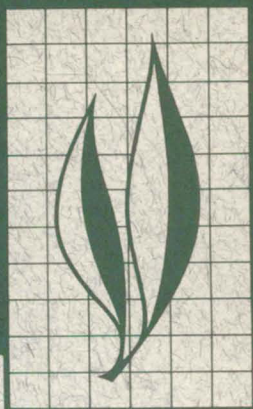


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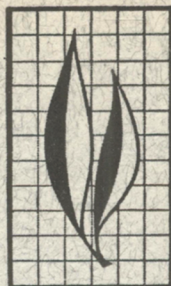


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Interchange Between Inorganic and Organic Nitrogen in Soils

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Immobilization of fertilizer nitrogen and mineralization of soil organic nitrogen were measured in three soils receiving ammonium sulfate or calcium nitrate labelled with the N^{15} tracer. In the presence of added straw deficient in nitrogen the rate of nitrogen immobilization was strongly temperature dependent, whereas the total quantity of nitrogen eventually incorporated in the organic fraction was little affected by temperature. Nitrifying bacteria were able to compete effectively for ammonium with the heterotrophic population in all three soils. Little remineralization of tagged nitrogen occurred, suggesting progressive stabilization of immobilized nitrogen.

Ammonium-nitrogen was immobilized in greater quantity than nitrate-nitrogen in all soils. An appreciable fraction of the ammonium-nitrogen was fixed within the crystal lattice of clay minerals in two of the soils. The data indicate that this clay-fixed ammonium was completely unavailable to nitrifying bacteria or other microorganisms.

Absolute mineralization and immobilization rates were calculated for periods of maximum activity at the beginning of the experiments. The highest mineralization rate observed was 12 ppm nitrogen per day, compared with a concurrent immobilization rate of 16 ppm per day.

The data indicate that turnover rates of soil organic nitrogen are relatively low, and suggest that when nitrogen fertilizers are applied, part of the nitrogen remains unavailable to plants for many years.

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Interchange Between Inorganic and Organic Nitrogen in Soils^{1, 2}

INTRODUCTION

The availability of soil nitrogen to microorganisms and plant roots is controlled by the relative magnitude of opposing processes—those which make nitrogen less available, and those which produce more available nitrogen.

Among the processes which contribute to decreased availability are immobilization (conversion of inorganic nitrogen to organic forms and ammonium fixation (whereby ammonium ions are rendered inaccessible to soil microorganisms and plant roots)).

On the other hand, the supply of available nitrogen is increased by mineralization (the breakdown of organic forms of nitrogen and liberation of ammonia through the activities of microorganisms).

The interchange between inorganic and organic forms of nitrogen in soils has been understood in a general way for many years. Since both immobilization and mineralization result primarily from the activities of microorganisms, the supply of energy material is an important consideration, particularly the relative proportions of available carbon

and nitrogen. Unfortunately, it has not been possible thus far to progress much beyond an empirical understanding of the relationship between carbon: nitrogen ratios and net changes in inorganic nitrogen levels in soil.

The investigation reported here examines in some detail the interchange between inorganic and organic soil nitrogen under a variety of conditions and in soils of widely differing properties. This examination was facilitated by use of the stable isotope of nitrogen, N^{15} , as a tracer. Tagged nitrogen added to soils in the inorganic form could thus be identified in various fractions of organic matter as interchange occurred.

Previous findings from our laboratory (Broadbent and Tyler, 1962) have emphasized certain differences with the work of Jansson (1958) who also utilized tracer nitrogen to study immobilization-mineralization relationships. The present work provides detailed information on nitrogen turnover in a few California soils, but these observations may not be applicable to soils of different character.

EXPERIMENTAL

Effect of soil temperature on nitrogen interchange.

Because the rate of most biological reactions depends on temperature, ni-

trogen transformations were studied at four temperatures—45°, 75°, 90°, and 110° F—in an attempt to see what happened in slow motion as well as at accelerated rates. The soils used were: Aiken

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clay loam, a Red Podzolic soil derived from basic igneous rocks taken from a site in coniferous forest; Altamont clay loam, a Chernozem, taken from rolling upland in native grasses; and Columbia fine sandy loam, a non-calciic Brown alluvial soil taken from a field under cultivation.

Incubation procedure

Fifty-gram samples of soil and 0.5 gm of ground barley straw were weighed into small flasks and thoroughly mixed. Tagged $(\text{NH}_4)_2\text{SO}_4$ or $\text{Ca}(\text{NO}_3)_2$ equivalent to 100 ppm nitrogen, soil basis, was added in sufficient water to bring each sample to a moisture content approximating field capacity. The samples were incubated in controlled-temperature chambers where they were slowly aerated with a stream of air saturated with water vapor to prevent drying of the samples. At the desired time intervals samples were removed from the incubator for analysis.

Determination of inorganic nitrogen

Inorganic nitrogen was extracted by shaking the 50-gm soil sample with 50 ml of N KCl for 30 minutes, and then transferring the suspension to a Buchner funnel. The soil sample was washed with an additional 100 ml of KCl. Ammonia nitrogen in the filtrate was determined by steam distillation with MgO, after which Devarda's alloy was added and the distillation continued with a separate receiver for nitrate determination. Ammonia was collected in 2 per cent boric acid and titrated with N/10 HCl. Distillates were then redistilled

into an equivalent amount of H_2SO_4 . The resulting ammonium sulfate was degraded under vacuum by admitting sodium hypobromite, and the N^{15} content of the evolved nitrogen gas was determined in a mass spectrometer.

Hydrolysis of organic fraction

The extracted soil samples were vacuum dried at 40°C , and organic nitrogen was determined by a semimicro Kjeldahl procedure.

Twenty grams of the soil were refluxed for 16 hours with 6 N HCl and then filtered. Ammonia nitrogen in the hydrolyzate was determined by steam distillation with MgO, and total nitrogen was determined on a separate aliquot by a Kjeldahl procedure after water and HCl were evaporated off. Total nitrogen was also determined in the non-hydrolyzable soil residue. N^{15} content of all fractions was determined as described previously.

Clay-fixed ammonium

To provide a complete accounting of the tracer nitrogen added to the soil samples in the ammonium form it was necessary to determine how much ammonium was trapped within the crystal lattice of clay minerals. This was done by the procedure of Dhariwal and Stevenson (1958) which involves solution of most of the organic matter with hot potassium hydroxide (KOH), after which the clay minerals are destroyed by treatment with hydrofluoric acid (HF). Ammonium released by the HF treatment was then steam-distilled into boric acid and its N^{15} content obtained by mass spectrometer analysis.

