | 33 | 31 | 30 |
| 13 | 32 | 31 | 29 |
| 14 | 32 | 30 | 29 |
| 15 | 32 | 31 | 30 |
| 16 | 31 | 29 | 29 |

Table 2: Soil water content in the covered microplots at different depths and time of sampling. (means ± standard deviations).

| Time after covering | Soil depth (cm) | | | | |
|---|---|---|---|---|---|
| | 0 - 20 | 20 - 40 | 40 - 60 | 60 - 90 | 90 - 120 |
| weeks | g/100g | | | | |
| | High NPK level plot | | | | |
| 0 | 29.5±0.4 | 29.2±0.3 | 28.1±0.7 | 26.6±0.8 | 25.5±0.2 |
| 2 | 29.4±0.6 | 27.6±0.8 | 26.6±0.5 | 25.5±0.2 | 25.6±0.3 |
| 4.5 | 29.3±0.4 | 27.6±0.9 | 26.1±0.3 | 25.5±0.4 | 25.5±0.9 |
| 8 | 28.5±1.8 | 27.9±1.5 | 27.2±1.1 | 26.5±1.4 | 25.9±0.8 |
| 11 | 27.9±0.6 | 27.5±1.3 | 26.2±1.2 | 25.6±0.9 | 25.7±0.4 |
| 16 | 18.8±0.9 | 18.4±0.4 | 17.8±0.5 | 17.5±1.0 | 18.8±3.0 |
| | Control plot | | | | |
| 0 | 30.4±1.1 | 30.0±1.0 | 29.2±0.7 | 26.6±1.1 | 26.4±0.3 |
| 2 | 28.6±1.2 | 28.6±0.9 | 27.5±0.3 | 25.6±0.6 | 25.8±0.4 |
| 4.5 | 28.5±1.2 | 26.9±0.5 | 25.9±0.4 | 24.6±1.0 | 24.1±0.4 |
| 8 | 29.2±1.5 | 27.9±0.6 | 26.3±0.9 | 24.6±0.5 | 25.1±0.8 |
| 11 | 29.3±0.5 | 28.0±1.3 | 27.4±0.5 | 25.3±0.8 | 25.2±0.6 |
| 16 | 18.6±1.8 | 19.7±1.9 | 19.7±1.3 | 20.3±1.3 | 21.7±2.4 |

Table 3: Nitrate-N content of the soil in the microplots at different depths and time of sampling. (means ± standard deviations).

| Time after covering | Soil Depth (cm) | | | | |
|---|---|---|---|---|---|
| | 0 - 20 | 20 - 40 | 40 - 60 | 60 - 90 | 90 - 120 |
| weeks | | | mg $kg^{-1}$ | | |
| | | | Plot of high NPK level | | |
| 0 | 12.8±1.2 | 12.1±1.8 | 10.6±1.3 | 8.6±1.0 | 7.8±1.3 |
| 2 | 17.5±2.6 | 14.2±0.9 | 11.6±1.8 | 8.4±1.2 | 8.7±1.0 |
| 4.5 | 24.8±1.8 | 18.4±1.2 | 11.7±1.0 | 10.5±1.5 | 9.3±2.2 |
| 8 | 29.0±8.2 | 22.3±5.4 | 14.9±2.4 | 12.3±3.2 | 10.2±1.1 |
| 11 | 34.6±11.0 | 24.1±8.4 | 17.6±5.0 | 13.3±1.6 | 12.4±1.5 |
| 16 | 43.8±4.4 | 27.9±8.1 | 13.6±0.6 | 12.6±1.7 | 16.1±3.2 |
| | | | Control plot | | |
| 0 | 9.3±0.8 | 8.0±1.0 | 6.4±1.6 | 5.3±2.1 | 4.6±0.8 |
| 2 | 10.7±0.2 | 9.5±0.3 | 7.8±0.8 | 6.0±0.7 | 5.6±0.9 |
| 4.5 | 13.7±0.9 | 10.0±0.9 | 8.7±1.1 | 7.2±1.1 | 5.9±0.4 |
| 8 | 12.8±3.6 | 14.1±3.4 | 9.1±0.8 | 7.3±1.1 | 6.3±0.5 |
| 11 | 15.7±3.6 | 13.0±1.6 | 12.1±1.2 | 9.8±1.0 | 9.5±0.6 |
| 16 | 5.1±0.9 | 4.8±0.8 | 3.1±0.2 | 2.7±0.5 | 2.3±0.5 |

Table 4: Mineral N accumulation in the Bet Dagan field experiment (corrected for 30% soil moisture content and 35°C) compared with data from a previous incubation experiment.

| Period of mineralization | Experiment | Soil layer (cm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 - 20 | 20 - 40 | 40 - 60 | 60 - 90 | 90 - 120 | 0 - 120 |
| weeks | | mg $kg^{-1}$ | | | | | |
| | | High NPK level plot | | | | | |
| 2 | field | 11. | 5.3 | 2.5 | 0.6 | 2.7 | 3.9 |
| 2 | incubation | 14. | 4.0 | 6.2 | 5.4 | 2.0 | 5.8 |
| 4.5 | field | 22. | 13. | 2.9 | 5.3 | 4.1 | 8.8 |
| 4 | incubation | 24. | 11. | 14.1 | 8.3 | 8.2 | 12. |
| 8 | field | 28. | 20. | 8.6 | 8.7 | 5.8 | 13. |
| 8 | incubation | 34. | 20. | 20. | 11. | 8.1 | 17. |
| 11 | field | 36 | 22 | 13 | 10 | 7.0 | 16. |
| 12 | incubation | 42 | 24 | 22 | 12 | 8.8 | 20. |
| 16 | field | 49 | 28 | 5 | 9 | 17 | 20 |
| 16 | incubation | 52 | 30 | 28 | 16 | 12 | 25 |
| | | Control plot | | | | | |
| 2 | field | 3.2 | 4.2 | 3.8 | 2.1 | 3.0 | 3.1 |
| 2 | incubation | 5.4 | 5.8 | | | | |
| 4.5 | field | 8.1 | 5.2 | 5.8 | 4.9 | 3.2 | 5.2 |
| 4 | incubation | 11. | 11. | | | | |
| 8 | field | 6.8 | 12. | 6.6 | 5.1 | 4.4 | 6.6 |
| 8 | incubation | 31. | 31. | | | | |
| 11 | field | 10. | 10. | 12. | 9.7 | 7.2 | 9.6 |
| 12 | incubation | 39. | 39. | | | | |

Table 5: Mineral N accumulation in wet top soil layer samples taken near the Bet Dagan microplots, and incubated at 35°C (means of 4 microplots). Results of a previous incubation experiment with soils from the same plots but dried, crushed and stored prior to incubation, are presented for comparison.

| Time | $NO_3$-N in soil wet incubation | | Mineral N in soil previous experiment | |
|---|---|---|---|---|
| | Control | high NPK | Control | high NPK |
| | mg $kg^{-1}$ | | mg $kg^{-1}$ | |
| 0 | 8.0±0.4 | 12±1.1 | 10 | 47 |
| 2 | 11±0.7 | 21±2.9 | 15 | 61 |
| 4 | 19±1.5 | 41±7.2 | 21 | 71 |
| 8 | 40±5.6 | 65±10.2 | 41 | 81 |
| 12 | 46±3.6 | 73±8.4 | 49 | 89 |
| 16 | 53±4.8 | 83±6.0 | 57 | 99 |
| 20 | 60±6.0 | 93±13.7 | | |
| 24 | 70±3.8 | 101±11.0 | 62 | 109 |
| 32 | 70±5.0 | 103±9.8 | 69 | 128 |

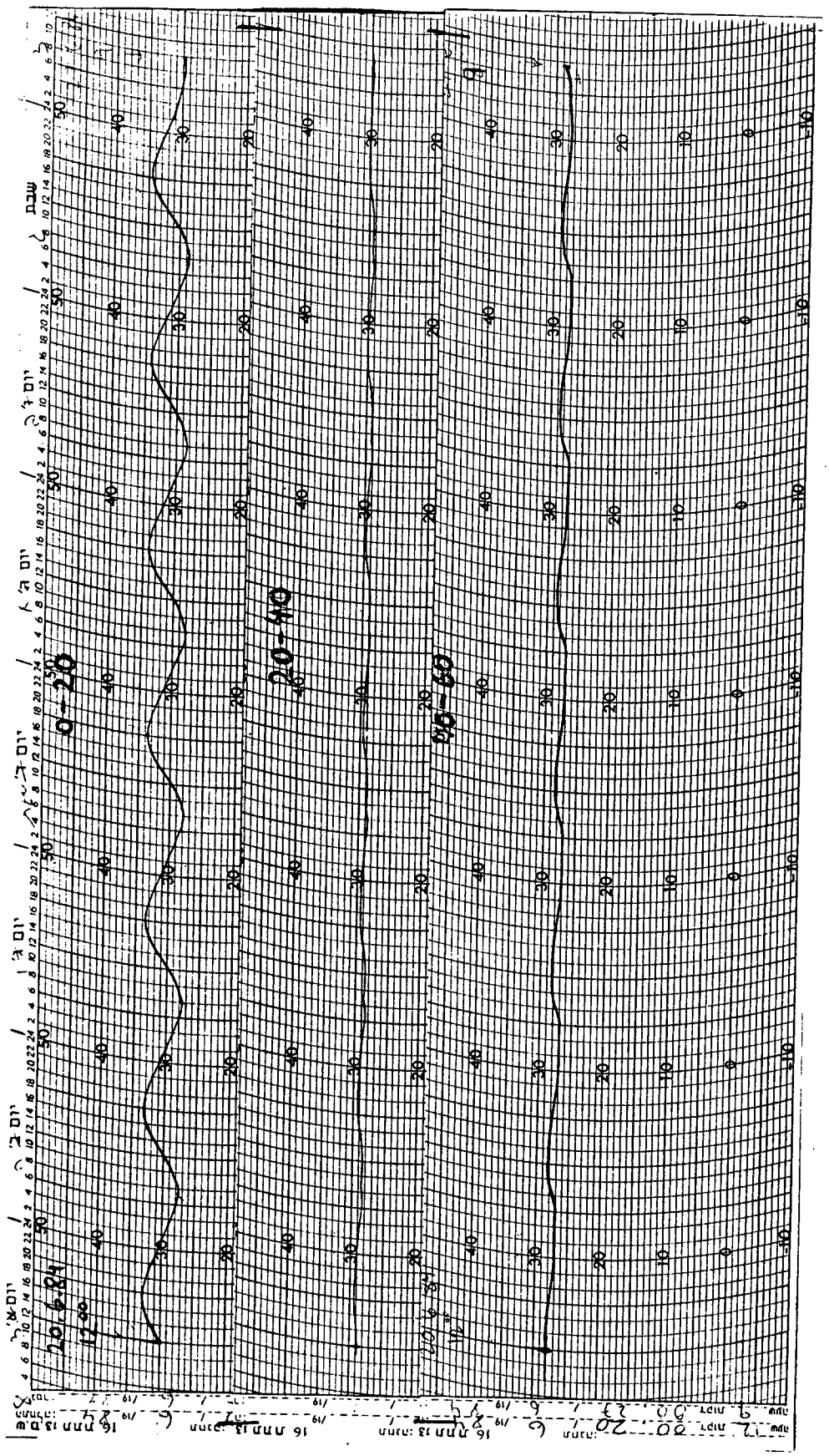


Figure 1: Soil temperature recordings (°C) at 3 soil depths, 0–20, 20–40 and 40–60cm, in a covered microplot, between June 20 and 27, 1984.

# IV. NITRIFICATION RATES IN PROFILES OF DIFFERENTLY MANAGED SOIL TYPES

Aviva Hadas, Sala Feigenbaum, A. Feigin, Rita Portnoy

Abstract

The rate of nitrification in profiles of various soil types and under different agricultural management was determined at optimal temperature and moisture content. Verhulst's equation was used to express the accumulation of $No_3$ with time and modified to describe the rate of $NH_4$ decrease. The maximal rate of nitrification ($K_{mx}$) and the delay period (t') were derived from the equation and used to characterize the nitrification process in various soil samples. $K_{mx}$ and t' of surface soil samples were from 5 to 70 mg $kg^{-1}$ $day^{-1}$ and from 0.2 to 8 days, respectively. $K_{mx}$ decreased and t' increased with soil depth. Soil factors mostly affecting the rate parameters were: 1. pH decreasing from 7.8 to 6.6 or $HCO_3^-$ decreasing below 1 mol $m^{-3}$. 2. Previous agricultural management. 3. Soil depth. Data obtained by means of tagged N(N-15) indicated that mineralization rate of soil organic N in $NH_4$ treated soils was not always negligible relative to nitrification, and in some cases was even enhanced, a phenomenon known as "priming effect".

Introduction

The nitrifying population in soil is relatively small but it increases rapidly upon addition of ammonium to the soil. Consequently, the rate of nitrification yields a sigmoidal curve indicating a presence of a delay phase during which the number of bacteria grows, a maximum rate phase, and a retarded rate phase due to the depletion of $NH_4$ in soil (Sabey et al., 1959; Walker, 1975). Sabey et al. (1969) described nitrate (N) accumulation with time (t) as $N = K(t-t')$ where K is the maximal rate of nitrification and t' is the delay period. K and t' were constants for different soils at standard conditions and changed with temperature and moisture. The ratios of these constants' values at different environmental conditions to their value at the standard condition were, however, similar in many soils and could therefore be used as correction coefficients. This equation describes only the accumulation of nitrate at the maximum rate phase.

A microbiological approach to the kinetics of nitrification uses Michaelis-Menten type equations and describes the rate of nitrification as a function of the substrate (ammonium) concentration and several biological parameters, such as the number of bacteria and their specific growth rate (Van Veen and Frissel, 1981; Ardakani et al., 1974). These equations describe all the phases of nitrification, but the necessary information regarding their microbiological parameters makes it difficult to use them for the prediction of the nitrification process.

The maximal rate phase occurs when ammonium concentration is not limiting nitrification and soil bacteria have reached their maximal

activity. The number of bacteria or maximal rate of nitrification depend on soil properties like pH (Schmidt, 1982; Hagin et al., 1976) surface area, as suggested by Beek and Frissel (1973) and probably on some other properties (additional to temperature and moisture, which are environmental parameters and their effect has been well established).

Ammonium addition to soil involves several other processes besides nitrification. A decrease in ammonium concentration could be partially due to fixation by clay (Kowalenko and Cameron, 1976), immobilization in organic compounds and $NH_3$ volatilization (Van Veen and Frissel, 1981), whereas an increase in nitrate could also be derived from mineralization of organic nitrogen, which might even be accelerated by the addition of N fertilizer - the phenomenon of priming effect (Westerman and Tucker, 1974; Caskey and Tiedje, 1979). Labelling of added ammonium will identify nitrate derived from soil organic nitrogen and ammonium incorporated in the total N pool.

The following nitrification experiments were performed in various soil profiles, in order to fit rate equations to the nitrification process and to evaluate the effect of different soil properties and depth on the rate parameters. The involvement of processes other than nitrification in $NO_3$ accumulation and $NH_4$ depletion was also tested.

Materials and Methods

Soil profiles representing various soil types and managements were sampled from various locations in Israel. The soils and their general properties have been fully described previously (Hadas et al.,

1985, Tables 1,2,3). All soils were air-dried, passed through a 2 mm sieve and stored at room temperature for at least 3 months.

Soil samples of 40g (air dry basis) were poured into a predetermined quantity of water containing 8 mg N as $(NH_4)_2SO_4$ in 200 $cm^3$ incubation flasks. The quantity of water used for each soil was equal to the moisture held by the top 40g of soil, 24 hours after wetting about 3/4 of 200g soil placed in a 200 $cm^3$ incubation flask and covered to prevent drying. The moisture content of the soils varied from 14 to 50% (Table 1) which was about 5-6 times greater than the hygroscopic water content. The incubation flasks containing 40g wetted soil samples and 200 mg $kg^{-1}$ $NH_4$-N were covered with a thin polyethylene sheet (0.01 mm) and placed in an incubator under high humidity conditions at 35°C.

After various periods of time, depending on the rate of nitrification, duplicate samples were extracted with 100 ml KCl 2N and the level of $NH_4$ and $NO_3$ were determined in the extract by steam distillation. The initial concentrations were determined immediately after wetting the soil with the $(NH_4)_2SO_4$ solution.

Several soil samples (Bet Dagan NPK profile from a high fertility treatment of a long-term fertilization experiment, Eden and the surface soil layers of Alumim, soils relatively rich in organic matter, were treated with $(NH_4)_2SO_4$ enriched to 10.6 atom % $N^{15}$. These samples were washed after the extraction with additional 25 ml KCl 1N and 25 ml water, to remove the labeled $NH_4$ from the soil, and then freeze-dried. For the $N^{15}$ analysis, $NH_4$ and $NO_3$ were separated from the KCl extract by steam distillation and total N in the soil was

obtained by Kjeldhal digestion followed by microdifusion (Feigenbaum and Hadas, 1974). $N^{15}$ was detemrined by emission spectrometry with the Jasco $N^{15}$-analyser. Recovery of added N in each of the N forms analyzed was calculated as follows:

$$\text{Added N recovered} = \text{Amount N form} \frac{^{15}\text{N excess in N form}}{^{15}\text{N excess in added N}}$$

Rate equations of nitrification were calculated using the nonlinear least square procedure of SAS (Helwig and Council, 1979).

Results and Discussion

The initial concentration of ammonium-N in the soils, after the addition of $(NH_4)_2SO_4$, was in most cases less than 200 mg $kg^{-1}$ and decreased with soil depth (Table 1). The immediate disappearance of $NH_4$ was probably due to chemical fixation, which usually increased with soil depth (Nommik and Vahtras, 1982). The fixation was however smaller than reported by Kowalenko and Cameron (1976). A further support of this finding was shown by the $N^{15}$ balance in the Bet Dagan and Eden soil profiles (Table 4), where the unaccounted for added nitrogen also decreased with soil depth, and was probably fixed by the soil minerals.

The rate of nitrification varied greatly among soils and within the soil profiles. The time required to oxidize the $NH_4$, until its concentration was less than 10 mg $kg^{-1}$, varied from 5 days to much more than 10 weeks (Table 1). Comparing the different soils, the nitrification proceeded most slowly in the Golan soils, which are slightly acidic, and most rapidly in the cultivated and fertilized

soils of Bet Dagan, Eden and Gilat NM. Within the soil profiles the time required to complete the nitrificaiton of ammonium increased with soil depth.

The accumulation of $NO_3$ and the decrease of $NH_4$ with time in several soils is shown in Figs. 1-5 (all the data are presented in appendix IV). The curves obtained were sigmoidal, showing a delay phase, a maximal rate phase and a retarded rate phase. In Bet Dagan NPK and in Eden soils (Figs. 1 and 4) the main effect of depth was expressed by an extended delay period, while the maximal rate decreased only slightly. However, in Akko and Bet Dagan control (Figs. 2 and 5) these effects were not as evident. The Bet Dagan control showed a much smaller rate of nitrification than the Bet Dagan NPK, although both profiles were taken from the same field and differed only in their fertilization management (Chapter C.I.) The effect of fertility was not so pronounced in the Gilat fertilization experiment (Fig. 3).

In order to express the accumulation of nitrate with time (t) quantitavely, the Verhulst equation ($dN/dt = kN[a-N]$) which upon integration renders a sigmoidal curve, was used:

$$NO_3 = a/[1 + (\frac{a}{(NO_3)_0} - 1) \exp(-a\, k(t-t_o))] \qquad [1]$$

where a and $(NO_3)_0$ are the asymptotic and initial values of nitrate, respectively, k is a constant and $t_o$ is the initial time which equals zero. A logistic transformation of this equation was introduced by Lees and Quastel (1946) for the kinetics of nitrification. The

parameters a, k and $(NO_3)_o$ were calculated by the least squares fit of euation [1] to the experimental data of $NO_3$ versus t, and presented in Table 2, together with the standard deviation of the data from the curves. The asymptotic value of nitrate, a, depends on the amount of $NH_4$ added to the soil, while the maximal rate of nitrification, when $NH_4$ concentration is not rate limiting, is expected to depend on soil properties. Therefore the maximal rate ($K_{mx}$) was calculated as the slope of the curve at the inflection point (when $NO_3 = a/2$):

$$K_{mx} = k \cdot a^2/4 \qquad [2]$$

The delay period (t') was calculated as the value of t when the maximal slope was extrapolated to the initial value of $NO_3$:

$$t' = \frac{1}{ak} \ln \left( \frac{a}{(NO_3)_0} - 1 \right) + \frac{(NO_3)_0 - a/2}{Km_x} \qquad [3]$$

The contribution of soil organic N mineralization to $NO_3$ was assumed to be very little relative to that of nitrification, therefore the sum of ammonium and nitrate was assumed to be constant and equal to a:

$$(NH_4)_t = a - (NO_3)_t \qquad [4]$$

Thus, the initial value of ammonium was: $(NH_4)_0 = a - (NO_3)_0$. Combining equations [1] and [4] and substituting $(NO_3)_0$ by $a-(NH_4)_0$, equation[5] was obtained describing the concentration of $NH_4$ as a function of time:

$$NH_4 = \frac{a \cdot (NH_4)_0 \cdot \exp(-akt)}{a-(NH_4)_0 + (NH_4)_0 \exp(-akt)} \qquad [5]$$

The parameters a, k and $(NH_4)_0$ were calculated from the data of $NH_4$ versus t, independently from those of nitrate, and presented in Table 2 including the standard deviations of the data from the calculated curve. The maximal rate of $NH_4$ disappearance, or the slope at the inflection point (at $NH_4 = a/2$), was $K_{mx} = - k a^2/4$ and the delay period t' (the value of t when the maximal slope was extrapolated to the initial value of $NH_4$) was

$$t' = \frac{1}{a.k} \ln \frac{(NH_4)_0}{a-(NH_4)_0} + \frac{(NH_4)_0 - a/2}{k_{mx}} .$$

The calculated maximal rates and the delay periods of nitrification for the accumulation of nitrate and the depletion of ammonium are presented in Table 1. The maximal rates and the delay periods of $NO_3$ accumulation and $NH_4$ depletion were not exactly the same, but the differences were relatively small. Moreover, $K_{mx}$ or t' obtained from one of the nitrogen forms were not consistently larger than those obtained from the other form. This supports the assumption that nitrification was the dominant process and the effect of mineralization and immobilization on $NH_4$ and $NO_3$ concentrations was small. In most of the soils the asymptotic parameter 'a' (Table 2) was about 200 mg $kg^{-1}$, and slightly higher in the $NO_3$ accumulation, as could be expected from the experimental set up. In soils where the nitrification was very slow and uncompleted, 'a' was often experimentally unreal, namely considerably less or much higher than

200 mg $kg^{-1}$. The model did not really fit the nitrification process in these cases, although statistically the fitness was not worse than in the other soils. In those soil samples the delay period and maximal rate of $NO_3$ accumulation or $NH_4$ depletion were sometimes very different from each other (Table 1).

The nitrification was most rapid in the surface layers of the cultivated and fertilized soils of Bet Dagan, Eden and Gilat, with a maximal rate ($K_{mx}$) of 60-80 mg $kg^{-1}$ $day^{-1}$ and a delay period t' of 0-2 days. In the top 20 cm of the uncultivated unfertilized soils of Alumim and Qedma $K_{mx}$ and t' were about 20 mg $kg^{-1}$ $day^{-1}$ and 3-8 days respectively. Unfertilized Bet Dagan was similar to the uncultivated soils and much slower than the highly fertilized Bet Dagan soil, whereas unfertrilized Gilat was relatively faster and the difference from the highly fertilized Gilat soil was much smaller. The rate of nitrification in Akko was smaller than in the other cultivated soils. A possible explanation could be insufficient aeration due to its very high water holding capacity. The slowest of all surface soils were Golan 70 and Golan 37, having a pH of 6.6 and 6.0 respectively. Since pH of 6.6 is usually not considered inhibitory to nitrification (Schmidt, 1982; Hagin et al., 1976), the low concentrations of $HCO_3^-$, the carbon source of nitrifers, in the saturation extract (0.6 mmol/l) of the Golan Soils could explain the low rate of nitrification. The relative slow nitrification rate in Akko soil could be explained also by its lower $HCO_3^-$ concentration in the

surface soil relative to all the other non acidic soils (Chapter C.I., Table 2).

A comparison between the present data and nitrification rates reported in the literature is possible by using available information concerning soil and environmental conditions. For instance, the maximal rate of 15 mg $kg^{-1}$, obtained by Rice and Smith (1983) in a soil of pH 6.9, when corrected to the temperture of 35°C (Sabey et al., 1969), would be 23 mg $kg^{-1}$. This is a lower rate than the one obtained for cultivated soils in this experiment, but is still much greater than in the Golan soils.

Within the soil profiles the maximal nitrification rate decreased and the delay period increased with soil depth (Table 1). In the unciltivated soils (Alumim and Qedma) the change below 20 or 25 cm was very great, whereas in the cultivated soils the change with depth was more gradual. In Bet Dagan and Eden soils the $K_{mx}$ of $NH_4$ depletion decreased very little with soil depth and the main effect of depth was an extended delay period, as was evident in Figs. 1 and 4. The same could be observed in several other cases like the top 20 cm of Alumim and Qedma soils or the top 40 cm of Gilat soil, but generally both parameters were influenced by soil depth. The influence of depth on t' was anticipated since the supply of $NH_4$ from organic N mineralization and from fertilizers decreases with depth and maintains a smaller population of nitrifers, that needs more time to increase to its maximal capacity upon the addition of $NH_4$. However, the reason for the $K_{mx}$ decrease with soil depth is not so clear if $K_{mx}$ is considered characteristic to the soil, depending on properties as pH,

surface area, $HCO_3$ content, etc. Nitrification in Gilat soil did not change very regularly with depth, but the very slow rate at the 60-80 and 100-120 cm layers coincided with a slow rate of mineralization as well (Chapter C.II), probably due to some unidentified inhibition of microbial activity.

The main factors affecting nitrification rate parameters ($km_x$ and t') could be summarized as follows: 1) pH, decreasing from 7.8 to 6.6 or less (or very low $HCO_3^-$ concentrations) greatly decreased $K_{mx}$. 2) Previous management like cultivation and fertilization, increased $K_{mx}$ and decreased t'. 3) Soil depth increased t' and decreased $K_{mx}$. Since management has a very strong influence on the rate of nitrification in soil, it seems difficult to predict the rate parameters from soil properties. Microbiological tests are probably essential for a better prediction of nitrification in soil.

The use of $^{15}N$ in several soil samples provided additional information on nitrogen transformation processes that occurred during the incubation of the soils with $(NH_4)_2SO_4$. The recovery of added N in the form of $NH_4$ and $NO_3$ was used to calculate the nitrification rate parameters of the added N alone, excluding soil born mineral N (Table 3). The standard deviation of $NO_3$ concentrations from the calculated nitrification curve in Alumim soil samples was very large, therefore the calculated rate parameters could not represent the experimental results. The maximal rates and delay periods of $NO_3$ accumulation and $NH_4$ depletion were more similar to each other than when soil contribution was not excluded (Table 1). Thus the maximal rate of $NH_4$ depletion decreased with depth (Table 3) and was not

almost constant in the Bet Dagan and Eden soil profiles as shown before (Table 1). The rate of $NO_3$ accumulation in Bet Dagan soil was similar and even slightly greater when the soil contribution was excluded, indicating that mineralization had no significant effect on the nitrification rate. However, in the 0-20 cm soil layer of Eden soil, the lower rate of $NO_3$ accumulation from the added source (Table 3) compared with total $NO_3$ accumulated (Table 1) could be attributed to mineralization, which was very intensive in this soil, and could not be ignored when calculating the rate of nitrification.

The amount of N mineralized from native soil organic N (Table 4) was calculated as the difference between total mineral N in soil and that recovered from added N after substracting the initial soil mineral N. The mineralization of soil N during 1 week in the presence of 200 mg $kg^{-1}$ of added mineral N greatly exceeded that which was found in the same soil samples in a previous long-term incubation experiment under similar environmental conditions, but with no added N. This phenomenon is usually referred to as priming effect of added N on soil N mineralization. However the mineralization without added N represented the net N mineralization, whereas in the presence of labelled N, the calculated soil N mineralization could be considered as mineralization only, without accounting for the immobilization of the freshly added mineral N. If the amount of added N that recovered in the organic N form, representing the immobolization, was subtracted, the resulting "net mineralization" was still greater than in the previous mineralizaiton experiment in Alumim soil and in the top soil layer of Eden. However, the average net mineralization in

the Bet Dagan soil profile as well as in the Eden soil profile was almost the same whether mineral N was added to the soil or not. On a soil similar to Alumim the priming effect of N fertilizer has been shown in a field experiment (Feigenbaum et al., 1983). Since $^{15}N$ was used only in a few soil samples, it was not possible to relate the occurrence of priming effect to any particular soil properties such as mineralizable N quantity or composition.

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Table 1: Maximal rates and delay periods of nitrification in soil profiles.

| Soil | Layer | Soil moisture content | Initial $NH_4$-N conc. | Duration of nitrification | $NO_3$-N accumulation | | $NH_4$-N depletion | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Maximal rate | Delay period | Maximal rate | Delay period |
| | cm | $g.g^{-1}$ | $mg\ kg^{-1}$ | days | $mg\ kg^{-1}day^{-1}$ | days | $mg\ kg^{-1}day^{-1}$ | days |
| Alumim | 0- 5+ | 0.184 | 190 | 20 | 20 | 6.4 | -19 | 7.4 |
| | 5- 20+ | 0.184 | 180 | 20 | 25 | 7.9 | -22 | 8.6 |
| | 20- 50 | 0.184 | 195 | 70 | 6.3 | 29 | - 8.2 | 34 |
| | 50- 85 | 0.196 | 192 | >70 | 4.0 | 49 | - 4.1 | 40 |
| | 85-125 | 0.221 | 186 | >70 | 4.5 | 28 | - 4.4 | 26 |
| | 125-165 | 0.235 | 191 | 70 | 5.8 | 40 | - 6.8 | 38 |
| Bet Dagan control | 0- 20 | 0.375 | 190 | 20 | 19 | 3.3 | -15 | 2.1 |
| | 20- 40 | 0.38 | 190 | 20 | 17 | 3.6 | -14 | 2.6 |
| Bet Dagan NPK | 0- 20+ | 0.375 | 182 | 5 | 81 | 0.3 | -67 | 0.2 |
| | 20- 40+ | 0.38 | 178 | 5 | 64 | 0.4 | -61 | 0.4 |
| | 40- 60+ | 0.38 | 166 | 9 | 45 | 1.1 | -52 | 1.9 |
| | 60- 90+ | 0.375 | 170 | 9 | 39 | 2.0 | -50 | 2.9 |
| | 90-120+ | 0.37 | 168 | 15 | 29 | 2.6 | -50 | 4.0 |
| Gilat | 0- 20 | 0.143 | 209 | 9 | 37 | 1.8 | -37 | 1.5 |
| | 20- 40 | 0.142 | 204 | 9 | 38 | 2.5 | -42 | 2.8 |
| | 40- 60 | 0.154 | 206 | 14 | 28 | 6.8 | -21 | 6.3 |
| | 60- 80 | 0.202 | 200 | >35 | 7.8 | 15 | - 8 | 15 |
| | 80-100 | 0.198 | 199 | 35 | 18 | 12 | -19 | 13 |
| | 100-120 | 0.200 | 196 | >>56 | 0.3 | 3.9 | - 0.7 | 13 |
| | 120-150 | 0.206 | 195 | 20 | 18 | 6.3 | -20 | 6.4 |
| Gilat control | 0- 20 | 0.17 | 201 | 9 | 49 | 3.0 | -55 | 3.3 |
| Gilat NM | 0- 20 | 0.18 | 200 | 6 | 67 | 1.8 | -73 | 1.9 |
| Akko | 0- 20 | 0.505 | 195 | 15 | 27 | 1.4 | -23 | 0.6 |
| | 20- 40 | 0.49 | 193 | 15 | 19 | 3.1 | -16 | 2.4 |
| | 40- 60 | 0.49 | 188 | 30 | 10 | 6.6 | - 7 | 1.0 |
| Eden | 0- 20+ | 0.34 | 186 | 5 | 58 | 0.9 | -60 | 1.1 |
| | 20- 40+ | 0.355 | 182 | 9 | 46 | 1.9 | -52 | 2.7 |
| | 40- 60+ | 0.35 | 178 | 15 | 36 | 4.3 | -52 | 5.3 |
| Qedma | 0- 9 | 0.292 | 200 | 14 | 22 | 2.6 | -19 | 1.4 |
| | 9- 25 | 0.306 | 198 | 20 | 21 | 4.2 | -18 | 3.8 |
| | 25- 58 | 0.314 | 194 | >42 | 4.5 | 4.8 | - 4.7 | 8.5 |
| | 58- 86 | 0.364 | 192 | >56 | 1.7 | 9.5 | - 3.0 | 21 |
| | 86-160 | 0.415 | 194 | >>56 | 1.2 | 19 | - 2.3 | 33 |
| Golan 70 | 0- 20 | 0.264 | 201 | >56 | 5.0 | 5.8 | - 3.5 | 0.4 |
| | 20- 40 | 0.274 | 188 | >70 | 2.0 | 17 | - 1.7 | 17 |
| | 40- 60 | 0.338 | 186 | >>70 | 0.5 | 26 | - 0.2 | 105 |
| Golan 37 | 0- 20 | 0.243 | 186 | >>56 | 3.4 | 8.9 | - 2.2 | 7.3 |
| | 20- 40 | 0.25 | 184 | >>56 | 0.9 | 16 | - 0.03 | 123 |

+ $^{15}N$ - $NH_4$ added to the soil.

