On the Content of Nitrogen (NH_4-N, and NO_3-N) in Atmospheric Precipitation

By ANDERS ÅNGSTRÖM and LINUS HÖGBERG
Swedish Meteorological and Hydrological Institute

(Manuscript received 21 February 1952)

Abstract

In treating a still limited material of observations on the content of nitrogen in precipitation, collected under the supervision of Dr Egnér of the Agricultural College at Uppsala, we have obtained some preliminary results, which may be summarized as follows:

The concentration of NH_4-N and NO_3-N in precipitation is dependent upon the amount of precipitation previously fallen.

A mathematical expression is given for the dependence of concentration on amount of precipitation fallen. With aid of this relation a computation has been made of the normal supply of nitrogen at Uppsala, using known normal frequencies of different amounts of precipitation.

A pronounced dependence of the concentration on the character of the air mass has been found to exist. Thus the tropical air contains between 10 and 30 per cent greater amount of nitrogen than the polar air, and almost double the amount found in the arctic air.

From an agricultural point of view the question concerning the composition of precipitation is an important one. On the basis of earlier available data it can easily be shown that the supply of plant nutrients in this way is not neglible. Thus the supply of nitrogen in the form of NH_4-N and NO_3-N in Sweden amounts to between 1 and 5 kg per ha[1], a quantity much smaller but yet comparable to that generally furnished in an artificial way in the cultivated districts.

The interest of agriculture in the question just mentioned was the chief reason why Messrs Torstenson and Egnér of the Agricultural College of Sweden took up the problem in 1947 for closer examination. They applied modern methods partly devised and developed by Egnér.

The problem has also, however, a geophysical side, which is not less interesting. The question regarding the presence and nature of condensation nuclei in the atmosphere is closely connected to the composition of the precipitation as regards dissolved salts. Their concentration and properties may be expected to throw some light on the difficult problem concerning the formation of clouds and rain in the atmosphere. Furthermore the composition of the rain may show some interesting relations to the general properties of the air masses from which it is falling. Do the different air masses—tropical, polar or arctic air—show some caracteristic differences as regards the condensation products arising within them?

On account of the importance of these questions from a geophysical point of view, the present authors were attached to the enterprise, at first to some extent for contributing to the organization of a synoptic net of measuring stations and later for treating the mate-

[1] ha is used as an abbreviation of "hektar" = 10^4 m^2.

rial of observations with regard to meteorological aspects.

According to the program the technical and agricultural side of the matter would be treated by Dr Egnér and his collaborators. In their work would be included also the question of the annual and geographical variation of the composition of the precipitation.

In the following we are adhering to this plan and will report on some theoretical and statistical results as regards the content of NH_4-N and NH_3-N in the precipitation in Sweden.

I. The observations

The samples of precipitation, considered in the following, were all taken at the Agricultural College at Ultuna (Lat N 59° 49′ Long E 17° 40′). The technical procedure is described in detail by Hans Egnér, Erik Eriksson and Arne Emanuelsson (1949). Ion exchange resins were used for the analysis of NH_4-N and NO_3-N. With them the precipitation could be filtered practically immediately, thus lessening very effectively the time of contact with dust, insects and pollen. Careful tests were made in order to clarify how completely and rapidly the ions were taken up by the filter. Special arrangements were devised in order to eliminate errors from contamination through bird dropping, pollen, insects etc.

The observations cover the period 1. 10. 1947—30. 9. 1950. The measurements of the composition refer to the different occasions of precipitation. Thus, values of the total content of NH_4-N and NO_3-N in a given rain or snowfall of longer or shorter duration are obtained. The result of our analysis will show the desirability of a more detailed investigation of the changes in composition with time in the separate cases of rain or snow. The observations treated here refer, however, only to the integral content in the different cases. In the total, 117 cases of precipitation have been examined.

II. Analysis

1. *Change of concentration of NH_4-N and NO_3-N with duration of precipitation.*

Already, a superficial examination of the values obtained show a rather marked dependence of concentration on duration.