RESULTS

Changes in inorganic nitrogen

Ammonium sulfate added. Figure 1 shows the changes in inorganic forms of nitrogen at 45°F in Aiken, Altamont, and Columbia soils, where straw and

100 ppm N as $(\text{NH}_4)_2\text{SO}_4$ were added. In the Aiken and Altamont soils both total and tagged inorganic nitrogen decreased throughout the 60-day incubation period, indicating slow and gradual immobilization of nitrogen. Relatively

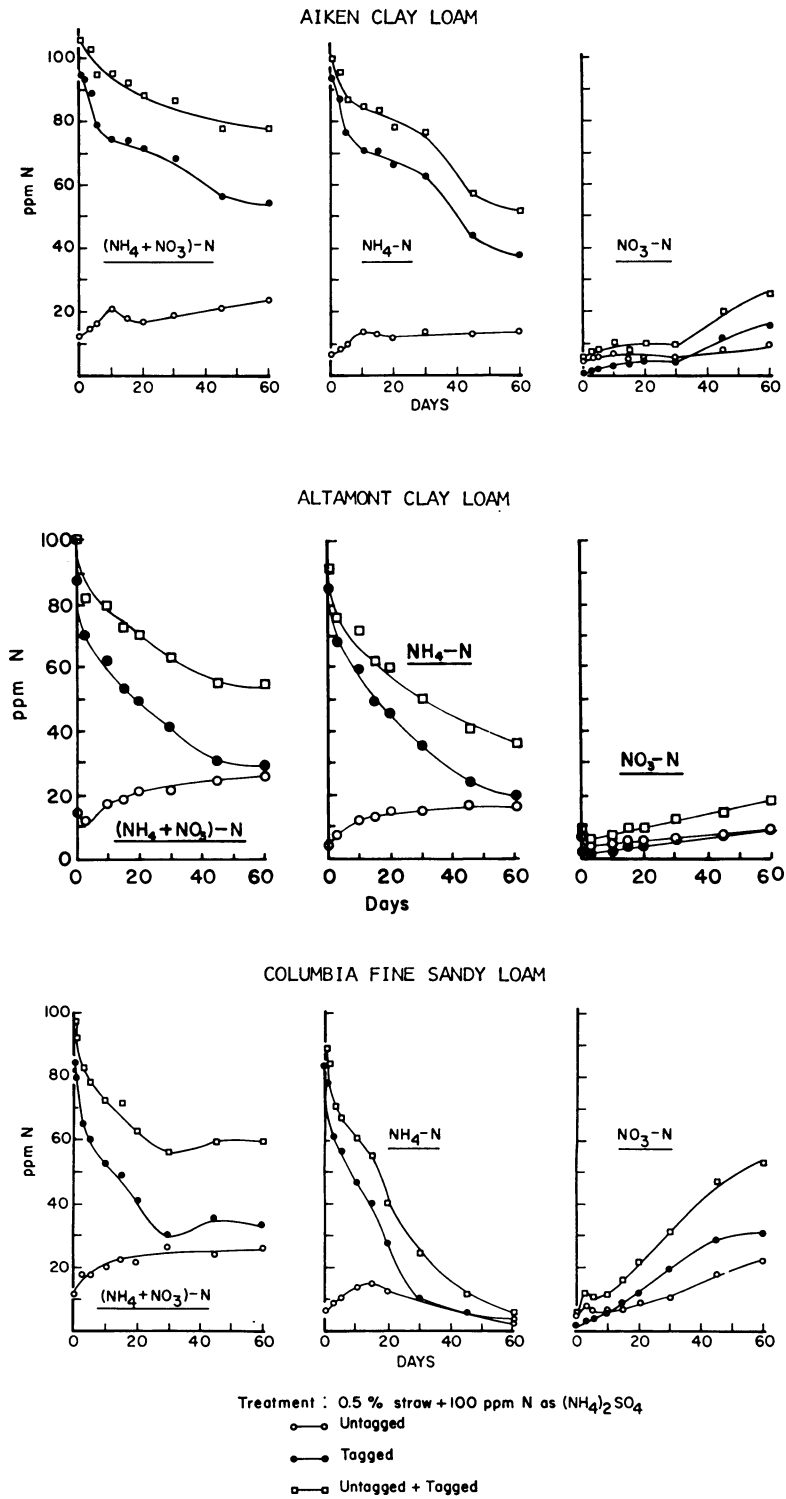


Fig. 1. Changes in inorganic nitrogen at 45°F in three soils receiving tagged ammonium sulfate.

