

NITROGEN FRACTIONS IN SANDY SOILS IN RELATION TO PLANT NITROGEN UPTAKE AND ORGANIC MATTER INCORPORATION

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Summary—Pot experiments carried out with rye grass focused on two major aims: (1) to examine the importance of extractable organic soil N for net N mineralization and N uptake of plants and (2) to study decomposition and mineralization of organic matter incorporated into the soils, as related to extractable organic soil N fractions. Soil extraction was carried out by electro-ultrafiltration (EUF) and 10 mM CaCl₂ solution. Ammonium, NO₃⁻, and organic N was analysed in the extracts. The investigation was carried out with 13 sandy soils derived from fluvial and aeolian deposits, Hessa, Germany. They were sampled in June from the top layer of field trials grown with rye.

CaCl₂-extractable organic N was significantly related to net N mineralization and N uptake by the grass ($r^2 = 0.60^{***}$ and 0.66^{***} , respectively). The relationship was less close for electro-ultrafiltration (EUF) extractable organic N ($r^2 = 0.16^*$ and 0.22^{**} , respectively); coefficients of determination for total soil N were $r^2 = 0.23^{**}$ and 0.33^{***} , respectively.

Decomposition and mineralization of sugar beet leaves incorporated into the soils enhanced available N for plants. This was clearly reflected by an increase of inorganic soil N as well as of extractable organic N fractions, followed by a decrease of organic and inorganic soil N as related to the N uptake of the grass. However, the amounts of extractable organic N determined at different times depended on the extraction method used. EUF extractable organic N was highest when the soils were sampled 2 weeks following amendment with organic matter. In contrast, the peak of CaCl₂-extractable organic N compounds was observed 4 weeks after incorporation of organic matter. Net N mineralization of the added plant matter hardly differed between the various soils, although there was much variation in the initial amount of extractable organic soil N, which suggested differences in the microbial activities of soils. It was concluded by the results of the present investigation that the extractable soil organic N fractions reflect the soils microbial activities, and represent easily-mineralizable N pools in soils. CaCl₂-extractable organic soil nitrogen appears to be a reliable indicator of the amount of organic soil N accessible for mineralization in sandy soils.

INTRODUCTION

Sandy soils are generally well drained and therefore nitrate is frequently leached out in the spring. In addition, these soils do not usually bind NH₄⁺ selectively. Hence in sandy soils inorganic N reserves are usually low for growing plants in climatic zones where there is a positive water balance during winter. Mineralization of organic-nitrogen fractions may play a major role in the N supply of plants. The electro-ultrafiltration (EUF) technique of Németh (1985) extracts an organic-N fraction, which is assumed to be easily mineralizable. This method attained practical importance for the estimation of mineralizable N in order to give fertilizer recommendations, particularly for sugar beets (Wiklicky and Németh, 1981). Efforts to substitute the EUF technique by a conventional extraction method were undertaken by Houba *et al.* (1986). They found that organic and inorganic soil N extracted by 10 mM CaCl₂ solution at 20°C was closely correlated with

EUF-extractable N. According to Appel and Steffens (1988) the organic N extracted by EUF as well as by CaCl₂ was significantly related to the N uptake of rye grass. With sandy soils it was shown that the correlations between extractable organic-N and net N mineralization and N uptake of rape could be improved, if in addition to a first fraction, extracted at 20°C, a second fraction, subsequently extracted at 80°C, was also considered (Appel and Mengel, 1990). The investigations cited above were carried out with air-dried soils. It was one aim of our study to confirm previous results by an experiment using fresh soils.

The practical importance of the EUF-extractable organic-N fractions (EUF-N_{org}) is generally based on the empirical relationship between the amount of N_{org} extracted from dried soil samples, and the extent of N mineralization during the following growing season. In fact, there is still no direct evidence as to what extent the organic N, which is found in EUF or CaCl₂ extracts, is actually mineralized during the growth period of crops. Recent investigations showed that the so-called N_{org} fractions comprised amino acids, proteins and other hydrolysable N^o compounds, which were assumed to be easily mineralizable in soils

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(Németh *et al.*, 1988; Recke *et al.*, 1990; Uischner-Peetz and Neumann, 1990). Similar results were found for the CaCl_2 -extractable N_{org} by Bogdanovic (1989). Danneberg *et al.* (1989) analysed EUF, CaCl_2 , and hot-water extractable organic-N fractions chromatographically. They found that all methods extracted a main peak corresponding to N compounds with molecular weights of about 14,000 Da. In addition, a second peak corresponding to $>90,000$ Da was found in the CaCl_2 and hot water extracts, but this was excluded in the EUF extracts due to the membranes used by this technique. According to Wenzl (1990) the main components of N_{org} were identified as nitrogen-containing nonhumic substances, which were assumed to be easily mineralizable. Hence the investigations cited above lead to the conclusion that the extractable organic-N compounds are of medium molecular weights and presumably consist of nonhumic decomposition products of organic matter which are mineralized during the growing season. Consequently this fraction was taken into account in order to predict available N for growing crops (Wiklicky and Németh, 1981; Mengel, 1991).

