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Distribution and Balance of N^{15} Labelled Fertilizer Nitrogen Applied to Young Pine Trees (*Pinus silvestris L.*)

Fördelning och återvinning av N^{15}-märkt kväve vid gödsling i tallungskog

by

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Introduction

The increasing use of fertilizers in forest practice has brought the question of the efficiency of fertilization into sharp prominence. Only a relatively insignificant proportion of the quantity of fertilizer taken up by the forest trees is fixed in the stem. Most of the absorbed nutrient elements find their way into the leaves and floral parts and into the root and are returned to the soil with the litter. The nitrogen budget of the forest stands is of special interest, since nitrogen often is the factor limiting the growth of forest trees. Ovington (1959) calculated that in a 55-year old stand of Scots pine 3% of the nitrogen had been used for cone production, 5% was bound in the stems, 9% in the branches, and 11% in the roots. No less than 72% had been accounted for by needle production. Thus some three-quarter of the nitrogen in the stand was returned to the soil during the period of growth. Although these figures may not be applicable to an old stand that has been thinned, where a considerable amount of the nutrients have been removed with the thinned timber, the proportions quoted give a fairly good estimate of the total nitrogen consumption during the growth of the stand. According to Ovington, the trees must take up nearly 20 units of nitrogen for every unit stored in the stem.

An example from a 60- to 70-year old stand of Norway spruce on peat soil in central Sweden shows, according to Holmen (1964), that the mean nitrogen consumption amounts to 38 kg per hectare per annum. Of this amount, about 11% is bound in the wood, 9% in the bark, 21% in living branches, 6% in dead branches, 38% in needles, and about 15% in the roots. In another example quoted by C. O. Tamm (1959) from a stand of Scots pine in North Sweden, the mean annual increment of 1.2 cu.m per hectare is matched by an annual fixation of 0.5 kg N in the stems. If the total absorption according to Ovington is estimated at 20 times the amount of nitrogen fixed in the stem, this would mean that 10 kg N would be required for each hectare each year, or 5 kg N per hectare if no more than 10 times the stem consumption were needed in the climatic conditions prevailing here.

The available nitrogen in a forest stand is also utilized by the ground vegetation and by microorganisms. In addition, some of it is removed from circulation through leaching and by gaseous losses.

There are, however, also credit posts in the soil nitrogen balance including *inter alia* the amount of inorganic nitrogen that is continually brought from the atmosphere through precipitation and through the fixation of atmospheric nitrogen by microorganisms. The decomposition of the litter also liberates large quantities of nitrogen in readily available form, although this source of supply does not constitute any real gain, being only a part of the natural biological cycle.

Most of the nitrogen in forest soil occurs in the form of complex organic compounds present in the humus layer as well as in the underlying mineral soil. The total amount of nitrogen varies a great deal in different forest soils but is usually very high in relation to the nitrogen available to the forest trees. The quantities of organically bound nitrogen in the soil are as a rule fairly high in relation to the annual needs of the vegetation. The total quantity of nitrogen in the humus layer in a coniferous forest of healthy *Vaccinium myrtillus*-type has been estimated at between 400 and 800 kg per hectare, while the corresponding amounts on lichen-rich pine heaths can be as low as 100 kg.

The point of greatest interest as far as the forest production is concerned, however, is the amount of nitrogen mobilized during the process of mineralization. Thanks to the work by Hesselman in this field, it is now well known how various types of forest behave in this respect. The essence of his results is, that a deficiency of available nitrogen exists in most types of Swedish forests on mineral soil. Although Hesselman's measure of "nitrogen mobilization", i.e. the formation of nitrates, cannot always be taken as an expression of the amount of nitrogen that can actually be utilized by the forest trees, his work has been of very great significance to our knowledge of the nutrient budget of the forest. By supplying extra nitrogen in the form of ammonium nitrate to forest soil in systematically planned experiments, Hesselman was able to obtain confirmation of his results concerning the importance of mineral nitrogen to the growth of forest trees. Later fertilizer experiments in Sweden, performed for scientific purposes by Romell, Malmström, Björkman, C. O. Tamm, Carbonnier, Ebeling *et al.* have led to the same results and have formed the basis of subsequent forest fertilization projects on a practical scale.

The greatest interest in connection with studies on forest fertilization has been associated with the increase in production obtained in a number of cases. Another very important question is the durability of the nitrogen effect. It is nowadays considered to be 4—5 years for Scots pine and 7—8 years for Norway spruce. After this time the nitrogen treatment must be repeated if the growth increment after fertilization is to be maintained. Several examples are known where the total increment in a 10-year period has been lower in a nitrogen treated stand of Scots pine, that was not refertilized, than in a stand that was not treated at all.

There is still very little information to hand on the utilization of nitrogen added with fertilizers. In the case of a young stand of Norway spruce it has been stated (Tamm, 1963) that 30—50% of the extra nitrogen supplied was actually utilized by the trees. The corresponding figures for older Norway spruce were 18—19%. According to the same source, however, Scots pine appears to utilize nutrient nitrogen much less efficiently (8—12%) than Norway spruce. From a fertilized stand of Scots pine in North Sweden, it is reported that only 15% of the nitrogen supplied was utilized (Popović & Burgtorf, 1964). Nömmik (1966) reports from fertilizer experiments with ammonium sulphate, calcium nitrate, and calcium cyanamide labelled with N^{15} that nitrogen utilization amounted only to 3—8% in Scots pine, giving no explanation of the low efficiency.