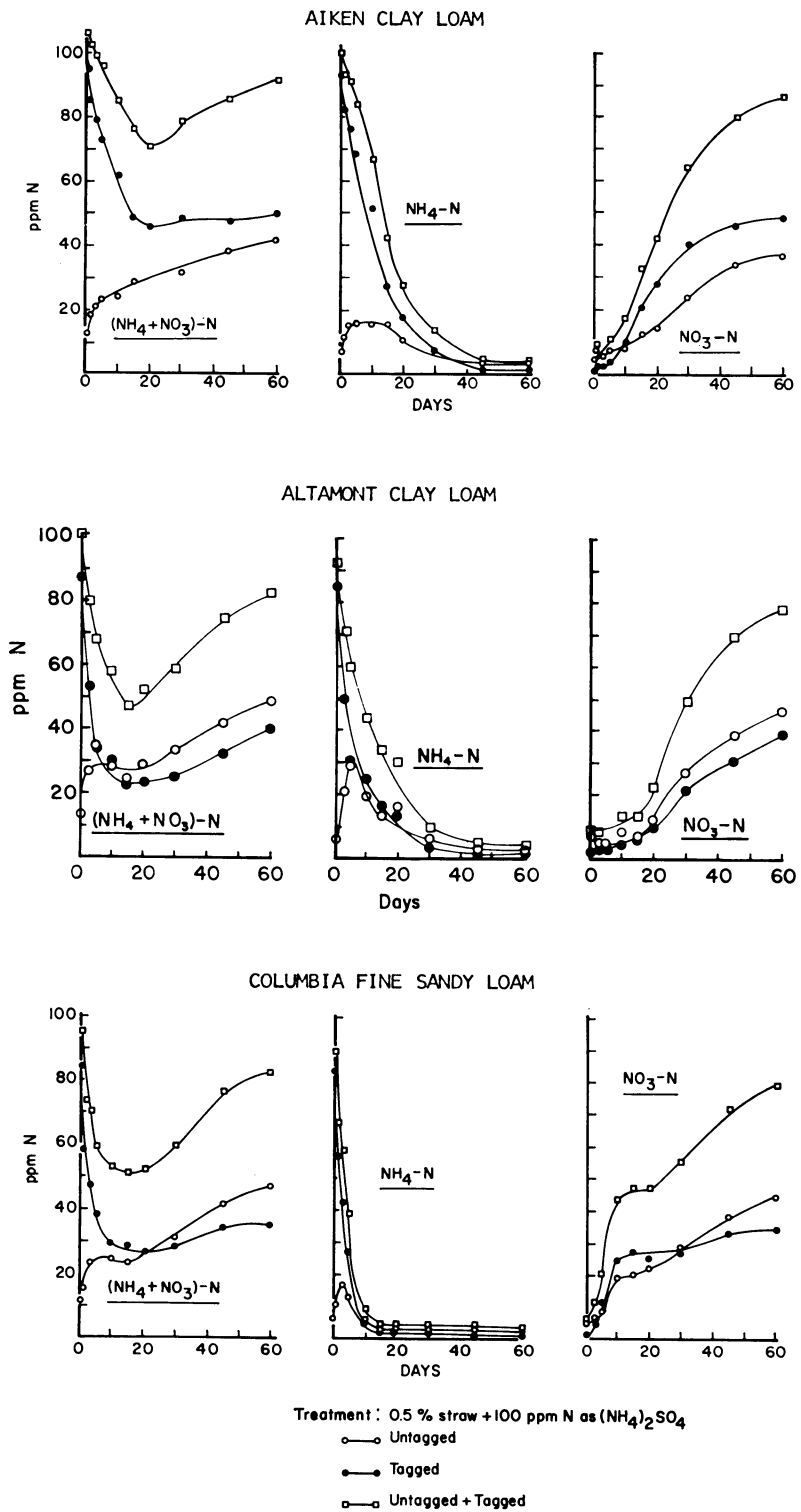


Fig. 2. Changes in inorganic nitrogen at 75°F in three soils receiving tagged ammonium sulfate.

little nitrification occurred in either soil at that temperature, and the observed decreases in ammonium were obviously due to immobilization and/or ammonium fixation. The behavior of Columbia fine sandy loam was somewhat different, in that total and tagged inorganic nitrogen leveled off at about 30 days. Nitrification was somewhat more rapid, as indicated by the formation of considerable nitrate and the reduction of ammonium nitrogen to low levels.

The quantity of untagged inorganic nitrogen mineralized was about the same in all three soils, reaching a value of 20 to 30 ppm at the end of 60 days incubation.

At 75° F the increased rate of biological activity produced several distinct differences in inorganic nitrogen changes. In all three soils (fig. 2) total inorganic nitrogen reached a minimum value at about 15 days, and then began to increase, indicating that rate of mineralization was greater than that of immobilization. The minimum value in all cases was lower at 75° F after 15 days than after 60 days at 45° F. In the Aiken and Columbia soils tagged inorganic nitrogen showed relatively little change after 15 days with only a small amount of remineralization of immobilized nitrogen, whereas in Altamont clay loam remineralization was of significant magnitude. Ammonium nitrogen disappeared rapidly, particularly in Columbia fine sandy loam. This was due to incorporation in the organic fraction by microbial assimilation, fixation by clay minerals, and rapid nitrification, as shown by the nitrate curves. The contribution of untagged inorganic nitrogen in the three soils was again comparable, and nearly double that at 45° F.

At 90° F (fig. 3) interchange of inorganic and organic nitrogen was still more rapid, with total inorganic nitrogen values reaching a minimum in about 10 days, followed by a rapid increase, particularly in Altamont clay loam. The organic nitrogen mineralized was derived primarily but not entirely from

untagged sources. In the Altamont soil after 60 days' incubation, inorganic nitrogen exceeded that added at the beginning, although only about one-third of the tagged nitrogen initially added was in the inorganic form at the end. In Aiken clay loam nitrification was somewhat inhibited by high (90° F) temperature (fig. 7) since the nitrification rate was lower than at 75°.

At 110° F (fig. 4) the effect of high temperature on nitrification was clearly manifest; nitrate production in Altamont and Columbia soils was greatly retarded. These data provide information on immobilization of an ammonium source of nitrogen without the complicating factor of simultaneous nitrification, and differ in several respects from those obtained at lower temperatures. The minimum values for total inorganic nitrogen were much higher, partly at least because of the more rapid mineralization of untagged organic nitrogen; the minimum values of tagged inorganic nitrogen were about the same as at 90° F. Decreases in tagged and total inorganic nitrogen up to 20 days, in Altamont clay loam, (fig. 4) are in sharp contrast to the abrupt decrease up to 5 days at 90° F followed by a rapid increase (fig. 3).

Calcium nitrate added. Where tagged calcium nitrate was supplied as a source of nitrogen for organisms decomposing added straw, the results were somewhat different from those obtained with ammonium sulfate. In these experiments, ammonium fixation by clays and nitrification of the added nitrogen were avoided.

Changes in nitrate nitrogen at three temperatures are shown in fig. 5. Three observations appear pertinent: (1) Qualitatively, the effects of temperature on inorganic nitrogen changes were similar to those obtained with ammonium sulfate. (2) The minimum values for inorganic nitrogen were always lower where ammonium was provided than where nitrate was the nitrogen source. (3) The quantity of un-