The hypothesis (H_0) set out above is open to criticism since recent investigations have shown that no decrease of N_{org} could be observed although mineralization of organic N had occurred (Kohl and Werner, 1987; Appel and Mengel, 1990; Gutser *et al.*, 1990a; Hütsch and Mengel, 1991). These results lead to the working hypothesis of the present study (H_1) that the N_{org} fractions initially extractable in soils were in fact not identical with organic N compounds that were mineralized in soil. The EUF method as well as the CaCl_2 -extraction technique, used soil samples which were dried at 40°C in a drying oven. This drying procedure presumably destroys cells of soil microbes and therefore extractable N_{org} may contribute to a high amount of microbial biomass. Using ^{15}N -labelled biomass Kelley and Stevenson (1985) found that the selectivity by which microbial N was extracted from soils was particularly high if mild extractants were used. They calculated that 31–42% of the N extracted by milder extractants (hot water, hot 10 mM CaCl_2 , cold 10 mM NaHCO_3 , hot

5 mM NaHCO_3) was derived from the microbial biomass. Redl *et al.* (1990) confirmed that organic substances in soil extracts (hot water, sodium pyrophosphate) were to a high extent derived from the microbial biomass. Kohl and Werner (1987) and also Rheinbaben (1988) found close correlations between extractable N_{org} and the content of biomass in various soils. Hence, there are good reasons to assume that the importance of the N_{org} fraction was based largely on its function as an indicator of microbial activity for decomposition of organic matter and not so much on its function as a source of mineralized N. If N_{org} merely indicates the microbial activity available for decomposition of organic matter, it may be that organic matter incorporated into soils is mineralized rapidly if soils contain high amounts of N_{org} . The second aim of our investigation was to confirm or negate this working hypothesis.

MATERIALS AND METHODS

Soils

A pot experiment was carried out with 13 sandy soils derived from fluvial and aeolian deposits. Samples were taken on 5 June 1989 from the upper layer (0–30 cm) of soils used for field trials in Hessia, Germany. The soils were selected to obtain a wide variation of soil characteristics and in particular of extractable soil N fractions. All sites had been fertilized with 40 kg N ha^{-1} applied as calcium ammonium nitrate in early spring. More detailed information about the cropping history of each field site is reported in Appel (1991). Soil characteristics are given in Table 1.

Experimental procedure

After sampling, the soil samples were covered with plastic to prevent evaporation and stored overnight at about 12°C . On the following day (day 0) each soil was homogenized and samples were taken from each bulk sample in order to estimate the initial amount of EUF and CaCl_2 -extractable N. One litre of each soil was placed in plastic pots 10 cm dia. The pots were closed at their base in order to prevent N losses by leaching. For each soil three pots (replicates) were

Table 1. Soil characteristics

Soil No.	Texture (%)			pH (CaCl_2)	Total N (g kg^{-1})	Total C (g kg^{-1})	C:N ratio	Bulk density (g ml^{-1})
	Sand	Silt	Clay					
1	88	5	6	5.9	1.11	13.6	12.3	1.21
2	86	7	7	5.9	0.73	8.6	11.9	1.28
3	82	11	8	6.9	0.61	7.8	12.9	1.37
4	79	10	11	6.5	3.99	47.1	11.8	0.86
5	73	14	13	6.2	0.59	6.7	11.3	1.33
6	66	22	11	7.0	1.40	24.2	17.3	1.04
7	85	8	7	4.5	0.65	7.3	11.2	1.32
8	87	5	8	6.3	0.59	6.1	10.3	1.24
9	85	8	7	6.9	0.82	9.5	11.6	1.16
10	88	5	7	4.9	0.43	4.6	10.7	1.21
11	87	6	7	6.8	0.55	6.3	11.4	1.21
12	88	7	6	6.0	0.54	6.3	11.8	1.22
13	75	17	8	6.5	0.54	5.9	10.9	1.28