Table 2: Calculated parameters and standard deviations of nitrification rate equations [1] and [5] for $NO_3$-N accumulation and $NH_4$-N depletion, respectively.

| Soil | Layer | $NO_3$-N accumulation | | | | $NH_4$-N depletion | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $(NO_3)_o$ | a | $k \cdot 10^4$ | SD | $(NH_4)_o$ | a | $k \cdot 10^4$ | SD |
| | cm | mg $kg^{-1}$ | | kg $mg^{-1}day^{-1}$ | mg $kg^{-1}$ | mg $kg^{-1}$ | | kg $mg^{-1}day^{-1}$ | mg $kg^{-1}$ |
| Alumim | 0- 5 | 3 | 224 | 16 | 14 | 180 | 181+ | 23 | 8.5 |
| | 5- 20 | 0.7 | 210 | 22 | 7.7 | 179 | 179+ | 28 | 6.3 |
| | 20- 50 | 1.3 | 232 | 5.0 | 14 | 191 | 191+ | 9.0 | 10. |
| | 50- 85 | 13 | 472 | 0.7 | 23 | 189 | 190 | 4.6 | 14. |
| | 85-125 | 3 | 214 | 4.0 | 4.5 | 190 | 192+ | 4.8 | 4.6 |
| | 125-145 | 10 | 477 | 10 | 20 | 190 | 190+ | 7.5 | 12. |
| Bet Dagan control | 0- 20 | 13 | 229 | 15 | 3.8 | 184 | 203 | 15 | 4.6 |
| | 20- 40 | 12 | 225 | 13 | 4.0 | 185 | 203 | 13 | 5.5 |
| Bet Dagan NPK | 0- 20 | 33 | 237 | 57 | 5.0 | 190 | 235 | 49 | 7.5 |
| | 20- 40 | 29 | 230 | 48 | 11.8 | 182 | 204 | 57 | 11 |
| | 40- 60 | 14 | 212 | 40 | 10.0 | 170 | 172+ | 70 | 7.6 |
| | 60- 90 | 6 | 197 | 40 | 8.2 | 168 | 168+ | 71 | 2.6 |
| | 90-120 | 6 | 192 | 31 | 6.5 | 172 | 173 | 69 | 12 |
| Gilat | 0- 20 | 10 | 225 | 29 | 6.0 | 203 | 216 | 32 | 9.4 |
| | 20- 40 | 6 | 228 | 29 | 5.6 | 202 | 205 | 40 | 6.8 |
| | 40- 60 | 3 | 302 | 12 | 3.8 | 195 | 197 | 21 | 23 |
| | 60- 80 | 1 | 163 | 12 | 14. | 200 | 203+ | 7.7 | 14 |
| | 80-100 | 0 | 198 | 19 | 17. | 187 | 187+ | 22 | 15 |
| | 100-120 | 5 | 25 | 21 | 1.1 | 194 | 248 | 0.44 | 4.2 |
| | 120-150 | 3 | 214 | 16 | 12. | 197 | 199 | 20 | 11 |
| Gilat control | 0- 20 | 2 | 213 | 43 | 4.2 | 195+ | 195+ | 57 | 6.8 |
| Gilat NM | 0- 20 | 3 | 213 | 59 | 5.4 | 196 | 197 | 75 | 3.7 |
| Akko | 0- 20 | 27 | 264 | 15 | 7.4 | 192 | 235 | 16 | 4.1 |
| | 20- 40 | 17 | 262 | 11 | 8.8 | 186 | 202 | 15 | 8.7 |
| | 40- 60 | 18 | 288 | 4.9 | 11. | 194 | 255 | 4.5 | 11. |
| Eden | 0- 20 | 26 | 304 | 25 | 18. | 183 | 190 | 67 | 5.2 |
| | 20- 40 | 8 | 239 | 32 | 10.0 | 178 | 179+ | 65 | 7.9 |
| | 40- 60 | 1 | 200 | 36 | 8.3 | 176 | 176+ | 67 | 7.5 |
| Qedma | 0- 9 | 16 | 245 | 14 | 9.1 | 196 | 222 | 16 | 10 |
| | 9- 25 | 7 | 234 | 16 | 12 | 192 | 200 | 19 | 8.8 |
| | 25- 58 | 29 | 215 | 3.9 | 14 | 201 | 220 | 3.9 | 16 |
| | 58- 85 | 21 | 157 | 2.7 | 22 | 200 | 210 | 2.8 | 17 |
| | 85-160 | 8 | 110 | 4.0 | 6.5 | 197 | 204 | 2.3 | 7.9 |
| Golan 70 | 0- 20 | 17 | 182 | 6.1 | 9.7 | 197 | 303 | 1.5 | 11 |
| | 20- 40 | 13 | 168 | 2.8 | 7.4 | 187 | 209 | 1.6 | 5.4 |
| | 40- 60 | 10 | 90 | 2.3 | 6.4 | 193 | 231 | 0.12 | 6.8 |
| Golan 37 | 0- 20 | 8 | 124 | 8.6 | 8.4 | 194 | 233 | 1.6 | 16 |
| | 20- 40 | 5 | 69 | 7.8 | 4.8 | 183 | 257 | 0.02 | 5.4 |

+ a was slightly larger than $(NH_4)_o$; If $a = (NH_4)_o$ equation [5] is reduced to $NH_4 = a$.

Table 3: Rate parameters of nitrification of added N recovered as $NH_4$ and $NO_3$ in soil (calculated from the $^{15}N$ excess).

| Soil | Depth | $NO_3$-N accumulation | | | $NH_4$-N depletion | | |
|---|---|---|---|---|---|---|---|
| | | maximal rate | delay period | SD | maximal rate | delay period | SD |
| | cm | mg $kg^{-1}$ $day^{-1}$ | days | mg $kg^{-1}$ | mg $kg^{-1}$ $day^{-1}$ | days | mg $kg^{-1}$ |
| Bet Dagan NPK | 0-20 | 84 | 0.7 | 5.5 | - 68 | 0.2 | 10. |
| | 20-40 | 60 | 0.7 | 17. | - 59 | 0.4 | 12. |
| | 40-60 | 55 | 1.9 | 6.1 | - 50 | 1.8 | 4.1 |
| | 60-90 | 42 | 2.7 | 3.9 | - 42 | 2.6 | 2.8 |
| | 90-120 | 29 | 3.4 | 5.3 | - 32 | 3.0 | 2.1 |
| Eden | 0-20 | 47 | 1.2 | 17. | - 57 | 0.9 | 6.4 |
| | 20-40 | 44 | 2.4 | 8.2 | - 46 | 2.6 | 7.3 |
| | 40-60 | 35 | 4.8 | 5.4 | - 30 | 4.2 | 5.1 |
| Alumim | 0- 5 | 9.0 | 7.1 | 53. | - 11 | 2.3 | 10. |
| | 5-20 | 7.3 | 9.0 | 55. | - 22 | 8.7 | 5.2 |

Table 4: Recovery of added $(^{15}NH_4)_2SO_4$-N as $NO_3$ at the end of the nitrification process, immobilization of added N and mineralization of native soil organic N during 1 week and the average of unaccounted for added N.

| Depth | N recovery in $NO_3$ | | | N immobilized in organic N | | | N unaccounted | | | N mineralized of na organic N+ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alumim | Eden | Bet Dagan NPK | Alumim | Eden | Bet Dagan NPK | Alumim | Eden | Bet Dagan NPK | Alumim | Eden |
| | mg $kg^{-1}$ | | | | | | | | | | |
| 0 - 5 | 142 | | | 28 | | | 21 | | | 44 (4) | |
| | | 168 | 178 | | 17 | 12 | | 10 | 16 | | 49 (24) |
| 5 - 20 | 142 | | | 9 | | | 10 | | | 51 (6) | |
| 20 - 40 | | 177 | 170 | | 12 | 14 | | 20 | 16 | | 30 (17) |
| 40 - 60 | | 172 | 169 | | 11 | 12 | | 24 | 20 | | 13 (9) |
| 60 - 90 | | | 161 | | | 13 | | | 30 | | |
| 90 -120 | | | 157 | | | 12 | | | 30 | | |

+ The numbers in brackets represent the amount of N mineralized during 1 week in a previous incubation experiment without added N.

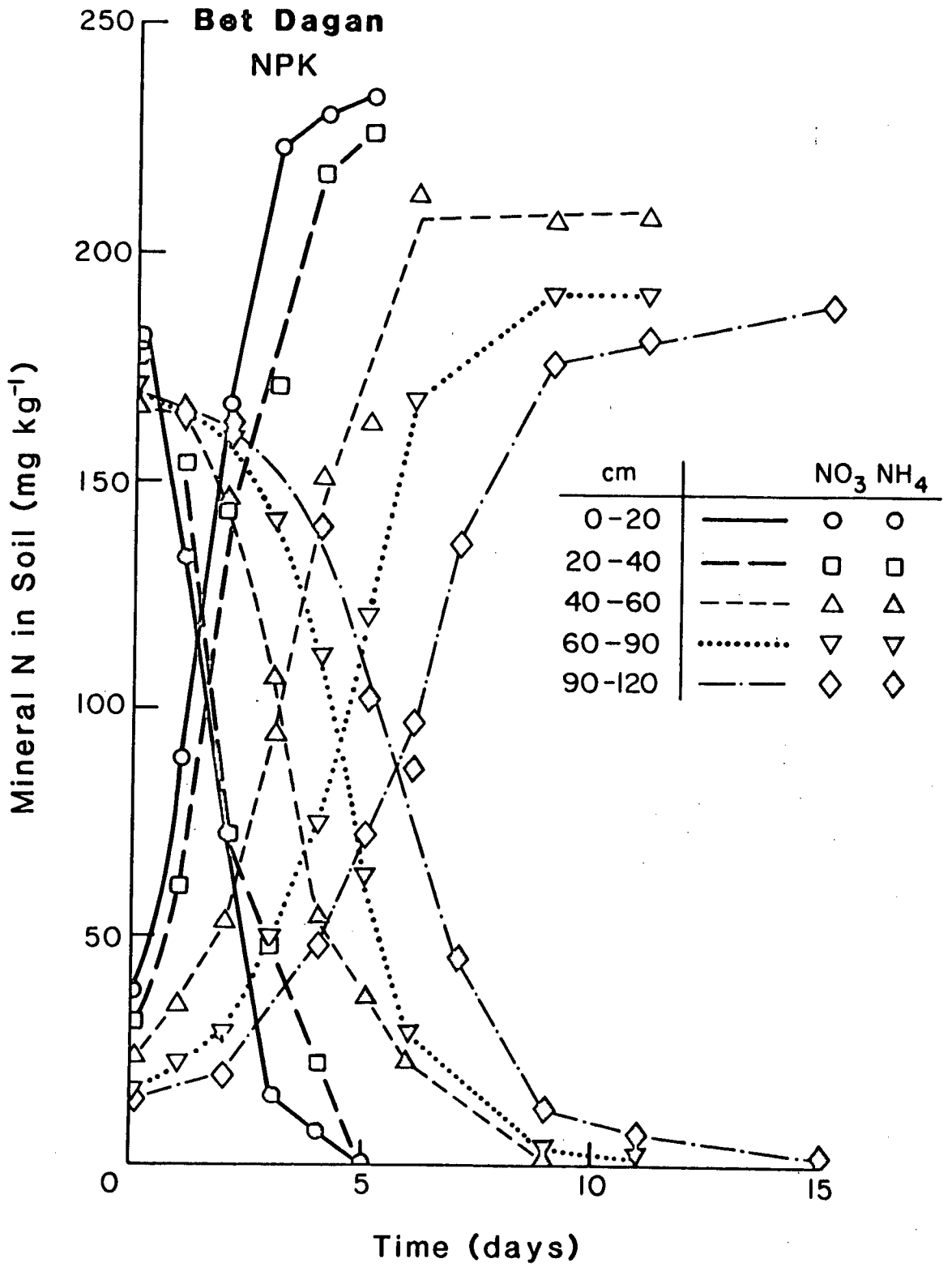


Figure 1: Nitrate accumulation and ammonium depletion in soil samples incubated with 200 mg $kg^{-1}$ $NH_4$-N at 35°C: Bet Dagan NPK soil

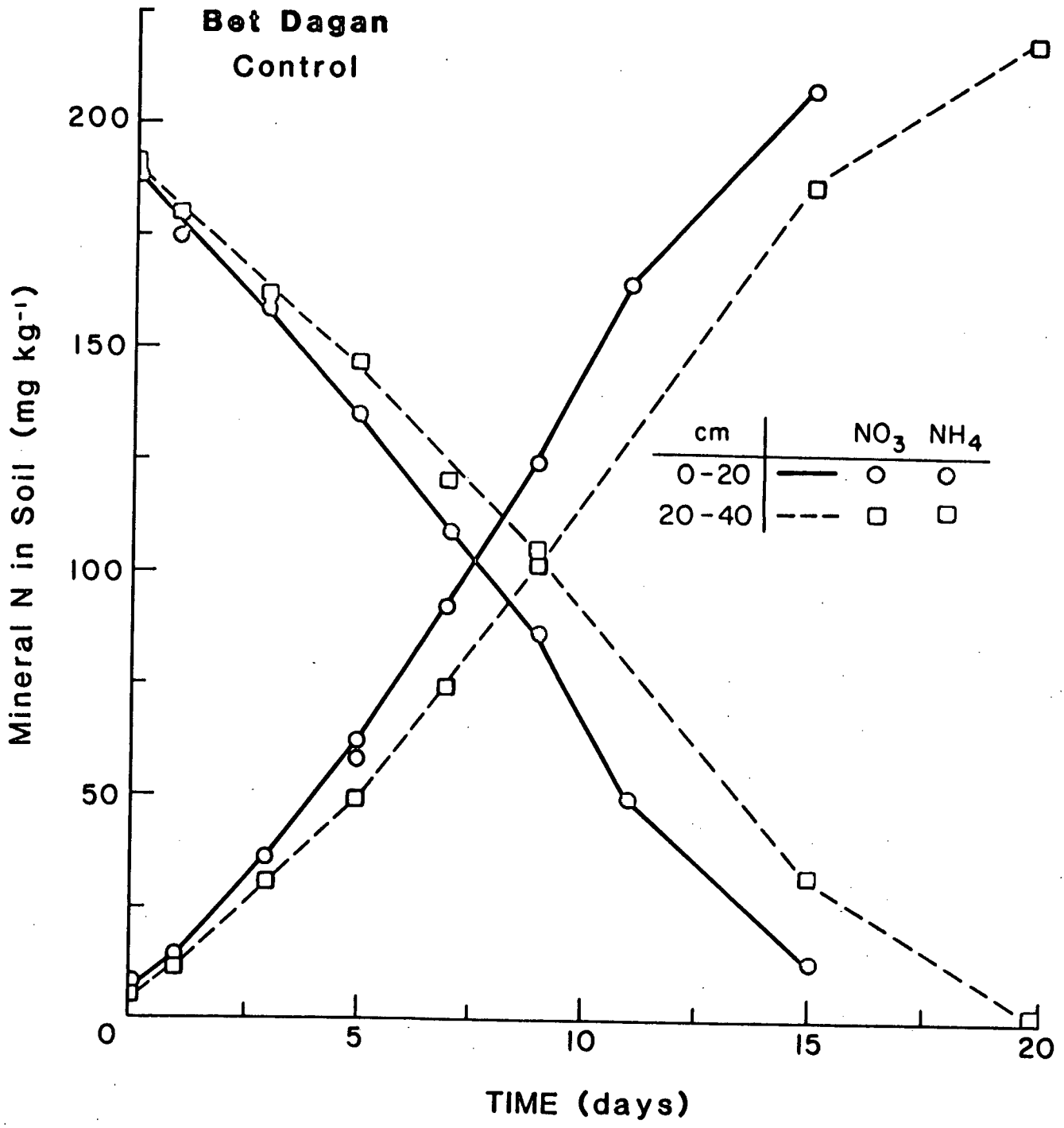


Figure 2: Nitrate accumulation and ammonium depletion in soil samples incubated with 200 mg $Kg^{-1}$ $NH_4$-N at 35°C: Bet Dagan Control

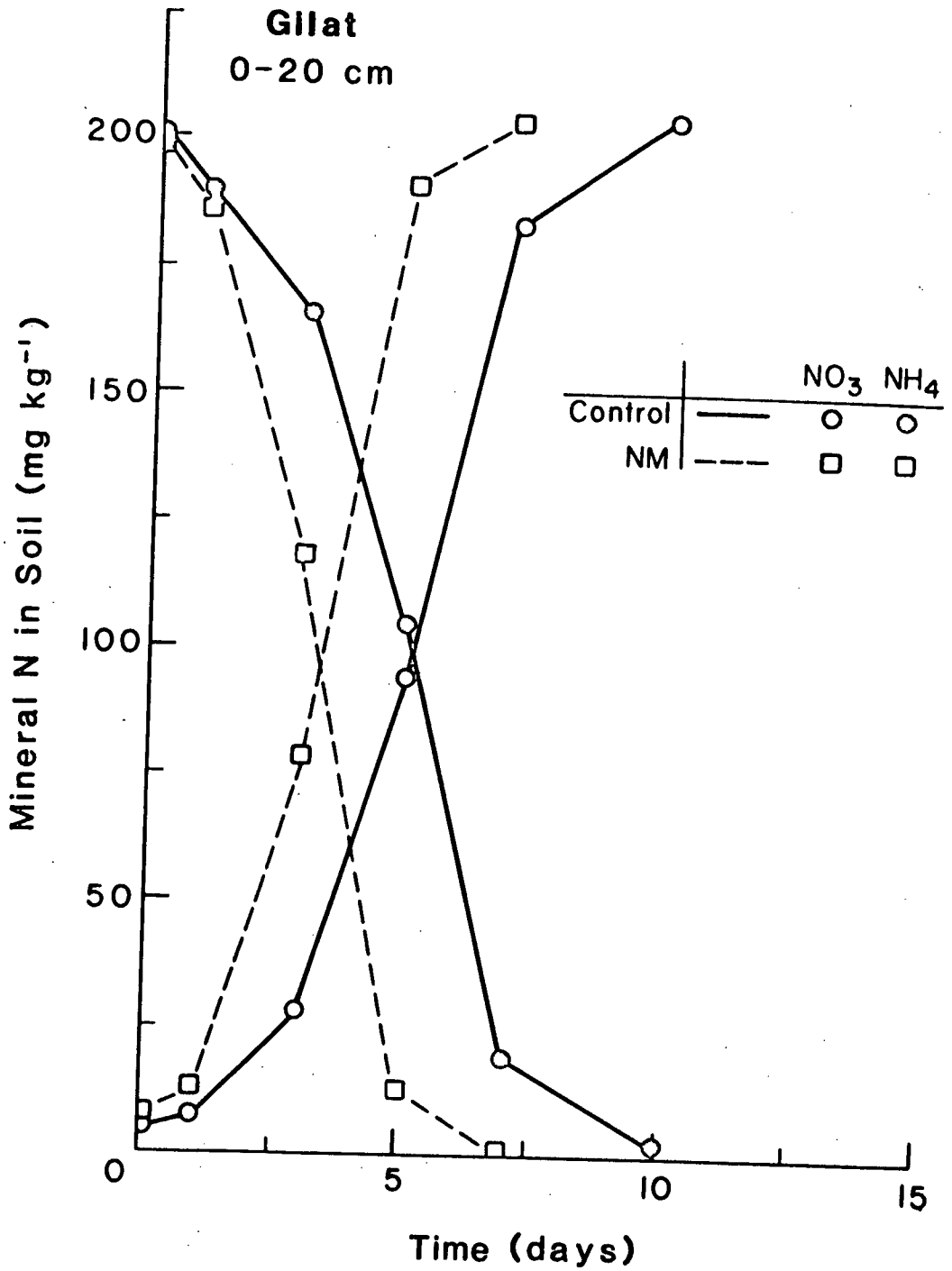


Figure 3: Nitrate accumulation and ammonium depletion in soil samples incubated with 200 mg $kg^{-1}$ $NH_4$-N at 35°C: Gilat 0-20 cm

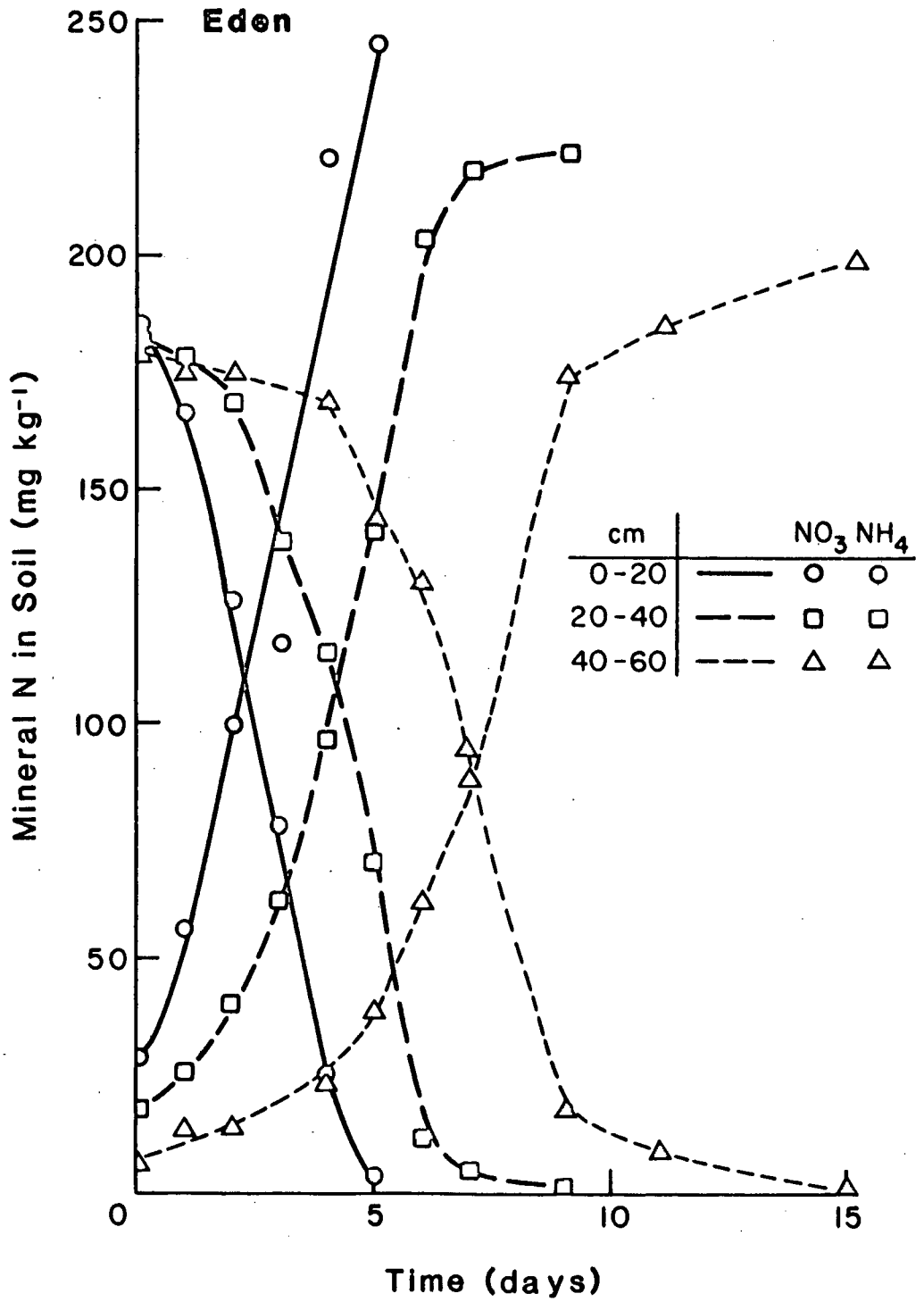


Figure 4: Nitrate accumulation and ammonium depletion in soil samples incubated with 200mg $kg^{-1}$ $NH_4$-N at 35°C: Eden

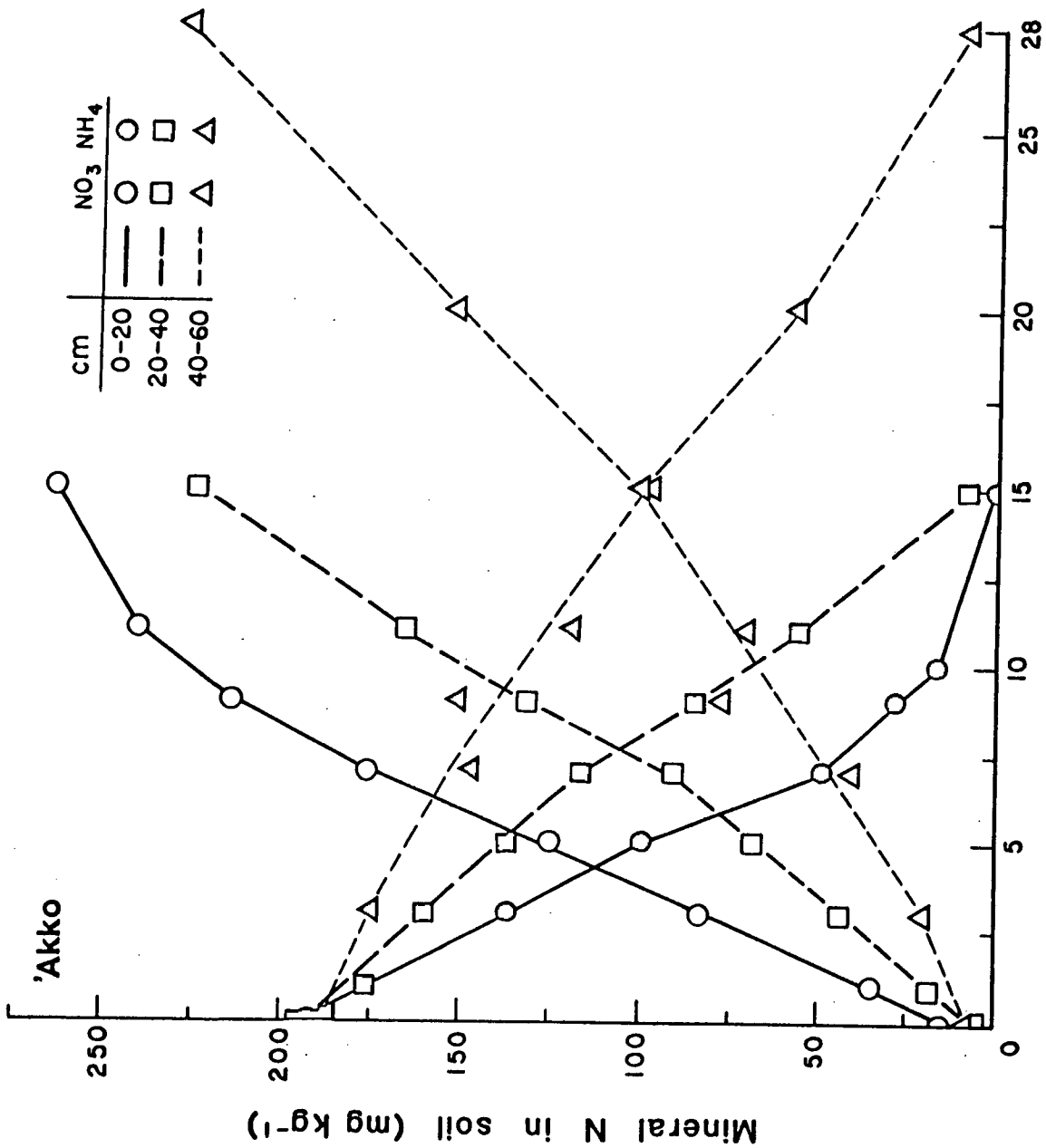


Figure 5: Nitrate accumulation and ammonium depletion in soil samples incubated with 200 mg $kg^{-1}$ NH4-N at 35°C: Akko.

APPENDIX IV

NH4-N AND NO3-N CONTENT IN SOIL DURING NITRIFICATION (MG KG-1)

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BET | | DAGAN | | NPK | | | | | | | | | |
| | 0-20 | | 20-40 | | 40-60 | | 60-90 | | 90-120 | | | | | |
| 0 | 183 | 39 | 182 | 34 | 166 | 24 | 170 | 14 | 167 | 15 | | | | |
| 0 | 180 | 38 | 173 | 28 | 165 | 23 | 170 | 16 | 168 | 15 | | | | |
| 1 | 134 | 90 | 156 | 61 | 167 | 35 | 167 | 22 | 166 | 21 | | | | |
| 1 | 133 | 88 | 152 | 62 | 164 | 35 | 162 | 22 | 163 | 21 | | | | |
| 2 | 72 | 168 | 70 | 157 | 147 | 53 | 161 | 29 | 163 | 18 | | | | |
| 2 | 74 | 166 | 76 | 135 | 145 | 53 | 159 | 29 | 163 | 18 | | | | |
| 3 | 15 | 221 | 47 | 170 | 107 | 95 | 143 | 49 | . | . | | | | |
| 3 | 15 | 225 | 47 | 172 | 107 | 94 | 141 | 50 | . | . | | | | |
| 4 | 8 | 230 | 23 | 216 | 56 | 151 | 113 | 73 | 140 | 49 | | | | |
| 4 | 6 | 231 | 22 | 218 | 53 | 151 | 111 | 76 | 139 | 47 | | | | |
| 5 | 0 | 233 | 0 | 226 | 37 | 164 | 65 | 119 | 102 | 75 | | | | |
| 5 | 0 | 235 | 0 | 225 | 35 | 162 | 62 | 121 | 104 | 71 | | | | |
| 6 | . | . | . | . | 23 | 213 | 29 | 169 | 86 | 98 | | | | |
| 6 | . | . | . | . | 23 | 212 | 29 | 167 | 88 | 96 | | | | |
| 7 | . | . | . | . | . | . | . | . | 45 | 137 | | | | |
| 7 | . | . | . | . | . | . | . | . | 48 | 136 | | | | |
| 9 | . | . | . | . | 1 | 209 | 3 | 194 | 12 | 178 | | | | |
| 9 | . | . | . | . | 1 | 204 | 2 | 188 | 12 | 174 | | | | |
| 11 | . | . | . | . | 1 | 208 | 2 | 193 | 7 | 182 | | | | |
| 11 | . | . | . | . | 1 | 208 | 1 | 189 | 7 | 181 | | | | |
| 15 | . | . | . | . | . | . | . | . | 1 | 188 | | | | |
| 15 | . | . | . | . | . | . | . | . | 1 | 189 | | | | |
| | EDEN | | | | | | GILAT CNT | | GILAT NM | | | | | |
| | 0-20 | | 20-40 | | 40-60 | | 0-20 | | 0-20 | | | | | |
| 0 | 185 | 29 | 183 | 17 | 179 | 7 | 201 | 6 | 200 | 7 | | | | |
| 0 | 187 | 28 | 181 | 17 | 178 | 7 | 201 | 5 | 200 | 7 | | | | |
| 1 | 166 | 57 | 177 | 25 | 174 | 14 | 189 | 7 | 187 | 13 | | | | |
| 1 | 166 | 55 | 179 | 26 | 175 | 13 | 191 | 8 | 188 | 12 | | | | |
| 2 | 126 | 100 | 168 | 40 | 175 | 14 | . | . | 167 | 40 | | | | |
| 2 | 126 | 109 | 169 | 40 | 175 | 13 | . | . | 165 | 41 | | | | |
| 3 | 80 | 118 | 140 | 60 | . | . | 167 | 27 | 118 | 79 | | | | |
| 3 | 76 | 116 | 137 | 63 | . | . | 165 | 29 | 119 | 78 | | | | |
| 4 | 22 | 223 | 115 | 96 | 168 | 24 | . | . | 43 | 157 | | | | |
| 4 | 26 | 220 | 116 | 97 | 168 | 24 | . | . | 48 | 157 | | | | |
| 5 | 3 | 245 | 70 | 142 | 140 | 40 | 104 | 94 | 13 | 191 | | | | |
| 5 | 3 | 246 | 70 | 140 | 145 | 37 | 105 | 93 | 12 | 192 | | | | |
| 6 | . | . | 11 | 205 | 130 | 63 | . | . | 0 | 204 | | | | |
| 6 | . | . | 12 | 202 | 130 | 60 | . | . | 0 | 204 | | | | |
| 7 | . | . | 4 | 220 | 90 | 93 | 21 | 181 | . | . | | | | |
| 7 | . | . | 4 | 216 | 99 | 83 | 17 | 186 | . | . | | | | |
| 9 | . | . | 1 | 222 | 18 | 174 | 2 | 204 | . | . | | | | |
| 9 | . | . | 1 | 222 | 17 | 174 | 2 | 204 | . | . | | | | |
| 11 | . | . | . | . | 8 | 185 | . | . | . | . | | | | |
| 11 | . | . | . | . | 9 | 184 | . | . | . | . | | | | |
| 15 | . | . | . | . | 0 | 198 | . | . | . | . | | | | |
| 15 | . | . | . | . | 0 | 198 | . | . | . | . | | | | |
| | GILAT | | | | | | | | KEDMA | | | | | |
| | 0-20 | | 20-40 | | 40-60 | | 120-150 | | 0-9 | | 9-25 | | | |
| 0 | 209 | 3 | 204 | 2 | 206 | 2 | 195 | 3 | 199 | 3 | 198 | 3 | | |
| 0 | 209 | 3 | 205 | 2 | 206 | 2 | 194 | 3 | 200 | 3 | 198 | 3 | | |
| 1 | 192 | 22 | 202 | 15 | . | . | . | . | . | . | . | . | | |
| 1 | 192 | 23 | 200 | 16 | . | . | . | . | . | . | . | . | | |
| 3 | 140 | 62 | 166 | 44 | 191 | 11 | 192 | 10 | 157 | 42 | 174 | 29 | | |
| 3 | 138 | 63 | 166 | 40 | 192 | 11 | 195 | 8 | 156 | 49 | 173 | 28 | | |
| 5 | 86 | 122 | 114 | 95 | . | . | . | . | . | . | . | . | | |
| 5 | 89 | 120 | 115 | 94 | . | . | . | . | . | . | . | . | | |
| 7 | 14 | 193 | 40 | 167 | 156 | 37 | 171 | 26 | 88 | 119 | 122 | 77 | | |
| 7 | 17 | 191 | 28 | 181 | 160 | 36 | 171 | 27 | 87 | 118 | 125 | 72 | | |
| 9 | 0 | 211 | 2 | 207 | 148 | 83 | . | . | 77 | 139 | 100 | 111 | | |
| 9 | 0 | 210 | 2 | 207 | 155 | 73 | . | . | 63 | 154 | 103 | 106 | | |
| 11 | . | . | . | . | 79 | 119 | 104 | 99 | 22 | 187 | 65 | 137 | | |
| 11 | . | . | . | . | 77 | 121 | 102 | 99 | 21 | 189 | 67 | 136 | | |
| 14 | . | . | . | . | 3 | 204 | 76 | 116 | 6 | 224 | 10 | 218 | | |
| 14 | . | . | . | . | 4 | 205 | 31 | 158 | 5 | 227 | 9 | 219 | | |
| 20 | . | . | . | . | . | . | 6 | 203 | . | . | 3 | 224 | | |
| 20 | . | . | . | . | . | . | 5 | 203 | . | . | 2 | 218 | | |