In the present project this problem has been taken up for closer study through application of N^{15}-labelled nitrogen on small experimental plots both at Riksten outside Stockholm and at Vifors 50 km north of Gävle. What follows here refers to the experiment at Riksten; the one at Vifors will be dealt with in a subsequent paper.

Material and Method

Description of the Experimental Area

The experiment was set up on land belonging to Riksten Manor at Tullinge, about 20 km south-west of Stockholm.

Soil: The experimental area was located on the crest of a narrow part of the Tullinge ridge, about 2 km south of the Manor farm buildings and about 50 m above sea level. The geology of the region is characterized by deep strata of glacifluvial (esker) gravel and sand resting on svecofennian gneisses. The soil profile was an iron podzol, with a thin but clearly distinguishable A_2 horizon (see Table 1). The humus layer (A_0 horizon) consists of a largely undecomposed acid raw humus with a thickness of up to 5 cm. In the course of sampling it proved difficult to separate the humus effectively from the underlying mineral soil (A_1). The combined soil material is referred to here as the A_0—A_1 horizon. The content of organic matter in this last-named material averaged 28%, and the ratio of carbon to nitrogen was about 40 : 1. The B horizon was of a dull brownish coloration and extended to a depth of 20—25 cm. No sharp boundary between the last-named horizon and the underlying layer of unconsolidated material (C horizon) could be distinguished.

The mechanical analysis shows that as a rule over 90% of the soil material consisted of sand or still coarser particle-size fractions. In the B and C horizons, gravel and stones made up about one-third by weight of the ground material.

Table 1 also includes data on pH and the amounts of ammonium lactate-

Table 1. Mechanical analysis and some chemical characteristics of the soil from the Riksten profile

Data on chemical analysis refer to soil material passing 2 mm sieve.

Horizon	Depth, cm	Textural composition, %					Loss on igni- tion, %	pH_{H_2O}	Phosphorus, mg/100 g		Potassium, mg/100 g	
		Gravel, stones (>2.0 mm)	Sand (2.0—0.2 mm)	Fine sand (0.2—0.02 mm)	Silt (0.02—0.002 mm)	Clay (<0.002 mm)			AL-* soluble	HCl- soluble	AL-* soluble	HCl- solubl
A_0—A_1	0—4	3					28.0	3.8	2.9	21	28.2	52
A_2	4—6	6	81	7	3	3	3.4	4.1	0.6	10	4.3	23
B	6—20	30	60	6	2	2	2.3	4.7	0.5	32	3.8	27
C	20—30	33	62	2	1	1	1.4	5.0	0.4	28	1.8	30
	30—40	36	61	1	1	1	0.9	5.2	0.5	21	1.5	29
	40—50	31	66	1	1	1	0.7	5.1	0.2	18	1.5	33
	50—60	28	68	2	1	1	0.8	5.2	0.3	18	1.6	32

* AL = ammonium lactate

soluble and HCl-soluble P and K present in soil materials from different horizons.

Description of vegetation: The site of the experiment was a naturally regenerated young stand of *Pinus silvestris* L., about 15 years old, developed under shelter trees. The trees in the young stand of Scots pine were fairly uniformly dispersed, but relatively freestanding individuals were chosen as experimental trees. Table 2 shows the composition of the ground vegetation.

Table 2. Covering in per cent of the ground vegetation on the experimental plots
Average figures of two replicants.

	Degree of covering, %		
	Control	Ammonium sulphate	Calcium nitrate
Calluna vulgaris	25	15	40
Vaccinium vitis idaea	10	10	15
Arctostaphylos uva ursi	15	5	5
Pleurozium Schreberi	20	35	20
Dicranum undulatum	5	10	5
Cladonia sp.	15	5	10
Other species	5	10	5
Bare soil	5	10	0

Temperature and precipitation: Data on temperatures and precipitation during the period of the experiment were obtained from the meteorological station at the Tullinge Air Force Base, about 3 km from the test plots. The data received are shown in Table 3.

Table 3. Precipitation and mean values of the maximum day temperature and the minimum night temperature at Tullinge Air Force Base

Date	Precipitation mm	Mean value of maximum day temperatures, °C	Mean value of minimum night temperatures, °C
27.5—28.6 1964	65	18.4	9.1
29.6— 3.8	33	20.1	9.3
4.8—15.9	62	22.7	9.0
16.9—21.10	65	12.1	5.5
27.5—21.10	225		

Experimental Procedure

In the autumn of 1963 six Scots pines, all about 15 years old, were individually isolated by the burying of iron sheets in a circle at a radius of 2 metres from each tree and at a depth of about 60 cm. Each experimental plot thus had an area of 12.56 sq.m.

On 27 May 1964, two of the experimental plots were treated with ammonium sulphate and two with calcium nitrate, while the other two were left as controls. The amount of nitrogen supplied was equivalent to 60 kg/ha. The N^{15} excess was 1.78 atomic % in the ammonium sulphate and 1.81% in the calcium nitrate. The fertilizers were topdressed in solid form.

Needle samples were collected throughout the progress of the experiment (on 27 May, 29 June, 4 August, 16 September, and 21 October) and the annual shoot length of the experimental trees was measured. One-year, two-year and three-year needles from the top shoots of the five uppermost whorls, except the very topmost, were collected for analysis.