From Table 1 and 2, which show the frequency distribution of the concentration of NH_4-N and NO_3-N in milligrams per liter (mg/l) and its dependence on the amount of precipitation, it is evident that the mean concentration of the total amount of precipitation is on the whole a decreasing function of the amount. It is consequently as if the precipitation drew its content of NH_4-N and NO_3-N from some source which is contributing less and less as the condensation and precipitation progresses. If we try to find a mathematical formula expressing the relation between the

Table 1. Frequency distribution of the mean concentration of NH_4-N (mg/l) for all air masses, given as a function of the total amount of precipitation

$\gamma_{NH_4\text{-}N}$ mg/l	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.00—0.19	4	3	2	6	5	3	—	3	—	2	1	1	—	—	1	—	1	32
0.20—0.39	5	10	6	7	5	1	3	1	1	—	—	1	—	—	—	—	—	40
0.40—0.59	4	5	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	12
0.60—0.79	7	3	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	14
0.80—0.99	3	4	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	9
1.00—1.19	1	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
1.20—1.39	3	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
1.40—1.59	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1.60—1.79	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	27	29	13	14	15	4	3	4	1	2	1	2	—	—	1	—	1	117

Table 2. Frequency distribution of the mean concentration of NO_3-N (mg/l) for all air masses given as a function of the total amount of precipitation

$\gamma_{NO_3\text{-}N}$ mg/l	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29,9	30.0—31.9	32.0—33.9	
0.00—0.09	4	8	2	3	6	2	—	2	—	—	1	1	—	—	—	—	1	30
0.10—0.19	10	9	7	8	5	2	3	2	1	2	—	1	—	—	1	—	—	51
0.20—0.29	5	5	1	2	2	—	—	—	—	—	—	—	—	—	—	—	—	15
0.30—0.39	3	5	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	10
0.40—0.49	1	1	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	5
0.50—0.59	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
0.60—0.69	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
0.70—1.09	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
1.10—1.19	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	27	29	13	14	15	4	3	4	1	2	1	2	—	—	1	—	1	117

total nitrogen amount supplied in kg per ha (s) and the amount of precipitation P up to the moment to which s refers, the simplest expression satisfying the general conditions indicated by the frequency tables seems to be:

$$s = \alpha \operatorname{logn} (1 + P) \qquad (1)$$

where α is a certain constant, the physical meaning of which will be clear from the following.

For the mean concentration in milligrams per liter of the substance (NH_4-N or NO_3-N) in the precipitation P, we get

$$\gamma = 100\,\alpha \frac{\operatorname{logn} (1 + P)}{P} \qquad (2)$$

The concentration σ in the falling precipitation at the moment, when the amount N has fallen is given by:

$$\sigma = 100 \cdot \frac{ds}{dP} = \frac{100\,\alpha}{1 + P} \qquad (3)$$

σ is here the concentration of the special ions in the precipitation falling at any given moment. As is seen from (3) σ decreases rather rapidly with an increase of P. Thus, for instance when 1 mm rain has fallen, σ has only half of the value which it had just at the beginning of the rain.

The observations available to us are not sufficient to justify more detailed conclusions regarding the mathematical expression used. It seems probable, however, that the rate of change of σ with P must to some extent depend upon which kind of ions we consider, viz. that the effectivity of the rain in "washing out" various substances from the atmosphere may be dependent upon the nature of the substance in question. This may be taken into consideration by adding a constant and by giving (3) the form:

$$\sigma = \frac{100\,\alpha}{1 + kP} \qquad (4)$$

where k may then be a constant characteristic of the type of ions in question.

It would probably be still more satisfactory to give σ an exponential expression:

$$\sigma_0 = \frac{ds}{dP} = \alpha\, e^{-\beta P} \qquad (5)$$

which for s would give:

$$s_1 = \int_0^P \sigma_0 dP = \frac{\alpha}{\beta} \left(1 - e^{-\beta P}\right) \qquad (6)$$

Here α is as before the concentration at $P = 0$, and β is a measure of the rate at which the concentration decreases with an increase in P.

Within the interval of P available through the observations, either set of formulas, (1) and (3) on the one hand and (5) and (6) on the other, may be applied. The accuracy of the

Table 3. Total amount of NH_4-N supplied to the ground ($kg/10^4m^2$) as a function of total amount of precipitation. All air masses