NH4-N AND NO3-N CONTENT IN SOIL DURING NITRIFICATION (MG KG-1)

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACO | | | | | | BET DAGAN CONTROL | | | | ALUMIM | | | |
| | 0-20 | | 20-40 | | 40-60 | | 0-20 | | 20-40 | | 0-5 | | 5-20 | |
| 0 | 197 | 15 | 195 | 6 | 189 | 7 | 189 | 8 | 190 | 5 | 197 | 9 | 188 | 9 |
| 0 | 193 | 15 | 193 | 6 | 187 | 7 | 190 | 8 | 191 | 5 | 183 | 12 | 173 | 9 |
| 1 | 177 | 34 | 177 | 19 | . | . | 174 | 14 | 181 | 11 | 186 | 9 | 188 | 5 |
| 1 | 176 | 35 | 176 | 19 | . | . | 175 | 14 | 179 | 12 | 186 | 9 | 189 | 5 |
| 3 | 137 | 82 | 158 | 46 | 176 | 19 | 159 | 35 | 161 | 31 | 173 | 20 | 176 | 9 |
| 3 | 135 | 84 | 162 | 42 | 174 | 22 | 158 | 37 | 163 | 30 | 172 | 21 | 175 | 10 |
| 5 | 99 | 125 | 135 | 69 | . | . | 134 | 62 | 147 | 48 | 159 | 33 | 168 | 19 |
| 5 | 99 | 124 | 137 | 68 | . | . | 136 | 58 | 147 | 49 | 158 | 35 | 170 | 20 |
| 7 | 50 | 174 | 116 | 92 | 148 | 41 | 109 | 91 | 120 | 74 | . | . | . | . |
| 7 | 48 | 178 | 118 | 90 | 146 | 43 | 108 | 93 | 121 | 74 | . | . | . | . |
| 9 | 30 | 206 | 84 | 132 | 148 | 83 | 86 | 124 | 105 | 101 | . | . | . | . |
| 9 | 27 | 218 | 86 | 130 | 155 | 73 | 82 | 124 | 105 | 102 | . | . | . | . |
| 11 | 13 | 245 | 70 | 149 | 119 | 73 | 48 | 165 | . | . | 117 | 78 | 127 | 71 |
| 11 | 21 | 233 | 42 | 181 | 118 | 69 | 50 | 163 | . | . | 118 | 77 | 128 | 71 |
| 15 | 2 | 262 | 8 | 225 | 106 | 93 | 14 | 207 | 33 | 186 | 37 | 184 | 36 | 173 |
| 15 | 2 | 265 | 9 | 225 | 97 | 105 | 12 | 209 | 31 | 187 | 36 | 180 | 34 | 175 |
| 20 | . | . | . | . | 59 | 153 | . | . | 1 | 217 | 5 | 227 | 4 | 203 |
| 20 | . | . | . | . | 57 | 152 | . | . | 1 | 218 | 4 | 227 | 4 | 203 |
| 28 | . | . | . | . | 10 | 227 | . | . | . | . | 1 | 210 | 1 | 209 |
| 28 | . | . | . | . | 10 | 227 | . | . | . | . | 1 | 209 | 1 | 207 |

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|
| | GILAT | | | | | | GOLAN 37 | | | |
| | 60-80 | | 80-100 | | 100-120 | | 0-20 | | 20-40 | |
| 0 | 201 | 7 | 198 | 5 | 195 | 5 | 186 | 8 | 184 | 5 |
| 0 | 198 | 8 | 200 | 5 | 195 | 5 | 185 | 7 | 184 | 5 |
| 2 | . | . | . | . | . | . | 195 | 5 | 185 | 4 |
| 2 | . | . | . | . | . | . | 195 | 4 | 187 | 4 |
| 7 | 193 | 7 | 185 | 9 | 183 | 6 | 181 | 15 | 179 | 15 |
| 7 | 193 | 7 | 187 | 8 | 183 | 6 | 184 | 14 | 182 | 14 |
| 11 | . | . | 149 | 48 | . | . | 181 | 5 | . | . |
| 11 | . | . | 151 | 49 | . | . | 182 | 4 | . | . |
| 14 | 183 | 11 | 174 | 23 | 184 | 8 | 146 | 38 | . | . |
| 14 | 180 | 15 | 164 | 30 | 183 | 8 | 147 | 39 | . | . |
| 20 | 160 | 38 | 47 | 157 | . | . | 139 | 54 | 175 | 7 |
| 20 | 168 | 32 | 43 | 160 | . | . | 140 | 53 | 175 | 8 |
| 28 | 115 | 85 | 13 | 189 | 177 | 15 | 133 | 71 | 192 | 18 |
| 28 | 64 | 138 | 9 | 192 | 182 | 12 | 136 | 68 | 186 | 11 |
| 35 | 56 | 143 | 4 | 196 | . | . | . | . | . | . |
| 35 | 57 | 142 | 4 | 199 | . | . | . | . | . | . |
| 42 | . | . | . | . | 171 | 15 | 125 | 103 | 188 | 33 |
| 42 | . | . | . | . | 170 | 17 | 123 | 103 | 184 | 34 |
| 56 | . | . | . | . | 166 | 20 | 105 | 123 | 179 | 40 |
| 56 | . | . | . | . | 164 | 21 | 106 | 123 | 177 | 42 |

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|
| | KEDMA | | | | | |
| | 25-58 | | 58-86 | | 86-160 | |
| 0 | 193 | 38 | 192 | 37 | 193 | 7 |
| 0 | 195 | 37 | 192 | 36 | 194 | 9 |
| 7 | 196 | 45 | 198 | 40 | 193 | 10 |
| 7 | 196 | 47 | 200 | 40 | 194 | 11 |
| 14 | 175 | 66 | 198 | 24 | 199 | 14 |
| 14 | 178 | 63 | 196 | 25 | 198 | 16 |
| 20 | 144 | 93 | . | . | . | . |
| 20 | 146 | 92 | . | . | . | . |
| 28 | 78 | 156 | 168 | 40 | 182 | 21 |
| 28 | 102 | 129 | 174 | 32 | 179 | 21 |
| 36 | 75 | 166 | 158 | 54 | . | . |
| 36 | 84 | 160 | 144 | 66 | . | . |
| 42 | 30 | 204 | 122 | 88 | 163 | 35 |
| 42 | 81 | 152 | 134 | 74 | 163 | 35 |
| 56 | . | . | 62 | 148 | 157 | 41 |
| 56 | . | . | 134 | 70 | 128 | 68 |

| T | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 | NH4 | NO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ALUMIM | | | | | | | | GOLAN 70 | | | | | |
| | 20-50 | | 50-85 | | 85-125 | | 125-165 | | 0-20 | | 20-40 | | 40-60 | |
| 0 | 194 | 7 | 191 | 4 | 186 | 2 | 192 | 8 | 201 | 6 | 189 | 4 | 187 | 4 |
| 0 | 196 | 7 | 192 | 5 | 186 | 2 | 190 | 8 | 201 | 7 | 188 | 4 | 185 | 4 |
| 7 | 196 | 9 | 189 | 9 | 186 | 5 | 188 | 8 | 167 | 36 | 185 | 14 | 191 | 10 |
| 7 | 197 | 8 | 188 | 9 | 186 | 5 | 188 | 8 | 163 | 38 | 185 | 14 | 190 | 10 |
| 14 | 184 | 15 | 188 | 12 | 189 | 9 | 189 | 9 | 143 | 60 | 175 | 23 | 188 | 14 |
| 14 | 184 | 15 | 188 | 13 | 189 | 9 | 189 | 10 | 141 | 62 | 175 | 23 | 188 | 15 |
| 28 | 174 | 20 | 173 | 19 | 165 | 21 | 167 | 24 | 92 | 128 | 155 | 51 | 195 | 15 |
| 28 | 174 | 22 | 167 | 23 | 157 | 23 | 162 | 31 | 83 | 135 | 152 | 52 | 191 | 16 |
| 42 | 133 | 66 | 170 | 13 | 116 | 74 | 157 | 35 | 69 | 156 | 147 | 62 | 195 | 14 |
| 42 | 132 | 66 | 173 | 10 | 114 | 76 | 166 | 29 | 77 | 151 | 151 | 58 | 190 | 14 |
| 56 | 20 | 177 | 143 | 45 | 65 | 122 | . | . | 43 | 184 | 121 | 87 | 195 | 16 |
| 56 | 4 | 195 | 89 | 102 | . | . | 79 | 115 | 37 | 190 | 128 | 80 | 193 | 17 |
| 70 | 2 | 205 | 60 | 133 | 17 | 181 | 2 | 211 | . | . | 95 | 117 | 187 | 27 |
| 70 | . | . | 72 | 121 | 19 | 179 | 2 | 211 | . | . | 93 | 120 | 171 | 43 |

# V. BIOLOGICAL ASPECTS OF NITROGEN TRANSFORMATIONS IN SOIL PROFILES

by

Dan Levanon

1. Introduction

2. Nitrification

2.1 Materials and Methods

2.2 Results and Discussion

3. Mineralization

3.1 Materials and Methods

3.2 Results and Discussion

## 1. Introduction

The organic matter in the soil is subjected to biological degradation. This process is carried out by heterotrophic microorganisms that use organic materials as energy, carbon and nitrogen sources. The process is primarily aerobic respiration. Therefore $CO_2$ evolution can be used for measuring microbial biomass activity (the total mass of living microorganisms in the soil) (Seto 1983, Sato 1981). Nitrogen and carbon mineralization in the soil are governed by a number of ecological parameters, the most important of which are water content (moisture), pH, temperature, chemical composition of the organic matter and especially it's C/N ratio, and availability of other macro and micro elements (Alexander, 1978). A wide variety of microorganisms, degrade and utilize organic materials in the soil. The main groups of these microorganisms are bacteria, fungi and actinomycetes. The ease by which organic material is attacked by soil microflora varies drastically with the material structure and composition. Simple materials (like mono-saccharides and amino-acids) are degraded in a few days. More complex materials (like lignin and the soil humus) are degraded slowly over a period of years (Jenkinson 1977). Changes in soil microflora are noted due to the composition of the soils organic matter and ecological conditions (Mitchell 1974).

In this research we studied the activity and amount of microorganisms during incubation of soil samples from nine Israeli soil profiles. $CO_2$ evolution from the soil was measured daily and microflora counts were taken before the incubation and at the seventh and 35th days of incubation.

Nitrification is biological oxidation of ammonium to nitrate. The

process is divided schematically into two main stages as follows:

$$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-.$$

In each stage the oxidation is done by a different group of autotrophic (chemolithotrophic) bacteria. Those bacteria that are active in the first stage are ammonium oxidizers (like Nitrosomonas sp.) and in the second stage Nitrite oxidizers (like Nitrobacter. sp). Nitrification rates are usually faster than nitrogen mineralization rates. The rate of stage two (nitrite oxidation) of nitrification is faster than that of stage one (ammonium oxidation). Therefore there is an accumulation of nitrates in the soil as a result of nitrogen mineralization (rather than ammonium and nitrite), except when there are conditions in the soil that cause retardation of nitrification. In this research we studied the growth rate of the population of nitrifying bacteria, during soil incubation, of profiles from nine Israeli soils. Nitrate accumulation and ammonium oxidation were also recorded.

## 2. Nitrification

### 2.1 Materials and Methods

#### Soil Incubation

400 g. soil samples from each profile were incubated in an incubator. Soil moisture was adjusted to field capacity, 200 ug $N\text{-}NH_4^+/g^{-1}$ soil as $(NH_4)_2 SO_4$ were added to the soil as a substrate for the nitrifying bacteria. The incubation temperature was $25^oC$ ammonium, nitrite, and nitrate content in the soil were studied.

#### Enumeration Of Total Nitrifying Population

Enumeration of total nitrifying bacterial population in the

incubated soil samples was according to the M.P.N. technique. The method used was modification of microtechnique for M.P.N. (Rowe et al 1976).

## 2.2 Results and Discussion

The results of M.P.N counts of nitrifiers and nitrate accumulation during incubation of soil profiles is presented in the above figures:

| Soil Profile | | Fig |
|---|---|---|
| Gilat | - | 1a, 1b, 1c |
| Golan 70 | - | 2 |
| Eden | - | 3a, 3b |
| Acco | - | 4a, 4b |
| Bet Dagan | - | 5a, 5b, 5c |
| Alumim | - | 6a, 6b |
| Kedma | - | 7a, 7b |
| Gilat No, $N_2$ $M_3$ | - | 8 |

The results of incubation studies of Golan 37 soil profile are not represented, since nitrate accumulation was very slow, and the amounts of nitrifying bacteria were small (50-100/$gr^{-1}$) and remained so during 35 days of incubation.

The connection between changes in the amounts of nitrifying bacteria in the soil and nitrate accumulation during the incubation period was also studied.

The correlation coefficients between nitrate accumulation and the growth in the number of nitrifying bacteria is presented in Table 1. Only in the Golan 70 soil profile was there no correlation between bacterial counts and nitrate accumulation. In this soil the

nitrification rates were low with relating small numbers of nitrifying bacteria.

All the other soil profiles showed positive correlation between changes in the number of nitrifiers and the rate of nitrate accumulation in the soil. This correlation is expressed by two formulas: $y = B \times +A$ and $Y = B \text{ Sin } x + A$ when x is the number of nitrification bacteria (per $gr^{-1}$ soil) and y is $N\text{-}NO_3^-$ content in the soil (ppm) measured at the same day from the beginning of soil incubation.

An unusual phenomenon was recorded in the Gilat soil profile. The accumulation of nitrates was much slower at a depth of 60-120 cm than at a depth of 120-150 cm. The number of nitrifying bacteria was also higher at a depth of 120-150 cm than at a depth of 60-120 cm. This situation is unusual and in all the other soil profiles nitrification rates and numbers of nitrifying bacteria decreased with depth.

A special study was conducted to get more information about nitrification retardation found in the Gilat soil profile at a depth of 60-120 cm and in the Golan 37 and Golan 70 soil profiles. Soil samples were incubated with an additional 200 ppm of $N\text{-}NH_4^+$ and $N\text{-}NH_4^+$; $N\text{-}NO_3^-$; $N\text{-}NO_2^-$ content after 12 days of incubation were measured. The results are presented in Table 2.

The results indicate that the only soil sample with nitrite accumulation was recorded in the Gilat profile at a depth of 60-80 cm. In the Golan profiles, nitrification is retarded but there is no accumulation of nitrite. These results also indicate that the phenomenon found in Gilat soil profile is retardation of oxygenation of $NO_2^-$ to $NO_3^-$ rather than inhibition of the first step of nitrification (oxygenation of $NH_4^+$ to $NO_2^-$). A general conclusion according to our

results, from incubation experiments of nine Israeli soil profiles is that nitrification rates depend on the growth rates of the nitrifying bacterial population in the soil. There is a decrease in the growth rate of nitrifying population with the depth in most of the soil profiles.

Table 1. Correlation coefficients[1] between the rate of nitrate accumulation[2] and changes in the numbers of nitrifying bacteria[3], during incubation of samples of soil profiles.

| Soil Profile | Depth (cm) | Regression formula | A | B | R |
|---|---|---|---|---|---|
| Gilat | 0-20 | 1 | 24.4 | 11.1 | 0.53 |
| -"- | -"- | 2 | 24.3 | 643.0 | 0.53 |
| -"- | 20-40 | 1 | 25.2 | 8.6 | 0.55 |
| -"- | -"- | 2 | 25.0 | 500.2 | 0.55 |
| -"- | 40-60 | 1 | 21.7 | 6.3 | 0.52 |
| -"- | -"- | 2 | 21.5 | 370.8 | 0.53 |
| -"- | 60-80 | 1 | -0.3 | 0.16 | 0.98 |
| -"- | -"- | 2 | -0.3 | 9.4 | 0.98 |
| -"- | 80-100 | 1 | 2.7 | 0.03 | 0.99 |
| -"- | -"- | 2 | 3.3 | -9.2 | -0.99 |
| -"- | 100-120 | 1 | 1.9 | 0.2 | 0.86 |
| -"- | -"- | 2 | 1.9 | 10.4 | 0.86 |
| Eden | 20-40 | 1 | 1.9 | 0.7 | 0.96 |
| -"- | -"- | 2 | 1.8 | 42.6 | 0.96 |
| Acco | 0-20 | 1 | 67.0 | 46.0 | 0.58 |
| -"- | -"- | 2 | 67.0 | 2638.2 | 0.58 |
| Acco | 40-60 | 1 | 13.2 | 10.3 | 0.76 |
| -"- | -"- | 2 | 13.1 | 593.4 | 0.76 |
| Bet Dagan N.O. | 20-40 | 1 | -15.6 | 18.1 | 0.75 |
| -"- | -"- | 2 | -15.6 | 1039.9 | 0.75 |
| Bet Dagan N.4. | 60-80 | 1 | 11.6 | 20.6 | 0.99 |
| -"- | -"- | 2 | 11.5 | 1184.6 | 0.99 |

| | | | | | |
|---|---|---|---|---|---|
| Alumim | 0-5 | 1 | -5.5 | 7.5 | 1.0 |
| -"- | -"- | 2 | -5.5 | 434.0 | 1.0 |
| -"- | 20-50 | 1 | -34.0 | 21.1 | 0.93 |
| -"- | -"- | 2 | -34.0 | 1212.5 | 0.93 |
| -"- | 125-165 | 1 | -7.6 | 49.5 | 0.99 |
| -"- | -"- | 2 | -7.6 | 2837.6 | 0.99 |
| Kedma | 58-86 | 1 | -8.6 | 9.2 | 0.98 |
| -"- | -"- | 2 | -8.6 | 529.8 | 0.98 |
| -"- | 86-160 | 1 | -8.6 | 9.2 | 0.98 |
| -"- | -"- | 2 | -8.6 | 529.8 | 0.98 |
| Gilat N.O. | 0-20 | 1 | 6.8 | 0.1 | 0.99 |
| | 20-40 | 2 | 6.9 | 177.2 | 0.98 |
| Gilat N.2.M.3. | 0-20 | 1 | 16.6 | 4.3 | 0.94 |
| | 20-40 | 2 | 16.1 | 262.9 | 0.94 |

1. formula 1. $Y = B \times +A$

   -"- 2. $Y = \text{Sin } B \times +A$

2. Y = $N\text{-}NO_3^-$ content in soil sample

3. X = Number of nitrifying bacteria in the soil sample

Table 2. Content of mineral N forms: Ammonium, Nitrate, Nitrite in soil samples after 12 days of incubation (with amendment of 200 ppm $N-NH^{+}_{4}$ at the beginning of the incubation).

| | | Mineral N $\mu g/g^{-1}$ soil | | |
|---|---|---|---|---|
| Soil profile, | Depth | $N-NH^{+}_{4}$ | $N-NO^{-}_{3}$ | $N-NO^{-}_{2}$ |
| Gilat | 0-20 | 0.4 | 157 | 0.6 |
| -"- | 20-40 | 3.2 | 148 | 4.3 |
| -"- | 40-60 | 15.8 | 166 | 2.95 |
| -"- | 60-80 | 161.2 | 4.8 | 27.2 |
| -"- | 120-150 | 35.9 | 120.6 | 7.7 |
| Golan 37 | 0-20 | 165.0 | 15.1 | 2 |
| Golan 70 | 0-20 | 105.0 | 67.0 | 1.6 |
| Bet Dagan N.4. | 0-20 | 0.8 | 202.0 | 1.5 |
| Alumim | 0-5 | 93.7 | 129.2 | 1.1 |
| Alumim | 85-125 | 183.1 | 12.7 | 2.3 |

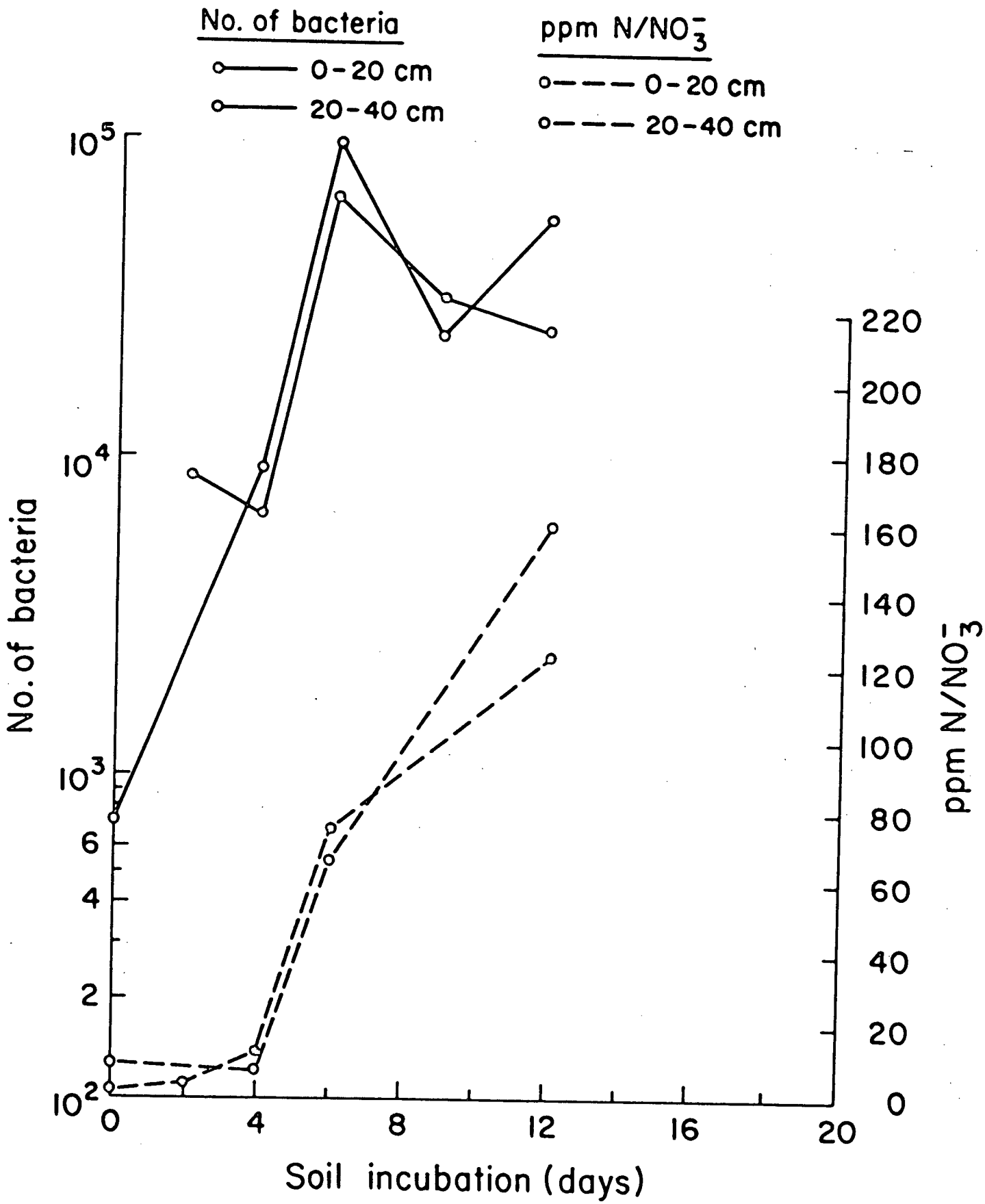


Fig. 1a, 1b, 1c. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Gilat.

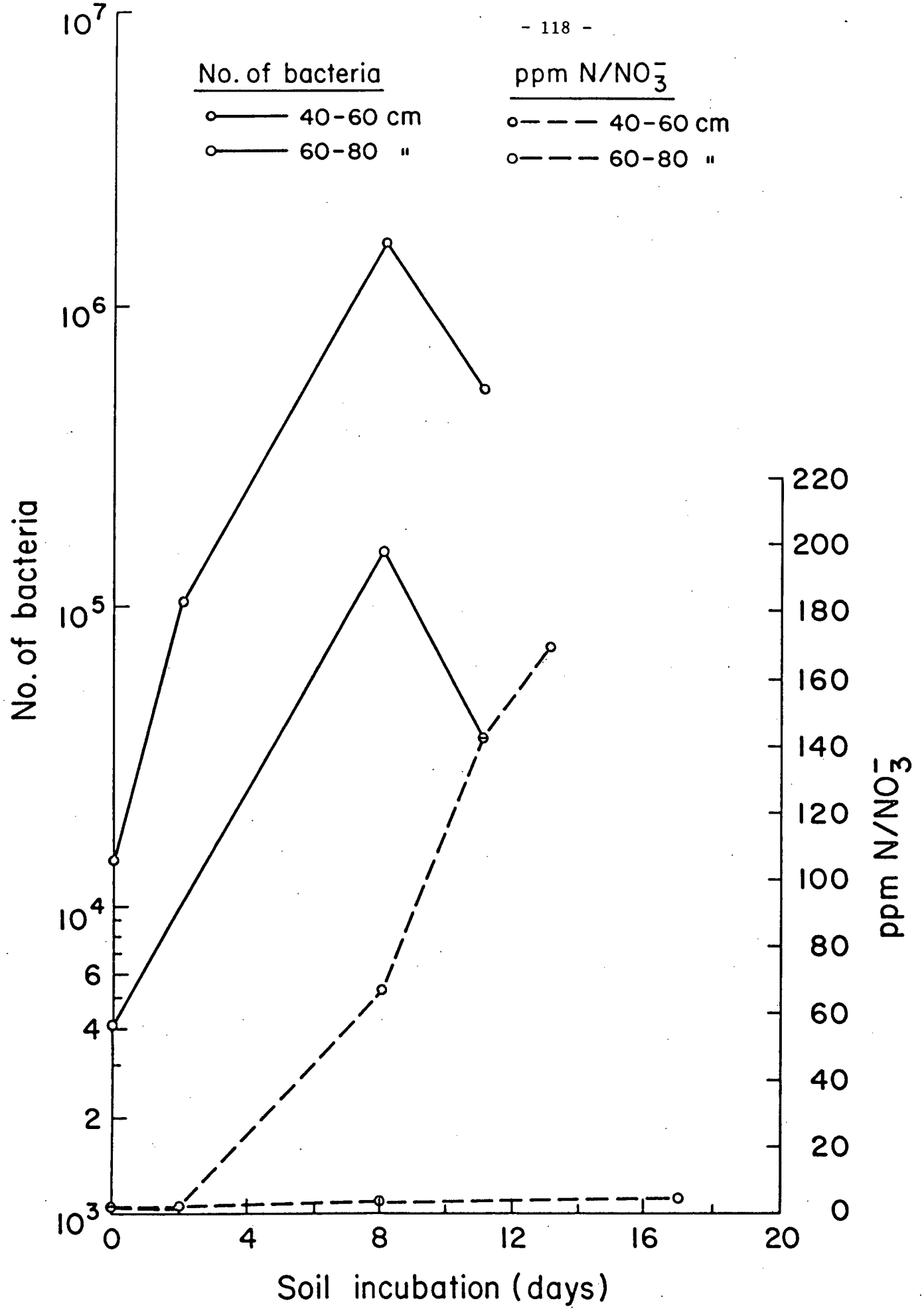


Fig. 1a, 1b, 1c. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Gilat.

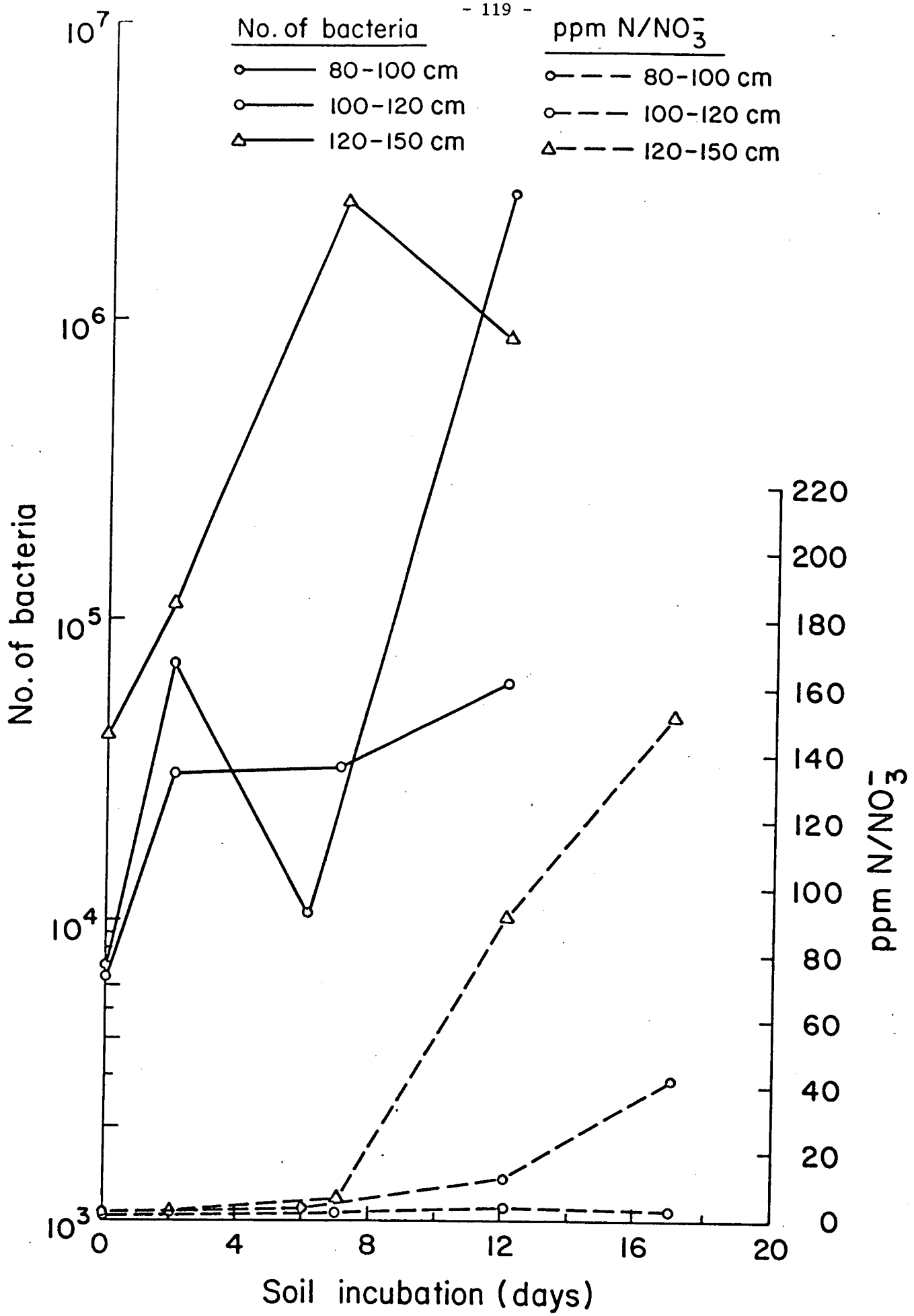


Fig. 1a, 1b, 1c. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Gilat.

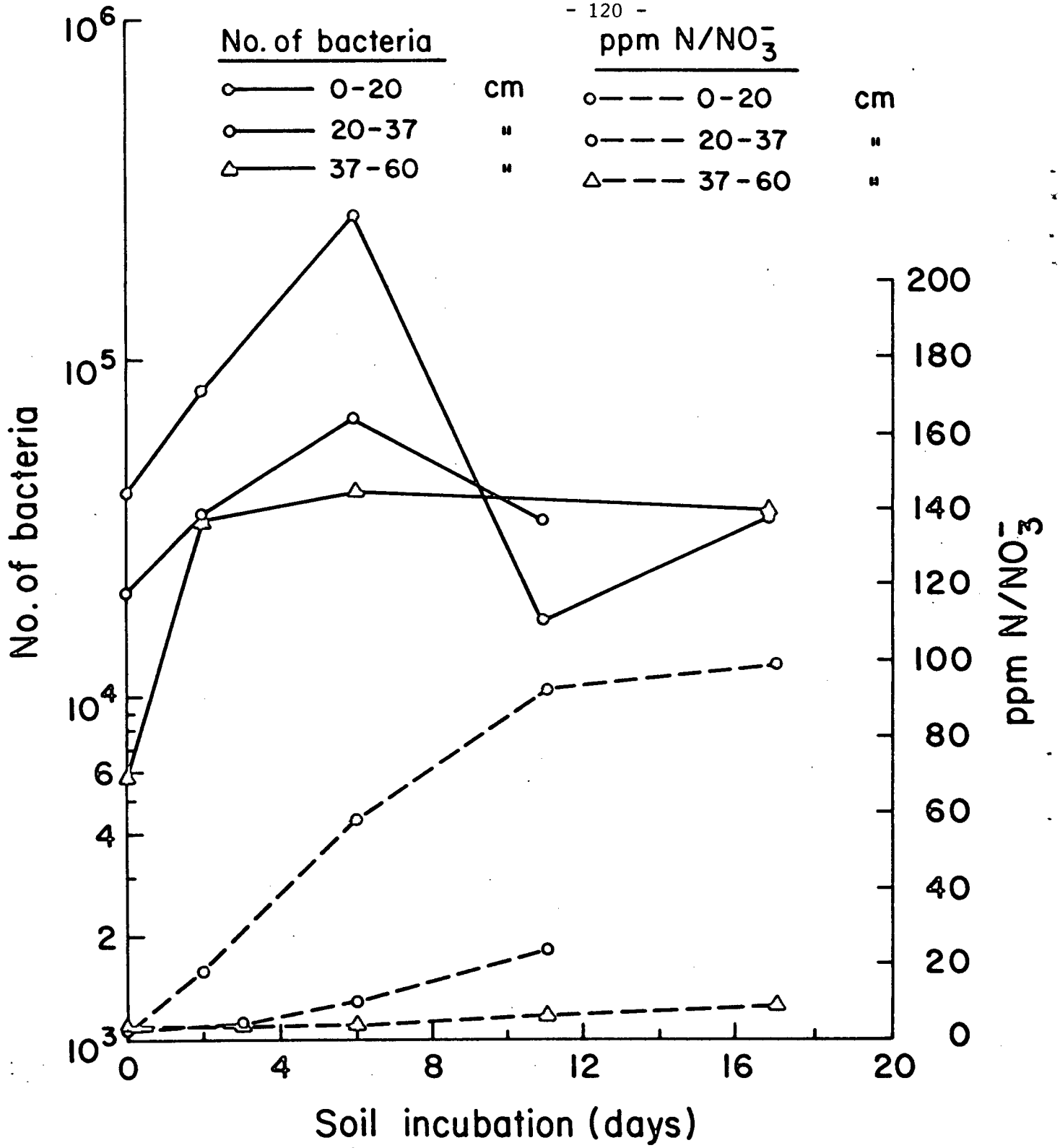


Fig. 2 Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Golan 70.