The final sampling took place on 22—27 October 1964. The experimental trees were then felled and sawn into three sections in such a way that stem parts of all three sections were of equal length. Each unit was dealt with individually. The total fresh weight and dry weight of needles, branches and stems were determined, and all these components were analysed for total nitrogen content and atomic per cent N^{15} excess. The same data were determined for *Vaccinium vitis idaea* and *Calluna vulgaris*. A 30-degree sector of the circular experimental plot was then selected at random, and within this sector the total weight of litter, humus, A_2 horizon and B horizon was determined. The mineral soil under the B horizon was divided into four layers, each 10 cm thick. As far as possible, all roots were separated from the various layers of soil, partly by hand and partly by screening.

Three analyses of total nitrogen and N^{15} excess were performed on each sample of plant material collected during the progress of the experiment, and two analyses at the final sampling.

Analytical Methods

Soil samples were air-dried. All analytical results are expressed on the basis of oven-dry weight. Plant materials were dried for 48 hours at 60° C. Both soil and plant materials were ground and passed through a 2 mm sieve.

Mechanical analyses were carried out according to a modification of the pipette method described by Piper (1950). The particle size grades are based on the international system of classification.

Ammonium lactate and HCl-soluble P and K in the soil were determined according to a procedure devised by Egnér *et al.* (1960).

pH of the soil-water suspensions (1 : 2.5) were measured electrometrically using a glass electrode.

Total N in soil and plant materials was determined by the Kjeldahl macro-digestion procedure. In soil samples the procedure included pretreatment with salicylic-sulphuric acid mixture to include nitrate.

Exchangeable ammonium and nitrate N was extracted from the soil with 1 *n* KCl solution; the extract was distilled in the presence of borate buffer (pH 8.8), ammonia being released. The quantitative estimation of ammonia was made either volumetrically or by nesslerization. The residue from the ammonia distillation was used for determination of nitrate by means of Devarda's alloy.

Nitrogen isotope ratio analyses were performed according to a method described by Rittenberg (1946), using a Consolidated Nier isotope ratio mass spectrometer (Model 21—202).

Results

Distribution and Recovery of Added N in the Soil Profile

As was stated in the description of the experimental method, samples were taken at the end of the growing season of both litter and soil from different depths. These samples were later subjected to analysis comprising determination of total and mineral nitrogen as well as of the proportion of added labelled nitrogen in both these nitrogen fractions. The intention was to elucidate the quantitative distribution of the labelled nitrogen in the soil profile and on the basis of these data to make a calculation of the recovery of the added nitrogen in the ecosystem in question. The results obtained are summarized in Table 4.

These results show that the experimental plot down to a depth of 60 cm contained between 2,400 and 2,750 g N including the N in the litter, corresponding to 1,900—2,200 kg N per hectare. About 12% of this nitrogen was present in the litter, 20% in the humus layer (A_0+A_1), 8% in the A_2 horizon, and the remainder, making up about 60% of the nitrogen, in the B horizon and the C horizon.

The proportion of mineral nitrogen in the total soil nitrogen was low on all the experimental plots. Thus the content of exchangeable ammonium N on the control plots and those treated with calcium nitrate was about 5 g per plot or 4 kg per hectare. In the treatment where the nitrogen was applied in the form of ammonium sulphate, the ammonium nitrogen content was significantly higher, amounting to over 14 g per plot or 11 kg per hectare. According to these gross N data, 12% of the added nitrogen remained in the soil in the form of exchangeable NH_4 at the end of the first growing season. The concentration of ammonium nitrogen in the last-named experimental plots was highest in the humus layer, but a certain excess compared to the control plots also occurred in the A_2 horizon. The figures for exchangeable ammonium in the deeper horizons did not indicate that any appreciable loss of NH_4 by leaching had taken place.

The nitrate content was low in all the experimental plots (3.2—4.0 g N per plot) showing no increase after calcium nitrate treatment. It should be noted that this acid forest soil, principally the raw humus, had little or no nitrification capacity.

On the basis of data on the total nitrogen content of the soil down to a depth of 60 cm and on figures for atomic per cent N^{15} excess in the total

Table 4. Recovery of added N^{15} labelled nitrogen in the soil profile of different experimental plots

Data refer to a plot area of 12.56 m^2 and to soil material passing 2 mm sieve. Nitrogen application rate 75.0 g N per plot. Average figures of two replicants.

Treatment	Horizon (depth, cm)	Soil material kg/plot*	Total N %	Total N g/plot Gross	Total N g/plot Labelled	Ammonium ppm	Ammonium g/plot Gross	Ammonium g/plot Labelled	Nitrate ppm	Nitrate g/plot Gross	Nitrate g/plot Labelled
Control	A_{00}	31	1.16	360							
	A_0—A_1	156	0.333	519		4.2	0.7		2.0	0.3	
	A_2	250	0.078	195		1.5	0.4		0.8	0.2	
	B	720	0.058	418		1.2	0.9		0.9	0.6	
	20—30	910	0.040	364		0.6	0.5		0.6	0.5	
	30—40	820	0.029	238		1.1	0.9		0.5	0.4	
	40—50	870	0.021	183		0.9	0.8		0.8	0.7	
	50—60	900	0.016	144		0.8	0.7		0.6	0.5	
	0—60			*2 421*			*4.9*			*3.2*	
Ammonium sulphate	A_{00}	20	1.15	230	11.6						
	A_0—A_1	171	0.332	567	10.7	35.9	6.1	0.89	2.4	0.4	0.06
	A_2	340	0.076	258	5.6	8.3	2.8	0.35	0.9	0.3	0.02
	B	840	0.062	521	6.0	2.0	1.7	0.15	0.8	0.7	0.02
	20—30	950	0.048	456	4.0	1.4	1.3	0.15	0.6	0.6	0.02
	30—40	800	0.032	256	2.4	0.7	0.6	0.07	0.7	0.6	0.03
	40—50	890	0.024	214	2.0	1.2	1.1	0.18	0.8	0.7	0.03
	50—60	820	0.020	164	1.6	1.0	0.8	0.07	0.7	0.6	0.02
	0—60			*2 666*	*43.9*		*14.4*	*1.86*		*3.9*	*0.20*
Calcium nitrate	A_{00}	30	1.04	326	10.8						
	A_0—A_1	165	0.301	497	8.2	3.0	0.5	0.04	1.8	0.3	0.02
	A_2	290	0.080	232	4.7	1.9	0.6	0.04	1.4	0.4	0.03
	B	930	0.063	586	7.8	1.1	1.0	0.06	1.2	1.1	0.27
	20—30	840	0.048	403	3.7	0.8	0.7	0.01	0.8	0.7	0.14
	30—40	900	0.037	333	3.2	1.0	0.9	0.03	0.7	0.6	0.22
	40—50	840	0.026	218	2.0	0.7	0.6	0.02	0.5	0.4	0.16
	50—60	930	0.017	158	1.8	1.0	0.9	0.03	0.5	0.5	0.16
	0—60			*2 753*	*42.2*		*5.2*	*0.23*		*4.0*	*1.00*