$^{s}NH_4$-N kg/ha	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.001—0.010	18	11	2	2	—	2	—	—	—	—	—	—	—	—	—	—	—	35
0.011—0.020	8	11	5	6	6	1	—	—	—	—	—	—	—	—	—	—	—	37
0.021—0.030	1	3	2	4	3	—	—	2	—	1	1	—	—	—	—	—	—	17
0.031—0.040	—	4	1	1	3	1	2	1	—	1	—	—	—	—	—	—	—	14
0.041—0.050	—	—	1	—	1	—	1	—	—	—	—	1	—	—	1	—	1	6
0.051—0.060	—	—	1	1	1	—	—	1	—	—	—	1	—	—	—	—	—	5
0.061—0.070	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1
0.071—0.080	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
0.081—0.090	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	27	29	13	14	15	4	3	4	1	2	1	2	—	—	1	—	1	117

Table 4. Total amount of NO_3-N supplied to the ground in $kg/10^4m^2$ as a function of total amount of precipitation. All air masses

$^{s}NO_3$-N kg/ha	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.001—0.005	22	17	3	1	2	1	—	—	—	—	—	—	—	—	—	—	—	46
0.006—0.010	3	9	6	6	4	1	—	1	—	—	1	—	—	—	—	—	—	31
0.011—0.015	1	2	1	6	6	2	1	1	—	—	—	1	—	—	—	—	—	21
0.016—0.020	1	1	2	—	1	—	1	1	—	—	—	—	—	—	—	—	—	7
0.021—0.025	—	—	1	1	1	—	1	1	—	2	—	—	—	—	—	—	—	7
0.026—0.030	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	2
0.031—0.035	—	—	—	—	1	—	—	—	—	—	—	1	—	—	—	—	—	2
0.036—0.040	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1
Σ	27	29	13	14	15	4	3	4	1	2	1	2	—	—	1	—	1	117

results is practically the same. If we pass to the upper limit ($P = \infty$, or P very large) there is, however, a fundamental difference between the two equations (1) and (6). Both are alternative expressions for the amount of NH_4-N or NO_3-N conveyed to the soil through the rain. In both cases the actual concentration at a given moment, $\frac{ds}{dP}$, approaches zero when P increases above all limits. But if using formula (1) the quantity of substance conveyed to the soil increases without upper limit when P gets larger and larger, while the expression (6) shows an upper limit, $\frac{\alpha}{\beta}$, which will never be surpassed. The difference has at present more of an academic than a practical sense; probably neither of the formulas discussed will be able to give a true expression outside the limited interval covered by our observations. Therefore we will for the reasons indicated above, base the following discussion on the simple formulas (1) to (3), which seem to reflect rather well the main results of the observations on the content of NH_4-N and NO_3-N.

Applied to the 117 measurements of the content of NH_4-N_1 the equation (1) takes the form:

$$s_{NH_4\text{-}N} = 0.0275 \log (1 + P) \tag{7}$$

from which we get:

$$\gamma_{NH_4\text{-}N} = 2.75 \frac{\log (1 + P)}{P} \tag{8}$$

For the content of NO_3-N, we obtain in a similar way:

$$s_{NO_3\text{-}N} = 0.0132 \log (1 + P) \tag{9}$$

$$\gamma_{NO_3\text{-}N} = 1.32 \frac{\log (1 + P)}{P} \tag{10}$$

In Table 5 computed values of concentration are given for values of P up to 40 mm. From the table we find for instance that the mean concentration (γ) corresponding to 1 mm precipitation is about 8 times larger than the mean concentration in a rain or snow fall of 40 mm.

Table 5. Computed mean values of nitrogen concentration for all air masses as a function of total amount of precipitation

P mm	NH_4-N γ mg/l	NH_4-N s kg/ha	NO_3-N γ mg/l	NO_3-N s kg/ha
1	0.83	0.008	0.40	0.004
3	0.55	0.016	0.26	0.008
5	0.43	0.021	0.20	0.010
10	0.29	0.029	0.14	0.014
15	0.22	0.033	0.11	0.016
20	0.18	0.036	0.09	0.017
25	0.16	0.039	0.07	0.019
30	0.14	0.041	0.06	0.020
40	0.11	0.044	0.05	0.021

The total supply to the ground of the ions in question covers the period 1. 3. 1948—1. 3. 1949 and 1. 8. 1949—31. 12. 1949. Not all precipitation cases, however, were investigated in this study. The actually measured quantities supplied to the ground amount to:

For NH_4-N : 2.37 kg per ha
» NO_3-N : 1.09 » » »