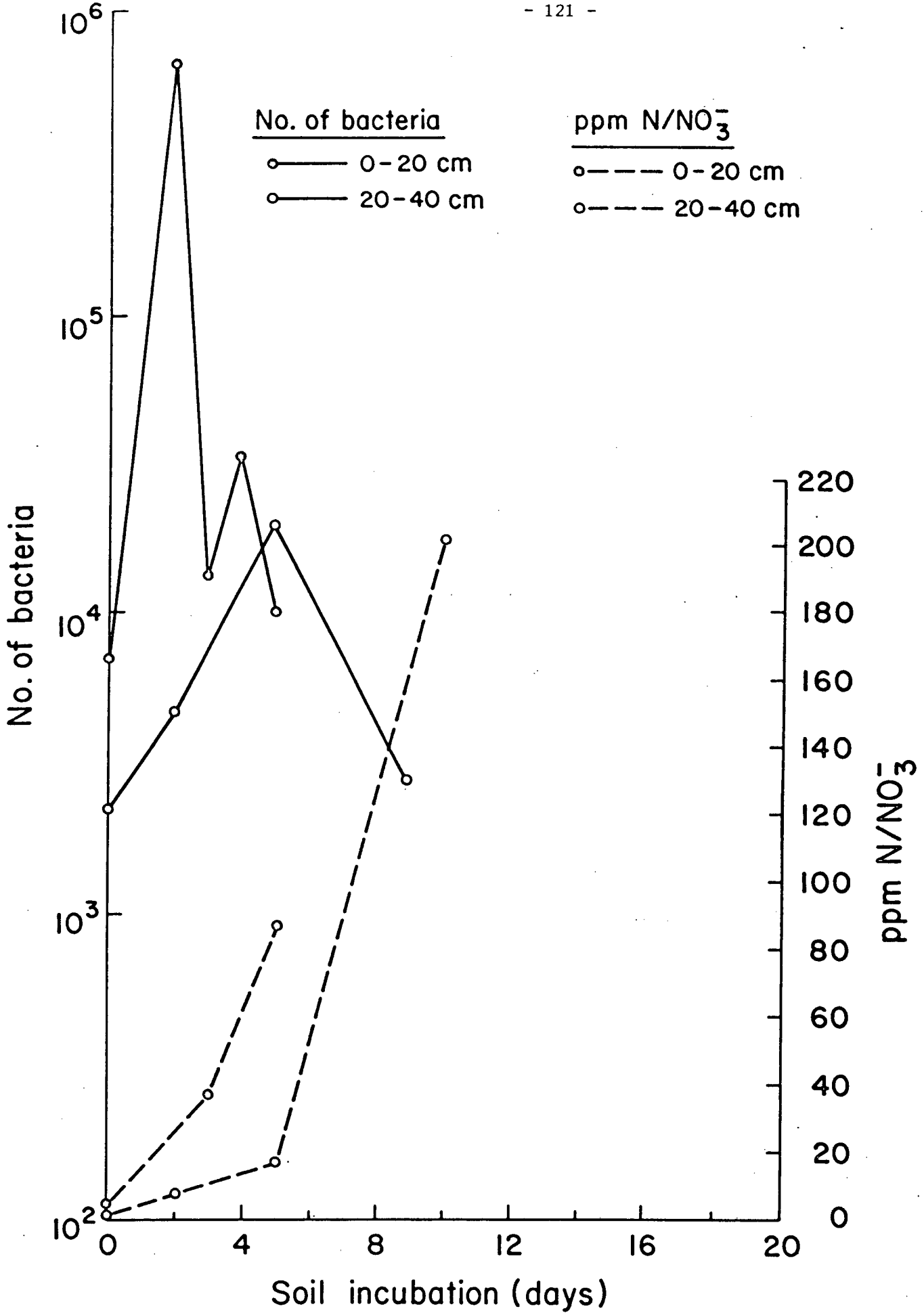


Fig 3a, 3b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Eden.

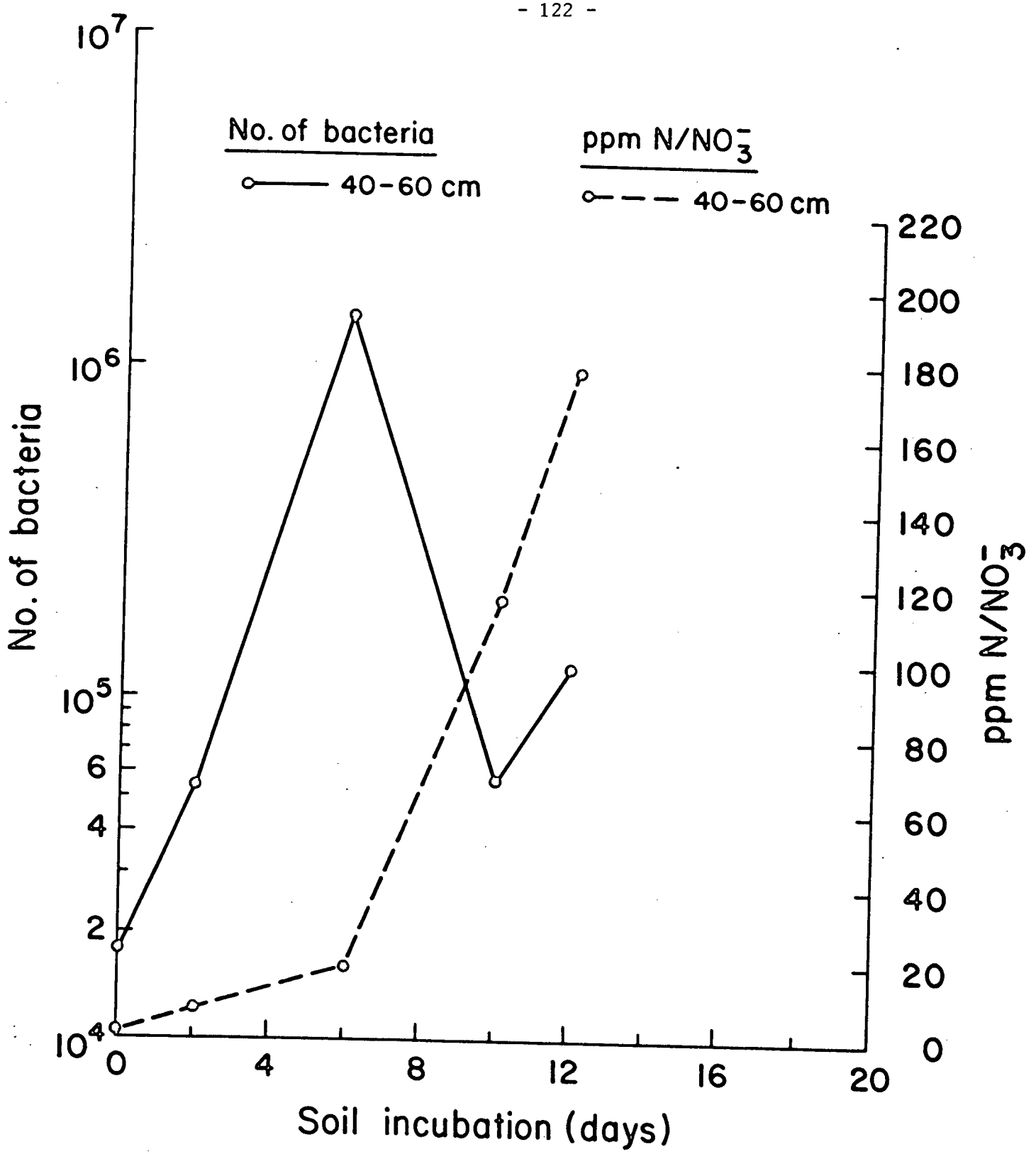


Fig 3a, 3b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Eden.

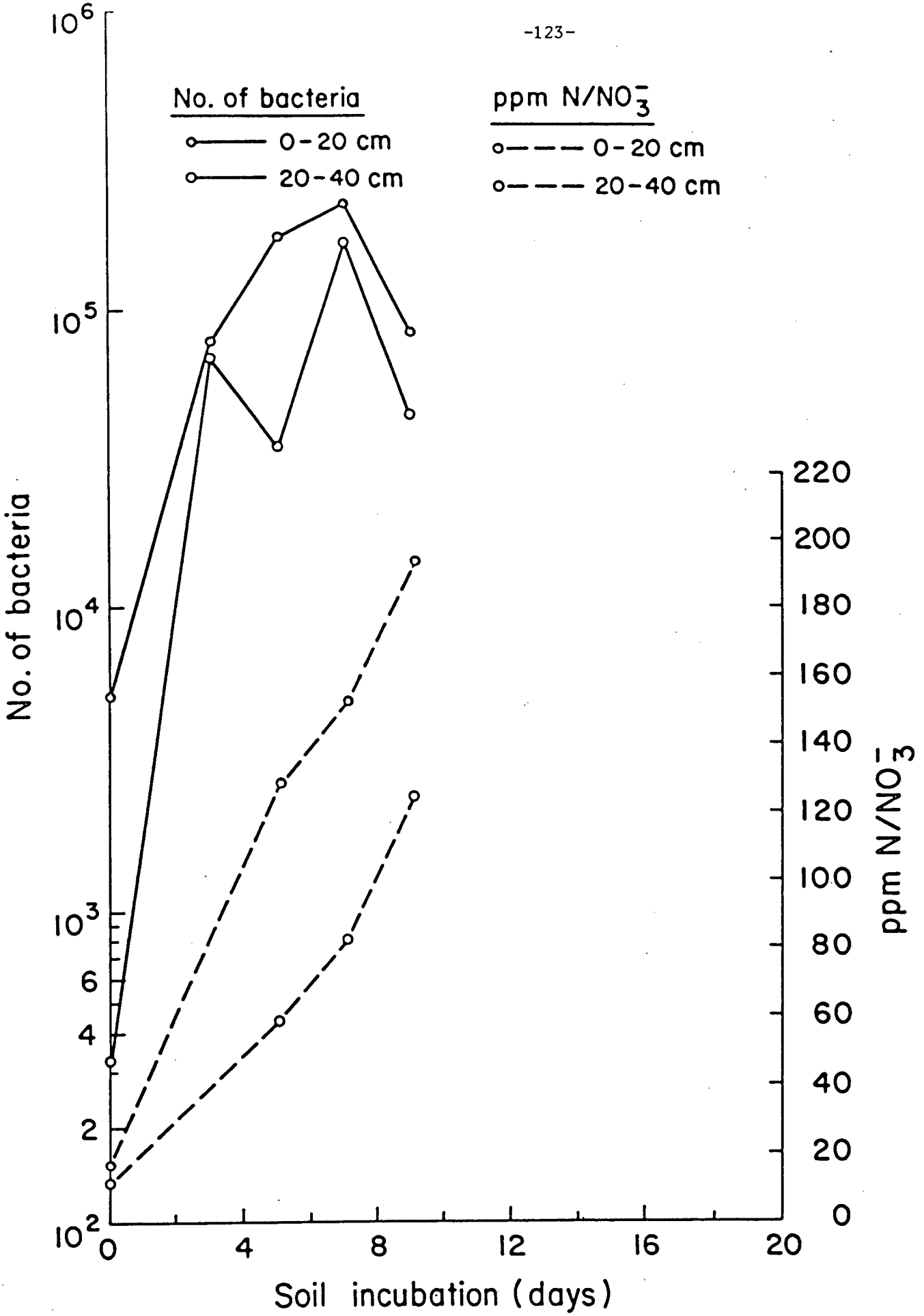


Fig 4a, 4b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Acco.

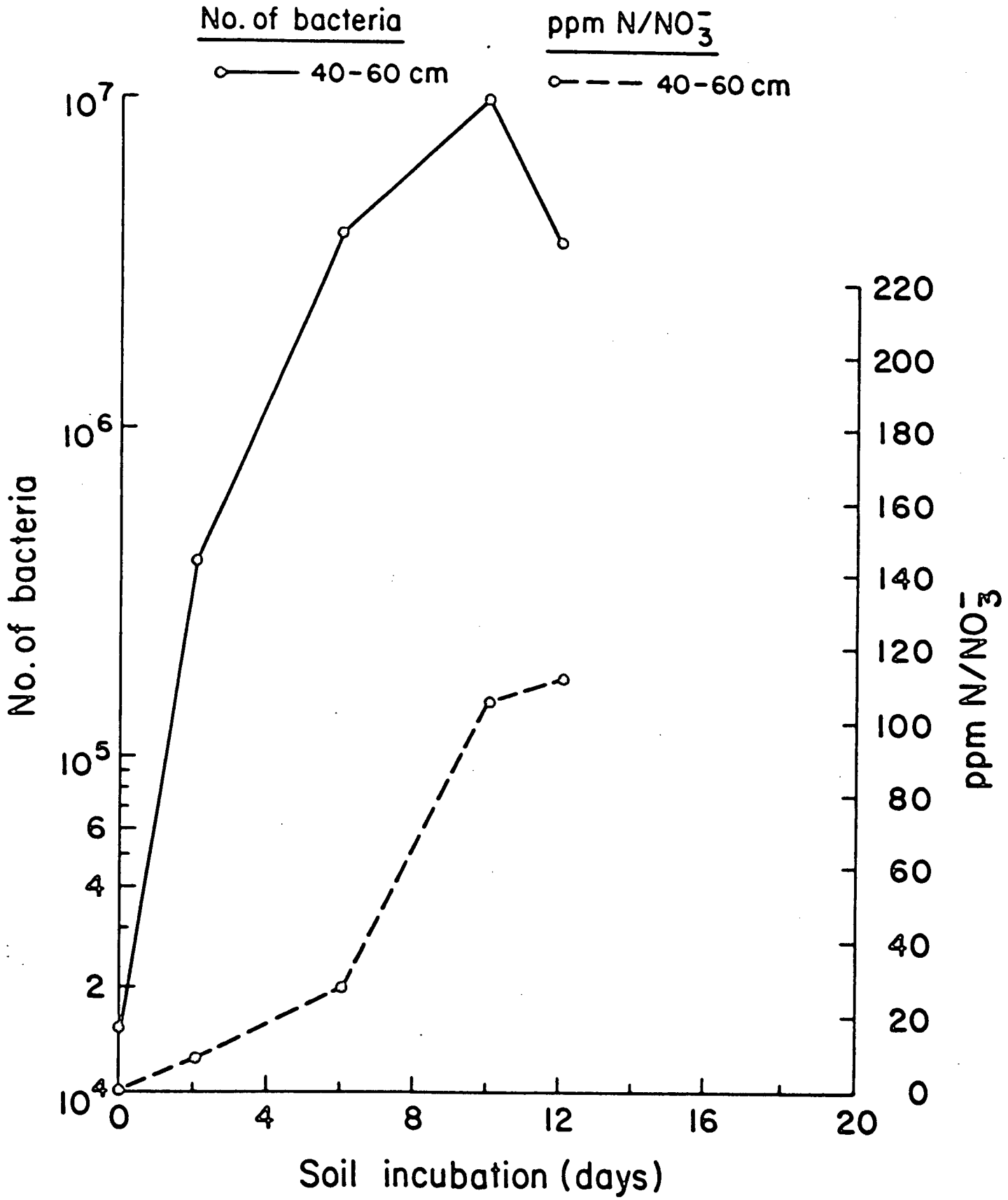


Fig 4a, 4b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Acco.

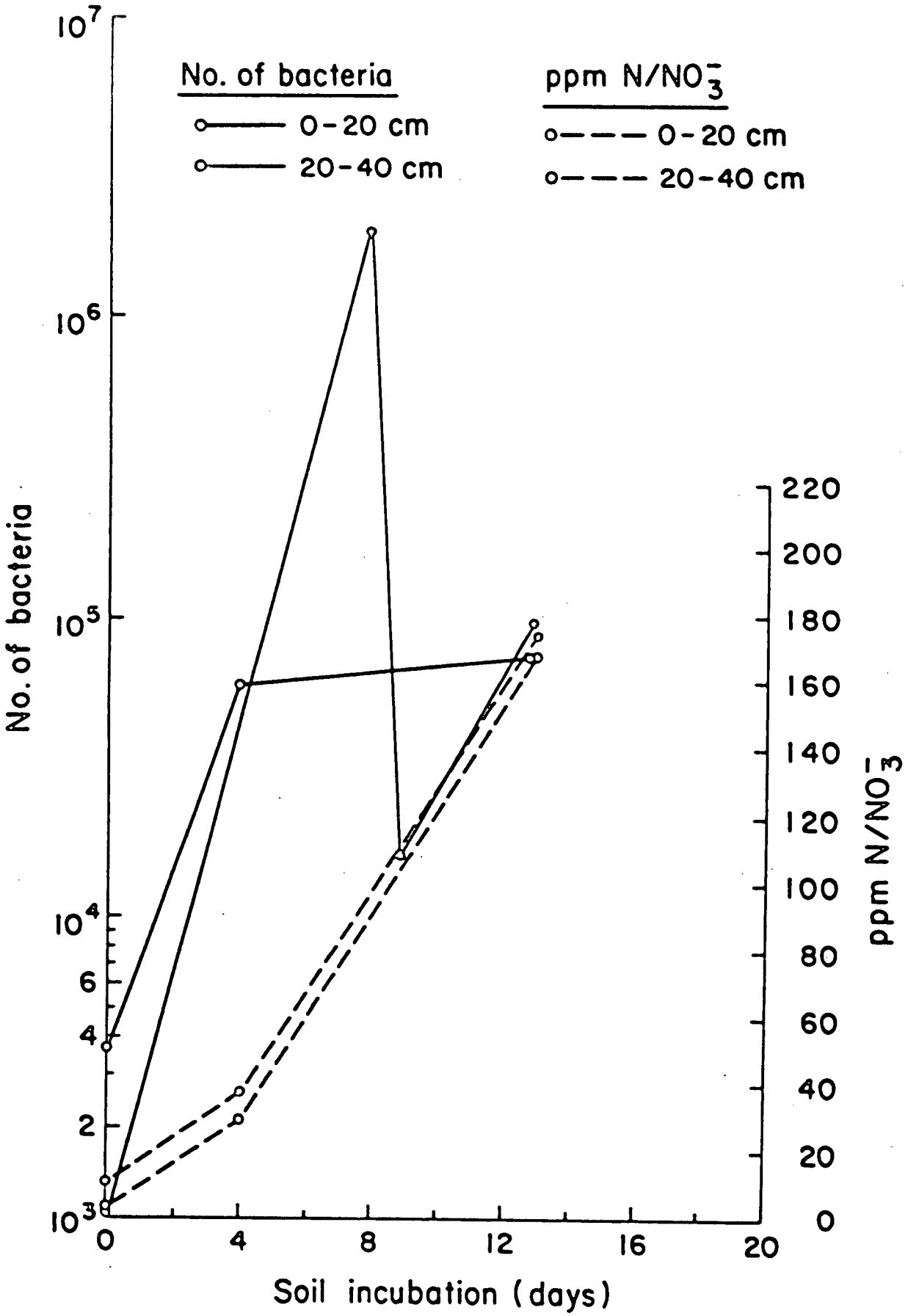


Fig 5a. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Bet Dagan N.O.

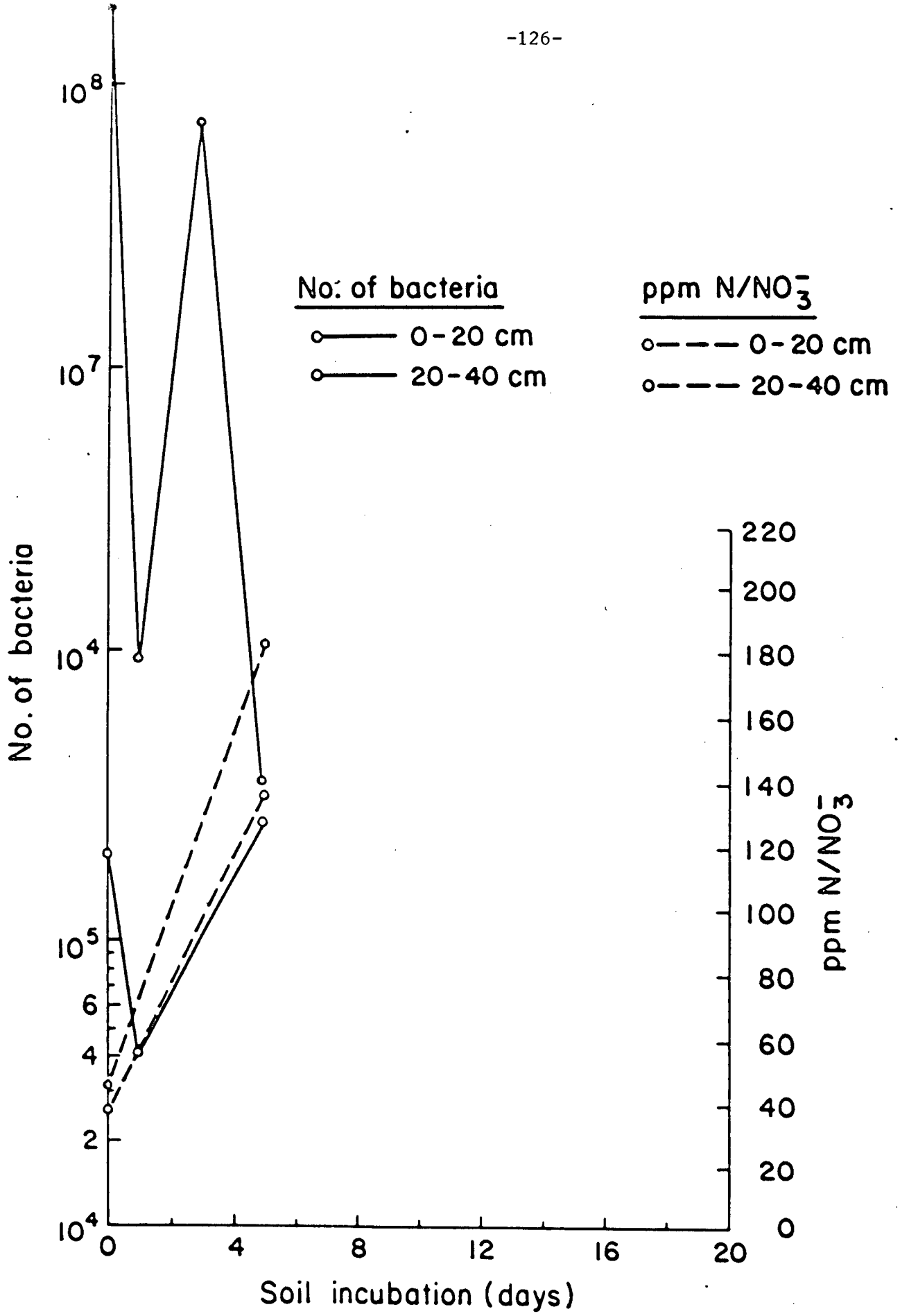


Fig 5b, 5c. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Bet Dagan N.4.

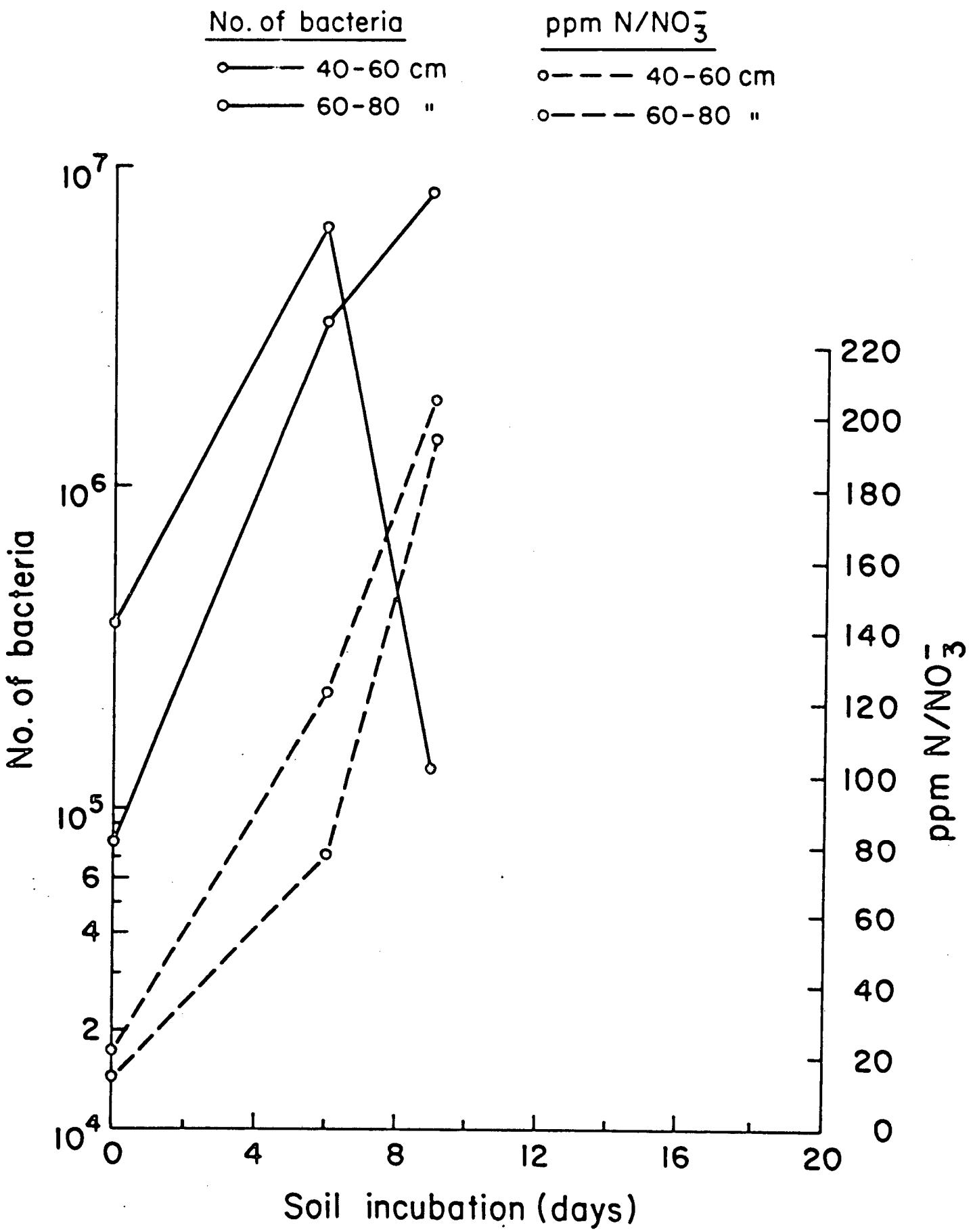


Fig 5b, 5c. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Bet Dagan N.4.

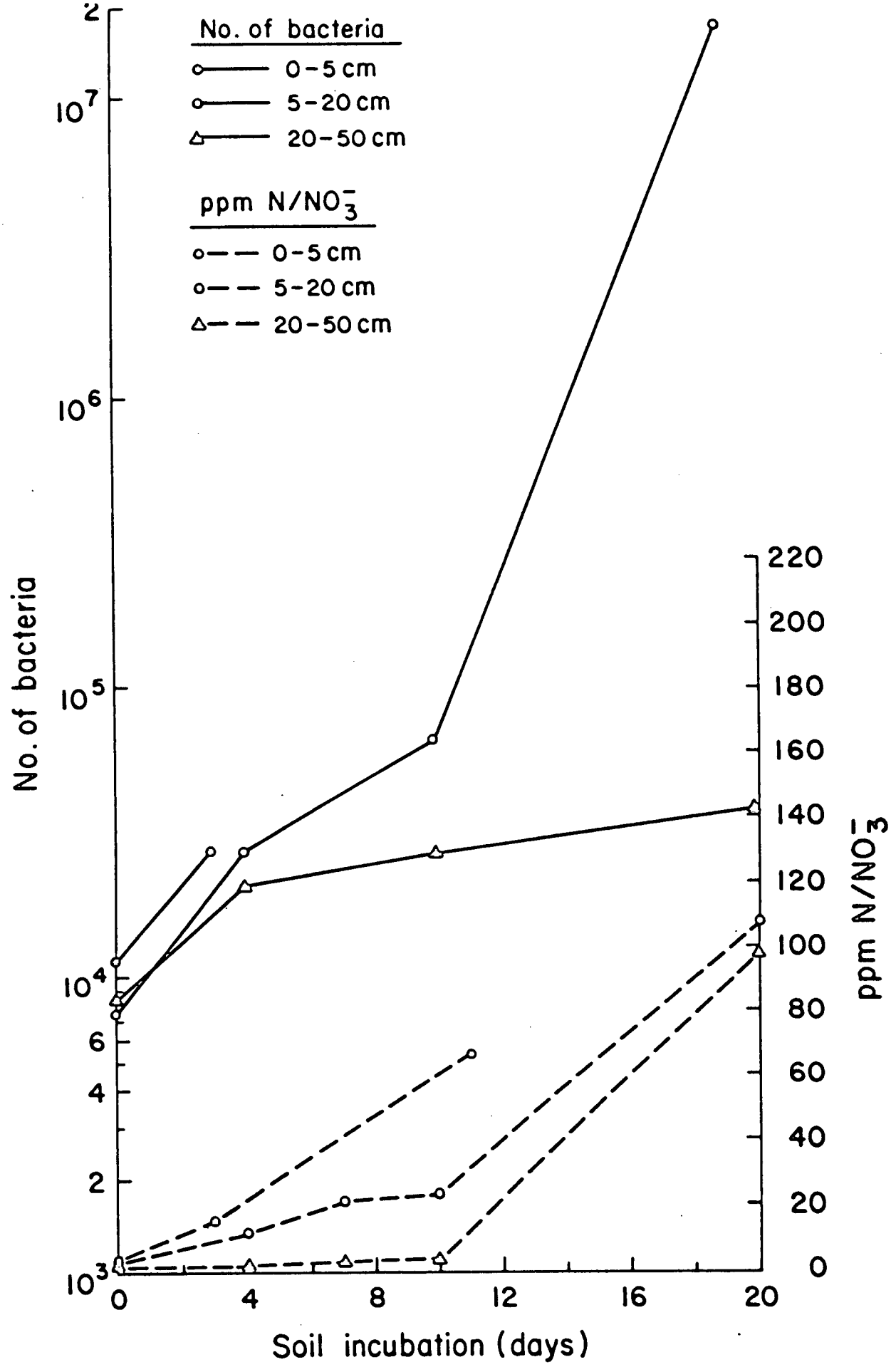


Fig. 6a, 6b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Alumim.