* oven-dried

nitrogen fraction, it was estimated that 59% of the nitrogen added as ammonium sulphate was still present in the soil at the end of the growing season. Of this N only 2.8% was recovered in inorganic forms. On the plots treated with calcium nitrate, the corresponding figures were 56% and 1.6% respectively. Thus most of the added fertilizer nitrogen was present in organically bound forms.

If we look at the distribution of the labelled nitrogen in the soil profile, we find that the greatest percentage accumulation has taken place in the litter, where the proportion of labelled nitrogen in the total nitrogen amounted to 5.0% for the plots treated with ammonium sulphate and 3.3% for those with calcium nitrate. The proportion of labelled nitrogen decreased with

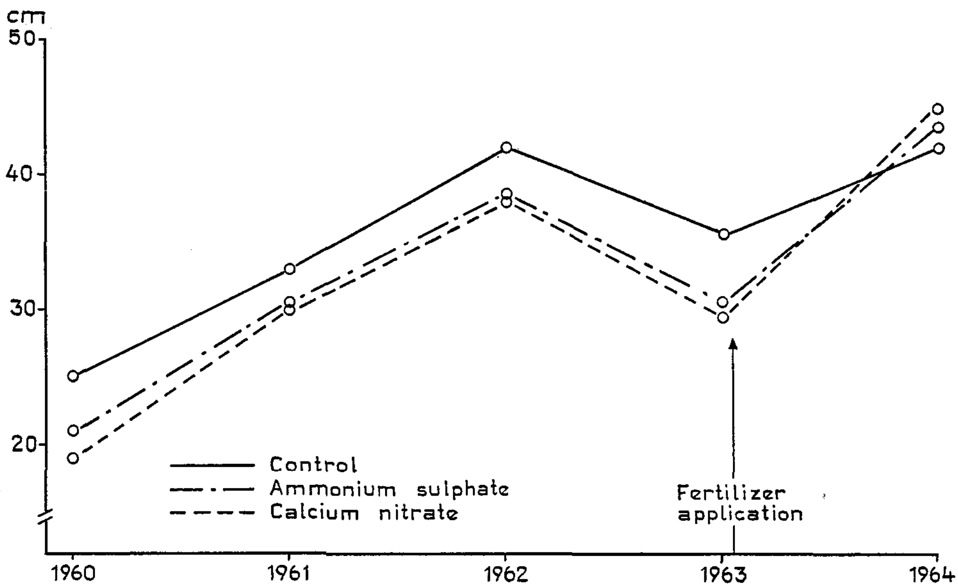

Fig. 1. Length of top shoot during 1960—1964.
Average figures of 2 replicants

increasing soil depth, the figure for the 30—60 cm layer being about 1%. In the exchangeable ammonium N fraction, the proportion of labelled nitrogen varied between 10 and 15% on the ammonium sulphate plots and between 2 and 8% on the calcium nitrate plots. In the nitrate fraction, the proportion of labelled nitrogen for the two treatments was 5 and 25% respectively. On plots with calcium nitrate, the proportion of labelled nitrogen in the nitrate fraction was greatest at a depth of 30—60 cm, indicating a considerable downward displacement of the added nitrate and a probable loss by leaching.

Distribution and Recovery of Added N in the Vegetation

This section deals with the results of determinations and analyses performed on both the experimental trees and the predominating ground vegetation. For the sake of simplicity, only mean values of the two replicant treatments are given. It was invariably found that the data from the replications were in good agreement.