The number of cases of precipitation during the period mentioned is, however, somewhat larger than the number on which measurements were made, namely 190 against 117. In order to find the real supply corresponding to all cases, we may use the relation between supply and amount of precipitation computed above and apply it to the frequency distribution of the precipitation within various intervals. This frequency distribution is as follows:

P mm	Number of cases
0.1—1	53
1—5	82
5—10	36
10—20	14
20—40	5
Total =	190

Taking the mean values of P within every interval as independent variable and using the formulas (7) and (9), we obtain through multiplication with the number of cases within each interval and through adding all cases, the following amounts:

For NH_4-N : 3.22 kg per ha
» NO_3-N : 1.54 » » »

We may now proceed a step further and estimate the average supply during a *normal year*. For the present purpose a computation based on a period of 10 years seems sufficient. Investigating the frequency distribution of various cases of precipitation at Uppsala, which is situated close to Ultuna, we obtain the following table:

P mm	Number of cases
0.1—1	2166
1—5	2207
5—10	664
10—20	302
20—40	54
40—60	8

Using these data in a similar way as above we obtain for the average annual supply:

For NH_4-N : 1.90 kg per ha
» NO_3-N : 0.91 » » »

The number of observations treated above is not so large as to allow us to attach more than a moderate weight to these numbers. Several circumstances may work in the direction to make the generalization, which we have attempted in order to compute average values, rather uncertain. It seems rather probable that the constant of the formulas (1) may be subjected to rather large variations from time to time, not only of a seasonal but also of a secular character. The fact, which will be discussed below, that we undoubtedly have a variation of α from one type of air mass to another, naturally indicates that long periodic changes in the frequency of certain air masses will reflect themselves also in the values of γ, which in their turn are measures of the concentration of the ions in the precipitation.

2. *Content of NH_4-N and NO_3-N in precipitation within different air masses.*

A preliminary investigation of the dependence of the nitrogen content on the time of the year and on the occurrence of thunderstorms gave on the whole a negative result. This may, however, be due partly to the limitation of the observations in time and space.

We then considered it to be of great interest to look for a possible connection with the type of air mass. A direct investigation of the physical conditions of the air masses in which precipitation occurs, viz. their temperature distribution, the height and character of clouds in the case of precipitation would probably be still more illuminating as regards the character of the physical process which furnishes the nitrogen content here in question. However, in the absence of accurate and sufficiently detailed data concerning these factors at the place of observation, we shall at present confine ourselves to determine *whether or not the influence of various physical factors may be reflected in connection with the rough synthesis of their influences, expressed through the air mass type.*

In designating the type of air mass in the 117 cases of precipitation we had the very valuable help of meteorologists of the forecasting section of the Swedish Meteorological and Hydrological Institute. Especially to Mr Bengt Magnusson, chief forecaster, we have the pleasure of expressing our most sincere thanks.

A very detailed indication of air mass is scarcely justified by the material as it is. A division into three chief types, namely *tropical*, *polar* and *arctic* air, seemed to meet the requirements of a preliminary analysis. The result was that in the 117 cases of precipitation, 20 took place in tropical, 92 in polar and 5 in arctic air. Whether this proportion ought to be considered as normal is difficult to say, but there is no reason to assume that it deviates considerably from average conditions. In Tables 6—9 the frequency distribution of the concentration is shown with its dependence on air mass in the case of the two nitrogen ions NH_4^+ and NO_3^-. The arctic air which is represented by only 5 cases is not included in the tables. Tables 10—13 show the corresponding frequency distribution for the supply (*s*) of nitrogen.

We find in all these cases the same diagonalic distribution as was previously discovered when the precipitation was studied independently of air mass.

A computation of the coefficient α gives for

Table 6. Frequency distribution of the mean concentration of NH_4-N (mg/l) in tropical air masses given as a function of the total amount of precipitation

$\gamma_{NH_4\text{-}N}$ mg/l	Precipitation mm												Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	
0.00—0.19	—	—	—	—	1	—	—	2	—	—	—	—	3
0.20—0.39	—	1	1	—	—	1	1	—	—	—	—	1	5
0.40—0.59	1	—	—	—	1	—	—	—	—	—	—	—	2
0.60—0.79	1	1	—	—	1	—	—	—	—	—	—	—	3
0.80—0.99	—	2	—	—	—	—	—	—	—	—	—	—	2
1.00—1.19	—	3	—	—	—	—	—	—	—	—	—	—	3
1.20—1.39	1	—	1	—	—	—	—	—	—	—	—	—	2
Σ	3	7	2	—	3	1	1	2	—	—	—	1	20