Table 2. Electro-ultrafiltration (EUF) and CaCl₂ extractable N fractions initially present in 13 soils on day 0 and nitrogen uptake of rye-grass during a growth period of 56 days (mg N pot⁻¹)

		Range		
		Mean	Minimum	Maximum
EUF method				
20°C fractions	NO ₃ -N	1.5	0.4	5.6
	NH ₄ -N	1.6	1.3	2.2
	Organic N	8.4	5.5	14.6
20 + 80°C fractions	NO ₃ -N	1.6	0.5	5.9
	NH ₄ -N	2.6	2.1	3.5
	Organic N	13.6	9.0	26.3
CaCl ₂ extraction				
20°C fractions	NO ₃ -N	1.6	0.3	5.6
	NH ₄ -N	1.3	0.1	2.0
	Organic N	6.9	4.2	11.3
20 + 80°C fractions	NO ₃ -N	1.7	0.3	6.1
	NH ₄ -N	2.7	0.7	4.6
	Organic N	15.8	7.7	25.5
N uptake of rye grass		19.0	7.6	33.4

filled. Six of the soils (Nos 2, 4, 6, 8, 9, 12), comprising a wide variation of extractable organic-N, were selected in order to study the effect of organic matter incorporation (organic manure) on N mineralization. Each pot received 50 g of fresh sugar beet leaves (3.67 mg N g⁻¹ fresh weight), which had been minced and homogenized and then carefully mixed into 1 litre of soil. Soils were moistured to 50% field capacity and covered with lids to avoid evaporation. Then they were incubated at 20°C for 14 days.

On 20 June (day 14) soil samples were drawn for analysis from each pot by a small drill (30 ml pot⁻¹). Rye grass (*Lolium multiflorum* c.v. Meritra) was sown (1 g seed per pot comprising 21.2 mg N per pot) and the seed was covered with quartz sand (100 g pot⁻¹) to prevent puddling of the soil surface. The small hole in the soil, caused by soil sampling, was also filled with quartz sand. The soils were fertilized with K, P, and Mg (60, 30, 24 mg pot⁻¹ in liquid form as K₂SO₄, NaH₂PO₄ and MgSO₄, respectively) and the pots were then placed in a growing chamber and illuminated 16 h day⁻¹ (84 J m⁻² s⁻¹ Philips TL F 65 W/33) at 25°C (18°C at night). Pots were watered daily to 50% field capacity.

The plants emerged 4 days after sowing and developed normally, but on the soils not manured with organic matter the grass showed symptoms of N deficiency, particularly yellowing of older leaves. Plants grown on organic-manured soils showed N deficiency symptoms 6 weeks after sowing.

On 4 July (day 28) and subsequently every 14 days (days 42, 56 and 70) soil samples were taken from each pot according to the technique described above for day 14. The first clipping of the grass was carried out on day 28 and subsequent clippings were made every 14 days. The plants were cut about 1.5 cm above the soil surface. The final clipping was performed on day 70. On this date roots were also harvested. The roots of each pot were washed out by means of cold deionized water. Shoots and roots were analysed for total N by the Kjeldahl procedure.

Soil samples taken for analysis on days 0–70 (D₀, D₁₄, D₂₈, D₄₂, D₅₆, D₇₀) were dried in a drying oven

at 40°C (18 h) immediately after sampling. Dried soils were crushed with a pestle and stored until EUF and CaCl₂ extraction were carried out.

Soil analysis

Electro-ultrafiltration analysis of samples was carried out according to Németh (1985). Two EUF fractions were extracted: (1) 0–30 min at 20°C, 200 V and ≤15 mA; (2) 30–35 min at 80°C, 400 V and ≤150 mA.

A fractionated soil extraction with 0.01 M CaCl₂ solution was carried out according to Appel and Mengel (1990). The first fraction (20°C, shaking for 120 min) of this extraction is equivalent to that obtained in the extraction procedure proposed by Houba *et al.* (1986). The second fraction was extracted at 80°C, shaking for 20 min. A continuous flow analyser was used to determine total N, NO₃⁻, and NH₄⁺ in the EUF and CaCl₂ extracts. Extractable organic N (N_{org}) was defined as total extractable-N minus inorganic extractable-N.

Plant N uptake and net N mineralization

N uptake was calculated as N in shoots (cumulative 1. to 4. clip) plus N in roots minus N in seed. Net N mineralization was defined as change in CaCl₂-extractable inorganic soil N (Δ20°C fraction) during the entire experimental period plus N uptake of the grass.