Determination of the annual top shoot length over a five-year period (Fig. 1) and the continuous determination of needle length (Fig. 2) and dry weight per 100 needles (Fig. 3) during the experimental period give an idea of the general reaction of the trees to fertilizer application. The three graphs show clearly that the randomly selected control trees were somewhat ad-

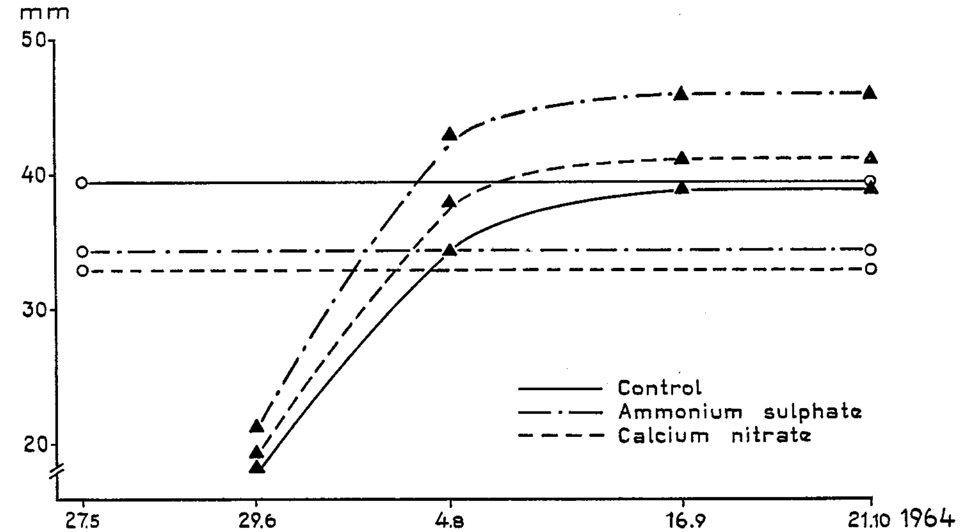

Fig. 2. Changes in needle length during the experimental period.
▲: Current needles — Average of 100 needles
○: 2-year and 3-year needles — " " 200 "

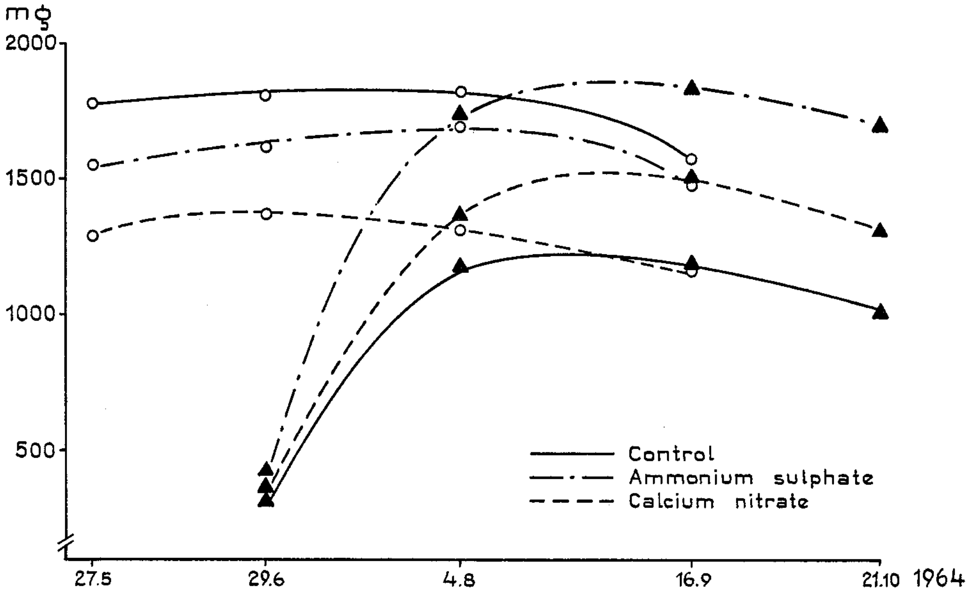

Fig. 3. Changes in dry weight of 100 needles during the experimental period.
▲: Current needles — Average of 6 replicants
○: 2-year and 3-year needles — " " 12 "

vanced in growth *before* the fertilizer was applied and that the treatment produced a positive growth reaction with respect to annual shoot length as well as to needle length and needle dry weight.