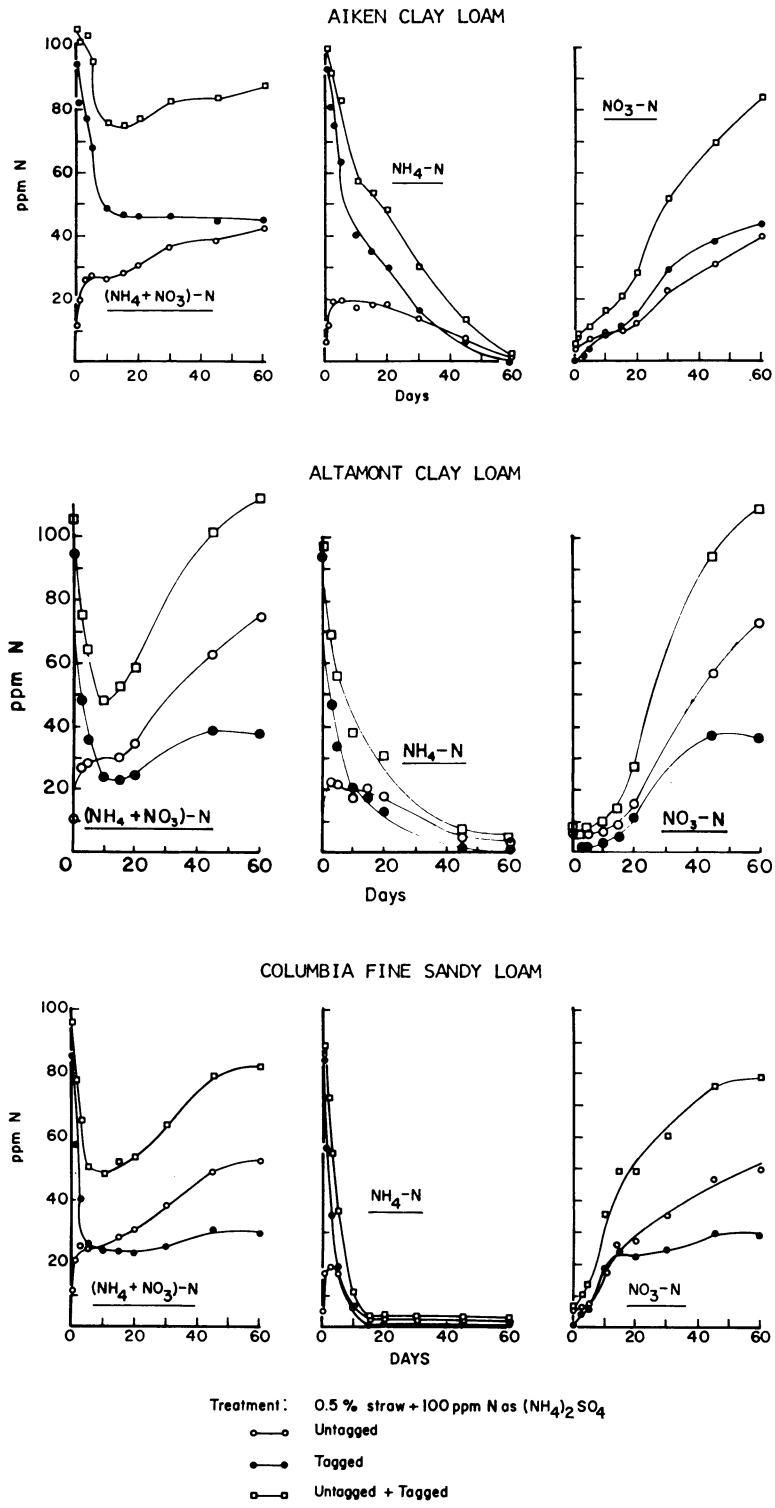


Fig. 3. Changes in inorganic nitrogen at 90°F in three soils receiving tagged ammonium sulfate.

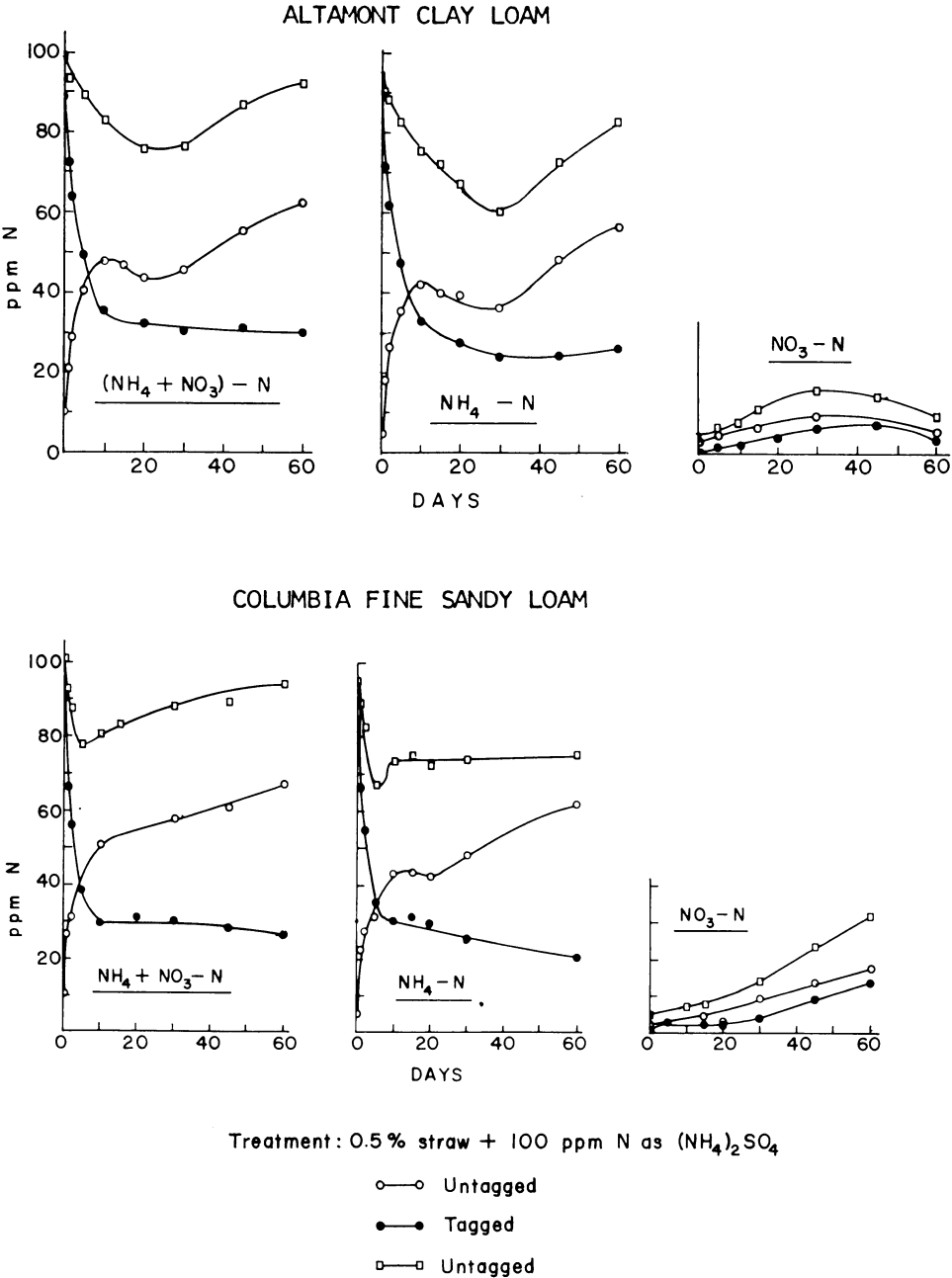


Fig. 4. Changes in inorganic nitrogen at 110°F in two soils receiving tagged ammonium sulfate.