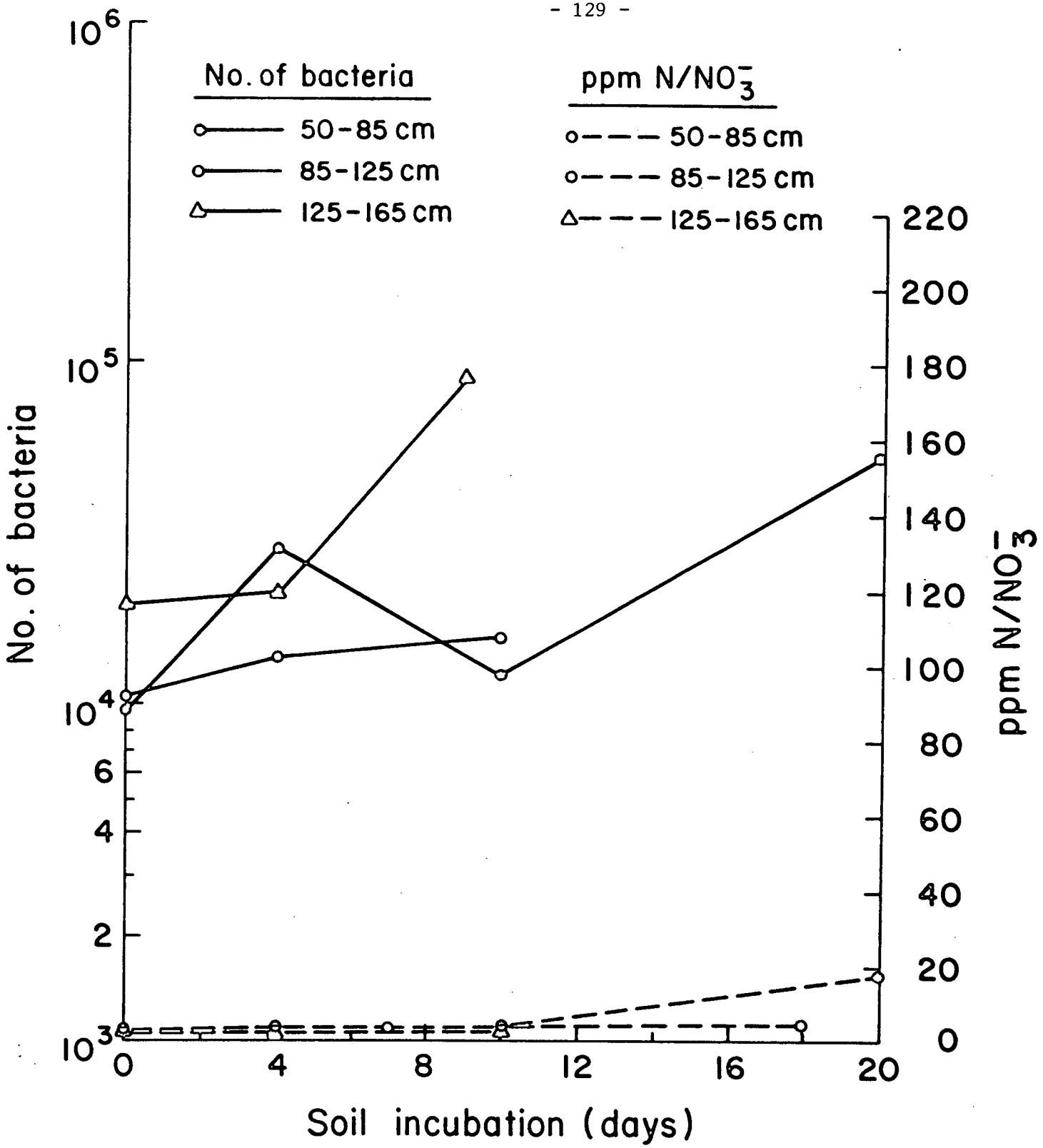


Fig. 6a, 6b. Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Alumim.

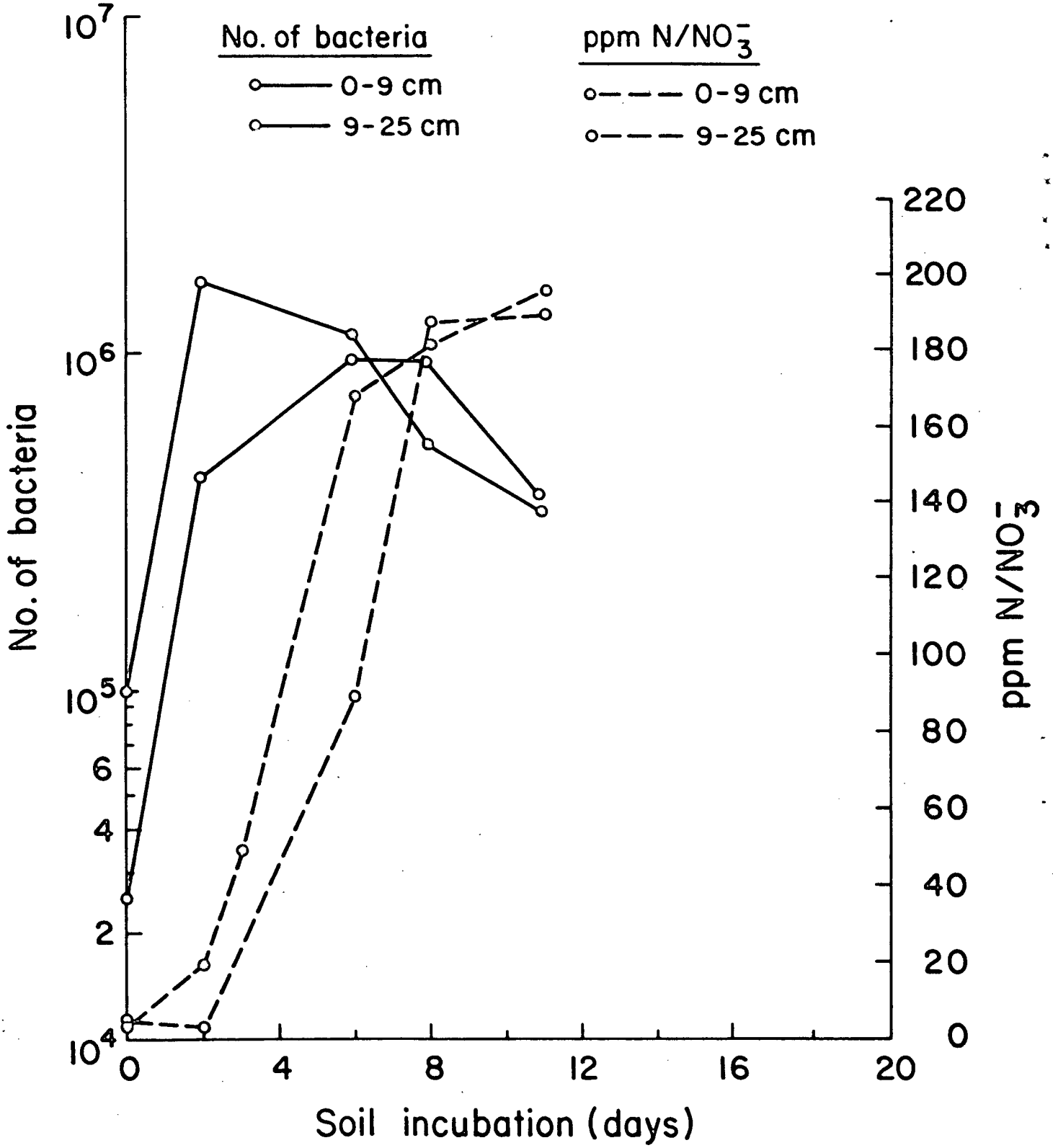


Fig. 7a, 7b. Accumulation of Nitrates and changes in nitrifying bacteria in soil profile of Kedma.

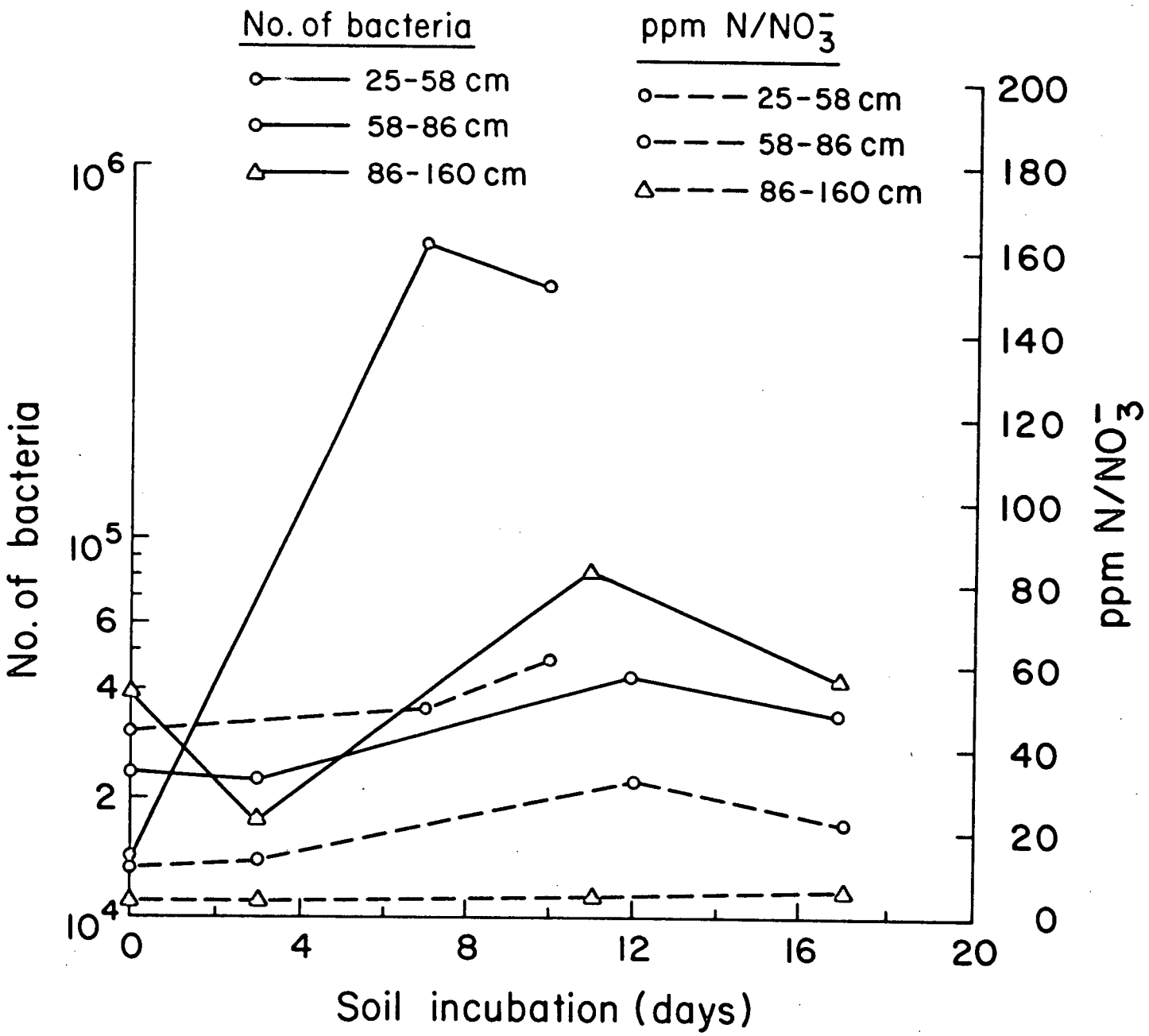


Fig. 7a, 7b. Accumulation of Nitrates and changes in nitrifying bacteria in soil profile of Kedma.

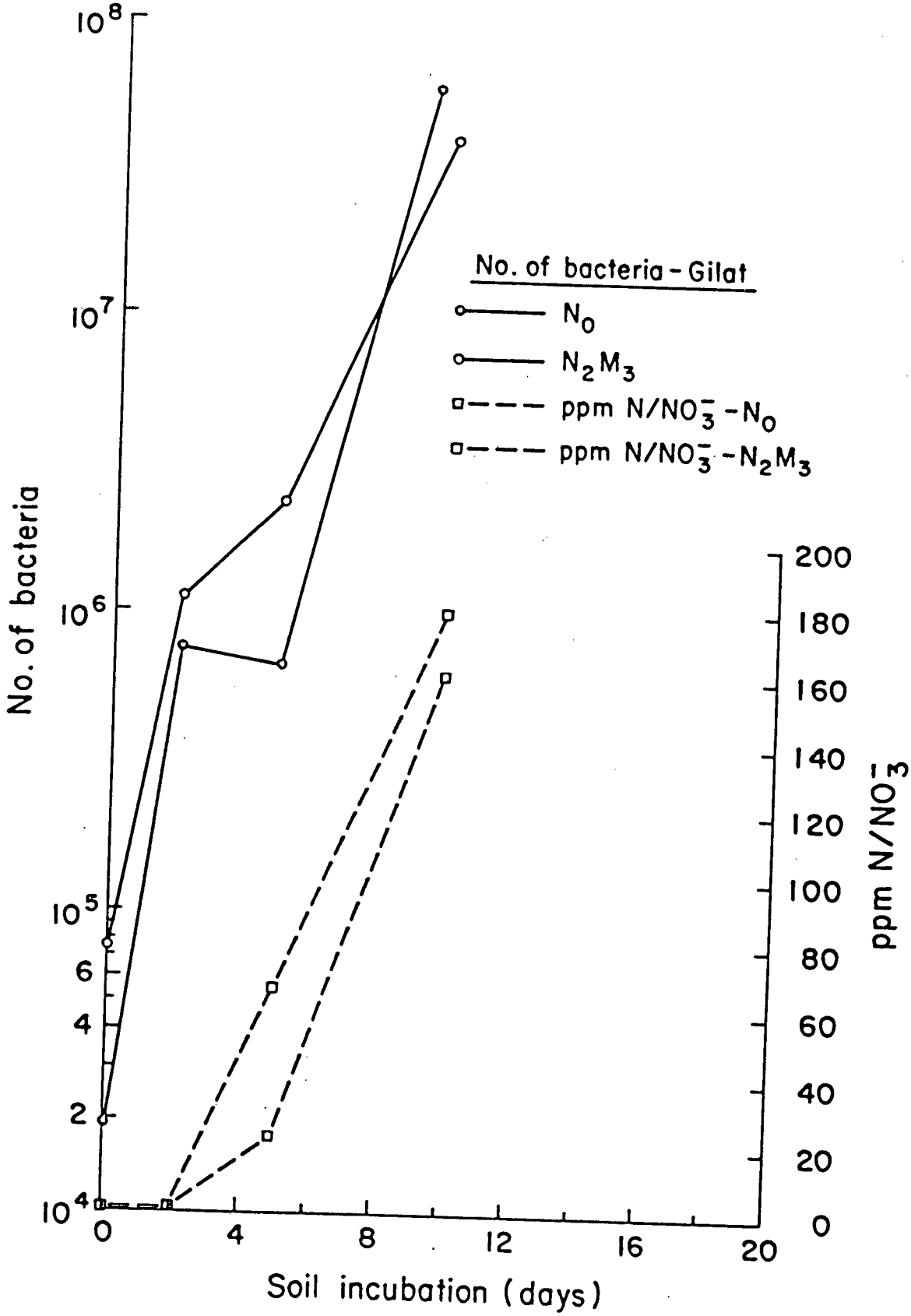


Fig. 8 Accumulation of Nitrates and changes in nitrifying bacteria population in soil profile of Gilat No, $N_2$ $M_3$.

## 3. Mineralization

### 3.1 Materials and Methods

Soil Incubation

400 g. samples from each soil profile were incubated (at 25°C, field capacity moisture). Ammonium and Nitrate content in the soil profiles were recorded.

Microflora Counts

Microflora counts were done according to plate count methods (Levanon et al 1982). The microflora counts included: total bacteria, proteolytic bacteria; fungi, actinomycetes.

$CO_2$ Production

$CO_2$ production of incubated soil samples were measured by an infra-red $CO_2$ analyzer (Siemens). 50 g soil samples were incubated in plastic columns and flushed with an air that its $CO_2$ was absorbed formally. An addition of $CO_2$ to this air (during its flow through the soil samples) was computed as production of $CO_2$ by the soil samples.

### 3.2 Results and Discussion

$CO_2$ Production

Mineralization of the soil's organic nitrogen is accompanied with mineralization of organic carbon. The production of $CO_2$ from incubated soil samples was measured and the results are presented in Table 3. $CO_2$ production was highest from the surface layers and decreased with the depth. The average $CO_2$ production was much higher during the first week of incubation than during the second week. The peak of $CO_2$ evolution from the incubated soil, is during the third-fourth days from the beginning of the incubation.

There is a connection between nitrogen mineralization rates (shown

in chapter II in this report) and $CO_2$ production of the soil profiles. In the soils where high mineralization rates were measured we found also high $CO_2$ production, especially during the first week of incubation (Table 3). Therefore $CO_2$ production of incubated soils, during the first days of incubation can be used to predict the mineralization potential of the soil. By this method a good estimation of mineralization potential of a soil sample is achieved after a few days of incubation (instead of many weeks) with a simple analysis system.

Microflora Counts

Microflora populations of the nine Israeli soil profiles before the beginning of incubation are presented in Table 4. The populations are highest close to the soil surface with gradual decrease with the depth. The average counts were $10^6$-$10^7$ bacteria and actinomycetes and $10^3$-$10^4$ fungi in a gram of air dried soil.

The population counts during incubation of soil samples are presented Table 5. The bacterial population increased to $10^7$-$10^8/g^{-1}$ soil. The amounts of proteolytic bacteria were 10%-20% of the total bacteria. The actinomycetes population increased to $10^6$-$10^7/g^{-1}$ soil. The fungal population increased to $10^4$-$10^5/g^{-1}$ soil. In Gilat soil profile at the depth of 60-120 cm where mineralization and nitrification rates were very low we found a most unusual result of 0 fungi before the incubation (Table 4) and very low amounts during incubation (Table 5). These results indicate that the low mineralization rates found in Gilat soil profile are probably due to the inhibition of the fungal population. In other soil profiles where high mineralization rates and high amounts of $CO_2$ production were found, high fungal counts were also recorded. These results indicate, that the fungal population in these nine Israeli soil profiles probably play a dominant role in both carbon

and nitrogen mineralization. Similar results were found in the study of the decomposition of the Hula peat soils in Northern Israel (Levanon et al 1982). Probably the local ecological conditions (high temperatures, low humidity) are favourable to the fungal population in the soil, rather than to bacteria.

Table 3. $CO_2$ Production, samples of soil profiles during incubation. ($\mu g/g^{-1}/h^{-1}$) average $CO_2$ evolution during a week.

| Soil Profile | 1st Week | 2nd Week |
|---|---|---|
| Golan 37 0-20 | 8.0 | 3.6 |
| " " 20-40 | 6.0 | 1.3 |
| Gilat 0-20 | 20.0 | 6.6 |
| " 20-40 | 5.0 | 1.5 |
| " 40-60 | 2.0 | 1.0 |
| " 60-80 | 1.4 | 1.0 |
| " 80-100 | 1.0 | 0.6 |
| " 100-120 | 2.0 | 1.0 |
| " 120-150 | 1.8 | 0.9 |
| Acco 0-20 | 25.0 | 9.1 |
| " 20-40 | 5.1 | 1.7 |
| " 40-60 | 4.7 | 1.6 |
| Eden 0-20 | 30.1 | 10.6 |
| " 20-40 | 6.2 | 2.2 |
| " 40-60 | 2.7 | 0.9 |
| Bet Dagan ($N_0$) 0-20 | 9.0 | 3.8 |
| " " " 20-40 | 4.3 | 1.6 |
| Bet Dagan ($N_4$) 0-20 | 10.2 | 6.8 |
| " " " 20-40 | 4.8 | 3.9 |
| " " " 40-60 | 1.2 | 1.1 |
| " " " 60-90 | 1.2 | 1.0 |
| Golan 70 0-20 | 10.0 | 6.6 |
| " " 20-37 | 4.9 | 3.7 |
| Golan 70 37-60 | 4.6 | 3.5 |

| Soil Profile | | 1st Weeks | 2nd Week |
|---|---|---|---|
| Kedma | 0-9 | 20.6 | 8.2 |
| " | 9-25 | 5.2 | 2.8 |
| " | 25-58 | 3.6 | 1.9 |
| " | 58-80 | 1.8 | 1.6 |
| " | 80-160 | 1.7 | 1.4 |
| Alumim | 0-5 | 14.0 | 10.0 |
| " | 5-20 | 7.0 | 3.1 |
| " | 20-50 | 3.5 | 1.1 |
| " | 50-85 | 1.8 | 0.9 |
| " | 85-125 | 1.6 | 0.8 |
| " | 125-165 | 1.6 | 0.7 |

Table 4. Microflora counts of samples of soil profiles.
(propagules/g$^{-1}$ soil)

| SOIL PROFILE | BACTERIA | FUNGI |
|---|---|---|
| Gilat cm 0-20 | $13.6 \times 10^6$ | $1.5 \times 10^4$ |
| " " 20-40 | $4.1 \times 10^6$ | $0.8 \times 10^4$ |
| " " 40-60 | $2.9 \times 10^6$ | $0.3 \times 10^4$ |
| " " 60-80 | $5.7 \times 10^6$ | 0 |
| " " 80-100 | $8.8 \times 10^6$ | 0 |
| " " 100-120 | $6.2 \times 10^6$ | 0 |
| " " 120-150 | $6.9 \times 10^6$ | $0.2 \times 10^4$ |
| Golan 37 cm 0-20 | $12.7 \times 10^6$ | $2.7 \times 10^4$ |
| " " " 20-40 | $14.5 \times 10^6$ | $1.6 \times 10^4$ |
| Kedma cm 0-9 | $5.1 \times 10^6$ | $0.2 \times 10^4$ |
| " " 9-25 | $5.9 \times 10^6$ | $2.4 \times 10^4$ |
| " " 25-58 | $3.2 \times 10^6$ | $0.2 \times 10^4$ |
| " " 58-86 | $11.8 \times 10^6$ | $0.05 \times 10^4$ |
| " " 86-160 | $8.3 \times 10^6$ | $0.1 \times 10^4$ |
| Alumim cm 0-5 | $10.5 \times 10^6$ | $3.9 \times 10^4$ |
| " " 5-20 | $4.2 \times 10^6$ | $0.9 \times 10^4$ |
| " " 20-50 | $2.1 \times 10^6$ | $0.2 \times 10^4$ |
| " " 0-85 | $1.6 \times 10^6$ | $0.2 \times 10^4$ |
| " " 85-125 | $4.3 \times 10^6$ | $0.9 \times 10^4$ |
| Golan cm 70 0-21 | $8.7 \times 10^6$ | $3.6 \times 10^4$ |
| " " " 21-37 | $11.2 \times 10^6$ | $1.2 \times 10^4$ |
| " " " 37-60 | $28.0 \times 10^6$ | $0.1 \times 10^4$ |
| Acco cm 0-20 | $21.7 \times 10^6$ | $5.4 \times 10^4$ |

| SOIL PROFILE | BACTERIA | FUNGI |
|---|---|---|
| Acco cm 20-40 | $3.3 \times 10^6$ | $0.7 \times 10^4$ |
| " " 40-60 | $8.3 \times 10^6$ | $0.8 \times 10^4$ |
| Eden cm 0-20 | $14.3 \times 10^6$ | $7.0 \times 10^4$ |
| " " 20-40 | $8.8 \times 10^6$ | $2.6 \times 10^4$ |
| " " 40-60 | $4.5 \times 10^6$ | $0.2 \times 10^4$ |

Table 5.

MICROFLORA COUNTS OF INCUBATED SOILS
No of Propagueles/g$^{-1}$ dry soil)

| Actinomycetes | | Fungi | | Proteolytic Bacteria | | Total Bacteria | | Soil Profile |
|---|---|---|---|---|---|---|---|---|
| 35 | 7 | 35 | 7 | 35 | 7 | 35 | 7 - Days | |
| $4.8 \times 10^6$ | $4.2 \times 10^6$ | $1.1 \times 10^4$ | $9.6 \times 10^3$ | $7.9 \times 10^6$ | $6.5 \times 10^6$ | $2.7 \times 10^7$ | $1.8 \times 10^7$ | 0-20 - Golan 37 |
| $2.5 \times 10^6$ | $2.3 \times 10^6$ | $4.3 \times 10^3$ | $1.5 \times 10^4$ | $7.3 \times 10^6$ | $5.8 \times 10^6$ | $1.4 \times 10^7$ | $1.2 \times 10^7$ | 20-40 |
| $3.1 \times 10^7$ | $1.0 \times 10^7$ | $7.1 \times 10^3$ | $6.0 \times 10^3$ | $2.0 \times 10^6$ | $8.9 \times 10^5$ | $3.0 \times 10^7$ | $2.5 \times 10^7$ | 0-20 - Gilat |
| $2.8 \times 10^7$ | $1.4 \times 10^7$ | $3.2 \times 10^3$ | $1.0 \times 10^3$ | $3.2 \times 10^6$ | $1.2 \times 10^6$ | $3.1 \times 10^7$ | $2.5 \times 10^7$ | 20-40 |
| $2.6 \times 10^6$ | $1.4 \times 10^6$ | $6.3 \times 10^3$ | $4.7 \times 10^3$ | $3.3 \times 10^6$ | $1.6 \times 10^6$ | $1.5 \times 10^7$ | $1.3 \times 10^7$ | 40-60 |
| $2.8 \times 10^6$ | $2.2 \times 10^6$ | $2.1 \times 10^1$ | 0 | $4.1 \times 10^5$ | $1.9 \times 10^5$ | $8.0 \times 10^6$ | $6.2 \times 10^6$ | 60-80 |
| $6.1 \times 10^6$ | $4.0 \times 10^6$ | $7.3 \times 10^1$ | 0 | $6.2 \times 10^6$ | $2.4 \times 10^6$ | $2.2 \times 10^7$ | $1.5 \times 10^7$ | 80-100 |
| $4.1 \times 10^6$ | $2.9 \times 10^6$ | $9.6 \times 10^2$ | $9.0 \times 10^2$ | $7.0 \times 10^5$ | $3.5 \times 10^5$ | $5.8 \times 10^6$ | $5.5 \times 10^6$ | 100-120 |
| $6.1 \times 10^6$ | $4.9 \times 10^6$ | $3.3 \times 10^3$ | $1.4 \times 10^3$ | $3.4 \times 10^6$ | $1.2 \times 10^6$ | $5.0 \times 10^6$ | $4.2 \times 10^6$ | 120-150 |
| $1.9 \times 10^7$ | $4.3 \times 10^6$ | $2.0 \times 10^4$ | $9.6 \times 10^3$ | $4.2 \times 10^6$ | $3.2 \times 10^6$ | $1.4 \times 10^7$ | $1.1 \times 10^7$ | 0-20 - Acco |
| $1.4 \times 10^7$ | $3.7 \times 10^6$ | $9.1 \times 10^3$ | $5.8 \times 10^3$ | $6.0 \times 10^6$ | $4.1 \times 10^6$ | $2.4 \times 10^7$ | $1.3 \times 10^7$ | 20-40 |
| $2.2 \times 10^7$ | $3.2 \times 10^6$ | $5.1 \times 10^3$ | $3.3 \times 10^3$ | $3.8 \times 10^6$ | $2.6 \times 10^6$ | $1.2 \times 10^7$ | $7.0 \times 10^6$ | 40-60 |
| $2.8 \times 10^7$ | $2.5 \times 10^7$ | $9.8 \times 10^4$ | $9.3 \times 10^4$ | $1.1 \times 10^6$ | $1.0 \times 10^6$ | $1.9 \times 10^7$ | $1.2 \times 10^7$ | 0-20 - Eden |
| $1.9 \times 10^7$ | $9.6 \times 10^6$ | $8.5 \times 10^4$ | $7.9 \times 10^4$ | $9.8 \times 10^5$ | $9.1 \times 10^5$ | $9.3 \times 10^6$ | $6.3 \times 10^6$ | 20-40 |
| $6.6 \times 10^6$ | $2.3 \times 10^6$ | $6.9 \times 10^3$ | $4.2 \times 10^3$ | $9.1 \times 10^5$ | $1.1 \times 10^6$ | $9.6 \times 10^6$ | $1.4 \times 10^7$ | 40-60 |
| $6.0 \times 10^6$ | $5.8 \times 10^6$ | $1.6 \times 10^4$ | $7.6 \times 10^3$ | $1.3 \times 10^6$ | $9.2 \times 10^5$ | $2.0 \times 10^7$ | $8.2 \times 10^6$ | 0-20 (N 0) - Bet Dagc |
| $7.0 \times 10^6$ | $4.6 \times 10^6$ | $1.3 \times 10^3$ | $7.9 \times 10^2$ | $1.9 \times 10^6$ | $1.2 \times 10^5$ | $8.7 \times 10^6$ | $6.7 \times 10^6$ | 20-40 |
| $5.8 \times 10^6$ | $4.9 \times 10^6$ | $4.0 \times 10^4$ | $3.7 \times 10^4$ | $1.0 \times 10^6$ | $7.7 \times 10^5$ | $1.7 \times 10^7$ | $9.8 \times 10^6$ | 0-20 (N 4) - Bet Dagc |
| $1.0 \times 10^7$ | $7.8 \times 10^6$ | $8.0 \times 10^3$ | $7.1 \times 10^3$ | $2.6 \times 10^6$ | $7.4 \times 10^5$ | $8.9 \times 10^6$ | $7.6 \times 10^6$ | 20-40 |
| $9.7 \times 10^6$ | $6.9 \times 10^6$ | $3.1 \times 10^3$ | $2.7 \times 10^3$ | $2.4 \times 10^6$ | $6.9 \times 10^5$ | $1.5 \times 10^7$ | $7.9 \times 10^6$ | 40-60 |
| $1.0 \times 10^7$ | $7.4 \times 10^6$ | $4.9 \times 10^3$ | $3.4 \times 10^3$ | $3.4 \times 10^6$ | $7.5 \times 10^5$ | $3.2 \times 10^7$ | $8.0 \times 10^6$ | 60-90 |
| $2.5 \times 10^7$ | $8.8 \times 10^6$ | $2.1 \times 10^4$ | $7.9 \times 10^3$ | $5.1 \times 10^6$ | $9.6 \times 10^5$ | $3.4 \times 10^7$ | $8.6 \times 10^6$ | 0-20 - Golan 70 |
| $2.8 \times 10^7$ | $6.9 \times 10^6$ | $1.0 \times 10^4$ | $6.8 \times 10^3$ | $3.2 \times 10^6$ | $8.8 \times 10^5$ | $2.8 \times 10^7$ | $7.7 \times 10^6$ | 20-37 |
| $2.8 \times 10^7$ | $9.1 \times 10^6$ | $1.8 \times 10^4$ | $8.2 \times 10^3$ | $3.1 \times 10^6$ | $7.6 \times 10^5$ | $2.8 \times 10^7$ | $7.4 \times 10^6$ | 37-60 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $6.2 \times 10^6$ | $4.5 \times 10^6$ | $1.9 \times 10^4$ | $1.4 \times 10^4$ | $6.2 \times 10^6$ | $2.9 \times 10^6$ | $2.7 \times 10^7$ | $2.0 \times 10^7$ | 0-9 - Kedna |
| $7.9 \times 10^6$ | $4.7 \times 10^6$ | $2.2 \times 10^4$ | $1.6 \times 10^4$ | $8.0 \times 10^5$ | $7.1 \times 10^5$ | $7.1 \times 10^6$ | $6.1 \times 10^6$ | 9-25 |
| $8.4 \times 10^6$ | $4.8 \times 10^6$ | $5.3 \times 10^3$ | $4.8 \times 10^3$ | $1.1 \times 10^6$ | $1.1 \times 10^5$ | $2.1 \times 10^7$ | $1.4 \times 10^6$ | 25-58 |
| $3.6 \times 10^6$ | $2.8 \times 10^6$ | $8.8 \times 10^3$ | $5.1 \times 10^3$ | $7.1 \times 10^5$ | $1.0 \times 10^5$ | $3.7 \times 10^6$ | $2.0 \times 10^6$ | 58-80 |
| $4.5 \times 10^6$ | $3.1 \times 10^6$ | $2.8 \times 10^3$ | $1.2 \times 10^3$ | $8.2 \times 10^5$ | $9.3 \times 10^4$ | $1.3 \times 10^7$ | $9.5 \times 10^5$ | 80-160 |
| $1.3 \times 10^7$ | $7.2 \times 10^6$ | $1.4 \times 10^5$ | $7.2 \times 10^4$ | $9.6 \times 10^5$ | $5.1 \times 10^5$ | $1.0 \times 10^7$ | $6.9 \times 10^6$ | 0-5 Alunia |
| $4.9 \times 10^6$ | $3.4 \times 10^6$ | $4.3 \times 10^3$ | $3.1 \times 10^3$ | $1.0 \times 10^6$ | $7.8 \times 10^5$ | $1.4 \times 10^7$ | $8.6 \times 10^6$ | 5-20 |
| $3.5 \times 10^6$ | $2.9 \times 10^6$ | $1.1 \times 10^3$ | $1.0 \times 10^3$ | $5.1 \times 10^5$ | $3.2 \times 10^5$ | $4.4 \times 10^6$ | $2.2 \times 10^6$ | 20-50 |
| $3.7 \times 10^6$ | $2.8 \times 10^6$ | $1.5 \times 10^3$ | $1.0 \times 10^3$ | $8.2 \times 10^5$ | $2.6 \times 10^5$ | $2.8 \times 10^7$ | $2.1 \times 10^6$ | 50-85 |
| $3.3 \times 10^6$ | $2.5 \times 10^6$ | $2.7 \times 10^4$ | $2.8 \times 10^3$ | $3.2 \times 10^5$ | $1.0 \times 10^5$ | $1.9 \times 10^6$ | $2.1 \times 10^6$ | 85-125 |
| $9.4 \times 10^6$ | $5.2 \times 10^6$ | $3.3 \times 10^4$ | $3.6 \times 10^3$ | $1.1 \times 10^5$ | $7.0 \times 10^4$ | $3.0 \times 10^6$ | $6.0 \times 10^5$ | 125-165 |

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# VI. Nitrogen Transformations and Movement Under Drip Irrigated Tomatoes

R. L. Mikkelsen, W. M. Jarrell and J. Letey

## Abstract

Tomatoes (Lycopersicon esculentum var 6718 VF Petoseed) were grown in soil columns in the greenhouse with simulated drip irrigation for 60 days. Nitrogen (urea ammonium-nitrate 32-0-0) was added with every irrigation at four concentrations (0, 50, 100, 200 mg N/L). The drip emitters were placed near the base of the plant stem on the soil surface for half of the columns and 2.5 cm below the surface for the remainder. Ammonia volatilization losses were measured and found to be less than 0.1% of the total N applied. The plants were harvested, weighed, and analyzed for total N. The soil was sampled at various distances from the emitter and analyzed for $NO^-_3$, $NH^+_4$, urea, and pH. Nitrate concentration was highest near the soil surface while $NH^+_4$ remained near the emitter. Less than 5 mg urea-N/kg soil were detected in any given sample at the conclusion of the experiment. Soil pH values as low as 5.0 were measured 5.7 cm beneath the emitter but approached the initial value (6.8) at increased distance from the emitter. The concentration of N in the plant increased with higher rates of N application regardless of emitter placement.

Achieving efficient, non-polluting use of applied fertilizers has been a major goal for agriculture. The exact fate of N fertilizers may be difficult to predict because fertilizer uptake and movement are dependent on factors such as the fertilizer form, rate, method and time of application, soil reaction, irrigation practices, as well as environmental conditions.