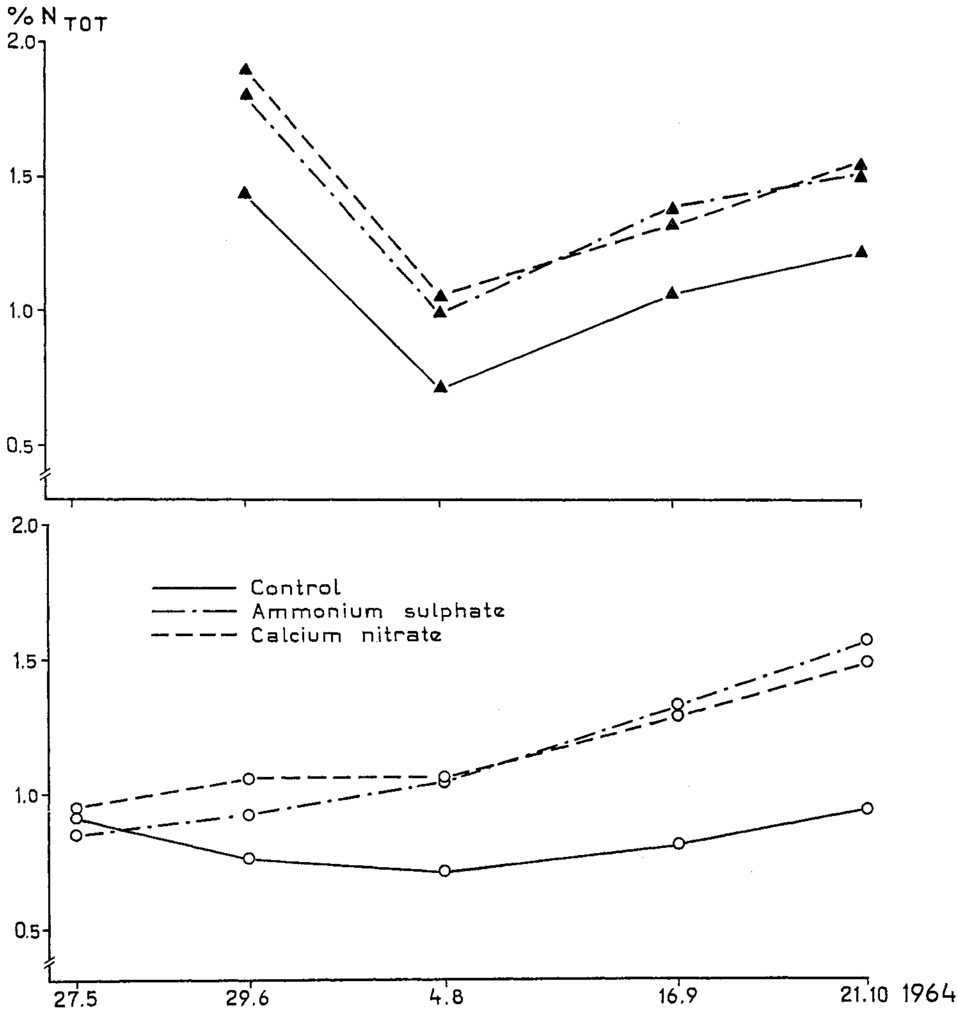

Fig. 4. Changes in total N content of the needles during the experimental period. Data refer to dry weight

▲: Current needles — Average of 6 replicants

○: 2-year and 3-year needles — " " 12 "

As was expected, the nitrogen application also resulted in an increased total nitrogen content in the needles irrespective of their age (Fig. 4) and in a high percentage excess of N^{15} (Fig. 5), this being highest in 1-year needles and somewhat lower for the older needles — about 0.5 and 0.3% respectively — at the end of the experiment. The figures for older needles from the sampling in October refer only to 2-year needles, as most of the 3-year needles had been shed during the period 16 September—21 October. Figures 2—5, all of which are based on data from the successive sampling, also show that the trend is the same throughout for both $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ fertilized plots.

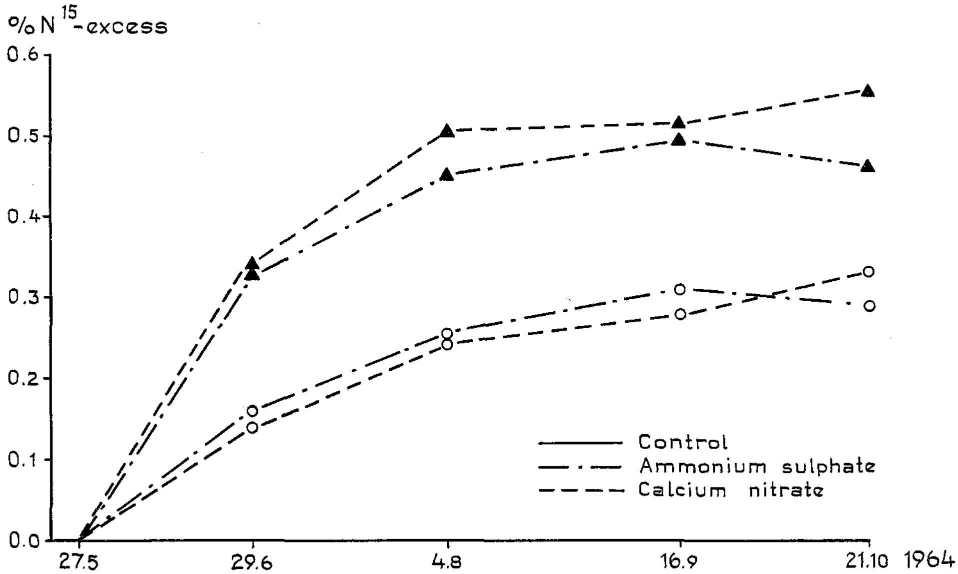

Fig. 5. Atomic % N^{15} excess in the total N fraction of the needles during the experimental period.
▲: Current needles — Average of 6 replicants
○: 2-year and 3-year needles — " " 12 "

As was mentioned in the introduction, the main object of the experiment was to compute a balance based on the quantity of added N recovered set in relation to the quantity supplied as well as to study the distribution of labelled N within the plot after one growing season. In order to make such a computation, each sample must be analysed for both its total nitrogen content and its percentage excess of N^{15}. Table 5 shows that the nitrogen fertilizer treatment resulted in an increased total nitrogen content in stem, branches and needles, and that the increase, as had been expected, was greatest in the needles. With regard to the roots, only a slight increase in the total nitrogen content could be detected, and this would agree fairly well with their relatively low N^{15} excess (Table 6). When we come to the figures for ground vegetation (above ground parts), the picture is more heterogeneous, as the treatment did not produce any overall increase in the nitrogen content of the vegetation, but did produce a high N^{15} excess. No explanation of this anomaly can be given.

If we look more closely at the distribution of total nitrogen content within the tree itself, we find that this decreases from crown to base in the stem and in the branches, but increases in the needles. The figures here parallel at all points those from the N^{15} excess analyses. In this connection it may be interesting to point out that Yassoglou (unpublished) found a similar con-

Table 5. Total N in different parts and organs of trees and in predominating ground vegetation, per cent

Data refer to dry weight.
Average figures of 4 replicants (8 replicants for the needles).