RESULTS

Soil nitrogen fractions as related to plant available N

Table 2 shows the initial amount of various extractable N fractions in the soils at day 0 and the N uptake of the grass. Inorganic N was generally low and almost the same for EUF and CaCl₂ extraction. Extractable organic-N was on average about three-fold higher than extractable inorganic soil N. The N uptake of the grass considerably exceeded the inorganic N reserves, which indicates that most of the N supply was provided by mineralization of organic soil-N.

Table 3 shows coefficients of determination of various soil-N fractions extracted at day 0 versus N uptake and net N mineralization. CaCl₂-extractable N_{org} was significantly related to net N mineralization ($r^2 = 0.60$, $P > 0.001$) and N uptake of the grass ($r^2 = 0.66$, $P > 0.001$). In contrast, EUF-extractable N_{org} could explain only 16% of the variation of net N mineralization ($r^2 = 0.16$, $P > 0.05$), which was less than explained by total soil N ($r^2 = 0.23$, $P > 0.01$). Coefficients of determination were little improved if instead of just one fraction the sums of the first and the second fractions of EUF and of the CaCl₂ extractions were considered. Surprisingly, even the initial amount of NO₃⁻ was related not only to N uptake but also to net N mineralization. Initial NH₄⁺ determined by EUF or CaCl₂ extraction was not related to N mineralization and was of minor

Table 3. Coefficients of determination (r^2) of total soil nitrogen and various soil N fractions extracted at day 0 versus N uptake and net N mineralization

Soil characteristics and soil N fractions		versus N uptake	versus N mineralization
Total soil N		0.33***	0.23**
CaCl ₂ extraction			
NO ₃ -N + NH ₄ -N + N _{org}	1.fct	0.59***	0.46***
	1. + 2.fct	0.61***	0.51***
NO ₃ -N	1.fct	0.58***	0.44***
	1. + 2.fct	0.57***	0.43***
NH ₄ -N	1.fct	n.s.	n.s.
	1. + 2.fct	0.10*	n.s.
N _{org}	1.fct	0.63***	0.56***
	1. + 2.fct	0.66***	0.60***
EUf method			
NO ₃ -N + NH ₄ -N + N _{org}	1.fct	0.35***	0.25***
	1. + 2.fct	0.34***	0.24***
NO ₃ -N	1.fct	0.63***	0.49***
	1. + 2.fct	0.63***	0.49***
NH ₄ -N	1.fct	0.17**	n.s.
	1. + 2.fct	0.16*	n.s.
N _{org}	1.fct	0.15*	0.10*
	1. + 2.fct	0.22**	0.16*

Significance at the 5, 1, 0.1% level is indicated by *, **, ***, respectively; n.s. = not significant; $n = 39$ determinations.

importance for the N uptake of the grass. Total extractable N (NO₃-N + NH₄-N + N_{org}) determined by CaCl₂ extraction did not improve r^2 values over those calculated when nitrate or N_{org} was taken into consideration. However, when results obtained using the EUf method were considered, some improvement in r^2 values was noted when total extractable-N or nitrate-N data were used instead of N_{org} data (Table 3).

Organic manure

Incorporation of sugar beet leaves into the soils enhanced available N for plants. This was reflected by higher N uptake and dry matter production of the shoots clipped at intervals of 14 days (Table 4). Nitrogen in the roots at the end of the experiment

(D₇₀) was on average 15.3 (12.1–20.8) mg N pot⁻¹ in unmanured pots (controls) and 22.4 (17.8–27.7) mg N pot⁻¹ in organic-manured pots. Because N in roots amounted to about the same as was analysed in the seed (21.2 mg N pot⁻¹) the N amount yielded in the shoots closely represented the N uptake of the grass.

Soil nitrate reserves in controls were low at seeding time (D₁₄) and were used up quickly by the plants during the following growth period. Therefore dry matter production and N uptake of plants grown on controls were limited by the insufficient N supply. No major change of extractable NH₄⁺ and organic N was observed in unmanured soils during the growth period.

With sugar beet leaves incorporated into the soils, nitrate reserves were on average 10-fold higher at seeding time (D₁₄) than were the controls.

This observation indicates that conditions were favourable for net N mineralization of the added plant matter, because on average about 58% of the N added by means of the organic matter applied was found as inorganic N, particularly as NO₃⁻, after 2 weeks of incubation. N uptake of the grass during the following growth period was reflected by a decrease of soil NO₃⁻. After a growth period of 28 days (D₁₄–D₄₂) the nitrate reserves were almost taken up by the plants.