Table 7. Frequency distribution of the mean concentration of NH_4-N (mg/l) in polar air masses given as a function of the total amount of precipitation

$\gamma_{NH_4\text{-}N}$ mg/l	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.001—0.191	4	3	2	6	4	2	—	1	—	2	1	1	—	—	1	—	1	28
0.201—0.391	4	8	5	6	5	—	2	1	1	—	—	—	—	—	—	—	—	32
0.401—0.591	3	5	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	10
0.601—0.791	6	2	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	11
0.801—0.991	2	2	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	6
1.001—1.191	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1.201—1.391	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
1.401—1.591	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1.601—1.791	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	22	21	11	13	12	2	2	2	1	2	1	1	—	—	1	—	1	92

the different air masses in the case of NH_4-N (cf. figs. 1 and 2):

Tropical air : $\alpha = 0.0354$
Polar » : $\alpha = 0.0262$
Arctic » : $\alpha = 0.0172$

For NO_3-N we get: (cf. figs. 3 and 4):

Tropical air : $\alpha = 0.0142$
Polar » : $\alpha = 0.0131$
Arctic » : $\alpha = 0.0094$

Table 8. Frequency distribution of the mean concentration of NO_3-N (mg/l) in tropical air masses given as a function of the total amount of precipitation

$\gamma_{NH_4\text{-}N}$ mg/l	Precipitation mm												Σ
	0.0 — 1.9	2.0 — 3.9	4.0 — 5.9	6.0 — 7.9	8.0 — 9.9	10.0 — 11.9	12.0 — 13.9	14.0 — 15.9	16.0 — 17.9	18.0 — 19.9	20.0 — 21.9	22.0 — 23.9	
0.00—0.09	—	1	—	—	1	—	—	2	—	—	—	—	4
0.10—0.19	—	1	1	—	1	1	1	—	—	—	—	1	6
0.20—0.29	1	—	—	—	1	—	—	—	—	—	—	—	2
0.30—0.39	1	4	—	—	—	—	—	—	—	—	—	—	5
0.40—0.49	—	1	1	—	—	—	—	—	—	—	—	—	2
0.50—0.59	—	—	—	—	—	—	—	—	—	—	—	—	—
0.60—0.69	1	—	—	—	—	—	—	—	—	—	—	—	1
Σ	3	7	2	—	3	1	1	2	—	—	—	1	20

Table 9. Frequency distribution of the mean concentration of NO_3-N (mg/l) in polar air masses given as a function of the total amount of precipitation

$\gamma_{NO_3\text{-}N}$ mg/l	Precipitation mm																	Σ
	0.0 — 1.9	2.0 — 3.9	4.0 — 5.9	6.0 — 7.9	8.0 — 9.9	10.0 — 11.9	12.0 — 13.9	14.0 — 15.9	16.0 — 17.9	18.0 — 19.9	20.0 — 21.9	22.0 — 23.9	24.0 — 25.9	26.0 — 27.9	28.0 — 29.9	30.0 — 31.9	32.0 — 33.9	
0.001—0.091	3	6	2	3	5	1	—	—	—	—	1	1	—	—	—	—	1	23
0.101—0.191	10	8	6	8	4	1	2	2	1	2	—	—	—	—	1	—	—	45
0.201—0.291	4	5	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	12
0.301—0.391	2	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	5
0.401—0.491	1	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	3
0.501—0.591	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
0.601—1.091	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.101—1.191	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	22	21	11	13	12	2	2	2	1	2	1	1	—	—	1	—	1	92

As α can be regarded as a measure of the average content reduced to a certain quantity P of precipitation, it is evident that the tropical air in general contains more nitrogen ions than polar air, and considerably more than arctic air. If we denote α for the tropical air with 1.00, the values for polar and arctic air are the following:

Air mass	NH_4-N	NO_3-N
Tropical.......	1.00	1.00
Polar	0.74	0.92
Arctic.........	0.49	0.66

The table is of interest in throwing some light upon the importance of various air masses for the supply of nitrogen. These conditions are of great interest when it comes to evaluating the supply of nitrogen at places with different geographical position; for instance for making clear the differences between the northern and southern parts of Sweden. On the other hand the difference seems in that case to be larger than would be implied from our present investigation. Northern Sweden receives less tropical air than southern Sweden, which also is true in case of precipitation. The supply