Drip irrigation is a relatively new method of irrigation that allows great flexibility in the distribution of water over the field. This irrigation method facilitates nutrient application to the plants with the irrigation water. The addition of fertilizers through the irrigation system can result in improved fertilizer efficiency, labor and energy savings, and flexibility in timing (Rolston et al., 1979).

Nitrogen fertilizers are commonly added to vegetable crops through drip irrigation systems in frequent applications to maintain a constant nutrient supply in the root zone. The N added to irrigation water can be derived from a variety of water-soluble sources such as ammonium sulfate, ammonium nitrate, anhydrous ammonia, urea, or mixtures of these sources such as urea ammonium nitrate.

Emitters are often buried 2 to 4 cm below the soil surface to reduce damage to the drip system due to machinery, field workers, pests, and temperature fluctuations. The effects of emitter placement on nitrogen use efficiency have received little attention thus far. In particular, the pH and the ionic composition of the soil soilution surrounding the drip emitter may be markedly different from the surrounding bulk soil solution.

A glasshouse study was underaken to determine the fate of N from surface and subsurface applied liquid UAN-32 (urea ammonium nitrate 32-0-0) added to tomatoes through a simulated dip system and to determine the influence of UAN on soil pH.

## Mateials and Methods

Hanford sandy loam (Typic Xerorthent) was air-dried, sieved through a 2 mm screen, and thoroughly mixed with 55 mg P/kg as 3 $Ca(H_3PO_4)H_2O$ (Table 1). Plexiglas columns 20 cm in diameter and 44 cm high were filled to within 3 cm of the top with 19 kg of soil. The top of each column was sealed with a fitted plexiglass lid with three evenly spaced holes in a line. Tensiometers were inserted to depths of 25 and 40 cm through the two outer holes and sealed to the lid.

Tomato seeds (Petoseed var. 6718 VP) were germinated in sand with 1/4 strength Hoaglands solution. Fourteen days after emergence one seedling was transplanted through the center hole into each column. The area around the stem was sealed with cotton and split rubber tubing and then covered with a paraffin/beeswax mixture. This sealed space above the soil surface provided an area for gas exchange. Leachate was collected from a drainage tube on the side at the base of the column. A portafor intake and exhaust of gas were placed on opposite sides of the column 1.5 cm from the top. Air above the soil surface was continually pulled from the column headspace by vacuum (300 ml/min or 1 exchange/180 sec.). The air was bubbled through an $HN_3$ trap containing 100 ml solution of 20 g $H_3BO_3$/L containing a bromcresol-methyl red indicator. The acid traps were examined daily for color change and when necessary titrated with standardized $H_2SO_4$ to quantitatively determine volatized $NH_3$.

Solution was applied to the soil columns from 1000 ml Erlenmeyer flasks hung 45 cm above each column and fitted with 2.4 mm I.D. tubing

leading to a 5 ml glass syringe with 0.356 mm O.D. hypodermic needle. The needle tip was located at the soil surface at the base of the plant for half of the columns and 2.5 cm below the soil surface for the remainder of the columns.

Nitrogen fertilizer was added with every irrigation at concentrations of 0, 50, 100, and 200 mg N/L as urea ammonium nitrate 32-0-0 (UAN-32). The UAN-32 was analyzed and found to contain 78 g $NH_3$/L, 76 g $NO^-_3$-N/L, and 164 6 urea-N/L with a pH of 7.95. Columns were irrigated as necessary to keep the tensiometer readings below 30 kPa and minimize drainage from the column. All treatments received the same amount of water. The glasshouse temperature was 25C+6. Each emitter placement was replicated four times at each level of N in a randomized block design.

The aerial portions of the plants were harvested 60 days after transplanting and fresh and oven dry weights determined. The fourth leaf and petiole were analyzed for Kjeldahl total N.

Soil samples were taken from each column at distances of 0, 4, and 8 cm radially from the emitter and at depths of 0-2, 2-7, 7-12, 12-20, 20-30, and 30-40 cm below the soil surface and immediately frozen to minimize soil moisture loss and soil activity. Ammonium and $NO_3$ were extracted with 2M KCl and analyzed colimetrically with a Technichon Autoanalyzer using an ascorbic acid assay. Residual urea was analyzed in the soil from the 200 mg N/l treatments using the modified diacetyl monoxime method (Mulvaney and Bremner, 1979). Urea concentrations were less than 5 mg N/kg for all treatments and therefore were not included in calculations. Soil pH was measured in a 1:1 soil and 0.01 M $CaCl_2$ solution.

## Results and Discussion

The quantity of $NH_3$ volatilized was found to be related to both the emitter placement and the concentration of N applied (Table 2). At each N rate the above-ground application lost greater amounts of $HN_3$ through volatilization than the below-ground treatments, although in no case did the cumulative losses exceed 0.1% of total applied N. This observation is consistent with the findings of Cummings et al. (1958) who found that $NH_3$ volatilization losses did not exceed 0.032% of the total N applied to the soil surface as a 2.5% solution of UAN 32.

The placement of the N below the soil surface resulted in smaller $NH_3$ losses. Ernst and Massey (1960) found that a large decrease in $NH_3$ volatilization occurred upon mixing urea with the upper 3.5 cm of soil compared with surface application. Fenn and Kissel reported that volatilization of $NH_3$ from $NH_4$-N based fertilizers was greatly dependent on the depth of placement (Fenn and Kissel, 1976) as well as the rate of application (Fenn and Kissel, 1974). Ammonia volatilization losses as high as 10.5% of the total applied N were found from bare surface applications of undiluted UAN 32 (Meyer et al. 1961).

The amount of volatilized $NH_3$ collected in the acid tap is often related to the air flow rate through the gas exchange chamber. Overrein and Moe (1967) reported that where both the gas exchange chamber and the soil atmosphere were continually renewed, the $NH_3$ volatilization rate was linearly related to the gas exchange rate. Vlek and Stumpe (1978) found a curvilinear relationship between $NH_3$ loss and the air exchange rate of 3.5 to 5 renewal volumes per minute was sufficient for

maximum removal of $NH_3$. Other researchers using similar methods have failed to report the rate of air exchange in the containers (Ernst and Massey, 1960; Meyer et al., 1961). Due to the relatively low rate of exchange used in this experiment, the total amounts of $NH_3$ volatilized may be less than if a higher air exchange rate had been used, due to readsorption of $NH_3$ gas by the soil.

There was no significant difference in dry weight among the treatment (Table 3). However, at any given N concentration, the emitter below-ground consistently produced a smaller plant than the corresponding above-ground placement at the 100 and 200 mg N/L level. The concentration of N in the petioles increased with increasing concentrations of N in the irrigation water.

The application of fertilizer through buried drip irrigation sytems may be throught of as a dynamic, controllable fertilizer band or point source. Since water and solutes move in a three dimensional pattern from the emitter, the pH and the ionic composition of the soil surrounding the point source differ from the surrounding bulk soil. The N distribution at the conclusion of the experiment was related to the form of N applied, ion mobility, and the associated microbiological transformations. Because these data were collected at a single point in time, five days after the final irrigation, the dynamics of N transformation-urea hydrolysis, nitrification, leaching, $NH_3$ volatilizaiton, and denitrification cannot be quantitatively determined.

Nitrate was found throughout the profile with especially high concentrations in the upper 7 cm (Fig. 1). Nitrate moved freely with the irrigation water from the emitter (Goldberg et al., 1971) and

undoubtedly accumulated near the soil surface as water was lost through evaporation (Luckhardt, 1983).

Ammonium accumulation in the soil varied both with the rate of application and with the location of the emitter (Fig. 2). The $NH_4$ concentration was greatest surrounding the emitter due to its relatively low mobility in the soil. Only small amounts of urea were detected at the time of sampling, again confirming the common finding that urea is rapidly hydrolyzed under favorable soil conditions (Broadbent et al., 1958; Bauder et al., 1980).

Soil pH varied with distance from the emitter, with the degree of soil acidification dependent on the rate of N application and emitter placement (Fig. 3). For the 200 mg N/L treatments, the soil pH was depressed as much as 1.7 units below that of the control columns. Lowest pH values in all treatments were 5-7 cm beneath the emitter. Because of the relatively coarse sampling grid, pH changes over short distances near the emitter could not be measured.

Microbial N transformations in the soil can greatly influence soil pH (Wolcott et al., 1965). Upon hydrolysis of urea to ammonia, the pH of the soil may be increased above 9 in the region surrounding the point of application (Doak, 1952). The potential for $NH_3$ volatilization loss increases with increasing soil pH (Ernst and Massey, 1960) as the chemical equilibrium shifts to favor $NH_3$ over $NH_4^+$ (duPlessis and Kroontje, 1964). DuPlessis and Kroontje (1964) found that $NH_3$ losses incresed with increasing soil pH over a range of pH 4.5 to 7.1. In the case of UAN 32, both the initial $NH_4$ and the $NH_4$ formed as a result of urea hydrolysis are subsequently nitrified. During nitrification, hydrogen ions are released which lowers soil pH (Alexander, 1977). Thus, the

decreased pH near the emitter reduced the potential for $NH_3$ volatilization losses.

Morrill and Dawson (1967) found that pH was the single best indicator of the nitrification potential of a soil. The conversion of $NH_4$ to $NO_3$ has been generally assumed to occur most rapidly in the range of pH 5.5-10 (Martin and Focht, 1977) although nitrification will proceed slowly at soil pH values below 5 (Wolcott et al., 1965; Dancer et al., 1973). Although not directly measured in this experiment, nitrification rates may be lower where the soil pH is substantially depressed around the emitter.

Drip irrigation encourages the development of a relatively shallow root systm (Goldberg et al. 1971; Earl and Jury, 1977). In this experiment, the greatest depression of soil pH occurred in the surface 10 cm beneath the emitter. Arnon and Johnson (1942) found in solution cultures that tomatoe plants produced maximum growth between pH 5 to 7, while Islam et al. (1980) reported a pH optimum between pH 7 and 9. Although it is difficult to determine the optimal pH for plant growth, this factor needs to be considered when adding acid-forming fertilizers at a point source. In addition, the rhizosphere pH has been reported to be a better indicator of nutrient availability and biological activity near the root zone than the bulk soil pH (Smiley, 1974). Smiley, 1974) found that the rhizosphere pH may vary as much as 1.2 units from the bulk soil pH depending on the source of N fertilizer decreasing with $NH_4$ and increasing with $NO_3$ nutrition (Raven and Smith, 1976).

Because the majority of the root zone is located in the region surrounding or below the emitter, acid-producing fertilizers should be applied with caution in drip irrigation systems (Goldberg et al., 1971).

The effect of the soil pH depression surrounding the emitter may be even more pronounced at higher N concentrations, in acidic soils, and in soils with low pH buffering capacity. The increase in soil acidity may influence the solubility and availability of plant micronutrients in the soil (Wallace and Mueller, 1978). In particular, acidification of calcareous soils has been found to cause greater P solubility and increased micronutrient uptake, resulting in increased plant growth (Ryan and Stroehlein, 1979). Further work is presently being conducted on soil acidification under drip irrigation emitters.

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Table 1. Physical and chemical characteristics of Hanford sandy loam.

| Ca | Mg | K | Na | CEC (NH4HCO3) |
|---|---|---|---|---|
| ---------- mmol/kg ---------- | | | | |
| 63 | 10 | 5 | 12 | 90 |

| clay | Organic-C | NO3-N | NH4-N |
|---|---|---|---|
| % | % | ---- mg/kg ---- | |
| 6.3 | 0.91 | 7.2 | 4.3 |

Table 2. Average Total NH3-N losses as affected by N solution concentration in irrigation water and emitter placement.

| Treatment | | Total N volatilized | % of applied N volatilized |
|---|---|---|---|
| mg N/L | | (ug N/column) | |
| 0 | A | 0 | 0 |
| 0 | B | 0 | 0 |
| 50 | A | 205 ± 117 | 0.096 |
| 50 | B | 0 | 0 |
| 100 | A | 180 ± 104 | 0.042 |
| 100 | B | 162 ± 20 | 0.038 |
| 200 | A | 613 ± 296 | 0.072 |
| 200 | B | 74 ± 53 | 0.009 |

A=Above-ground emitter placement

B=Below-ground emitter placement

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

Table 3. Effects of emitter placement and N fertilization rate on dry matter production and N accumulation.

| Treatment concentration mgN/L | | Dry weight g/plant | Petiole N g N/kg | |
|---|---|---|---|---|
| 0 | A | 15.6 ± 1.1 | 25.0 | DC |
| 0 | B | 14.9 ± 1.0 | 20.3 | D |
| 50 | A | 15.9 ± 2.5 | 34.0 | CB |
| 50 | B | 15.7 ± 2.2 | 33.5 | CB |
| 100 | A | 17.1 ± 1.1 | 39.5 | BA |
| 100 | B | 16.2 ± 1.8 | 40.7 | BA |
| 200 | A | 17.8 ± 1.6 | 42.6 | BA |
| 200 | B | 14.5 ± 1.7 | 49.2 | A |

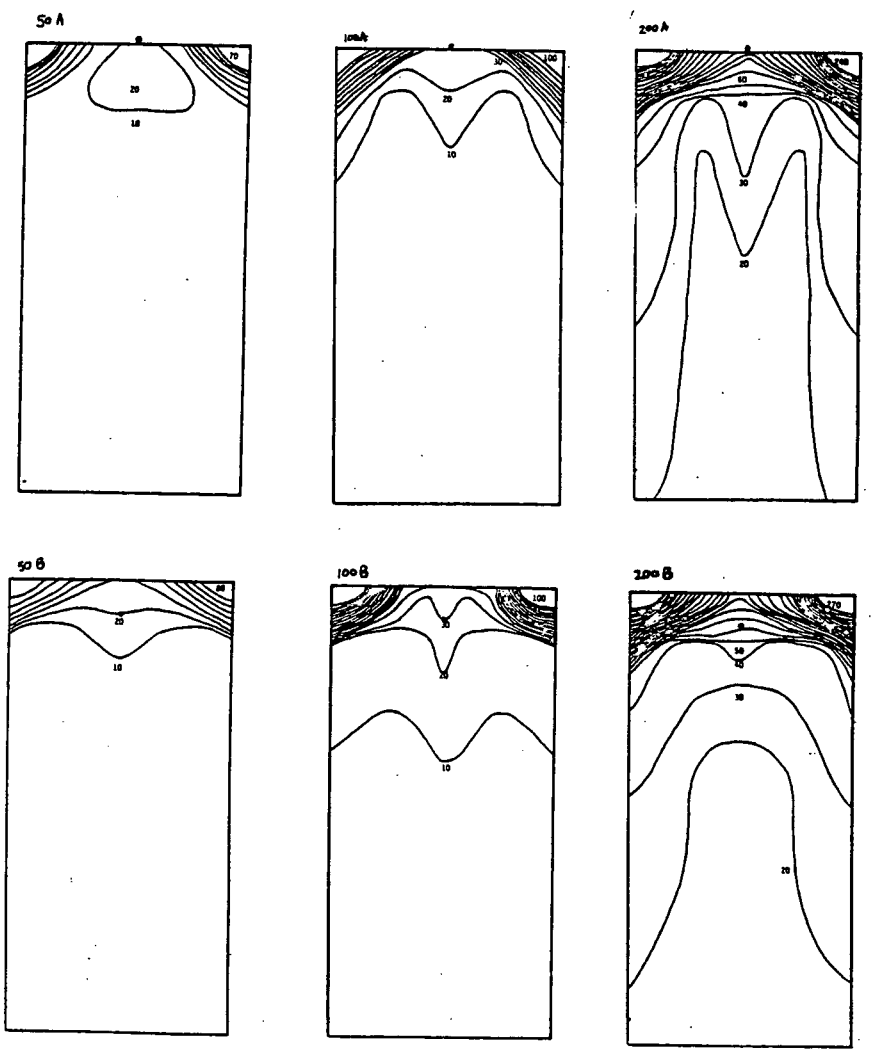
may need to go into text.

A=Above-ground emitter placement

B=Below-ground emitter placement

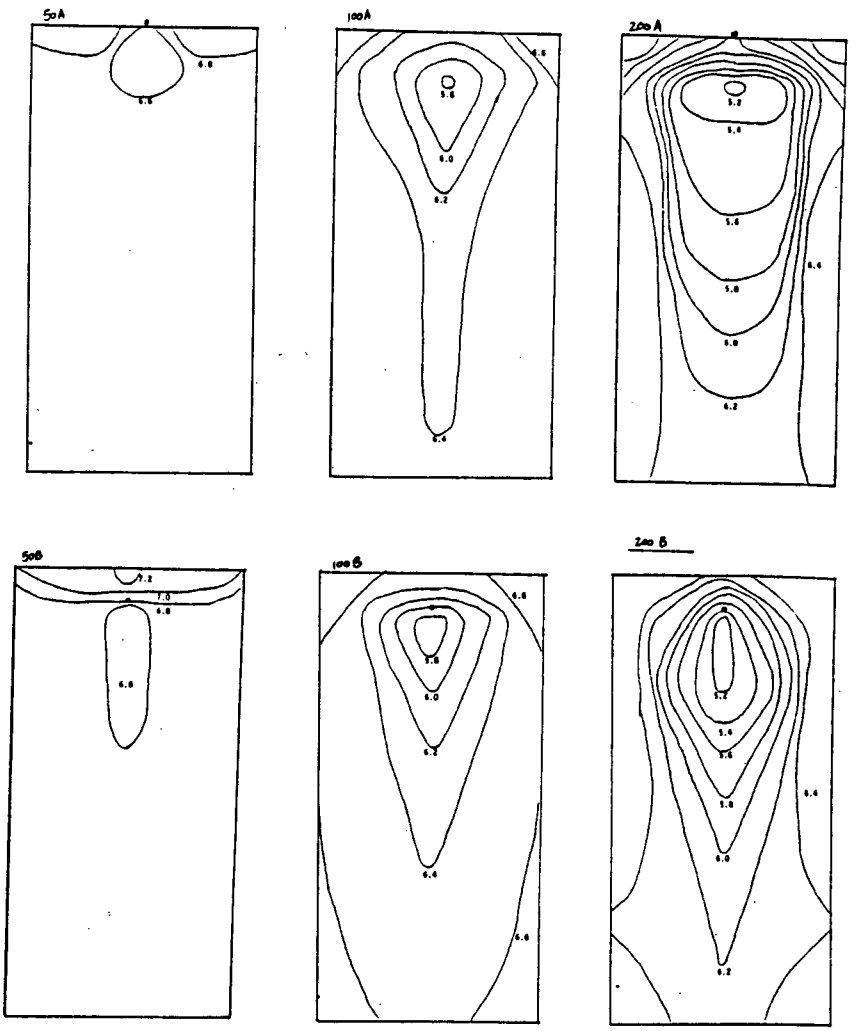
Means followed with the same letter are not significantly different at the 1% level (Duncan's Multiple Range Test)

Fig. 1 Final $NO_3$-N distribution as influenced by N application rate and position of emitter.




Lines spaced in incrments of 10 mg $NH_4$-N/kg

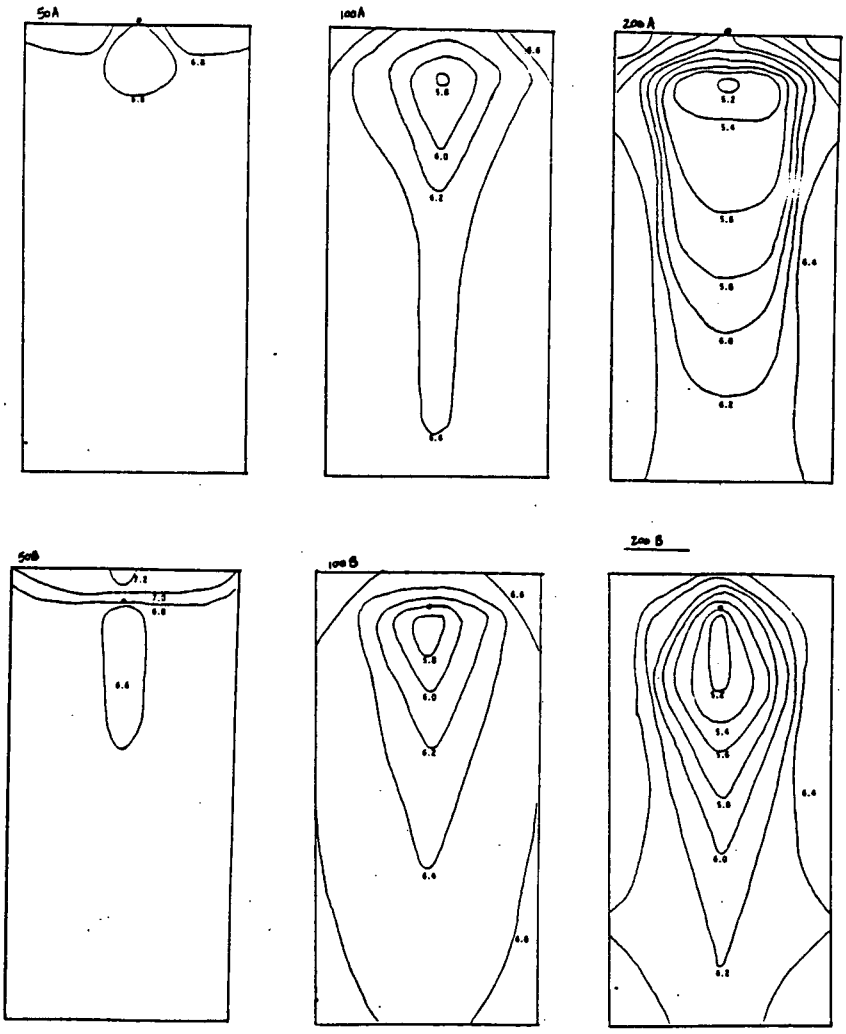
Fig. 2 Final $NH_4$-N distribution as influenced by N application rate and position of emitter.




Lines spaced in increments of 10 mg $NH_4$-N/kg

·= emitter

Fig. 3 Final pH distribution as influenced by N application rate and position of emitter



Lines spaced in increments of 0.2 pH

· = emitter

# VII. EFFECT OF TERRAZOLE ON NITROGEN TRANSFORMATIONS AND MOVEMENT

R. L. Mikkelsen, W. M. Jarrell, J. Letey, and S. Whaley

## ABSTRACT

A field study was conducted on two sandy loam soils to determine the effect of Terrazole nitrification inhibitor (5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole) on N movement and transformations. Sweet corn (Zea mays L.) was fertilized with $(NH_4)_2SO_4$ twice during the season for a total application of 250 kg N/ha. The N applied to half of the fertilized treatments was coated with Terrazole. Three levels of irrigation were established for each field. The treatments on Arlington sandy loam received 55.9, 69.0, and 78.1 cm infiltrated water. The Hanford sandy loam treatments received 62.0, 76.7, and 88.2 cm infiltrated water. Soil samples were taken throughout the season and analyzed for $NO_3$ and $NH_4$. Movement of N was correlated with both the presence of Terrazole and the quantity of water applied. Soil $NH_4$ was consistently higher in Terrazole treatments, suggesting that nitrification was reduced by the Terrazole. However, there was no significant increase in N tissue concentrations or yield due to Terrazole additions. Denitrification losses were measured and found to be reduced 64% due to the presence of Terrazole.

Interest in efficient use of N has increased as environmental concerns and fertilizer prices continue to rise. Although $NH_4$ added to the soil is held by the cation exchange complex, it generally converted quickly to nitrite and then nitrate. Under natural conditions the proportion of N found in the soil as $NH_4$, $NO_2$ and $NO_3$ is determined by the factors affecting the rate of nitrification (Focht and Verstraete, 1977). In the oxidized form, N is subject to leaching and denitrification.

Leaching can cause large losses of N as $NO_3$ moves below the root zone with percolating water (Letey et al., 1978). Nitrate leaching results in low N use efficiency, an economic loss of an essential plant nutrient, and waste of a valuable resource. In addition, $NO_3$ can accumulate in groundwater and become a potential water pollutant and environmental hazard (Timmons and Dylla, 1981).

There has been considerable interest recently in the use of nitrification inhibitors (NI) as a means of prolonging the presence of applied ammoniacal fertilizers in the root zone. Several nitrification inhibitors are presently available commercially as soil additives to maintain the $NH_4$ form of N (Huber et al., 1977). Nitrapyrin (2-chloro-6-(trichloromethyl)pyridine) in particular has been the subject of extensive research. The effects of nitrapyrin on corn yield have been highly variable, with reports ranging from large yield increases (Warren et al., 1975) to no effect on yield (Hendrickson et al., 1978). The lack of yield response may result from ineffective inhibition of nitrification or the lack of substantial leaching (Chancy and Kamprath, 1982).

# VII. EFFECT OF TERRAZOLE ON NITROGEN TRANSFORMATIONS AND MOVEMENT

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Nitrification inhibitors other than nitrapyrin have received much less attention, and require study to determine their effectiveness in slowing N transformations in the field. One such inhibitor is Terrazole, also known as Ethazole, which was originally developed as a fungicide for control of pythium and phytophthora (Sijpesteijn, 1977). It was found that Terrazole also inhibits ammonia oxidation and was suitable as an agricultural nitrification inhibitor (Hauck, 1980). This experiment was designed to study soil N transformations and monitor N movement as influenced by water application rate and Terrazole nitrification inhibitor.

## MATERIALS AND METHODS

Sweet corn (Zea mays L., var. B. Jubilee) was planted in 1982 in two soils on the Agricultural Experiment Station of the University of California, Riverside. The two soil types were Hanford sandy loam (Typic Xerorthent) and Arlington sandy loam (Typic Durixeralf) which has a weakly cemented pan at depths ranging from 90 to 150 cm. Important properties of the surface soils are shown in Table 1.

Seven treatments consisting of four rows replicated three times in each field received banded nitrogen on both sides of the seedbed at planting as $(NH_4)_2SO_4$ at a rate of 125 kg N/ha except for the control treatment. Each field was approximately 29 m long with rows spaced on 76 cm centers. The N applied to half of the fertilized treatments was coated with nitrification inhibitor (NI) DWELL 4E, also known as Terrazole (5-ethoxy-3-(trichloromethyl-1,2,4-thiadiazole; Olin Corp., Little Rock, Ark.) in a cement mixer immediately prior to application

at a concentration of 418 mL/100 kg $(NH_4)_2SO_4$ (2.3 L NI/ha). The N application was repeated 45 days after planting (DAP) In addition, all treatments received a uniform application of P (27 kg P/ha as $3Ca(H_2PO_4)_2$) at the time of the second N application.

To accurately determine the amount of water applied to each field, the irrigation for each treatment was individually regulated so that flow rates were controlled and measured for each furrow. Water run-off for each field was directed throuh a Repogle flume and measured using an automatic water-level stage recorder. Three levels of irrigation were established for each field. Each level of water was applied to a treatment with NI and a treatment without NI. The unfertilized control received the intermediate water level. Irrigation was scheduled to maintain tensiometer readings at >30 KPa for the low water treatment.

Field measurements of denitrification were taken for the period of 48-63 DAP using the acetylene inhibition method (Ryden et al., 1979). Denitrification was only measured on one replication of the treatment receiving the high water level on the Arlington sandy loam. Steel sampling boxes were centered over the fertilizer band, extending from the plant row out into the furrow.

Soil samples were taken from each treatment at 0, 20, 40, 60, 80 DAP and immediately after harvest. Samples were obtained 0, 9, 18, 28, and 36 cm from the center of the bed at depth increments of 0-15, 15-30, 30-45, and 45-60 cm. The final sampling also included samples from 60-75 and 75-90 cm depths at each location.

The soil samples were air-dried, mixed and analyzed for $NO_3$-N and $NH_4$-N KCl extracts on a Technicon AutoAnalyzer.

Leaf tissue samples were taken 38 and 70 DAP and analyzed for total-N using Kjeldahl digestion and steam distillation. Plants were harvested 90 DAP on Arlington sandy loam and 93 DAP on the Hanford sandy loam. Total N, fresh weight, and dry weight of the ears and stalks were determined from a subsample of 6 meters of 2 rows harvested from the center of each replication.

## RESULTS AND DISCUSSION

The irrigation water added to each field succeeded in establishing three distinct levels of water management (Fig. 1). Since $NO_3$ leaching and denitrification are intimately related with soil water (Smika and Watts, 1978; Firestone, 1982), the three irrigation levels allowed evaluation of NI effectiveness under different water regimes.

All fertilized treatments were significantly different ($P < .05$) from the controls in concentrations of N and total N accumulation in both ears and stover (Table 2). In addition, the controls yielded significantly less ($P < .05$) in dry weight of ears and stover than the fertilized treatments (Table 3). However, the fertilized treatments did not vary significantly from one another in these measurements. Because of this, plant N uptake from the soil was considered to be equal for all the treatments receiving N. Therefore, all differences found in N transformations and movement were assumed to be independent of crop removal for the fertilized treatments.

Terrazole was effective in suppressing nitrification and prolonging the presence of $NH_4$ in the soil. The treatments with NI generally resulted in both higher concentrations of $NH_4$ in the soil surrounding

the fertilizer band as well as reduced downward movement of $NO_3$ through the profile. Helling et al. (1974) reported that Terrazole is quite immobile in a silty clay loam soil. It is likely therefore in the experiment reported here that the NI remained in intimate contact with the applied fertilizer and was able to inhibit nitrification for a longer period than if it were quickly leached. Higher irrigation rates, however, appeared to hasten the leaching of the soil $NO_3$.

The distribution on mineral N in the soil is represented here based on the average $NO_3$ and $NH_4$ concentrations within each 9 cm x 15 cm soil sampling zone. The average concentration found was assumed to be the value of $NO_3$-N or $NH_4$-N at the center of the zone. Isoquant lines were drawn between the points to complete the diagrams (Fig. 2). Although this method of graphing gives only a qualitative estimate of N distribution, a comparison among the treatments is nonetheless beneficial.

The ratio of the total quantities of $NO_3$-N and $NH_4$-N present in the entire sampling zone of each treatment was determined throughout the season. The common log transformation of this ratio gives equal weight to the abundance of either $NO_3$-N or NH-N, which was plotted (Fig. 3). The center vertical axis at 0 indicates a $NO_3$-N/$NH_4$-N ratio equal to one while points above or below the vertical axis indicate a $NO_3$-N/$NH_4$-N ratio greater or less than one, respectively. Throughout the season the ratio of $NO_3$-N/$NH_4$-N generally remained less for the treatments with NI compared to the treatments without NI, regardless of the level of water applied.

Denitrification losses were measured from the high water treatment on the Hanford sandy loam immediately after the second N application.

Over the time period studied, the treatment with NI evolved $N_2O$ at an average rate of only 35% that of the -NI treatment (Table 4). In addition, a noticeable increase in $N_2O$ evolution, and presumably denitrification rate, was observed immediately following each irrigation. A similar surge in denitrification following irrigation of California soils has been reported by a number of workers (Ryden et al., 1979; Ryden and Lund, 1980; Stark et al., 1983). At 45 DAP immediately following fertilization the -NI treatment had only a moderate rate of $N_2O$ evolution. However, 51 DAP, following the next irrigation, the -NI treatment had greatly increased rates of denitrification compared with the +NI treatment. The presence of NI appears to have retarded the rate of $NH_4$ oxidation of the newly added fertilizer and thus greatly reduced $N_2O$ losses.

By inhibiting nitrification and prolonging the presence of $NH_4$ in the crop root zone, Terrazole appeared to reduce N losses due to both leaching and denitrification. These results show that although use of a NI may slow nitrification, a yield response does not automatically follow. The use of NI is most appropriate under conditions with a potential of high N loss due to $NO_3$ leaching or denitrification. It appears in these two soils that nitrification was inhibited; however, rates of N fertilization were high enough that crop yields, even with the lowest residual N, were not affected.

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Table 1. Selected physical and chemical characteristics of Arlington sandy loam and Hanford sandy loam.

| Soil series | pH 1:1 soil water | Organic carbon | Clay | Ca ($NH_4OAc$-extractable) | Mg | K | Na |
|---|---|---|---|---|---|---|---|
| | | -------% | ------- | cmol ($p^+$) $kg^{-1}$ | | | |
| Arlington | 7.3 | 1.27 | 10.5 | 7.8 | 1.9 | 0.3 | 0.9 |
| Hanford | 6.8 | 0.91 | 6.3 | 6.3 | 1.0 | 0.5 | 1.2 |

Table 2. Influence of irrigation level and Terrazole on N leaf concentration during the growing season.

| Soil series | Infiltrated water | NI† | Stover | | | Ears |
|---|---|---|---|---|---|---|
| | | | Days after planting | | | |
| | | | 38 | 70 | 90 | 90 |
| | cm | | g N/kg | | | |
| Arlington | 55.9 | + | 47.8 | 30.5 | 17.5 | 18.6 |
| | | - | 48.3 | 30.4 | 19.3 | 17.8 |
| | 69.0 | + | 48.2 | 31.1 | 18.8 | 17.6 |
| | | - | 48.3 | 30.8 | 17.2 | 18.0 |
| | | control‡ | 36.3 | 20.7 | 9.6 | 14.1 |
| | 79.4 | + | 47.5 | 29.4 | 17.7 | 19.5 |
| | | - | 48.5 | 32.1 | 17.6 | 22.8 |
| | L.S.D. 0.05 | | 2.1 | 2.5 | 2.7 | 4.0 |
| Hanford | 62.0 | + | 47.2 | 31.8 | 18.2 | 19.8 |
| | | - | 47.7 | 31.3 | 16.7 | 21.4 |
| | 76.7 | + | 46.4 | 30.9 | 15.4 | 20.7 |
| | | - | 45.8 | 31.2 | 14.6 | 21.6 |
| | | control | 38.5 | 18.9 | 9.4 | 16.9 |
| | 88.2 | + | 43.9 | 33.0 | 19.3 | 21.1 |
| | | - | 46.0 | 29.8 | 18.3 | 19.6 |
| | L.S.D. 0.05 | | 4.7 | 2.5 | 4.0 | 2.2 |

†NI, Terrazole.

‡Control received 0 kg N/ha.