	Control			Ammonium sulphate			Calcium nitrate		
	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree
stem	0.36	0.18	0.15	0.39	0.23	0.19	0.42	0.23	0.17
branches	0.52	0.44	0.35	0.89	0.56	0.51	0.70	0.53	0.40
needles	1.09	1.14	1.16	1.52	1.49	1.60	1.44	1.52	1.57
	Calluna vulgaris	*Vaccinium vitis idaea*	*Pleurozium Schreberi*	*Calluna vulgaris*	*Vaccinium vitis idaea*	*Pleurozium Schreberi*	*Calluna vulgaris*	*Vaccinium vitis idaea*	*Pleurozium Schreberi*
ground vegetation*	0.63	0.63	0.84	0.55	0.35	0.94	0.66	0.32	0.91
	A_0 horizon	A_2 horizon	B horizon	A_0 horizon	A_2 horizon	B horizon	A_0 horizon	A_2 horizon	B horizon
roots	0.70	0.54	0.44	0.81	0.69	0.54	0.68	0.54	0.53

* above ground

Table 6. Atomic per cent N^{15} excess in total N fraction in different parts and organs of trees and in predominating ground vegetation

Average figures of 4 replicants (8 replicants for needles).

	Ammonium sulphate			Calcium nitrate		
	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree
stem	0.324	0.255	0.224	0.336	0.251	0.238
branches	0.376	0.329	0.304	0.401	0.361	0.283
needles	0.367	0.376	0.423	0.384	0.448	0.458
	Calluna vulgaris	*Vaccinium vitis idaea*	*Pleurozium Schreberi*	*Calluna vulgaris*	*Vaccinium vitis idaea*	*Pleurozium Schreberi*
ground vegetation*	0.370	0.602	0.298	0.492	0.604	0.252
	A_0 horizon	A_2 horizon	B horizon	A_0 horizon	A_2 horizon	B horizon
roots	0.146	0.178	0.136	0.131	0.204	0.291

* above ground

centration gradient with respect to Mn and Fe running from crown to base in the needles of 1-year old specimens, 50—70 cm tall, of *Pinus radiata* and *P. halepensis*, while the content of Cu and Zn in the needles was much the same in all parts of the plant. Yassoglou also points out in this connection that one of the greatest difficulties in studying the occurrence of trace ele-

Table 7. Recovery of added N^{15} labelled nitrogen in trees and predominating ground vegetation

Data refer to a plot area of 12.56 m^2. Nitrogen application rate 75.0 g N per plot. Average figures of two replicants.

	Ammonium sulphate						Calcium nitrate					
	Labelled N, g/plot				%		Labelled N, g/plot				%	
	upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree	Total			upper 1/3 of the tree	middle 1/3 of the tree	lower 1/3 of the tree	Total		
stem.......	0.101	0.146	0.252	0.499	0.7		0.100	0.161	0.282	0.543	0.7	
branches...	0.084	0.438	0.325	0.847	1.1		0.066	0.476	0.304	0.846	1.1	
needles.....	0.297	2.463	1.071	3.829	5.1	6.9	0.249	2.269	1.118	3.636	4.8	6.7
	Calluna vulgaris *	*Vaccinium vitis idaea* *					*Calluna vulgaris* **	*Vaccinium vitis idaea* **				
ground vegetation[1] .	1.038	0.752		1.790		2.4	11.917	1.207		13.124		17.5
	A_0 horizon	A_2 horizon	B horizon				A_0 horizon	A_2 horizon	B horizon			
roots.......	7.870	0.415	0.365	8.650		11.5	5.131	0.648	1.074	6.853		9.1
Total sum..				15.615		20.8				25.002		33.3

* cover together approx. 25% of the plot area.
** cover together approx. 55% of the plot area.
[1] ground vegetation = above-ground parts.

ments lies in the selection of representative samples. The results of the present investigation indicate that the same difficulty may also be encountered in connection with the determination of macro-nutrient elements, at least as far as nitrogen is concerned. It was mentioned in the introduction that another experiment similar to that at Riksten has been conducted at Vifors. In the latter experiment, too, the nitrogen content of the needles was studied in different parts of the canopy, but in this case no concentration gradient with resectp to nitrogen was found. It must, however, be noted that the experimental trees at Riksten were about 15 years old and had needle-bearing branches all the way from top to base, while the trees at Vifors were about 80 years old, with all the branches concentrated to the top third of the stem.

Table 7 gives a summary of the quantities of N^{15} found in the vegetation in relation to the total amount added. Remarkably good agreement was obtained between plots treated with ammonium sulphate and those treated with calcium nitrate, with the exception of the ground vegetation, where the variations are probably in the main due to the difference in degree of cover (cf. Table 2). However, it can be pointed out here that the table is not complete as far as the ground vegetation is concerned, as the N^{15} determination, for technical reasons, was made only on *Vaccinium vitis idaea* and *Calluna vulgaris* and not on the other species. Nevertheless, a calculation for the experimental plots in question showed that these plants accounted for the greater part of the production of dry matter, while mosses and lichens, despite their high degree of cover, accounted only for a relatively small part.

If we accept as a rough estimate that half of the root mass belongs to the trees, we arrive at the conclusion that *the trees had utilized about 12% of the added nitrogen during the first growing season.*

Relatively high excesses of N^{15} (about 0.12%) were found in seedlings of Scots pine planted in the spring of 1965 after the experimental trees had been removed. This shows that the organically bound residual nitrogen had partly been mineralized and that the Scots pine seedlings had been able to utilize it.