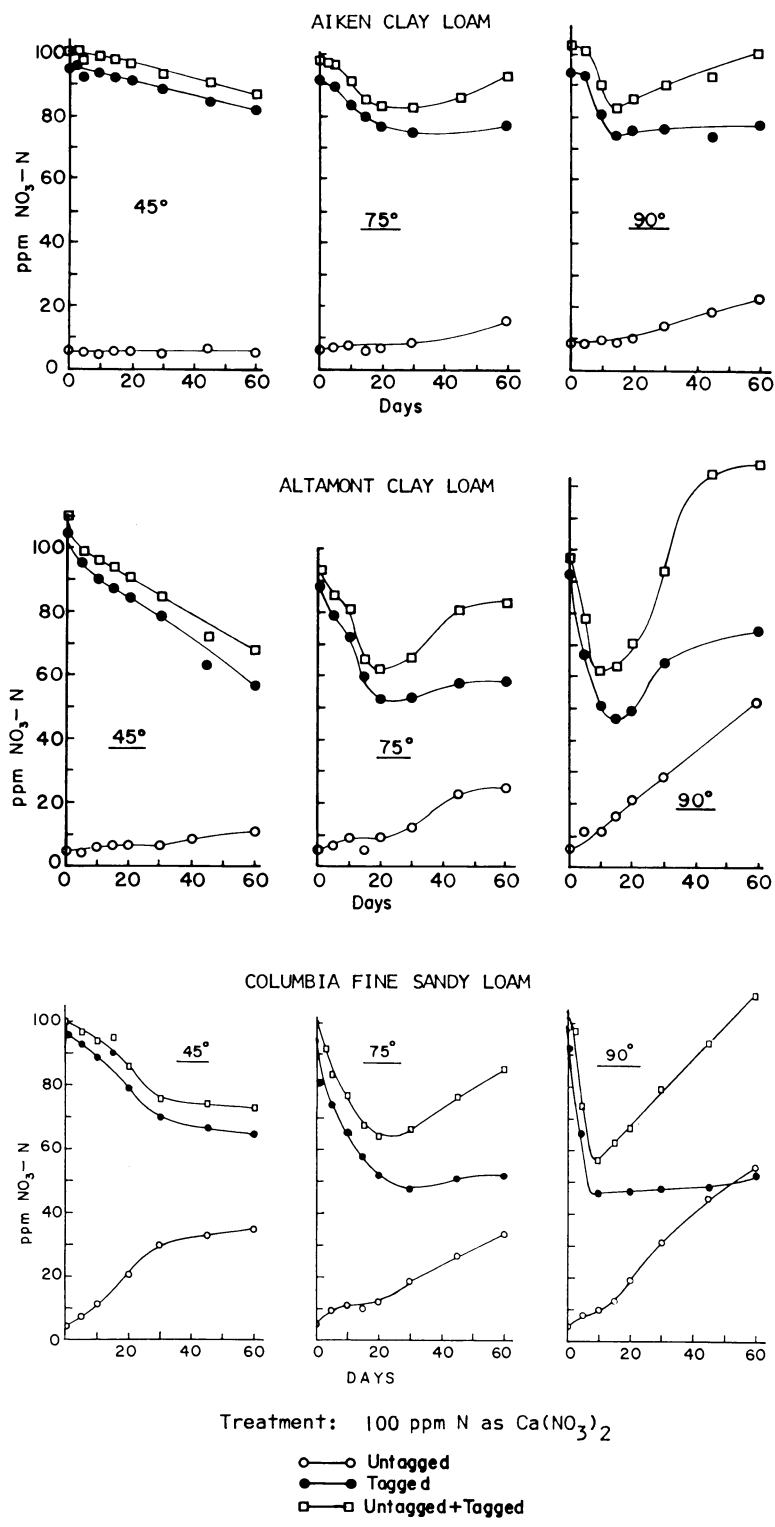


Fig. 5. Nitrate-nitrogen changes in three soils receiving 100 ppm N as tagged calcium nitrate.

tagged nitrogen mineralized, with the single exception of Columbia fine sandy loam at 45° F, was greater in the ammonium sulfate treatments. This stimulating effect of tagged fertilizer nitrogen on release of untagged nitrogen, first reported by Broadbent and Norman (1946) and subsequently referred to as a priming effect by some investigators (Bingeman *et al.*, 1953) appears to be related not only to the quantity but also the kind of tagged nitrogen supplied. Reasons for this so-called priming effect will be discussed in detail in another paper.

The incorporation of some tagged nitrate into the organic fraction is evidence that nitrate is not outside the pathway of the internal nitrogen cycle as Jansson (1958) has suggested.

Tagged organic nitrogen

Quantities of added nitrogen immobilized in these experiments are best shown by tagged nitrogen in the organic fraction, data for which are shown in figures 6, 7, and 8. In the cases of Altamont and Columbia soils, the total nitrogen values (figs. 7 and 8) have been corrected by subtracting the clay-fixed ammonium, which is determined along with organic nitrogen in the Kjeldahl procedure. The quantity of tagged fixed ammonium in Aiken clay loam was negligible.

The organic nitrogen curves support the deductions previously made from inorganic nitrogen data showing the effect of temperature on both quantity and rate of nitrogen immobilization. Some remineralization of tagged nitrogen clearly occurred at 75° F and above in the Altamont and Columbia soils. These curves emphasize the preferential use of ammonium nitrogen by the soil population, although the differences between ammonium and nitrate decreased with increasing temperature in the Columbia and Altamont soils.

Values for ammonia nitrogen in the organic matter hydrolyzates were cor-

rected for clay-fixed ammonium, because it was found that virtually all of the tagged ammonium fixed by clays was removed by the 16-hour hydrolysis treatment with 6 N HCl. The curves in figures 6, 7, and 8 show that little change occurred in the ammonia fraction of the hydrolyzates after the first few days, and that the proportion of the total organic nitrogen in this form was relatively small although larger in the ammonium sulfate than in the calcium nitrate treatments. As pointed out by Stevenson (1957), the origin of this hydrolyzable ammonia is uncertain, but derives in part from amides and amino sugars.

The bulk of the tagged organic nitrogen was in the amino form, as would be expected under conditions favoring biological assimilation. In general these curves resemble those for "non-distillable acid soluble N" reported by Stewart *et al.* (1963). Small quantities of tracer nitrogen were found in the nonhydrolyzable residue of soils refluxed with 6 N HCl. Some representative values are presented in table 1. The gradual incorporation of added nitrogen into this resistant fraction suggests a form of reversion, or progressive stabilization of soil nitrogen.

Clay-fixed ammonium

Almost immediately after addition of tagged ammonium sulfate to the Altamont and Columbia soils, some of it was detected in the clay-fixed fraction (table 2). This usually reached a maximum in 1 to 3 days, and remained essentially unchanged thereafter, indicating that it was not available either to the nitrifying bacteria or to heterotrophic organisms decomposing the added straw. For example, in Columbia fine sandy loam at 75° F the tagged exchangeable ammonium decreased from 83 to 1.5 ppm in 15 days and remained at about 1 ppm thereafter, whereas tagged clay-fixed ammonium was 16.9 ppm at 15 days, with no further decrease up to 60 days.