Table 10. Total amount of NH_4-N supplied to the ground ($kg/10^4m^2$) as a function of total amount of precipitation. Tropical air masses

$^SNH_4$-N kg/ha	Precipitation mm												Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	
0.001—0.010	1	1	—	—	—	—	—	—	—	—	—	—	2
0.011—0.020	2	1	1	—	1	—	—	—	—	—	—	—	5
0.021—0.030	—	3	—	—	—	—	—	1	—	—	—	—	4
0.031—0.040	—	2	—	—	1	1	—	1	—	—	—	—	5
0.041—0.050	—	—	—	—	—	—	1	—	—	—	—	—	1
0.051—0.060	—	—	1	—	1	—	—	—	—	—	—	1	3
Σ	3	7	2	—	3	1	1	2	—	—	—	1	20

Table 11. Total amount of NH_4-N supplied to the ground ($kg/10^4m^2$) as a function of total amount of precipitation. Polar air masses.

$^SNH_4$-N kg/ha	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.001—0.010	16	9	2	2	—	1	—	—	—	—	—	—	—	—	—	—	—	30
0.011—0.020	5	10	4	5	5	1	—	—	—	—	—	—	—	—	—	—	—	30
0.021—0.030	1	—	2	4	3	—	—	1	—	1	1	—	—	—	—	—	—	13
0.031—0.040	—	2	1	1	2	—	2	—	—	1	—	—	—	—	—	—	—	9
0.041—0.050	—	—	1	—	1	—	—	—	—	—	—	1	—	—	1	—	1	5
0.051—0.060	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	2
0.061—0.070	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1
0.071—0.080	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
0.081—0.090	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Σ	22	21	11	13	12	2	2	2	1	2	1	1	—	—	1	—	1	92

of nitrogen through precipitation is on that account larger in the south than in the north. But the difference is more pronounced, for the tropical air arriving in the northern parts seems to have a lower nitrogen content than it has at a lower latitude; whether from the effect of being diluted with polar air or from being already somewhat washed out by precipitation during its journey is difficult to say. Probably both these causes are at work.

Finally, if we compute the ratio between the deviation of the observed values from the computed curve, according to formulas 1—3 on the one hand, and the standard deviation of the observed values on the other, we get the values of the following table:

Air mass	NH_4-N	NO_3-N
Tropical.......	1.25	1.27
Polar..........	1.22	1.37
Arctic.........	1.03	0.95

With exception for the arctic air with its weak representation in the material, the rela-

Table 12. Total amount of NO_3-N supplied to the ground (kg/10^4m^2) as a function of total amount of precipitation. Tropical air masses

$^{S}NO_3$-N kg/ha	Precipitation mm												Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	
0.001—0.005	2	2	—	—	1	—	—	—	—	—	—	—	5
0.006—0.010	1	3	1	—	—	—	—	1	—	—	—	—	6
0.011—0.015	—	1	—	—	1	1	—	1	—	—	—	—	4
0.016—0.020	—	1	1	—	1	—	—	—	—	—	—	—	3
0.021—0.025	—	—	—	—	—	—	1	—	—	—	—	—	1
0.026—0.030	—	—	—	—	—	—	—	—	—	—	—	—	—
0.031—0.035	—	—	—	—	—	—	—	—	—	—	—	1	1
Σ	3	7	2	—	3	1	1	2	—	—	—	1	20

Table 13. Total amount of NO_3-N supplied to the ground (kg/10^4m^2) as a function of the total amount of precipitation. Polar air masses

$^{S}NO_3$-N kg/ha	Precipitation mm																	Σ
	0.0—1.9	2.0—3.9	4.0—5.9	6.0—7.9	8.0—9.9	10.0—11.9	12.0—13.9	14.0—15.9	16.0—17.9	18.0—19.9	20.0—21.9	22.0—23.9	24.0—25.9	26.0—27.9	28.0—29.9	30.0—31.9	32.0—33.9	
0.001—0.005	19	14	3	1	1	1	—	—	—	—	—	—	—	—	—	—	—	39
0.006—0.010	2	6	5	6	4	—	—	—	—	—	1	—	—	—	—	—	—	24
0.011—0.015	—	1	1	5	5	1	1	—	—	—	—	1	—	—	—	—	—	15
0.016—0.020	1	—	1	—	—	—	1	1	—	—	—	—	—	—	—	—	—	4
0.021—0.025	—	—	1	1	1	—	—	1	—	2	—	—	—	—	—	—	—	6
0.026—0.030	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	2
0.031—0.035	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
0.036—0.040	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1
Σ	22	21	11	13	12	2	2	2	1	2	1	1	—	—	1	—	1	92

tion of these numbers to one another seems to form a support for the relevancy of the mathematical treatment.