Ammonium in the soils was generally low and organic manure had no significant effect on the EUf-extractable NH₄⁺-N (data not shown) and only a small effect on CaCl₂-extractable NH₄⁺ (Table 4). This lack of major NH₄⁺ accumulation indicates that conditions for nitrification were always favourable, even in manured pots.

Decomposition of sugar beet leaves was reflected by a significant increase in extractable organic-N (Table 5). However, the time-dependent pattern of extractable N_{org} in the treatments with organic matter application differed between CaCl₂ extraction and

Table 4. Grand means of inorganic soil nitrogen (CaCl₂ extraction 20°C fraction), dry matter and N uptake in shoots of rye grass grown on six organic manured (+OM) and unmanured (-OM) soils on day 0 to day 70 (mg pot⁻¹)

		Day					
		0	14	28	42	56	70
NO ₃ -N	-OM	2.4	8.8	0.7	0.6	0.6	0.5
		n.d.	***	***	***	n.s.	n.s.
NH ₄ -N	+OM	2.4	113.3	31.7	3.1	1.1	1.0
	-OM	1.4	2.8	3.2	2.6	3.6	3.1
N in shoots		n.d.	***	**	n.s.	n.s.	n.s.
	+OM	1.4	4.0	3.6	2.8	3.7	3.2
Dry matter in shoots	-OM			16.7	6.7	2.7	1.6
				***	***	***	***
	+OM			70.2	54.4	16.1	6.2
	-OM			559	309	161	93
				***	***	***	***
				1155	1375	733	292

Organic manure (183.5 mg N pot⁻¹) was incorporated into the soils as fresh sugar beet leaves on day 0 after bulk samples had been drawn; rye grass was sown on day 14 and clipped in 14 day periods; grand means of six soils with three replicates were shown for day 14–day 70, values of bulk samples for day 0; significant effects of organic manure are indicated as *, **, *** for the 5, 1, 0.1% level, respectively; n.s. = not significant, n.d. = not determined.

Table 5. Grand means of organic nitrogen fractions (mg N pot⁻¹) from organic manured (+OM) soils on day 0-70

		Day						
		0	14	28	42	56	70	
EUF method	20°C	-OM	9.8	10.5	9.5	10.4	11.2	10.0
		fractions	n.d.	***	***	*	**	*
	20 + 80°C	-OM	9.8	21.0	14.2	11.6	12.6	11.7
		fractions	n.d.	***	***	**	**	*
CaCl ₂ extraction	20°C	-OM	7.5	9.8	7.6	7.9	8.5	7.2
		fractions	n.d.	n.s.	***	***	***	***
	20 + 80°C	-OM	7.5	10.4	15.6	9.9	9.9	8.8
		fractions	n.d.	***	***	***	***	***
	+OM	17.7	26.2	28.8	21.6	20.7	20.3	

Legend see Table 4.

EUF. As shown in Fig. 1 the EUF extractable N_{org} (1. and 2. fraction) showed a peak 14 days after the beginning of the incubation. At this time also the 2. fraction of the CaCl₂-extractable N_{org} showed a peak. The 1. fraction of the CaCl₂-extractable organic N, however, peaked 28 days after the beginning of incubation. The data in Fig. 1 represent the differences in N_{org} between manured soils and controls and are means of the six soils used.

All organic N fractions in soil from manured pots were still significantly higher 42 and 56 days after the beginning of incubation than that of the controls and even 70 days after the beginning of incubation only the amount of the 2. EUF-N_{org} fraction was not significantly different from the control. In general the pattern of organic N, obtained by the second CaCl₂ fraction, was similar to that of the EUF-extractable N_{org} fractions (20 and 80°C fractions), but the changes in soil organic N, as determined by the first

CaCl₂ fraction (20°C fraction), differed from EUF-N_{org}. Table 6 shows the initial N_{org} content extracted from samples on day 0 and the net N mineralization of the organic manure. In contrast to our working hypothesis (H₁) the N_{org} concentrations, initially present in the soils on day 0, were not related to net N mineralization of added organic matter. On the contrary, there was a tendency that soils high in initial N_{org} were relatively low in net N mineralization of organic manure.

DISCUSSION

Importance of extractable nitrogen

One of our aims was to confirm our observations (Appel and Mengel, 1990) on the importance of extractable organic-N fractions (N_{org}) for N mineralization in sandy soils. The soils were initially low in inorganic N reserves and therefore mineralization of organic N was a major source for plant-available N (Table 2).