AIKEN CLAY LOAM

□ Total Organic N ● Amino N ○ Ammonia N

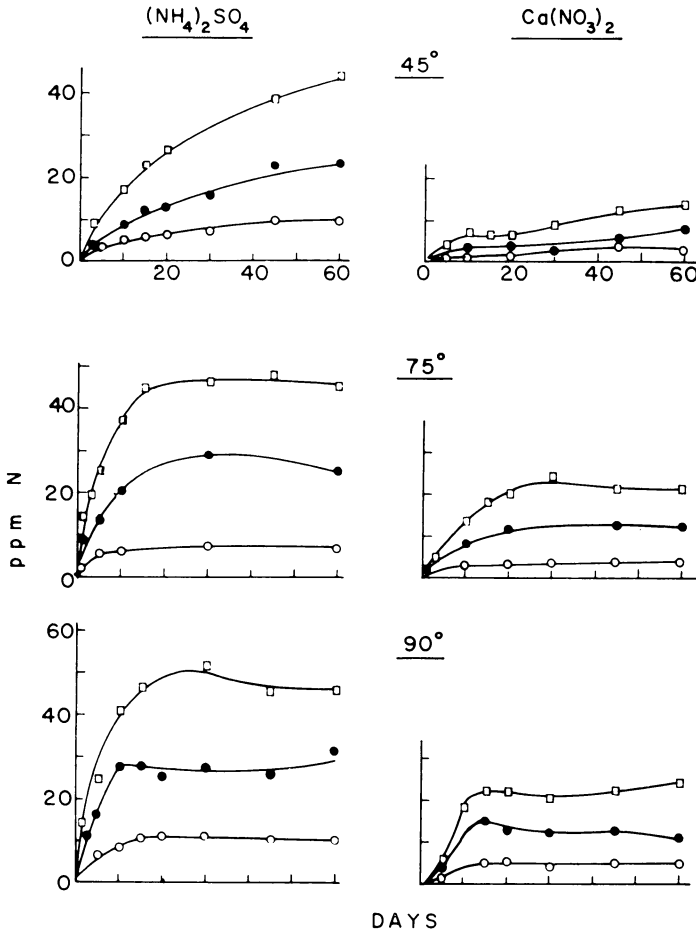


Fig. 6. Tagged organic nitrogen in Aiken clay loam.

Analysis of the soil residues for clay-fixed ammonium after hydrolysis with 6 N HCl revealed that somewhat more than half the total clay-fixed ammonium was removed by the hydrolysis treatment, but virtually none of the tagged ammonium remained. This suggests that the most recently fixed ammonium, of tracer origin, was less firmly held within the clay crystal lattice.

All of the Aiken soil samples were analyzed for clay-fixed ammonium, and values ranging from 35 to 48 ppm

nitrogen were obtained. In no case, however, was the tagged nitrogen in this fraction greater than a few tenths of a part per million. Similarly, only negligible amounts of clay-fixed ammonium from tracer sources were found in the Altamont and Columbia sources receiving tagged calcium nitrate.

Overall recovery of tracer nitrogen

In tracer experiments dealing with interchange between inorganic and or-

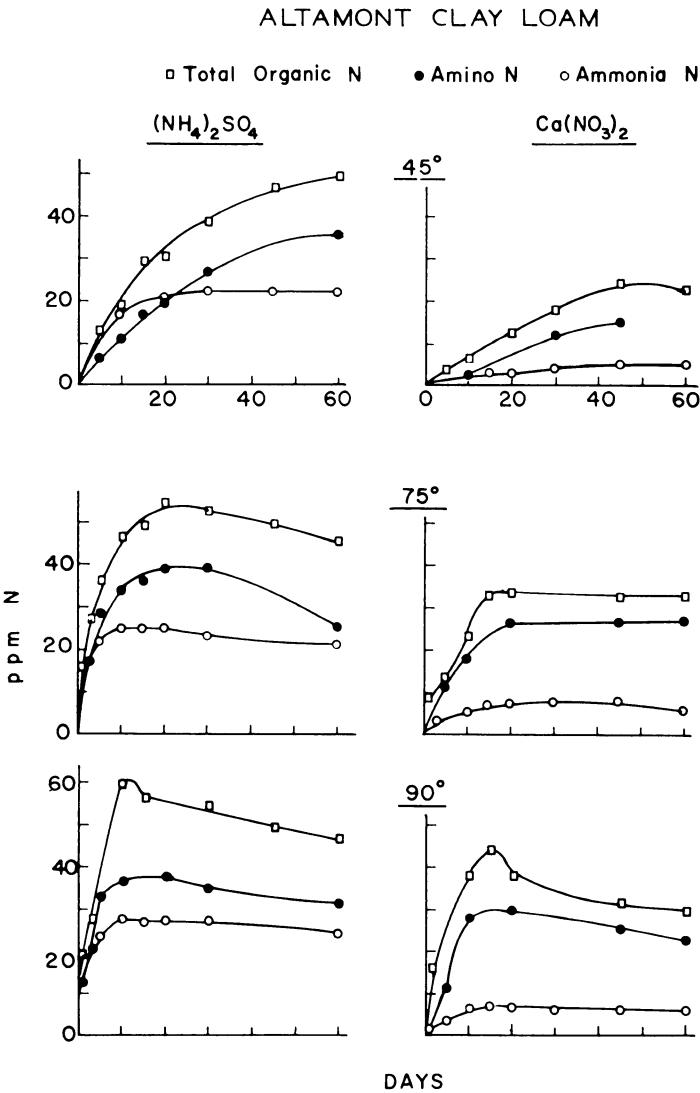


Fig. 7. Tagged organic nitrogen in Altamont clay loam.

ganic forms of nitrogen it is essential to provide a complete accounting of tracer nitrogen in the system. This serves as a check on the reliability of the analytical procedures and indicates whether losses are taking place.

Data given in table 3 show that recovery of tracer nitrogen was better than 90 per cent in most instances, although some of the values for longer incubation periods clearly indicate small losses, probably as a result of denitrification. No attempt was made

in these experiments to measure gaseous losses of nitrogen directly.

Rates of mineralization and immobilization

Where two opposing processes are proceeding simultaneously, as in the case of mineralization and immobilization, it is of interest to consider actual turnover rates, as well as net changes of inorganic and organic nitrogen. In tracer systems of the kind used in these experiments, calculation