The figures included here graphically give a comprehensive idea of the content of the tables and the mathematical expressions used.

III. Summary of results and survey of some unsolved problems

In the present paper we have shown:

(1) The amounts of NH_4-N and NO_3-N contained in precipitation are dependent upon the amount of precipitation which has previously fallen.

As the precipitation continues to fall it will contain fewer and fewer of these ions.

(2) A mathematical expression is given for the dependence of concentration on the amount of precipitation fallen.

(3) With aid of this relation a computation has been made of the normal supply of NH_4-N and NO_3-N at Uppsala (Ultuna),

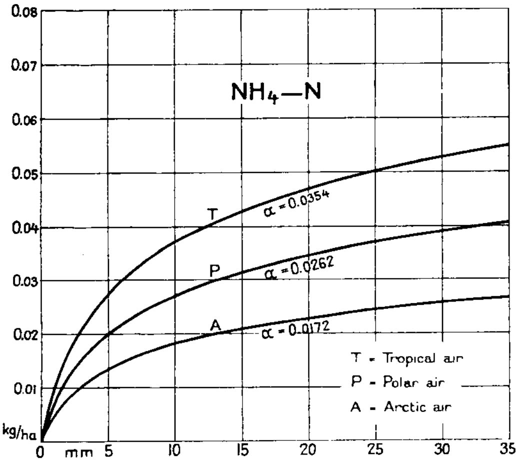

Fig. 1. Content of NH_4-N in precipitation within different air masses.

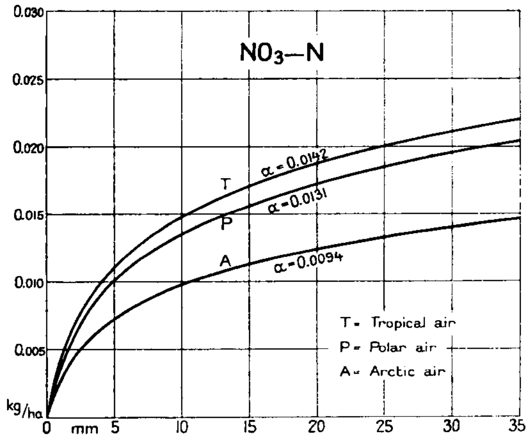

Fig. 3. Content of NO_3-N in precipitation within different air masses.

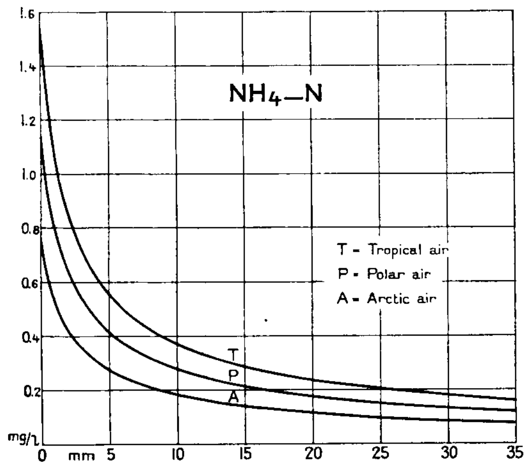

Fig. 2. Mean concentration of NH_4-N in precipitation within different air masses.

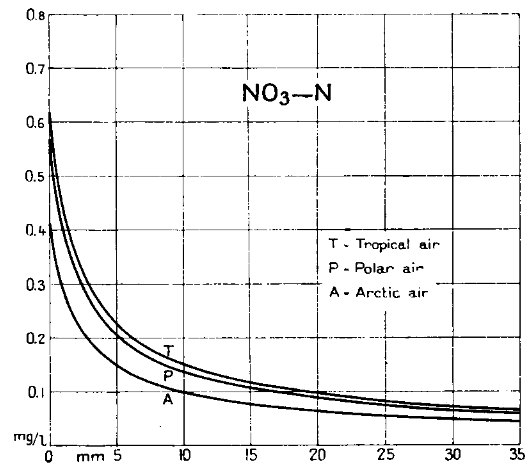

Fig. 4. Mean concentration of NO_3-N in precipitation within different air masses.

using known normal frequencies of different amounts of precipitation.