CaCl₂-extractable organic N was most closely related to net N mineralization and N uptake of the grass (Table 3). In contrast to the findings of Appel and Steffens (1988) and Appel and Mengel (1990) the correlation between EUF-N_{org} and N mineralization was less close than for CaCl₂-N_{org}. This result may be

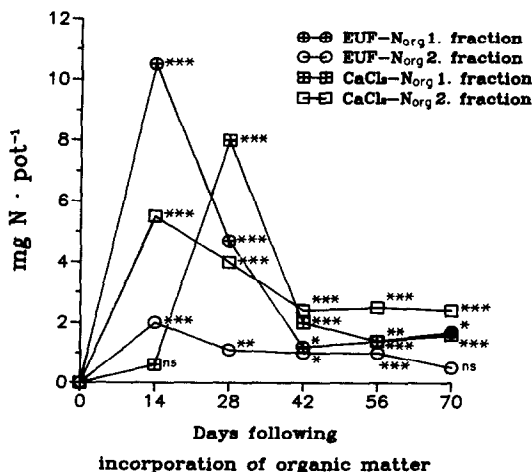


Fig. 1. Effect of organic matter application on EUF and CaCl₂-extractable organic N fractions. The curves represent the difference between the treatment with or without organic matter application; grand means of six soils, each three times replicated; *, **, *** significant differences between both treatments at the 5, 1, and 0.1% level, respectively; ns = not significant.

Table 6. Initial organic nitrogen in soils, obtained by EUF and CaCl₂ extraction (20 + 80°C fractions), and net N mineralization of added organic manure (mg N pot⁻¹)

Soil No.	Organic N on day 0		Net-N-mineralization of added plant matter		
	EUF	CaCl ₂	Day 0-14	Day 14-70	Day 0-70
2	13.6	19.2	111.3	24.1	135.4
4	26.3	25.5	103.4	10.7	114.2
6	20.3	19.4	97.3	22.6	119.9
8	12.4	11.2	112.6	22.6	135.1
9	14.1	19.9	107.2	25.6	132.9
12	10.2	10.8	101.9	22.8	124.8

Organic manure was incorporated into the soils as 50 g fresh sugar beet leaves after soil samples had been taken on day 0; total N of added organic matter was 183.4 mg N pot⁻¹; net N mineralization of the added organic manure was calculated from the difference of net N mineralization between manured and unmanured soils.

due to the use of fresh soils in contrast to air-dried soils in the studies cited above. This interpretation agrees well with results of Gutser *et al.* (1990a, 1990b), who used fresh soils sampled in 1988 and 1989, respectively. According to Beck (1983), a considerable amount of originally inert soil organic matter becomes soluble and accessible for mineralization due to the drying procedure of the soils. Hence drying of soils generally causes a flush of mineralization after rewetting (Nordmeyer and Richter, 1985). Furthermore, it is well known that increasing temperatures during the drying procedure of soil samples enhances the amount of extractable organic N (Houba *et al.*, 1990). Since EUF as well as CaCl_2 -extraction methods were based on dried (40°C) soil samples, both methods presumably extract considerable amounts of organic N compounds, which were originally not accessible to mineralization in fresh soils.

According to Danneberg *et al.* (1989) the major difference between EUF and CaCl_2 -extraction is based on the use of membranes by EUF, which exclude molecules $> 20,000$ Da, while CaCl_2 extracts an additional peak of organic compounds $> 90,000$ Da. It is not yet known to what extent this high molecular weight organic fraction is accessible to mineralization. However, the finding that CaCl_2 -extractable N_{org} is even more related to N mineralization in fresh soils than EUF- N_{org} (Table 3) indicates that the high molecular weight fraction, which is excluded by EUF, may be of particular importance for N mineralization. The extractable low molecular weight fraction presumably is related to soil organic compounds, which become accessible to mineralization throughout the drying process of soils. This interpretation is in good agreement with our finding that the second fractions (EUF as well as CaCl_2 extraction) did not improve the correlation between N_{org} and N mineralization for fresh soils (Table 3), but did remarkably improve the correlation for dried soils (Appel and Mengel, 1990). According to Wenzl (1990) a higher extraction temperature as well as further soil extractions enhances the low molecular weight organic fraction. The assumption that the EUF and CaCl_2 -extractable organic compounds were not completely accessible to mineralization in fresh soils may also explain why the N_{org} amount in the soils did not decline to zero although conditions for mineralization were most favourable and when the rye grass suffered from N deficiency after the NO_3^- reserves had been taken up (Table 4). In contrast, nitrate was almost completely depleted by the plants, indicating the high availability of this N fraction.