Table 3. Influence of irrigation level and Terrazole on ear and stover yield.

| Soil series | Infiltrated water | NI† | Yield | | | |
|---|---|---|---|---|---|---|
| | | | Ears | | Stover | |
| | cm | | kg/ha | g/ear | kg/ha | g/ear |
| Arlington | 55.9 | + | 8457 | 63.9 | 4087 | 76.0 |
| | | - | 8993 | 56.4 | 3817 | 71.0 |
| | 69.0 | + | 7474 | 64.2 | 4516 | 83.2 |
| | | - | 6807 | 57.8 | 4696 | 87.3 |
| | | control‡ | 4168 | 44.6 | 2437 | 45.2 |
| | 79.4 | + | 7901 | 60.4 | 4874 | 90.7 |
| | | - | 6709 | 55.4 | 4086 | 76.4 |
| | L.S.D. 0.05 | | 1486 | 14.3 | 965 | 17.8 |
| Hanford | 62.0 | + | 4244 | 43.4 | 6471 | 120.3 |
| | | - | 5106 | 50.7 | 6292 | 96.4 |
| | 76.7 | + | 5926 | 49.6 | 5484 | 102.0 |
| | | - | 6237 | 53.5 | 6558 | 121.9 |
| | | control | 1631 | 23.2 | 2043 | 37.7 |
| | 88.2 | + | 5010 | 45.4 | 6309 | 117.5 |
| | | - | 6319 | 52.2 | 4874 | 90.8 |
| | L.S.D. 0.05 | | 1650 | 11.9 | 2181 | 36.3 |

†NI, Terrazole.

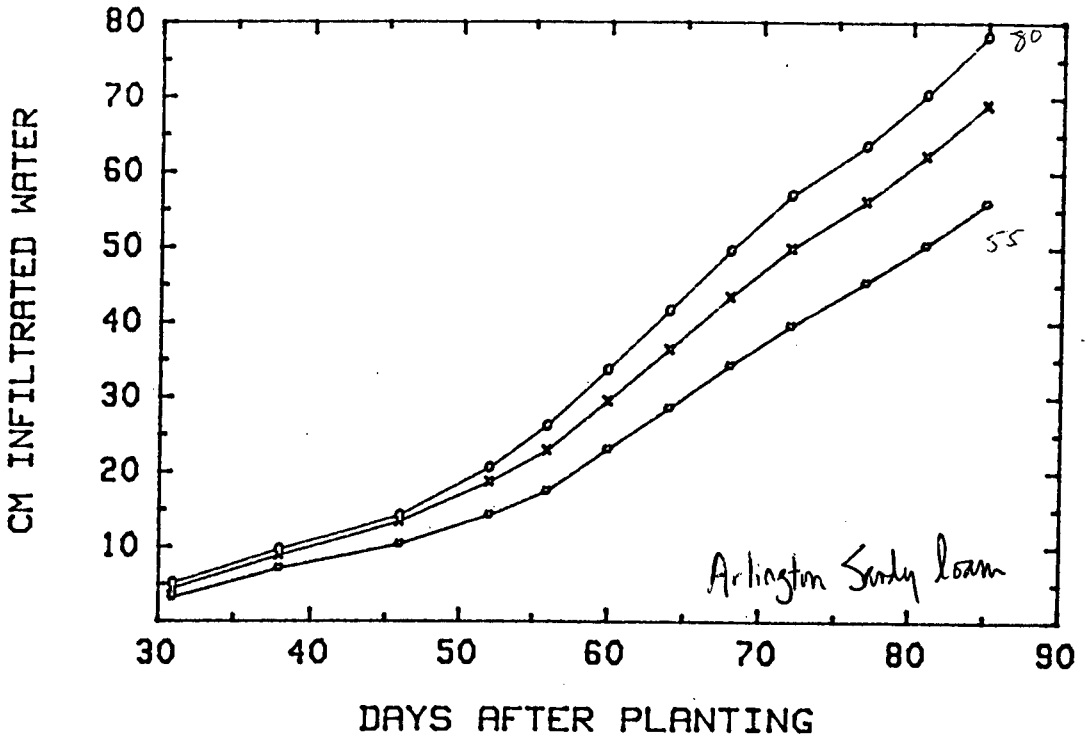
‡Control received 0 kg N/ha.

Table 4. Influence of terrazole on nitrous oxide evolution on Arlington sandy loam

| Sampling date | +NI† | -NI |
|---|---|---|
| (DAP)‡ | ----------g N/hr/ha---------- | |
| 45 | 0.6 | 3.2 |
| 46 | 0.4 | 0.8 |
| 47 | 0.2 | 0.3 |
| 51 | 2.9 | 17.24 |
| 52 | 2.5 | 6.5 |
| 53 | 1.6 | 2.0 |
| 55 | 1.8 | 3.7 |
| 56 | 3.0 | 8.2 |
| 59 | 4.7 | 5.4 |
| 60 | 2.6 | 9.1 |
| average | 2.0 | 5.6 |

†NI, Terrazole.

‡DAP, days after planting.

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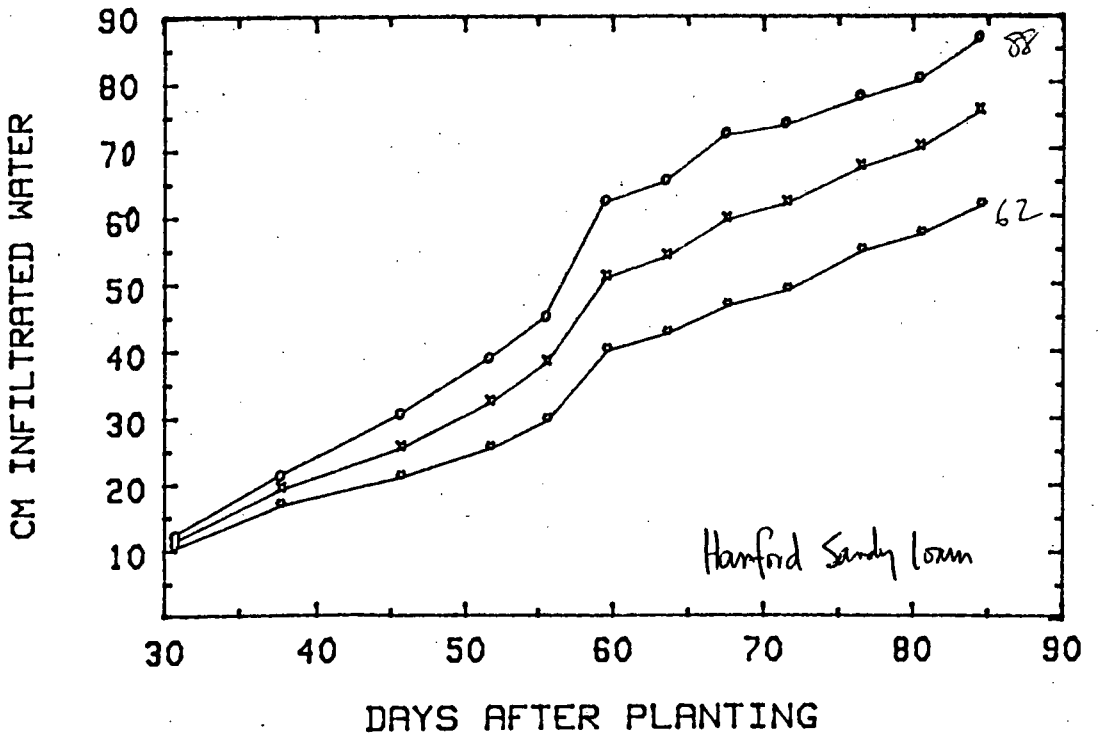


Fig. 1. Infiltrated water on Arlington sandy loam and Hanford sandy loam at three different irrigation levels through the growing season.

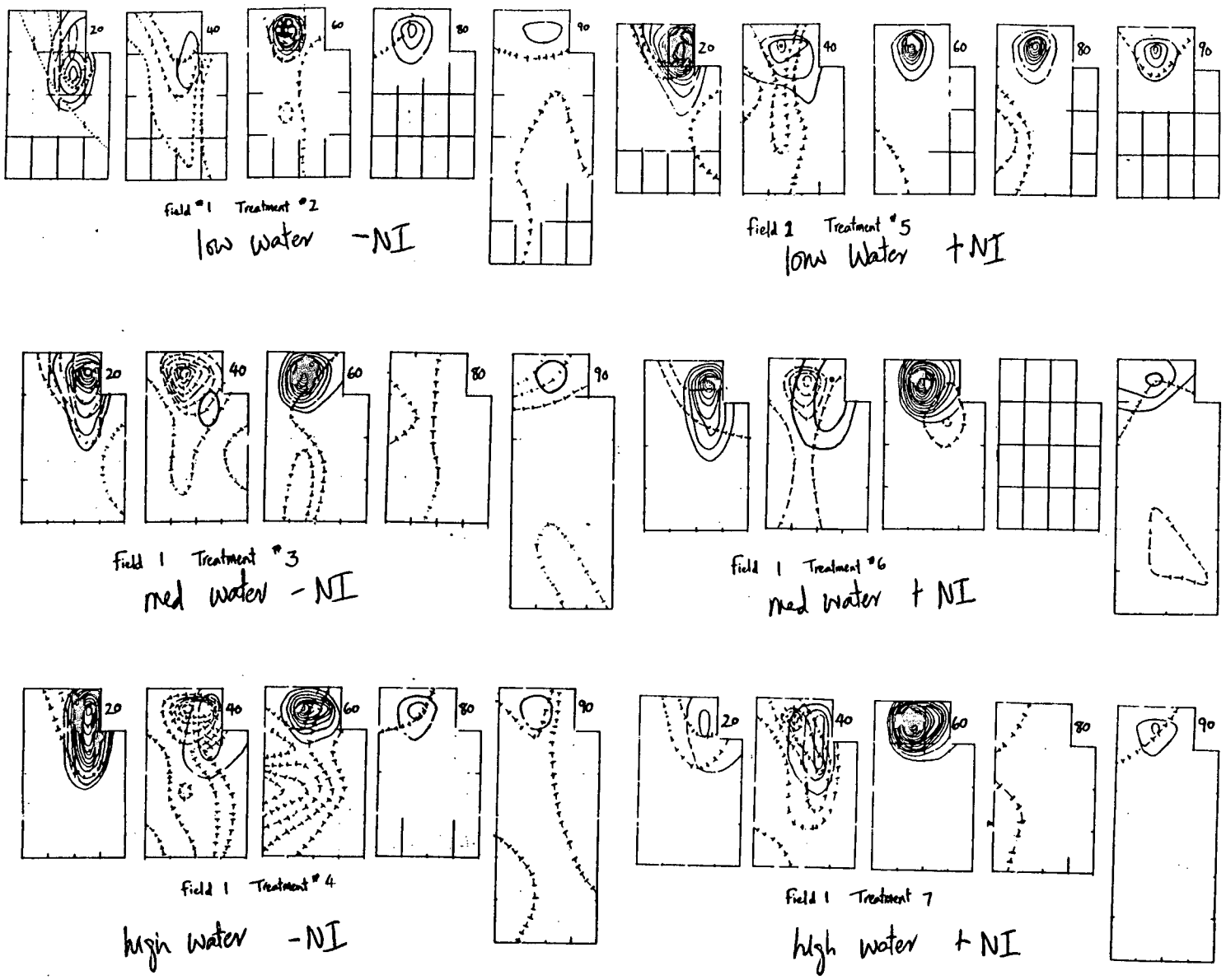


Fig. 2. Distribution of $NH_4$-N and $NO_3$-N in two soils throughout the growing season as influenced by irrigation and Terrazole.

Arlington Sandy Loam

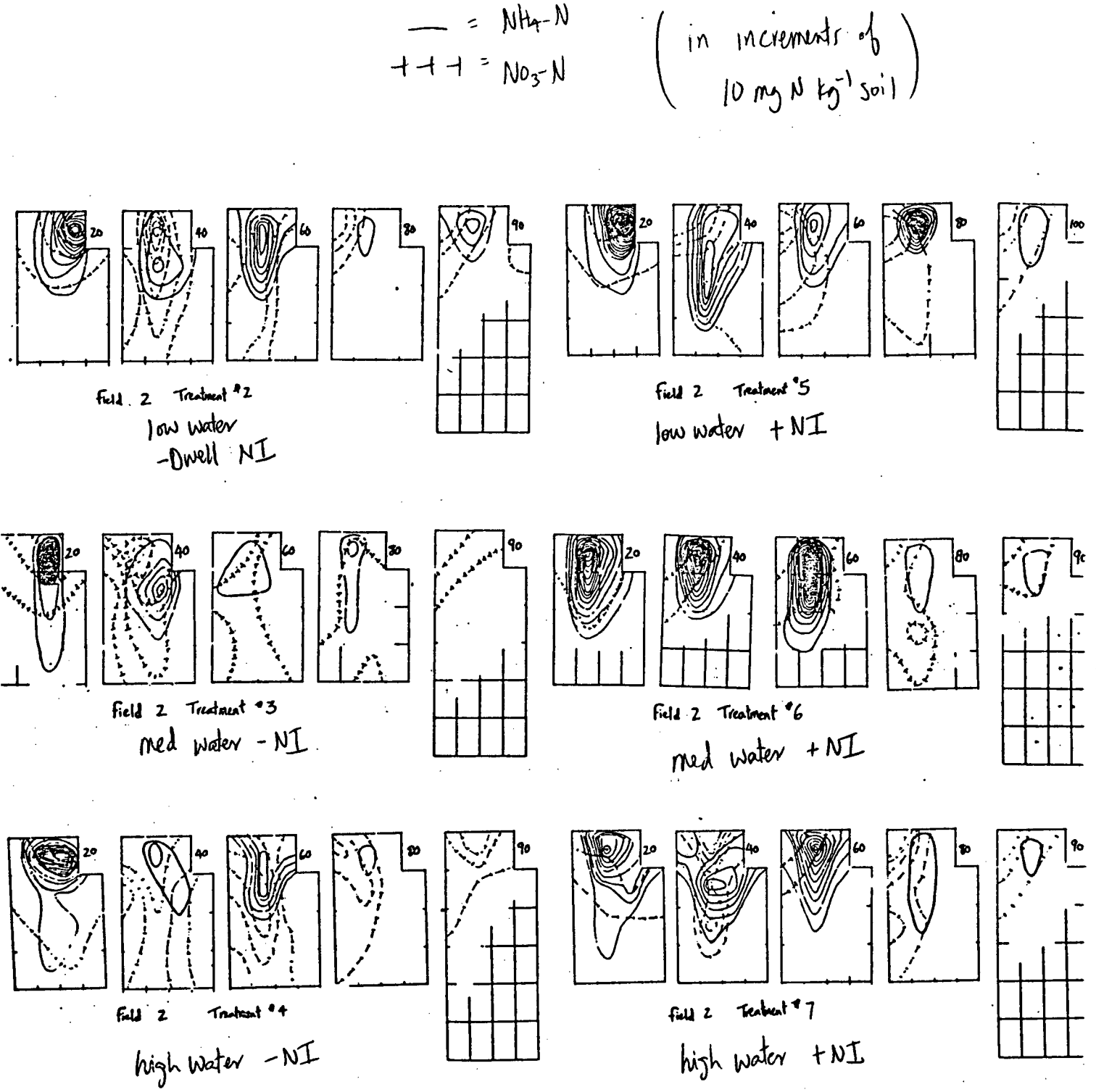


Fig. 2. Distribution of $NH_4$-N and $NO_3$-N in two soils throughout the growing season as influenced by irrigation and Terrazole.

Hanford Sandy Loam

fig 3 p. 1 of 2



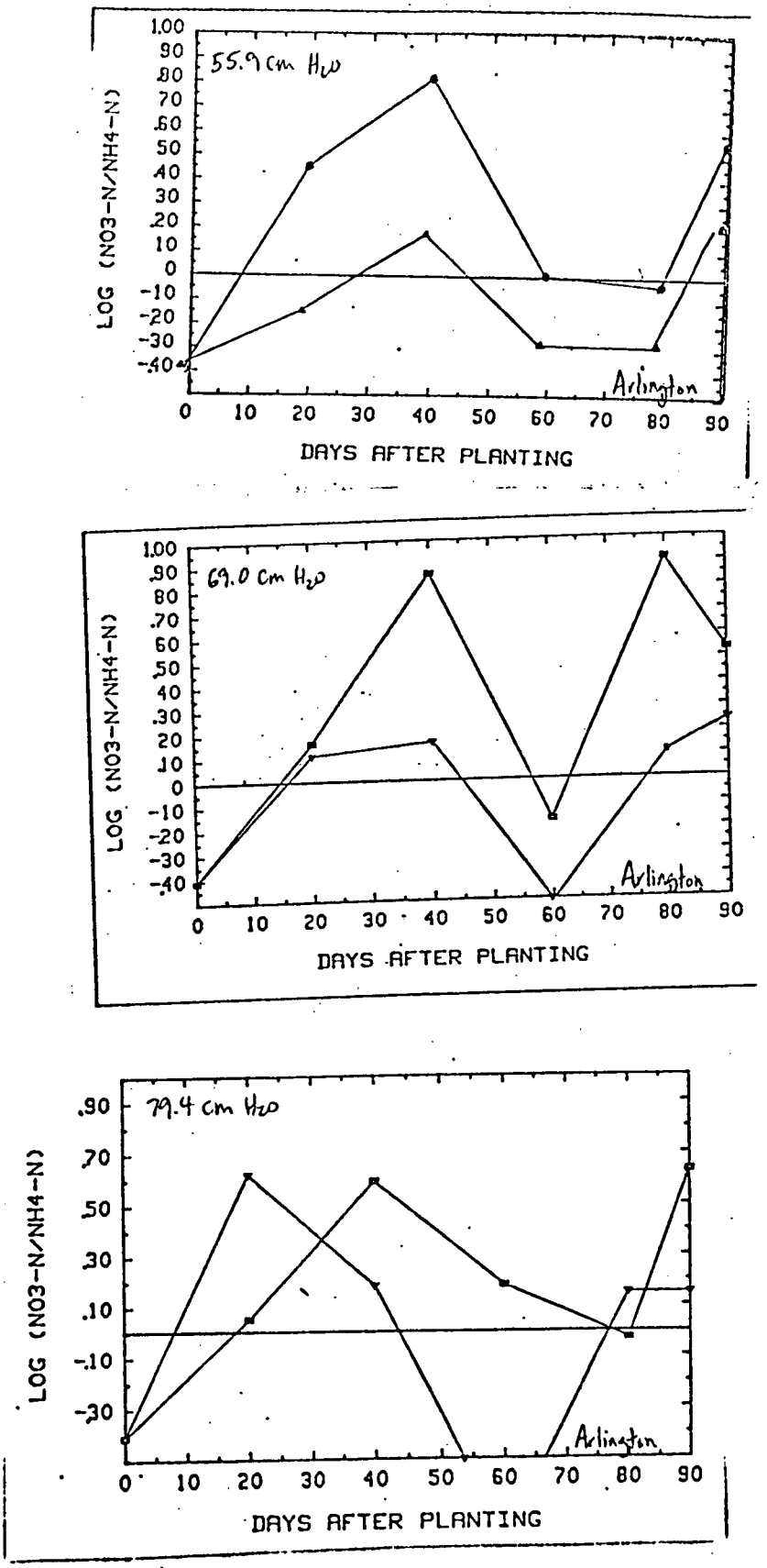


Fig. 3. Common log of $NO_3$-N/$NH_4$-N ratio in the sampling zone of two soils throughout the growing season as influenced by irrigation and Terrazole.

† ▫ without terrazole.
▽ with terrazole.

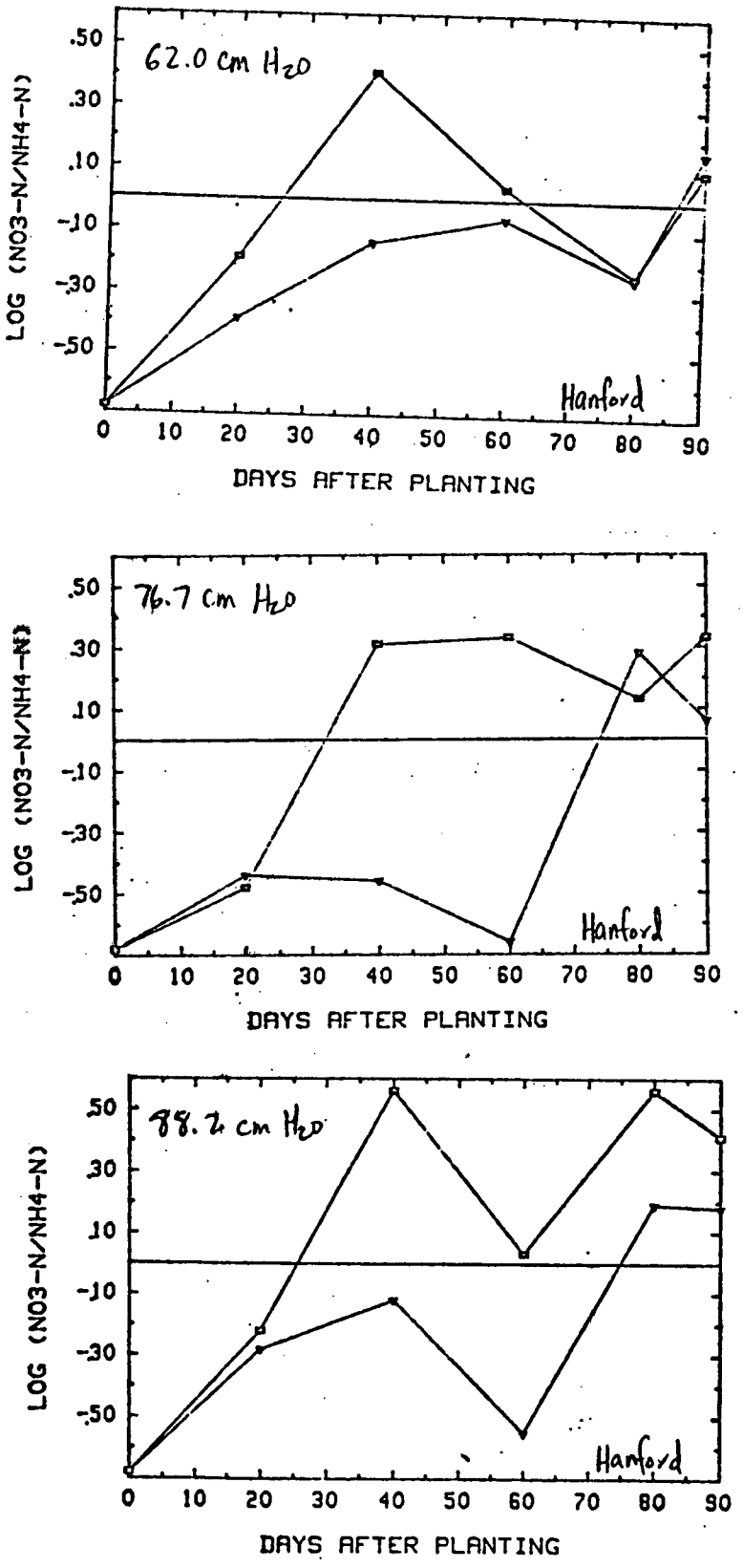


Fig. 3. Common log of $NO_3$-N/$NH_4$-N ratio in the sampling zone of two soils throughout the growing season as influenced by irrigation and Terrazole.

† □ without terrazole.
△ with terrazole.

# VIII. SOIL NITROGEN TRANSFORMATIONS AS AFFECTED BY SALINITY

G. McClung and W. T. Frankenberger, Jr.[1/]

Department of Soil and Environmental Sciences,
University of California, Riverside, CA 92521

## ABSTRACT

The results presented in this paper reveal that salinity has a major influence on soil N transformations. Studies were conducted to test the effects of $Na_2SO_4$, NaCl, and $CaCl_2$, applied at rates that produced electrical conductivities of saturation extracts ($EC_e$) of 5, 10, 15, and 20 dS $m^{-1}$, on ammonia volatilization, ammonification of urea, and nitrification in three diverse soils. The effects of salinity on ammonia volatilization and nitrification varied depending on the N source, the amounts and types of salts added, and the soils used. In two of the three soils in which ammonia volatilization occurred, increased salinity promoted ammonia loss (up to a 3.7-fold increase), however, calcium-reduced $NH_3$ loss of applied urea was observed in one of the two soils. There was no apparent effect of salinity on ammonification of urea in any of the three soils regardless of the type of salts added. Generally, increased salinity progressively decreased

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[1/] Graduate Research Assistant and Assistant Professor of Soil Microbiology and Biochemistry, respectively, Univ. of Calif., Riverside.

nitrification. Appreciable amounts of $NO_2^-$-N (up to 6.8 $\mu g\ g^{-1}$ soil; 3.4% of the total N applied) were recovered in salinized soils. The percent of inhibition of nitrification ranged from 8 to 83%, varying among the soils studied as well as the type of salts added. In most cases, $Na_2SO_4$ was less inhibitory to nitrification than the chloride salts. Inhibition of nitrification at $EC_e$ values of 20 dS $m^{-1}$ (NaCl) were as high as 75 and 83% when $(NH_4)_2SO_4$ and urea were applied to soils, respectively.

# INTRODUCTION

Salt addition to soils has been shown to be inhibitory to several microbial processes including enzyme activities, carbon mineralization, and nitrification. Frankenberger and Bingham (1982) assessed the levels of soil enzyme activities that had a specific role in the N, C, P, and S cycles of saline soils. Soil enzyme activities decreased with increasing $EC_e$ (up to 22 dS $m^{-1}$); however, the degree of inhibition varied among the enzymes assayed and the nature and amount of salts added. Laura (1974) reported that the total microbial activity in soils (as indexed by $CO_2$ evolution) was generally depressed as soil salinity was increased. McCormick and Wolf (1980) reported that NaCl applied at a rate of 0.25 mg $g^{-1}$ soil significantly reduced nitrification in a sandy loam soil.

The objective of this study was to provide a comprehensive report on the effects of both chloride and sulfate salts on N transformations in soils. A substantial amount of applied N fertilizer may be lost through ammonia volatilization under certain conditions. Studies were carried out to assess ammonia loss with increasing soil salinity. Conflicting views have been reported on the effects of salinization on ammonification. Some researchers (Singh et al., 1969; Agarwal et al., 1971) have reported an increase in ammonification, whereas others (Greaves and Lund, 1921; Greaves, 1922) reported a decrease with increasing salinity. The process of nitrification appears to be sensitive to the addition of NaCl, but additional studies are needed

to test the effects of other soluble salts typically found in saline soils. We report the effects of increasing electrical conductivity with $Na_2SO_4$, NaCl, and $CaCl_2$ added to soils on ammonia volatilization, ammonification of urea, and nitrification.

## MATERIALS AND METHODS

The three soils used in this study were Domino clay loam (fine-loamy, mixed, thermic Xerollic Paleorthids), Fallbrook sandy clay loam (fine-loamy, mixed, thermic Typic Haploxeralfs) and Hesperia sandy loam (coarse-loamy, mixed, nonacid, thermic Xeric Torriorthents). The soil samples were noncultivated surface (0- to 15-cm) samples selected to obtain a wide range in pH (5.8 to 8.0), organic C (0.28 to 1.65%), and texture (18 to 29% clay and 43 to 74% sand) (Table 1). Characterization of the soils were conducted on sieved (<2-mm), air-dried samples according to the methods previously described by Frankenberger and Johanson (1982).

Transformations of N were studied by using a procedure similar to that described by Frankenberger and Tabatabai (1981). In the incubation experiments, 10 g samples (on a dry weight equivalent basis) of field-moist soils were place in 250-mL (8 oz) French square bottles and treated with 1 mL of the appropriate salt solution. The treatments of $Na_2SO_4$, NaCl, and $CaCl_2$ produced electrical conductivity levels of 5, 10, 15, and 20 dS $m^{-1}$ in saturation extracts ($EC_e$). These salinity levels were selected to bracket the range encountered in arid and semi-arid regions. The nonsalinized soil samples had $EC_e$ values of 1.2, 1.6, and 0.3 dS $m^{-1}$ for the Domino, Fallbrook, and Hesperia soils, respectively. To allow a comparison of our results to those reported in the literature, Table 2 shows the required amounts of salts added to soils to produce the desired $EC_e$ levels. Several investigators have reported their results in terms of percentage or weight basis of soluble salts

added to soils. This method of reporting, however, fails to allow comparison of results among different soils (Laura, 1976). Table 2 shows that the amount of salt required to produce a specific $EC_e$ value for one soil does not produce the same $EC_e$ for another soil. Therefore, measurements of $EC_e$ appears to be a suitable method for comparing the effects of salinity on soil N transformations.

After the salt solutions were added, the bottles were stoppered and allowed to equilibrate at 25°C for 7 days. The 7-day equilibration period was chosen to allow ample time for the soil microflora to adapt to the salinized conditions. Soils were then treated with $(NH_4)_2SO_4$ or urea at the rate of 200 ug N $g^{-1}$ soil by the addition of 1 mL (Domino, Fallbrook) or 0.5 mL (Hesperia) of solutions. The resultant moisture contents were 65, 57, and 57% of the water holding capacities for the Domino, Fallbrook, and Hesperia soils, respectively.

The French square bottles were then fitted with an aeration device having an acid trap containing 5 mL of 0.5N $H_2SO_4$ for absorption of the volatilized ammonia. The soil samples were incubated for 14 days at 30° C and aerated for 20 min every 3 days.

The ammonia volatilized was determined by steam distillation of $NH_4^+$ after the addition of 5 mL of 1N NaOH to the $H_2SO_4$ (Bremner and Edwards, 1965). The incubated soil samples were extracted with 100 ml of 2M KCl, and the extracts thus obtained were analyzed for $NH_4^+$-N and $NO_2^-$- + $NO_3^-$-N by steam distillation (Bremner and Keeney, 1966) and for $NO_2^-$-N by the diazonium coupling reaction (Barnes and Folkard, 1951). For the nonsalinized controls, the procedure described for incubation of N-treated soil samples was followed, but 1 mL of deionized water was added instead of the salt solutions.

The percent inhibition of nitrification as defined by Bundy and Bremner (1973) was calculated by (C-S/C)100 where C is the amount of $NO_3^-$-N produced in the nonsalinized soil and S is the amount of $NO_3^-$-N produced in the treated samples.

All values reported are averages of duplicate determinations expressed on a moisture-free basis. Each soil was treated as a separate experiment in a completely randomized design.

## RESULTS AND DISCUSSION

### Effects of Salinity on Ammonia Volatilization

Increasing salinity promoted ammonia volatilization from the Domino soil when treated with $(NH_4)_2SO_4$ (Fig. 1). With the application of three salts, a 2.5-, 2.4-, and 2.2-fold increase in $NH_3$ volatilization was observed at the highest salinity level (20 dS $m^{-1}$) of $Na_2SO_4$, NaCl, and $CaCl_2$, respectively. Volatilization of $NH_3$ from the $(NH_4)_2SO_4$ treated Hesperia soil increased only slightly with increased salinity (Fig. 1).

Figure 2 shows the effects of salinity on $NH_3$ volatilization from the Domino and Hesperia soils treated with urea. Similar levels of $NH_3$ loss were observed from the Domino soil when treated with both N sources. Increased salinity promoted $NH_3$ volatilization from 4% of the applied urea-N in the nonsalinized Domino soil to 12, 15, and 13% when salinized to 20 dS $m^{-1}$ with $Na_4SO_4$, NaCl, and $CaCl_2$, respectively. Appreciable amounts of $NH_3$ were evolved when the Hesperia soil was treated with urea (Fig. 2). The amount of N lost through $NH_3$ volatilization in the nonsalinized Hesperia soil was 81 ug $g^{-1}$ soil (40.5% of the total N applied). With increasing amounts of $Na_2SO_4$, there was a progressive increase in $NH_3$ volatilization. Up to 58% of the total N applied was lost at the 20 dS $m^{-1}$ $EC_e$ level. There was a slight increase in $NH_3$ loss with increased NaCl treatments up to 45% of the total N at the highest salinity level. However, all levels of $CaCl_2$ added resulted in decreased $NH_3$ volatilization by 8.5-9.5%

compared to the nonsalinized Hesperia control. Our results support the work of Fenn et al. (1981) who suggested that Ca-reduced $NH_3$ volatilization of applied urea occurs when the carbonate ion of ammonium carbonate (formed during urea hydrolysis) precipitates as $CaCO_3$ in the presence of $CaCl_2$ as shown by the following reactions:

$$NH_2CONH_2 \xrightarrow[H_2O]{\text{urease}} (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 + CaCl_2 \longrightarrow CaCO_3 \downarrow + 2\ NH_4Cl$$

The resulting product, ammonium chloride, is a weakly acidic compound which is less conducive to $NH_3$ loss.

Ammonia volatilization that occurred in the Domino soil can most likely be attributed to the high initial soil pH 8.0, and possibly competition for exchange sites imposed by the added cations. It would appear that the buffering capacity of the Domino clay loam (CEC = 16.8 cmol $[NH_4^+]$ $kg^{-1}$ soil) was sufficiently high to prevent appreciable loss of $NH_3$ that would be expected to occur with increased soil pH upon urea hydrolysis. Apparently, the low buffering capacity of the Hesperia sandy loam (CEC = 6.6 cmol $[NH_4^+]$ $kg^{-1}$ soil) was not great enough to avoid the rise in soil pH accompanied by urea hydrolysis, and consequently, $NH_3$ loss was greater with urea than with $(NH_4)_2SO_4$ as the N source. Ammonia volatilization from the Fallbrook soil was $\leq$ 1% of the applied N regardless of the N source or salt treatments. The Fallbrook sandy clay loam was not conducive to $NH_3$ volatilization because of its acidic pH and high buffering capacity (Table 1).