(4) The normal annual supply at Uppsala is thus found to be: for NH_4-N : 1.90 kg/ha; for NO_3-N : 0.91 kg/ha.

(5) A pronounced dependence of the concentration on the character of the air mass has been found to exist. Thus the tropical air contains between 10 and 30 per cent greater amount of the nitrogen ions of the investigated kind than the polar air and almost double the amount found in the arctic air.

The investigation reported on here is mainly of statistical character. No attempt has been made to go into the ultimate causes of the relations which have been established. Are the nitrogen ions treated here bound to some kind of solid or liquid particles on which the water particles perhaps condense (nuclei) or are they present to a considerable extent in a gaseous state in the atmosphere and absorbed by the water particles to which the affinity certainly must be great? No definite answer to this question can be given here. *On the other*

Table 14. Computed mean values of nitrogen concentration for different air masses as a function of total amount of precipitation

Air masses	P mm	NH_4-N mg/l	NH_4-N kg/ha	NO_3-N mg/l	NO_3-N kg/ha
Tropical air	1	1.07	0.011	0.43	0.004
	3	0.71	0.021	0.28	0.008
	5	0.55	0.028	0.22	0.011
	10	0.37	0.037	0.15	0.015
	15	0.28	0.043	0.11	0.017
	20	0.23	0.047	0.09	0.019
	25	0.20	0.050	0.08	0.020
	30	0.18	0.053	0.07	0.021
	40	0.14	0.059	0.06	0.023
Polar air	1	0.79	0.008	0.39	0.004
	3	0.53	0.016	0.26	0.008
	5	0.41	0.020	0.20	0.010
	10	0.27	0.027	0.14	0.014
	15	0.21	0.032	0.11	0.016
	20	0.17	0.035	0.09	0.017
	25	0.15	0.037	0.07	0.019
	30	0.13	0.039	0.06	0.020
	40	0.11	0.042	0.05	0.021
Arctic air	1	0.52	0.005	0.28	0.003
	3	0.35	0.010	0.19	0.006
	5	0.27	0.013	0.15	0.007
	10	0.18	0.018	0.10	0.010
	15	0.14	0.021	0.08	0.011
	20	0.11	0,023	0.06	0.012
	25	0.10	0.024	0.05	0.013
	30	0.09	0.026	0.05	0.014
	40	0.07	0.028	0.04	0.015

hand the almost constant ratio of about 2 : 1, in which the NH_4-N, and NO_3-N respectively appear in the precipitation seems to suggest a common origin — perhaps some kind of nuclei, in which they enter in an almost fixed ratio.

How is the concentration at the end of very heavy rain or snow falls? Does the concentration approach zero or a negligeable value, or will there arise some kind of equilibrium conditions, wherein as many nitrogen ions of the investigated types are produced through some process, as disappear through the "washing out" of the precipitation?

What is the reason for the greater concentration in tropical air masses than in polar and arctic ones? The facts seem to suggest a supply from the earths surface in the same way as pollen and dust and spores are brought to the air through the stronger convection processes at low latitudes. It seems also possible that the existence of nitrogen ions in the atmosphere is to some extent connected with electrical phenomena, as thunderstorms and other forms of discharges, which occur more frequently at low than at high latitudes. No definite conclusions can, however, be reached from the limited material treated here.

An investigation which suggests itself is on the connection between certain biological and agricultural phenomena, which are dependent upon the nitrogen supply as for instance plant growth and assimilation, and on the other hand the occurrence of precipitation from various kinds of air masses as defined through their frequency distribution. Such an investigation falls, however, outside the scope of our present field of research.

REFERENCES

Egnér, H., Eriksson, E. and A. Emanuelson. Composition of atmospheric precipitation: I. Sampling technique. Use of ion exchange resins. *The annuals of the Royal agricultural college of Sweden*, **16**, 593—602.

Feilitzen, H. von and J. Lugner, 1910. Undersökningar över de mängder bundet kväve, som tillföras jorden med nederbörden. *Kungl. Landtbruks-Akademiens Handlingar och Tidskrift*, **59**. 151—157.