Initial NO_3^- in the soils was also highly significantly related to N uptake by the plants (Table 3). Surprisingly, nitrate was also closely related to net N mineralization. This finding may be explained by taking into consideration, that the soils of the present study were derived from field trials, which had received only 40 kg N ha^{-1} in early spring. This rela-

tively poor N dressing, had already been taken up very soon after application by the crops on the various field sites (Appel and Mengel, 1992). Hence under these particular circumstances the variation of NO_3^- extractable in June from the various field sites was caused by previous N mineralization in the upper soil layer, which had exceeded the N uptake of the crops. Therefore the variation of NO_3^- reflected the mineralization potential of the soils. Similar observations were reported by Jenkinson (1968).

Green manure as related to soil N fractions

The second aim of our study was focused on extractable organic-N during decomposition of added organic matter. The aim was to test the hypothesis whether N_{org} is merely an indicator of microbial activity for decomposing organic-N compounds (H_1). The contrasting hypothesis H_0 was assuming that N_{org} represents an easily mineralizable N fraction, which becomes actually mineralized and therefore available for plants (H_0).

By comparing the N mineralization in soils supplied and not supplied with organic matter, it was shown that the N mineralization of added organic matter was not related to the N_{org} concentration initially extractable from soils (Table 6). Hence, our investigation did not support H_1 alternatively to H_0 .

It was found that the decomposition of organic matter enhances the plant-available N, which was clearly reflected by an increase of inorganic soil N as well as of extractable organic-N fractions, followed by a decrease of organic and inorganic soil N because of the N uptake by the grass (Tables 4 and 5). This result was in line with investigations of Feng *et al.* (1990), who studied the effect of plant matter, incorporated into a sandy and a loamy soil, on EUF and CaCl_2 -extractable N fractions. However, the present study shows that the time dependent pattern of CaCl_2 - N_{org} and EUF- N_{org} differed considerably (Fig. 1). This finding agrees well with the results discussed above, because the organic N fractions extracted by EUF and CaCl_2 were of different importance for N mineralization in fresh soils.

Although there is in fact still no direct evidence for hypothesis H_0 the present study confirms that the extractable organic-N fractions, particular CaCl_2 - N_{org} , are a reliable indicator of plant-available N in soils. Hence extractable organic-N fractions appear as a useful tool in order to improve N fertilizer recommendations on sandy soils. However, further knowledge is badly needed about the chemical nature of the " N_{org} " in order to resolve how this fraction is involved in turnover of soil organic matter.

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REFERENCES

- Appel Th. (1991) Der Stickstoff-Umsatz in Sandböden und seine Bedeutung für die Prognose des pflanzenverfü-