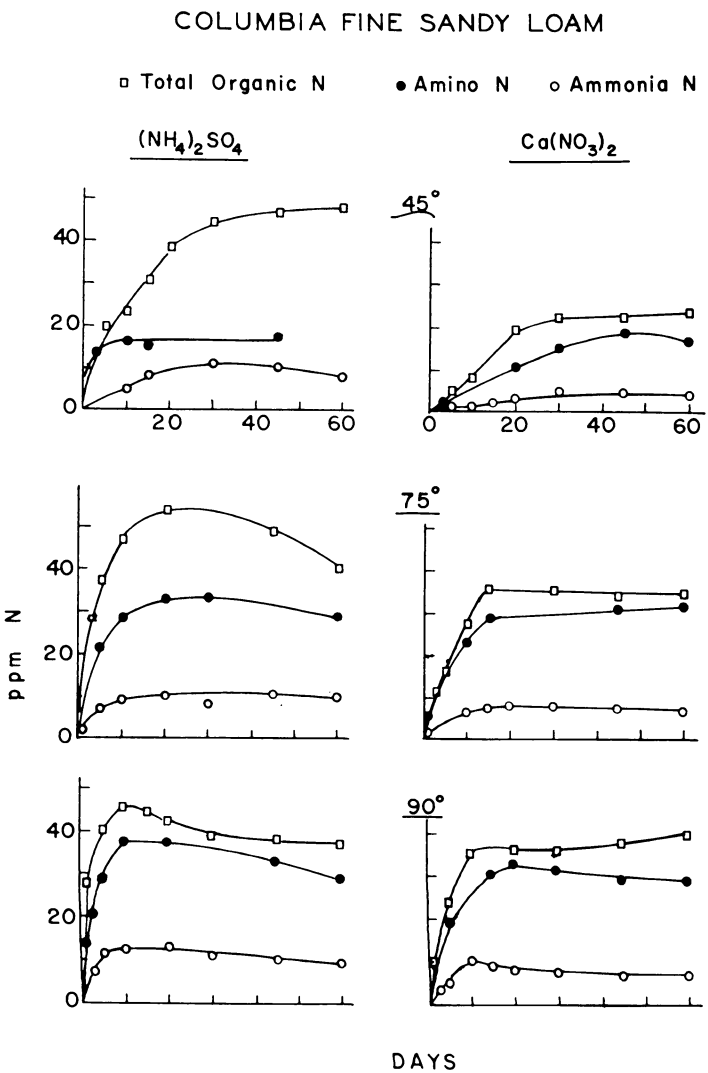


Fig. 8. Tagged organic nitrogen in Columbia fine sandy loam.

of mineralization and immobilization rates can be made by using the equations of Kirkham and Bartholomew (1955), provided the basic assumptions used in deriving the equations are valid for the system in question. Their equations are derived from the differential equations:

$$\frac{dx}{dt} = m - i,$$
$$\text{and } \frac{dy}{dt} = \left(\frac{b - y}{a - x} \right) m - \frac{y}{x} i$$

where x = total inorganic (available) N
 t = time
 m = mineralization rate
 i = immobilization rate
 y = tagged inorganic N
 a = total N in system
 b = total tagged N

In their case 1, these authors obtained particular solutions by assuming that mineralization and immobilization rates are constant. This assumption is applicable to any system if the time periods taken are sufficiently

TABLE 1
TAGGED NITROGEN IN THE NONHYDROLYZABLE FRACTION OF THREE SOILS
AT VARIOUS INCUBATION TIMES AND TEMPERATURES

Soil type and days after incubation	Tagged nonhydrolyzable N					
	(NH ₄) ₂ SO ₄ added, at:			Ca(NO ₃) ₂ added, at:		
	45°F	75°F	90°F	45°F	75°F	90°F
	<i>ppm</i>					
Aiken clay loam:						
5.....	2.0	3.6	5.2	0.7	2.4	1.7
10.....	2.1	5.8	9.6	2.0	2.7	2.6
30.....	5.0	7.4	11.7	0.8	4.1	3.8
60.....	6.4	8.2	11.4	2.3	6.0	4.5
Altamont clay loam:						
5.....	3.7	1.6	4.2	...	2.4	2.1
10.....	3.9	4.9	...	...	2.3	3.8
30.....	3.6	4.9	3.1	...	3.3	...
60.....	3.9	3.2	2.8	...	3.7	...
Columbia fine sandy loam:						
5.....	1.6	2.9	3.0	1.3	3.8	4.1
10.....	1.7	3.8	6.0	...	4.1	3.5
30.....	3.4	5.2	4.0	5.7	5.0	4.3
60.....	3.6	4.6	4.4	...	4.5	3.0

short, but obviously does not hold for the entire duration of experiments such as those described here. A plot of

TABLE 2
CLAY-FIXED AMMONIUM DERIVED
FROM ADDED (NH₄)₂SO₄ IN TWO SOILS
AT VARIOUS INCUBATION TIMES
AND TEMPERATURES

Soil type and days after incubation	Clay-fixed N		
	45°F	75°F	90°F
	<i>ppm</i>		
Altamont clay loam:			
1.....	10.7	....	14.8
3.....	17.4	14.0	16.0
5.....	13.5	14.7	16.3
10.....	14.2	15.7	16.7
15.....	14.4	14.9	16.4
20.....	13.2	14.6	16.1
30.....	14.4	12.8	16.3
45.....	14.0	12.7	13.7
60.....	12.6	....	13.6
Columbia fine sandy loam:			
1.....	10.8	17.3	....
3.....	16.7	....	21.4
5.....	17.0	18.2	19.9
10.....	16.9	17.3	18.1
15.....	17.1	16.9	16.1
20.....	16.6	16.7	17.4
30.....	17.2	17.7	17.9
45.....	16.1	16.3	18.7
60.....	16.3	16.5	18.0

inorganic nitrogen against time should be linear if the assumption is valid. An inspection of the data in figures 1 to 4 shows that several of the curves have segments which are linear or nearly so, particularly during the first few days of rapid immobilization. Mineralization and immobilization rates were calculated according to the equations:

$$m = \frac{x - x_o}{t} \cdot \frac{\log_e \left[\left(\frac{y}{b} - \frac{x}{a} \right) \left(\frac{xy_o}{bx_o} - \frac{x}{a} \right) \right]}{\log_e \left(\frac{x_o}{x} \cdot \frac{a - x}{a - x_o} \right)}$$

$$i = m - \frac{x - x_o}{t}$$

Table 4 gives some values for m and i for time periods during which x was linearly related to t , or nearly so. Rates of nitrogen interchange during the first few days of incubation were much higher than they were after microbial activity had subsided. Although the quantity of tagged nitrogen incorporated into the organic fraction of Columbia fine sandy loam was greater at 90° than at 110° F actual rates of mineralization and immobilization were higher at 110° F. In Altamont clay loam the maximum

TABLE 3
RECOVERY OF TRACER NITROGEN IN THREE SOILS AT VARIOUS
INCUBATION TIMES AND TEMPERATURES

Soil types and days after incubation	100 ppm (NH ₄) ₂ SO ₄ added, at:				100 ppm Ca(NO ₃) ₂ added, at:			
	45°F	75°F	90°F	110°F	45°F	75°F	90°F	110°F
	<i>per cent</i>							
Aiken clay loam:								
0.....	101	101	101	...	97	...	...	...
5.....	96	98	93	...	96	98	100	...
10.....	91	98	90	...	101	98	99	...
20.....	98	...	93	...	98	98	99	...
30.....	94	94	98	...	98	101	98	...
60.....	98	95	91	...	98	100	102	...
Altamont clay loam:								
0.....	98	98	105	95	...	...	103	...
5.....	96	...	85	98	101	95	85	...
10.....	96	92	101	90	98	98	90	...
20.....	93	93	...	96	98	88	88	...
30.....	95	91	...	94	97	...	...	...
60.....	91	94	98	92	82	99	...	...
Columbia fine sandy loam:								
0.....	102	102	98	96	97	...	100	...
5.....	97	93	87	99	99	91	90	...
10.....	93	94	89	94	98	94	83	...
20.....	96	97	84	...	100	87	84	...
30.....	91	93	83	97	94	85	85	...
60.....	98	90	85	97	90	87	93	...