## Effects of Salinity on Ammonification

There was no apparent effect of salinity on ammonification of urea in any of the three soils studied regardless of the type or amount of salt added. Our results confirm the work of Singh et al. (1969), Broadbent and Nakasha (1971), and Westerman and Tucker (1974) who reported that ammonification is less sensitive to salinity than nitrification. Furthermore, Laura (1974) found no inhibition of ammonification when soil was treated with 5.1% of $CaCl_2$ and NaCl salts.

## Effects of Salinity on Nitrification

Increased addition of $Na_2SO_4$ up to an $EC_e$ of 20 dS $m^{-1}$ had no effect on nitrification of the applied $(NH_4)_2SO_4$ or urea-N in the Domino clay loam as evident by the $NH_4^+$-N and $NO_3^-$-N contents (Fig. 3). The slight decrease in $NO_3^-$-N recovery at 15 and 20 dS $m^{-1}$ was apparently due to $NH_3$-N loss. In contrast, the chloride salts of both sodium and calcium markedly inhibited nitrification at $EC_e$ levels of 15 and 20 dS $m^{-1}$ in this soil. Our results support the work of Johnson and Guenzi (1963), Sindhu and Cornfield (1967), Agarwal et al. (1971), and Heilman (1975) who reported that chloride salts were more inhibitory to nitrification than sulfate salts. Also, this study showed that in most cases, nitrification was inhibited moreso by $CaCl_2$ than the NaCl treatment which is in good agreement to that reported by Westerman and Tucker (1974). Nitrification of $(NH_4)_2SO_4$ was inhibited by 57 and 68% when NaCl and $CaCl_2$, respectively, were added to the Domino soil at an $EC_e$ level of 20 dS $m^{-1}$ (Fig. 3). In comparison, nitrification of the $NH_4^+$ released upon urea hydrolysis was inhibited by 41 and 64% when the Domino soil

was salinized (20 dS $m^{-1}$) with the same respective salts (Fig. 3.). Similar effects of NaCl treatments on nitrification have been reported by other investigators. McCormick and Wolf (1980) found that the addition of 0.25 mg NaCl $g^{-1}$ soil significantly reduced $NO_3^-$-N levels in a sandy loam, but nitrification was not completely inhibited until 10 mg NaCl $g^{-1}$ soil was added. Sindhu and Cornfield (1967) reported that NaCl applications of 0.5 to 1.0% completely inhibited nitrification.

In the Fallbrook sandy clay loam soil, $Na_2SO_4$ was less inhibitory to nitrification of $(NH_4)_2SO_4$ when compared to the NaCl and $CaCl_2$ treatments (Fig. 4). The magnitude of inhibition by NaCl and $CaCl_2$ was somewhat less than that observed with the Domino soil. Inhibition of nitrification of $(NH_4)_2SO_4$ at an $EC_e$ level of 20 dS $m^{-1}$ was 17, 39, and 36% with the addition of $Na_2SO_4$, NaCl, and $CaCl_2$, respectively.

Figure 4 also shows the effects of salinity on $NO_3^-$-N recovery in the Fallbrook soil treated with urea. Inhibition of nitrification was evident at all $EC_e$ levels above 5 dS $m^{-1}$. The addition of $Na_2SO_4$ was less inhibitory to nitrification of urea-N than the chloride salts at $EC_e$ levels of 5, 10, and 15 dS $m^{-1}$. The percent inhibition of nitrification for the $Na_2SO_4$, NaCl, and $CaCl_2$ treatments at 20 dS $m^{-1}$ in the urea-amended Fallbrook soil were 54, 54, and 46%, respectively.

Nitrification occurred slowly in the nonsalinized Hesperia soil as evidenced by high $NH_4^+$-N recovery when treated with both $(NH_4)_2SO_4$ and urea (Fig. 5). Approximately 10 to 35% of the $(NH_4)_2SO_4$ was nitrified in the salinized Hesperia soil during the 14-day incubation. With increased salinity, there was a slight progressive decrease in nitrification of $(NH_4)_2SO_4$. The $Na_2SO_4$ treatment, again, was less inhibitory to

nitrification at the lower salinity levels than the chloride salts (Fig. 5).

Increased salinity resulted in decreased nitrification of urea-N in the Hesperia soil as evident by the low $NO_3^-$-N recovery (Fig. 5). The $Na_2SO_4$ treatment was, again, slightly less inhibitory to nitrification than the chloride salts. The percent inhibition of nitrification of applied urea-N ranged from 30 to 76%, 39 to 83%, and 40 to 81% with increased $EC_e$ levels from 5 to 20 dS $m^{-1}$ for the $Na_2SO_4$, NaCl, and $CaCl_2$ salts, respectively.

The $NH_4^+$-N levels in the urea-amended Hesperia soil varied greatly depending on the type of salt added as recovery was affected by the amount of N lost through volatilization. There was more $NH_3$ volatilized with increasing $Na_2SO_4$ than with the $CaCl_2$ treatment (Fig. 2). Consequently, less $NH_4^+$-N was available to be nitrified in the $Na_2SO_4$ treated Hesperia soil.

Table 4 shows the effects of salinity on the $NO_2^-$-N accumulation in the three soils treated with $(NH_4)_2SO_4$ and urea. With $(NH_4)_2SO_4$, there were relatively low levels of $NO_2^-$-N (0.1 to 2.5 ug $g^{-1}$ soil) without any consistent trend of accumulation with increased salinity in any of the three soils.

Recovery of $NO_2^-$-N was frequently higher in soils treated with urea (Table 4). Nitrite oxidizers are sensitive to low concentrations of $NH_3$. Both high soil pH and low buffering capacity would promote $NH_3$ loss from soil. In the urea-amended Fallbrook soil, in which little $NH_3$ volatilization was observed, the recovery of $NO_2^-$-N was always < 0.4 ug $g^{-1}$ soil. The Fallbrook soil had an initial low pH and high buffering capacity (Table 1) which are not conducive to $NH_3$ volatilization. Up to

15 and 58% of the applied urea-N was lost as $NH_3$ from the Domino and Hesperia soils, respectively, at the highest salinity level (20 $dS^{-1}$). There were some relatively high $NO_2^-$-N levels in the salinized Domino soil treated with urea at the 15 and 20 $dS^{-1}$ $EC_e$ levels, particularly with the sodium salts. The highest level observed, 6.8 ug $NO_2^-$-N $g^{-1}$ soil, accounted for 3.4% of the total N applied. Appreciable amounts of $NO_2^-$-N (1.3 to 4.8 ug $g^{-1}$ soil) were also observed in the Hesperia soil treated with urea. Perhaps the $NH_3$ released in the Domino and Hesperia soils was inhibitory to the nitrite oxidizers.

# CONCLUSIONS

The addition of salts to soils had no apparent effect on ammonification of urea, but greatly affected both $NH_3$ volatilization and nitrification of $(NH_4)_2SO_4$ and urea. In the two soils that were conducive to $NH_3$ volatilization, increased salinity enhanced $NH_3$ loss. There was one exception where a Ca-reduced $NH_3$ loss of applied urea was observed. The inhibition of nitrification from salt addition ranged from 8 to 83% and varied among the soils used as well as the type of salt added. Generally, $Na_2SO_4$ was less inhibitory to nitrification than either NaCl or $CaCl_2$. Appreciable amounts of $NO_2^-$-N accumulated in two of the soils, particularly when urea was applied as the N source at the higher salinity levels. The acidic Fallbrook soil with a high buffering capacity showed little $NH_3$ loss or $NO_2^-$-N accumulation with salt addition whereas the Hesperia soil with a neutral pH and low CEC showed substantial $NH_3$ volatilization and high $NO_2^-$-N levels. Nitrite-N recovery was greatest in the calcareous Domino soil treated with the highest levels of $Na_2SO_4$ and NaCl. The results of this study indicate that soil properties should be carefully considered with the application of ammoniacal fertilizers on salinized soils.

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TABLE 1

Characterization of the soils used

| Soil | pH (1:1) | Organic carbon, % | Total Nitrogen, % | CEC, $cmol(NH_4^+) \cdot kg^{-1}$ | Sand, % | Silt, % | Clay, % |
|---|---|---|---|---|---|---|---|
| Domino clay loam | 8.0 | 0.44 | 0.041 | 16.8 | 43 | 28 | 29 |
| Fallbrook sandy clay loam | 5.8 | 1.65 | 0.155 | 15.5 | 51 | 23 | 26 |
| Hesperia sandy loam | 7.0 | 0.28 | 0.021 | 6.6 | 74 | 8 | 18 |

TABLE 2

Amounts of salts added that produced desired $EC_e$ levels

| Salt | $EC_e$, dS $m^{-1}$ | Domino soil | Fallbrook soil | Hesperia soil |
|---|---|---|---|---|
| | | amount of salt added, mg $g^{-1}$ soil | | |
| $Na_2SO_4$ | 5 | 1.52 | 1.64 | 1.10 |
| | 10 | 3.90 | 4.26 | 2.36 |
| | 15 | 6.51 | 7.21 | 3.60 |
| | 20 | 9.00 | 9.72 | 5.32 |
| NaCl | 5 | 1.04 | 1.14 | 0.78 |
| | 10 | 2.53 | 2.64 | 1.68 |
| | 15 | 4.28 | 4.46 | 2.50 |
| | 20 | 6.18 | 6.24 | 3.42 |
| $CaCl_2$ | 5 | 1.04 | 1.12 | 0.74 |
| | 10 | 2.71 | 2.76 | 1.56 |
| | 15 | 4.69 | 4.72 | 2.80 |
| | 20 | 6.24 | 6.58 | 3.70 |

TABLE 3

Initial and final pH values of the salinized soils treated with $(NH_4)_2SO_4$ or urea.

| Treatment | $EC_e$, dS $m^{-1}$ | Domino Soil | | Fallbrook Soil | | Hesperia Soil | |
|---|---|---|---|---|---|---|---|
| | | $(NH_4)_2SO_4$ | Urea | $(NH_4)_2SO_4$ | Urea | $(NH_4)_2SO_4$ | Urea |
| Initial pH | | 8.0 | | 5.8 | | 7.0 | |
| Nonsalinized | | 7.1 | 7.2 | 4.8 | 5.4 | 5.8 | 7.2 |
| $Na_2SO_4$ | 5 | 7.0 | 7.3 | 5.0 | 5.4 | 5.8 | 7.4 |
| | 10 | 7.3 | 7.4 | 5.0 | 5.9 | 5.9 | 7.7 |
| | 15 | 7.5 | 7.6 | 5.5 | 6.1 | 6.2 | 7.9 |
| | 20 | 7.5 | 7.7 | 5.3 | 5.9 | 6.4 | 7.9 |
| NaCl | 5 | 7.0 | 7.1 | 5.1 | 5.6 | 6.1 | 7.5 |
| | 10 | 6.9 | 7.0 | 5.2 | 5.9 | 6.4 | 7.7 |
| | 15 | 7.2 | 7.3 | 5.5 | 6.1 | 6.4 | 7.7 |
| | 20 | 6.9 | 7.1 | 5.3 | 6.0 | 6.5 | 7.8 |
| $CaCl_2$ | 5 | 6.9 | 7.1 | 4.9 | 5.4 | 6.1 | 7.4 |
| | 10 | 6.9 | 7.0 | 5.1 | 5.8 | 6.2 | 7.4 |
| | 15 | 7.0 | 7.1 | 5.1 | 5.8 | 6.2 | 7.4 |
| | 20 | 6.7 | 6.9 | 5.1 | 6.0 | 6.2 | 7.3 |

TABLE 4

Effects of salinity on $NO_2^-$-N recovery in three soils treated with $(NH_4)_2SO_4$ or urea

| Treatment | $EC_e$, dS $m^{-1}$ | Domino Soil | | Fallbrook Soil | | Hesperia Soil | |
|---|---|---|---|---|---|---|---|
| | | $(NH_4)_2SO_4$ | Urea | $(NH_4)_2SO_4$ | Urea | $(NH_4)_2SO_4$ | Urea |
| | | μg $NO_2^-$-N $g^{-1}$ soil | | | | | |
| Nonsalinized | | 0.1 | 0.1 | 0 | 0 | 0 | 0 |
| $Na_2SO_4$ | 5 | 0.1 | 0.2 | 0.8 | 0 | 0.5 | 1.3 |
| | 10 | 0.1 | 0.1 | 0.5 | 0 | 0.5 | 3.9 |
| | 15 | 0 | 6.0 | 0.3 | 0 | 0.6 | 4.0 |
| | 20 | 0.4 | 6.1 | 0.2 | 0 | 2.5 | 4.4 |
| NaCl | 5 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 2.3 |
| | 10 | 0 | 0.1 | 0.3 | 0.4 | 1.2 | 4.0 |
| | 15 | 1.3 | 6.8 | 0.2 | 0.2 | 0 | 4.7 |
| | 20 | 0.4 | 6.6 | 0.4 | 0.2 | 0.6 | 4.8 |
| $CaCl_2$ | 5 | 0.1 | 0.1 | 0 | 0.1 | 0 | 1.5 |
| | 10 | 0.3 | 0.1 | 0.1 | 0 | 1.3 | 3.1 |
| | 15 | 0.1 | 2.3 | 0.8 | 0.3 | 0.5 | 2.0 |
| | 20 | 0.1 | 1.6 | 0 | 0.3 | 0 | 2.3 |

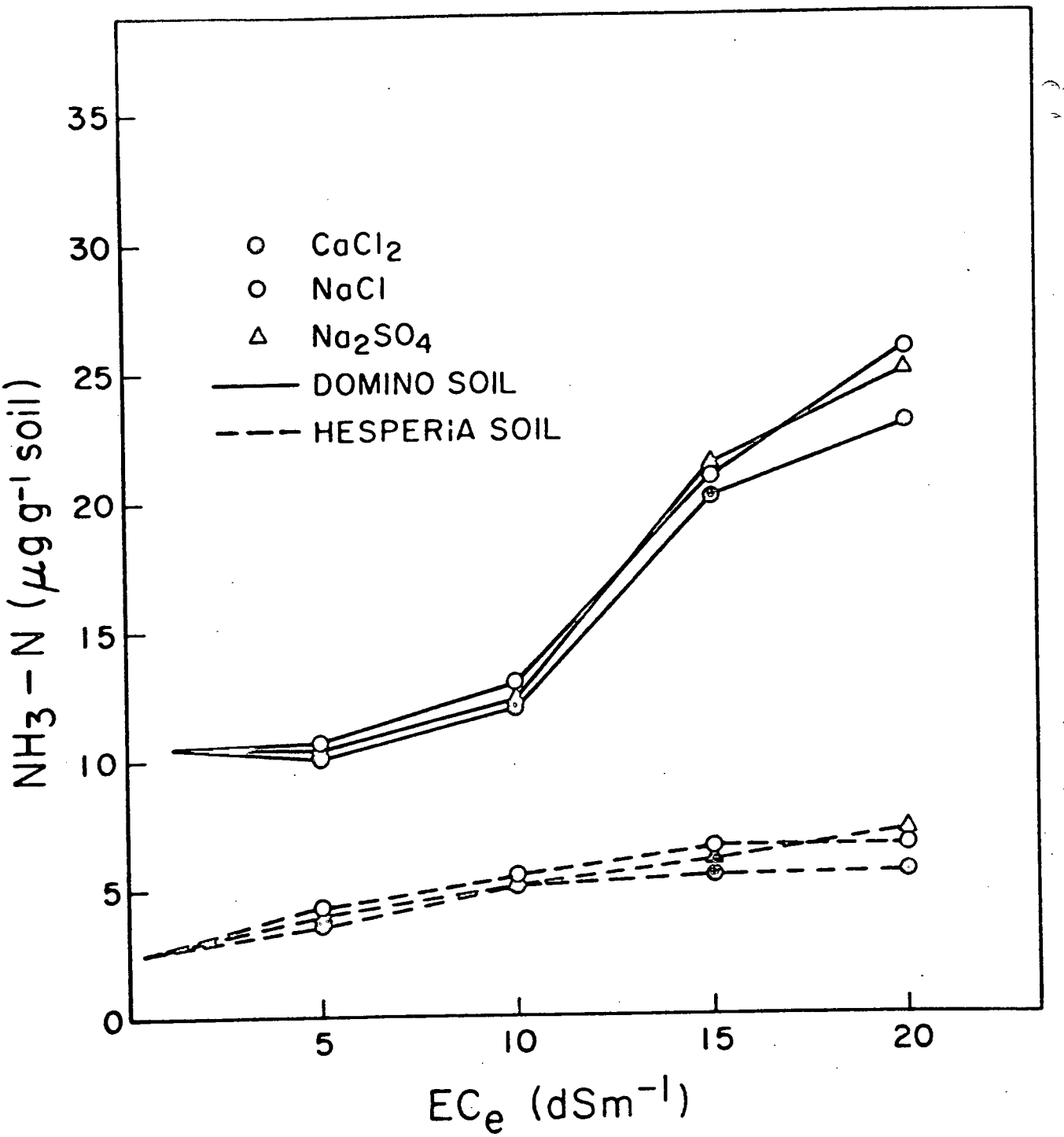


Figure 1. Effects of salinity on ammonia volatilization from the Domino and Hesperia soils treated with $(NH_4)_2SO_4$.

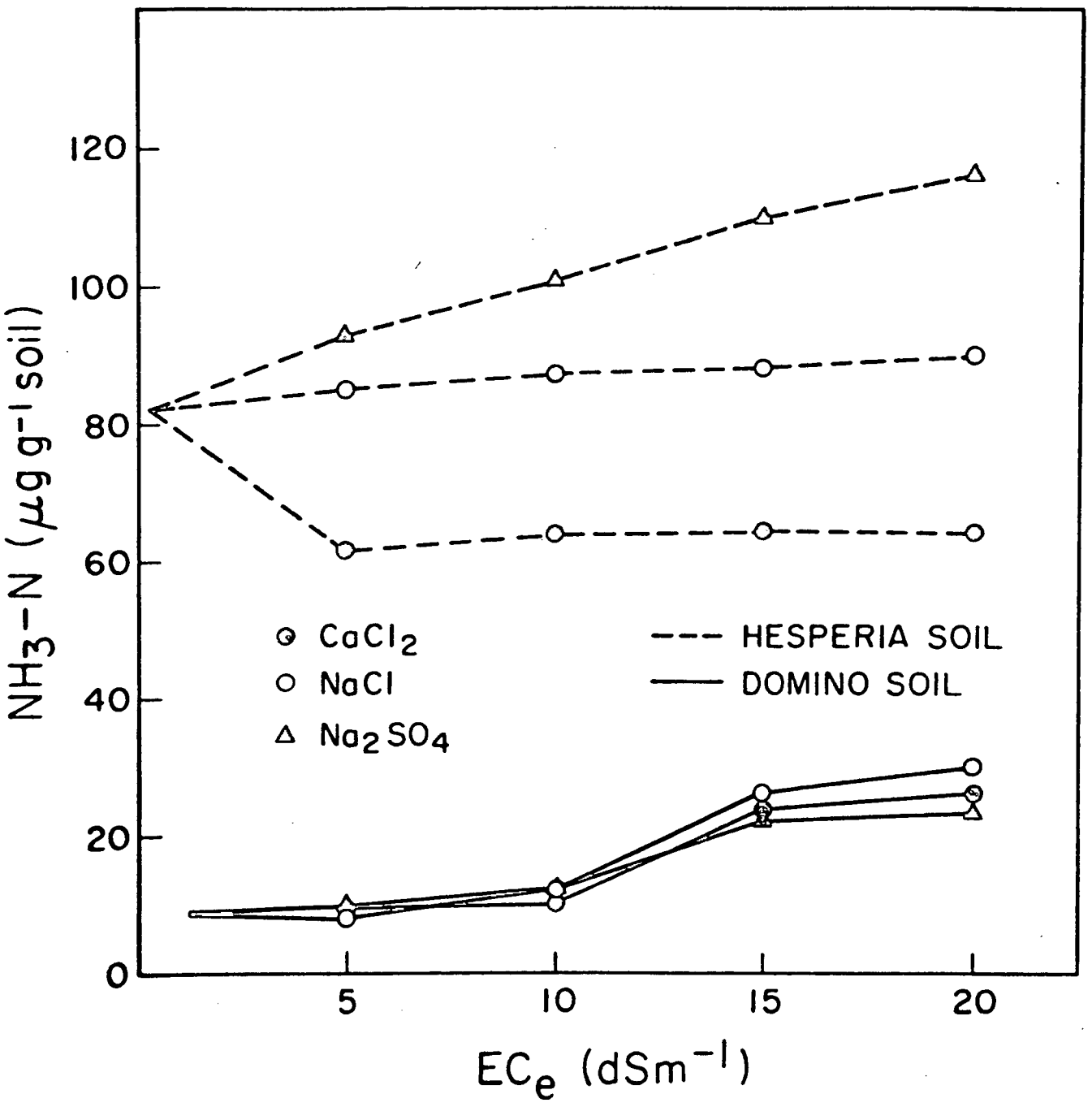


Figure 2. Effects of salinity and ammonia volatilization from the Domino and Hesperia soils treated with urea.

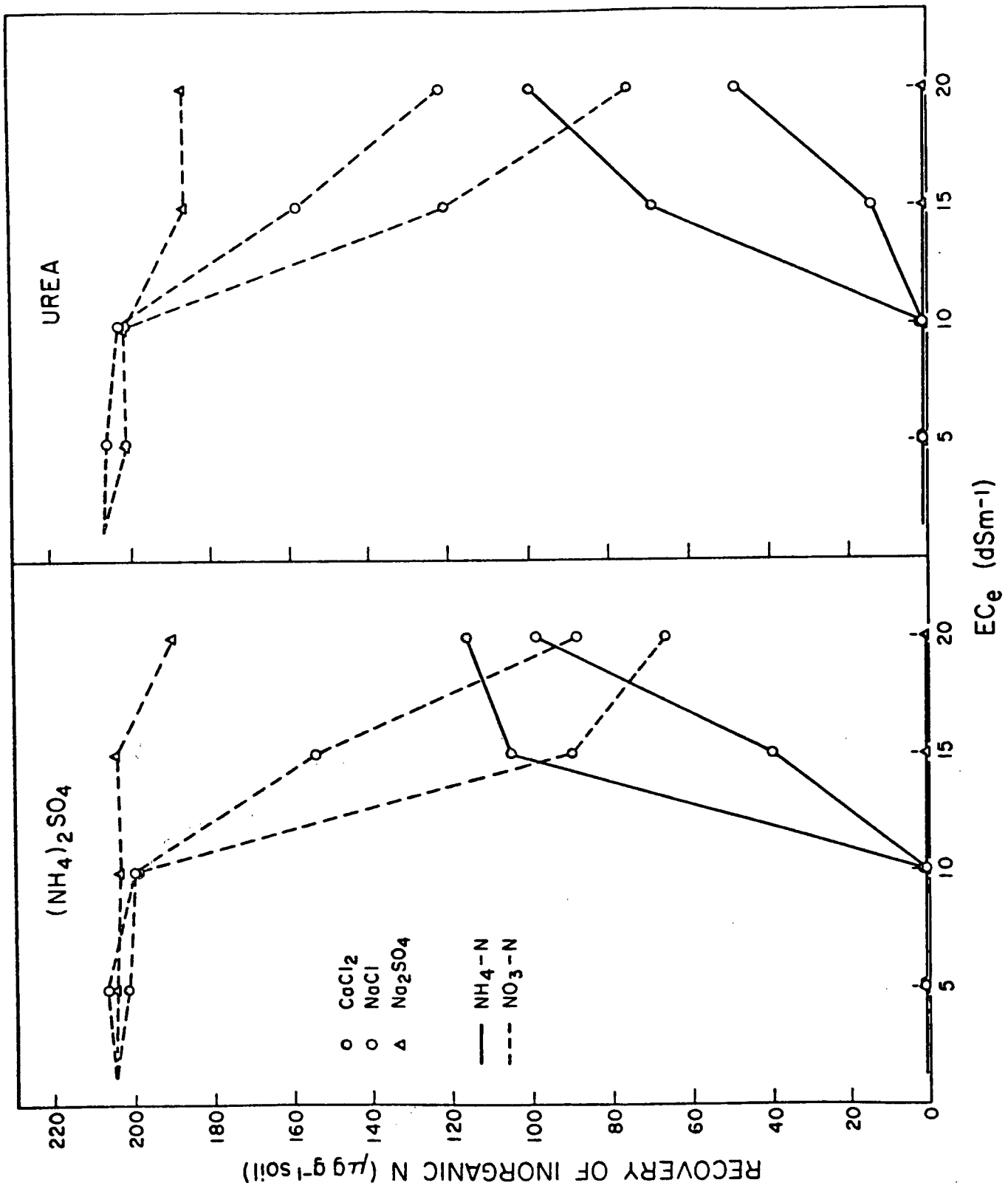


Figure 3. Effects of salinity on $NH_4^+$-N and $NO_3^-$-N recovery in the Domino soil treated with $(NH_4)_2SO_4$ or urea.

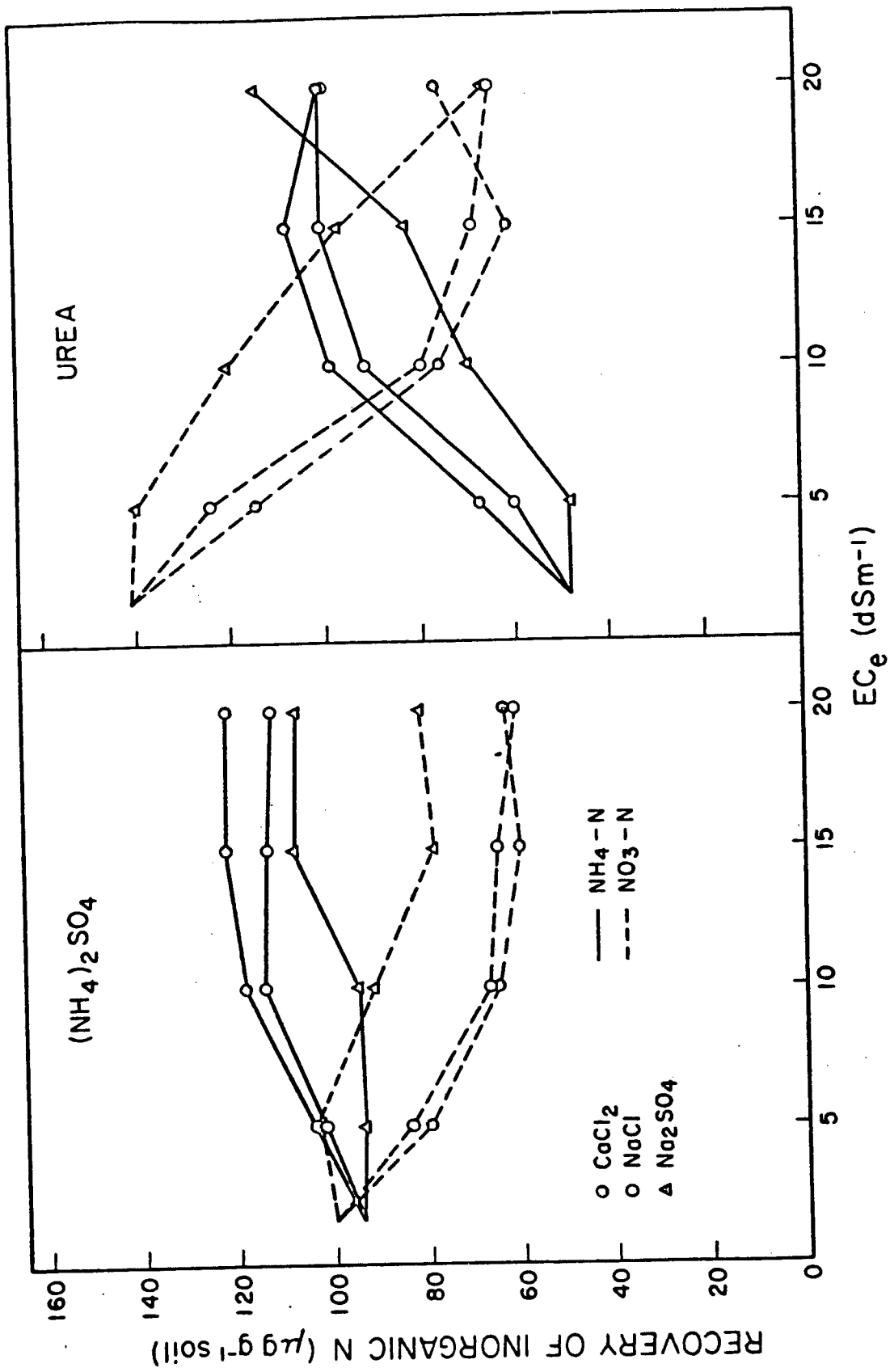


Figure 4. Effects of salinity on $NH_4^+$-N and $NO_3^-$-N recovery in the Fallbrook soil treated with $(NH_4)_2SO_4$ or urea.

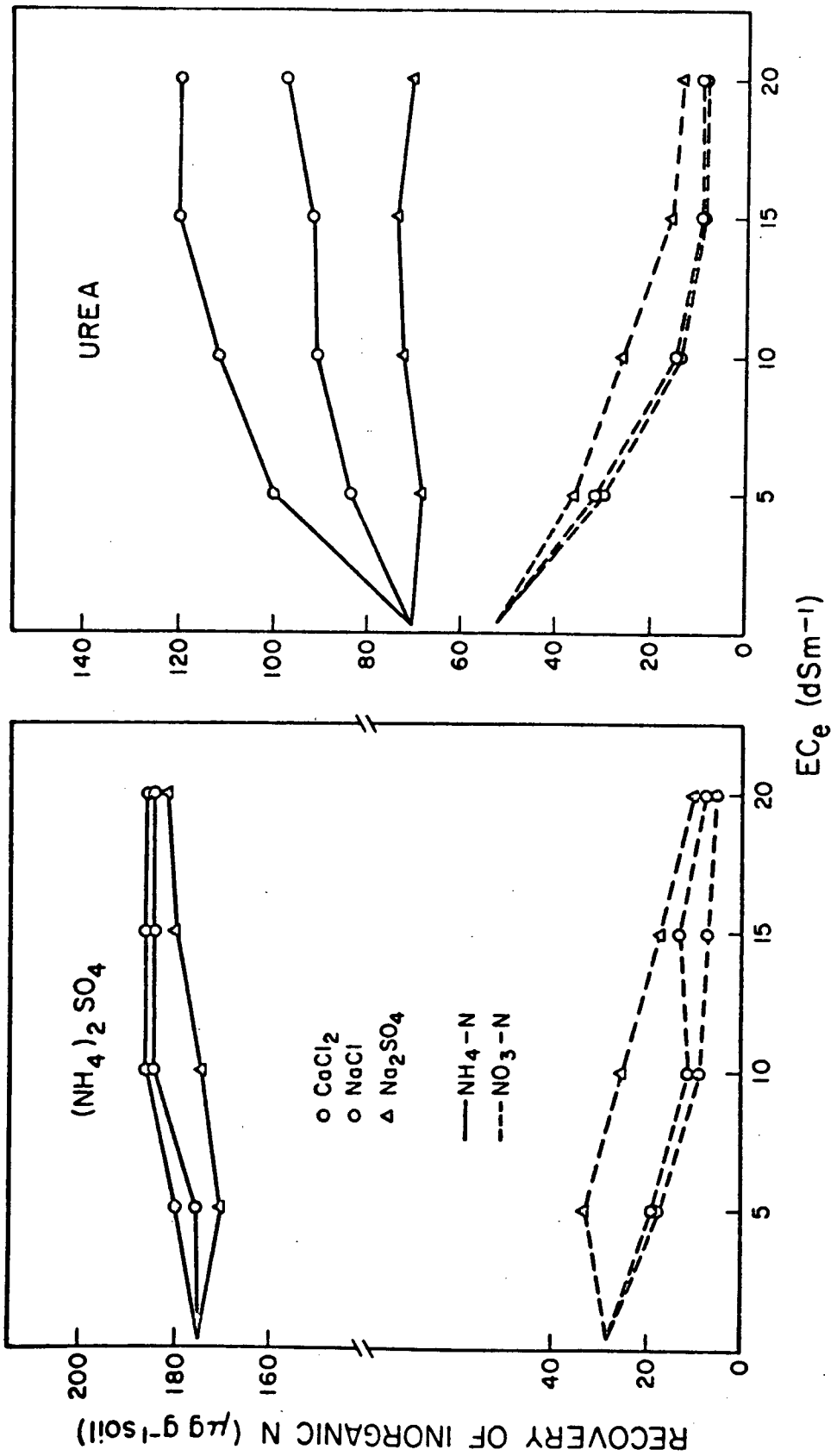


Figure 5. Effects of salinity on $NH_4^+$-N and $NO_3^-$-N recovery in the Hesperia soil treated with $(NH_4)_2SO_4$ or urea.

## D. Cooperation

The cooperation between the parties involved in this project was mainly in exchange of information and ideas and discussion of experimental results which took place mostly during meetings in Riverside and in Bet Dagan.

Nitrogen transformations in soil have been investigated by all parties but the general objective of the project has been divided into two main lines: The transformation of fertilizer N under different irrigation and fertilization practices or salinity of water added to soils was the main subject studied by the Riverside group. The Israeli group concentrated on studying the rate of soil N mineralization and nitrification as affected by soil depth and soil types receiving different previous agricultural management.

## E. Benefit to Agriculture

Basic knowledge on N transformation rates and its dependence on soil properties enables the prediction of nitrogen behavior in soil under different agricultural practices. Decisions to apply the proper amount of fertilizer, at the time it is required, are greatly improved when the contribution of available N from different soil layers, as a function of time, can be estimated by means of a chemical extract or a quick biological assay. The distribution of ammonium and nitrate with time and depth depends on the rate of nitrification, which has been investigated in different soil profiles as a function of soil properties and agricultural practices. Fertilizer use can be improved, minimizing $NH_4$ less by volatilization and $NO_3$ loss by leaching or denitrification, when knowing the $NH_4/NO_3$ distribution and its effect on soil For instance, urea ammonium nitrate applied by drip irrigation decreased soil pH, which might reduce $NH_4$ volatilization in alkaline soils and inhibit nitrification in neutral or acidic soils.