- baren Stickstoffs sowie des N-Düngerbedarfs von Getreide, untersucht mittels Elektro-Ultrafiltration (EUF) und CaCl_2 -Extraktion. *Gießener Bodenkundliche Abhandlungen*, Band 9, Wissenschaftlicher Fachverlag Dr. Fleck, Gießen.
- Appel Th. and Mengel K. (1990) Importance of organic nitrogen fractions in sandy soils, obtained by electro-ultrafiltration or CaCl_2 extraction, for nitrogen mineralization and nitrogen uptake of rape. *Biology and Fertility of Soils* **10**, 97–101.
- Appel Th. and Mengel K. (1992) Nitrogen uptake of cereals grown on sandy soils as related to nitrogen fertilizer application and soil nitrogen fractions obtained by electro-ultrafiltration (EUF) and CaCl_2 extraction. *European Journal of Agronomy* **1**, 1–9.
- Appel Th. and Steffens D. (1988) Vergleich von Electro-Ultrafiltration (EUF) and Extraktion mit 0,01 molarer CaCl_2 -Lösung zur Bestimmung des pflanzenverfügbaren Stickstoffs im Boden. *Zeitschrift für Pflanzenernährung und Bodenkunde* **151**, 127–130.
- Beck Th. (1983) Die N-Mineralisation von Böden im Laborbrutversuch. *Zeitschrift für Pflanzenernährung und Bodenkunde* **146**, 243–252.
- Bogdanovic D. (1989) Influence of drying temperature and drying conditions on extractable nutrients and elements by 0,01 M CaCl_2 . Dept of Soil Science and Plant Nutrition, Agricultural University, Wageningen, The Netherlands.
- Danneberg O. H., Wenzl W. and Ellinghaus R. (1989) Vergleich verschiedener Bodenextrakte zur Beurteilung des nachlieferbaren Stickstoffs mit Hilfe der Säulenchromatographie. Kongreßband 1988. *VDLUFA-Schriftenreihe* **28/II**, 551–573.
- Feng K., Dou H. and Mengel K. (1990) Turnover of plant matter in soils as assessed by electro-ultrafiltration (EUF) and CaCl_2 extracts. *Agribiological Research* **43**, 337–347.
- Gutser R., Vilsmeier K., Teicher K. and Beck Th. (1990a) Aussagekraft des N_{org} -Stickstoffs für die N-Nachlieferung von Böden. Kongreßband 1989. *VDLUFA-Schriftenreihe* **30**, 187–194.
- Gutser R., Teicher K. and Maier S. (1990b) Gefäßversuche zur Aussagekraft des N_{org} -Stickstoffs für das N-Potential von Böden. Kongreßband 1990. *VDLUFA-Schriftenreihe* **32**, 243–248.
- Houba V. J. G., Novozamsky I., Huybregts A. W. M. and Van der Lee J. J. (1986) Comparison of soil extractions by 0,01 M CaCl_2 , by EUF and by some conventional extraction procedures. *Plant and Soil* **96**, 433–437.
- Houba V. J. G., Novozamsky I. and Van der Lee J. J. (1990) Some aspects of determinations of nitrogen fractions in soil extracts. Kongreßband 1989. *VDLUFA-Schriftenreihe* **30**, 305–312.
- Hütsch B. and Mengel K. (1991) Messung von Denitrifikationsverlusten bei Pflugbearbeitung und Direktsaat. *Zeitschrift für Kulturtechnik und Landentwicklung* **32**, 70–79.
- Jenkinson D. S. (1968) Chemical tests for potentially available nitrogen in soil. *Journal of Science of Food and Agriculture* **19**, 160–168.
- Kelley K. R. and Stevenson F. J. (1985) Characterization and extractability of immobilized ^{15}N from the soil microbial biomass. *Soil Biology & Biochemistry* **17**, 517–523.
- Kohl A. and Werner W. (1987) Untersuchungen zur saisonalen Veränderung der EUF-N-Fractionen und zur Charakterisierung des leicht mobilisierbaren Bodenstickstoffs durch Elektro-Ultrafiltration (EUF). Kongreßband 1986. *VDLUFA-Schriftenreihe* **20**, 333–341.
- Mengel K. (1991) Organischer Stickstoff des Bodens: Seine Mineralisierbarkeit und seine Bedeutung für eine ökologisch orientierte Landwirtschaft. *Ergebnisse landwirtschaftlicher Forschung* **20**, 35–49.
- Németh K. (1985) Recent advances in EUF research (1980–1983). *Plant and Soil* **83**, 1–19.
- Németh K., Bartels H., Vogel M. and Mengel K. (1988) Organic nitrogen compounds extracted from arable and forest soils by electro-ultrafiltration and recovery rates of amino acids. *Biology and Fertility of Soils* **5**, 271–275.
- Nordmeyer H. and Richter J. (1985) Incubation experiments on nitrogen mineralization in loess and sandy soils. *Plant and Soil* **83**, 433–445.
- Recke H., Németh K. and Vogel M. (1990) Zusammensetzung der EUF- N_{org} -Fraktionen bei 20°C und 80°C in Abhängigkeit von Bodeneigenschaften. Kongreßband 1990. *VDLUFA-Schriftenreihe* **32**, 234–248.
- Redl G., Hübner C. and Wurst F. (1990) Changes in hot water soil extracts brought about by nitrogen immobilization and mineralization processes during incubation of amended soils. *Biology and Fertility of Soils* **10**, 45–49.
- Rheinbaben W. von (1988) Beziehungen zwischen der EUF- N_{org} -Fraktion und chemischen und mikrobiologischen Parametern in Böden. 3. In *Kostensenkung und Umweltschutz* (International Symposium on EUF, May 1988 in Mannheim), Vol. II, pp. 425–440. Süddeutsche Zucker-AG, Mannheim.
- Uischner-Peetz C. and Neumann K.-H. (1990) Untersuchungen zur molekularen Charakterisierung der N_{org} -Fraktion in verschiedenen Böden. Kongreßband 1990. *VDLUFA-Schriftenreihe* **32**, 853–859.
- Wenzl W. (1990) Extraktion und Charakterisierung von stickstoffreichen Nichtthuminstoffen einer Braunerde. Kongreßband 1990. *VDLUFA-Schriftenreihe* **32**, 337–344.
- Wiklicky L. and Németh K. (1981) Düngungsoptimierung mittels EUF-Bodenuntersuchung bei der Zuckerrübe. *Zuckerindustrie* **106**, 982–988.