TABLE 4
RATES OF NITROGEN MINERALIZATION AND
IMMOBILIZATION IN THREE (NH₄)₂SO₄-TREATED SOILS,
CALCULATED FROM THE EQUATIONS OF KIRKHAM
AND BARTHOLOMEW (1955)

Soil	Incubation temp.	Time	Mineralization rate	Immobilization rate
	<i>°F</i>	<i>days</i>	<i>ppm N/day</i>	<i>ppm N/day</i>
Aiken clay loam	45	0-10	0.76	1.82
	75	0-15	2.15	4.13
	90	0-10	2.97	6.01
Altamont clay loam	45	0-10	0.93	3.0
	75	0-5	10.1	16.6
	75	5-15	0.14	2.23
	90	0-10	4.78	10.5
	110	0-10	0.74	2.34
Columbia fine sandy loam	45	0-3	3.55	7.82
	45	3-15	0.99	1.89
	75	0-5	5.29	12.4
	75	30-45	0.62	-0.71
	90	0-5	5.58	14.7
	90	5-10	0.35	0.71
	110	0-5	11.6	16.2
	110	5-10	6.2	5.6
	110	10-30	0.42	0.1
	110	30-60	0.81	0.60

turnover rates were observed at 90° F.

Application of the Kirkham and Bartholomew (1955) equations to data obtained in the latter part of the incubation period occasionally yielded negative values for i , although these were small in magnitude. This indicates that the biological events taking place were not in strict conformance with these equations. Kirkham and Bartholomew's

case 2 solution, based on the assumptions that mineralization rate is proportional to tagged organic nitrogen and immobilization rate is proportional to tagged inorganic nitrogen was not found to be applicable to these data. A major difficulty with this solution is that m and i asymptotically approach a common value, whereas in reality m often exceeds i .

DISCUSSION

Although generalizations cannot safely be based on experiments with only three soils, the findings reported here may have value in contributing to an understanding of the soil nitrogen cycle and in predicting changes which may be expected when fertilizer nitrogen is applied under a variety of conditions.

Effect of soil temperature on nitrogen transformations

In the presence of added straw deficient in nitrogen, the rate of nitrogen immobilization strongly depended on temperature, but temperature little affected the quantity of fertilizer nitrogen ultimately incorporated in the organic fraction. Nitrification was inhibited both at 45° and 110° F, but was of appreciable magnitude at both extremes. In all three soils the nitrifying bacteria were able to compete effectively with the heterotrophic population for ammonium (at 75° and 90° F), as evidenced by the production of tagged nitrate.

Except for the Altamont clay loam at 75° and 90° F, there was little remineralization of tagged nitrogen once it was incorporated into the organic fraction. Quantities of untagged nitrogen mineralized, however, increased with increasing temperature up to 90° F. Absolute mineralization and immobilization rates reached their maximum at temperatures which varied somewhat among the three soils.

Fate of applied fertilizer

In considering the transformations

which may occur when ammonium fertilizers are added to soils, it is clear that an appreciable fraction may be fixed almost immediately by clay minerals in soils containing vermiculite and related minerals. Although Allison *et al.* (1953) reported that clay-fixed ammonium in isolated vermiculite can be utilized readily by nitrifying bacteria, and that this form of ammonium in soils was slowly nitrified, there is little if any indication in these experiments that clay-fixed ammonium is available to microorganisms. Analyses of soils incubated 120 days (unpublished data), indicate no change in clay-fixed ammonium during that period.

The incorporation of fertilizer nitrogen into the organic fraction may likewise be quite rapid, but once in the organic form, it is not readily released again. Most of the organic nitrogen derived from an inorganic source may be accounted for in the amino form, and as such may eventually be remineralized. However, some of it appears to undergo progressive stabilization, as indicated by plant recovery data reported elsewhere (Broadbent and Nakashima, 1965). Slow remineralization of tagged organic nitrogen in these incubation experiments tends to support this idea.

Of particular interest are the differences between ammonium and nitrate fertilizers with respect to the quantity of nitrogen immobilized, which appears to be caused chiefly by the preference of soil microorganisms for ammonia nitrogen. The quantity of ammoniacal fer-

tilizer incorporated into the organic fraction in a given situation will therefore depend in part on the rate at which it is converted to nitrate. In these experiments, nitrifying bacteria were able to compete effectively for ammonium with the heterotrophic flora.

These experiments indicate that when the equilibrium between inorganic and organic nitrogen in soils is altered by

addition of an organic amendment, an inorganic fertilizer, or both, interchange occurs quite rapidly for a short time and then stabilizes so that further changes are more gradual.

Both quantity and rate of nitrogen interchange depend not only on carbon: nitrogen ratios, but also on temperature, kind of inorganic nitrogen, activity of the nitrifying bacteria, nature of clay minerals, and other soil factors.

LITERATURE CITED

- ALLISON, F. E., E. M. ROLLER, and J. H. DOETSCH
1953. Ammonium fixation and availability in vermiculite. *Soil Sci.* **75**:173-80.
- BINGEMAN, C. W., J. E. VARNER and W. P. MARTIN
1953. The effects of the addition of organic materials on the biological decomposition of an organic soil. *Soil Sci. Soc. Amer. Proc.* **17**:34-38.
- BROADBENT, F. E., and T. NAKASHIMA
1965. Plant recovery of immobilized nitrogen in greenhouse experiments. *Soil Sci. Soc. Amer. Proc.* **29**: 55-60.
- BROADBENT, F. E., and A. G. NORMAN
1946. Some factors affecting the availability of the organic nitrogen in soil—a preliminary report. *Soil Sci. Soc. Amer. Proc.* **11**:264-67.
- BROADBENT, F. E. and K. B. TYLER
1962. Laboratory and greenhouse investigations of nitrogen immobilization. *Soil Sci. Soc. Amer. Proc.* **26**:459-62.
- DHARIWAL, A. P. S. and F. J. STEVENSON
1958. Determination of fixed ammonium in soils. *Soil Sci.* **86**:343-49.
- JANSSON, S. L.
1958. Tracer studies on nitrogen transformations in soil with special attention to mineralization-immobilization relationships. *Ann. Roy. Agr. Coll. Sweden* **24**:101-361.
- KIRKHAM, D. and W. V. BARTHOLOMEW
1955. Equations for following nutrient transformations in soil, utilizing tracer data. II. *Soil Sci. Soc. Amer. Proc.* **19**:189-92.
- STEVENSON, F. J.
1957. Distribution of the forms of nitrogen in some soil profiles. *Soil Sci. Soc. Amer. Proc.* **21**:283-87.
- STEWART, B. A., D. D. JOHNSON and L. K. PORTER
1963. The availability of fertilizer nitrogen immobilized during decomposition of straw. *Soil Sci. Soc. Amer. Proc.* **27**:656-59.

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