Discussion and Conclusions

Only very few studies have been made to estimate the amount of added plant nutrients actually utilized by the trees. Regarding the nitrogen the available information is limited to results showing the percentual recovery of added N in the above ground parts of the trees. In the present investigation, the use of N^{15} has made it possible to trace 7% to the above ground parts of the tree. This figure corresponds well with comparable figures found earlier by Tamm (1963) and Nömmik (1966). However, the 7% thus traced must be regarded as a minimum amount, since a certain biological exchange of isotopes can be presumed to have taken place in the soil.

The isotope technique used in the present experiments has also made it possible to trace almost the rest of the added nitrogen. Thus a quantity varying between 2 and 18% was found in the above-ground parts of the examined ground vegetation — *Calluna vulgaris* and *Vaccinium vitis idaea.* The large variation in this case can probably be attributed to the differing degree of cover afforded by these species on the experimental plots. Thus the quantity of nitrogen recovered from the ground vegetation was only 2% on plots with 25% covering, and 18% on plots with 55% covering. Between 9 and 12% of the applied labelled nitrogen was found in the roots of trees and ground vegetation. Small samples were also collected of mycorrhizae from the trees, but these samples, unfortunately, could not be analysed. It has previously been demonstrated that a high concentration of nutrients occur especially in the fungal mantles of the mycorrhizae (cf. Hatch, 1937 and Harley, 1959). The figures given here refer to the entire root mass including the mycorrhizae.

Altogether 21% of the applied nitrogen was found in the vegetation (the Scots pine + the ground vegetation + roots) on experimental plots with sparse brush vegetation cover, and 33% on plots with denser vegetation (Table 8).

The soil in the plots treated with ammonium sulphate and calcium nitrate was found to contain 59 and 56% respectively of the applied labelled nitrogen after one growing season (Table 8). About 30% of this quantity was present in the litter and humus layer. A significant amount of exchangeable ammonium, about 10 g, was found in each of the plots treated with ammonium sulphate. However, only 1.9 g of this consisted of labelled nitrogen, which may indicate that quite a considerable dilution of the labelled NH_4 nitrogen has taken place through microbial turnover (cf. Jansson, 1958), a circumstance that should be taken into account when the figures for recovered nitrogen are interpreted.

Table 8. Total amounts of labelled N recovered in vegetation and soil as per cent of added N

	Ammonium sulphate		Calcium nitrate	
VEGETATION				
Trees, above-ground parts . .	6.9%		6.7%	
Ground vegetation, above-ground parts	2.4%		17.5%	
Roots	11.5%	20.8%	9.1%	33.3%
SOIL		58.5%		56.3%
TOTAL		79.3%		89.6%

Thus after one growing season, altogether 79% of the total applied quantity of labelled nitrogen was still to be found in the plots fertilized with ammonium sulphate, and 90% on those treated with calcium nitrate.

An analyse of 2+2 Scots pine seedlings planted on the experimental plots in the following spring showed that these seedlings were able to a certain extent to utilize residual organically bound nitrogen. Experiments are in progress involving the application of N^{15} to graduated stands in an attempt to study the competition for nitrogen between trees of different ages.

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Sammanfattning

Fördelning och återvinning av N^{15}-märkt kväve vid gödsling i tallungskog

I samband med gödsling av skog har endast mycket få undersökningar utförts rörande mängden av den tillförda växtnäringen som verkligen kommer träden tillgodo. Ännu färre är de undersökningar i vilka en uppskattning utförts av det kväve som tillgodogjorts av trädens ovanjordiska delar i procent av hela kvantiteten tillfört kväve. I den föreliggande undersökningen har genom användning av N^{15}-märkta gödselmedel återfunnits 7 % i trädets ovanjordiska delar efter en vegetationsperiod.

Den använda isotoptekniken har även möjliggjort ett uppspårande av resten av det tillförda kvävet. Sålunda återfanns i de ovanjordiska delarna av den undersökta markvegetationen på försöksytorna — *Calluna vulgaris* och *Vaccinium vitis idaea* — en mängd som varierade mellan 2 och 18 %. Den stora variationen i detta fall kan sannolikt hänföras till den olika täckningsgraden på försöksytorna för dessa arter. Sålunda utgjorde mängden återfunnet kväve i markvegetationen endast 2 % på provytorna med 25 % täckningsgrad och 18 % på provytorna med 55 % täckningsgrad. I rötterna av såväl träd som markvegetation återfanns 9—12 % av det tillförda märkta kvävet. Sammanlagt återfanns i vegetationen (tallen + markvegetationen + rötter) 21 % av det tillförda kvävet på provytorna med glest risvegetationstäcke och 33 % på provytorna med tätare vegetation (tabell 8).

I marken återfanns på ammoniumsulfatgödslade och kalciumnitratgödslade ytor 59 resp. 56 % av det tillförda märkta kvävet efter 1 vegetationsperiod. Av detta förekom ca 30 % i förna-humusskiktet. På de ammoniumsulfatgödslade parcellerna återfanns en signifikant mängd utbytbart ammonium, utgörande ca 10 g per provyta. Av detta utgjorde dock endast 1,9 g märkt kväve, vilket kan tyda på att en icke oväsentlig utspädning av tillfört kväve har skett genom mikrobiell turn-over, en omständighet som bör beaktas vid tolkningen av värdena för återfunnet kväve.

Av den totala mängden tillfört märkt kväve kunde sålunda sammanlagt efter en vegetationsperiod på de ammoniumsulfatgödslade provytorna återfinnas 79 % samt på de kalciumnitratgödslade ytorna 90 %.

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