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Effect of grassland management on the amounts of soil organic N and C*

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Abstract

In the period 1985-1990 field trials with N fertilization, grazing and mowing were conducted on a sandy soil and a loamy soil to investigate the accumulation of organic N and C in intensively managed grassland systems. Annual fertilizer rates of N varied from 250 to 700 kg ha^{-1} under grazing and from 0 to 700 kg ha^{-1} under mowing. On the grazed plots no significant accumulation of soil organic N occurred in the sandy oil, whereas in the loamy soil an average N accumulation of 245 kg ha^{-1} yr^{-1} was found. The accumulation in the loamy soil was probably caused by the marine history of the soil and the fact that the soil was recently plowed and resown. The accumulation was independent of the level of fertilizer N applied, indicating that increased biomass production does not necessarily increase the return of dead organic material to the soil. These results confirm the suggestion that the surplus of fertilizer N is largely lost to the environment. About four years after the start of the experiment the amounts of soil N and C were considerably higher under grazing than under mowing. In spite of the higher amount of soil N under grazing compared to mowing, approximately 71 % and 57 % of the extra amount of N returned to the soil by grazing is lost to the environment on the sandy and the loamy soil, respectively. The C/N ratio of the soil organic matter was lower in plots with fertilizer N application than in plots without fertilizer N. This difference was probably caused by a difference in C/N ratio of dead grass and roots that were returned to the soil.

Keywords: grassland, soil organic N, soil organic C, management, C/N ratio

Introduction

Overall input/output balances for intensively managed grassland systems in the Netherlands have indicated that the difference between input of N via concentrates, fertilizers and atmospheric deposition and the output in the form of milk and beef is very large. An annual difference of 450 kg ha^{-1} is no exception (van der Meer & van Uum-van Lohuyzen, 1986). The N that is not accounted for in balances is either incorporated into soil organic matter or lost through a combination of leaching and emission of gaseous N compounds to the atmosphere. To estimate the

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amount of N that is lost to the environment, the quantity of N that is incorporated into soil organic matter should be known. There is only limited quantitative information on the incorporation of N into, and its release from the soil organic matter, and on the factors affecting these processes. In soils resown to grassland after arable cropping, the soil N content usually increases. Accumulation rates of N of 40-400 kg ha^{-1} yr^{-1} have been observed (Vetter, 1966). It is assumed that accumulation of organic N is asymptotic, reaching an equilibrium when management is unchanged (Ryden, 1984).

In past decades the use of fertilizers has been increased and management has been intensified considerably. If intensification of management increases the amounts of organic residues that are returned to the soil, the equilibrium level of organic N and C will rise and the amount of N that mineralizes will also increase with time. This will affect the optimum rate of application of fertilizer N. Van der Meer & van Uum-van Lohuyzen (1986) reasoned that the quality of organic matter might have changed due to increased fertilizer input during the last decade. They observed that recoveries of fertilizer N had increased during the last 10 years, possibly because a lowering of the C/N ratio of the soil reduced the immobilization of fertilizer N. Inputs of nitrogen into a grazed sward are usually larger than inputs into a mown sward. On a grazed sward there is a return of N via dung and urine. Under grazing the amount of herbage returned to the soil is larger because grazing losses will occur during grazing. In the longer term the greater return of organic N should lead to a higher level of soil organic N under grazing than under mowing.

In order to study the effect of different management systems on the amount of soil organic N and C, we examined the time course of the amounts of soil N and C in a sandy and loamy soil with different fertilizer levels under rotational grazing, and the difference in total soil N and C between grazed and mown fields.

Materials and methods

Site characteristics and treatments

The trials were carried out on two locations. The first location is a sandy soil in Achterberg which had been under grass for many years. The old sward was reseeded in 1981. The comparison between continuous grazing and mowing was started in 1985. From 1986 onwards continuous grazing was replaced by rotational grazing. The second location is a young sedimentary calcareous silty loam soil (loam) in Swifterbant reclaimed from the sea only 30 years ago. Here the old sward was reseeded in 1985, and from 1986 onwards continuous grazing and mowing treatments were compared. At both locations the grazed fields received four rates of mineral fertilizer N annually: 250, 400, 550 and 700 kg ha^{-1} (N1-N4), while the mown fields received 0, 250, 400, 550 and 700 kg ha^{-1} (N0-N4). On the sandy soil the grazed plots were laid out singly, on the loamy soil in duplicate. The size of the grazed fields was 0.2 ha on the sandy soil and 1.0 ha on the loamy soil. The mown fields were laid out in duplicate within one of the grazed fields, each plot having an area of 25 m^2. Fields were cut or rotationally grazed when the herbage reached about 2000

Table 1. Characteristics of the 0-5 cm layer of the sandy and loamy soil in March 1986.

Soil	pH-KCl	Particle size fractions (%)			P-AL (mg/100 g)	K-ox (mg/100 g)	CaCO3 (%)
		<2 μm	<16 μm	<50 μm			
Sand	5.0	3.0	5.2	9.5	57	36	0
Loam	7.1	22.7	39.4	74.6	17	30	10.0

kg ha^{-1} of dry matter (DM) on the sandy soil. On the loamy soil, a mean sward height of about 7 cm was maintained with continuous grazing by adjusting the stocking rate in the paddocks when necessary. The average number of grazing days was about 1500 on the sandy soil and 600 on the loamy soil. More organic N was returned to the sandy soil in manure and urine than to the loamy soil. On the sandy soil steers were used, on the loamy soil dairy cattle. Some soil characteristics of the two locations are given in Table 1.

Sampling

On the grazed plots soil samples were taken in March, before fertilizer application and in November in 1986, 1987 and 1988. The grazed plots of the sandy soil were sampled in November 1990 as well. Sampling was carried out at depths of 0-10 and 10-30 cm. Five replicates were taken per layer, each replicate being a combination of 10 cores.

In March 1989 mown and grazed plots were sampled. Soil samples were taken from 0-5, 5-10 and 10-25 cm depth. From the grazed plots, again five replicates were taken per layer as described above. From the mown plots one mixed sample consisting of ten cores was taken from every soil layer. Roots and stubble were included in the samples. At each sampling date, six cores from each field and depth were taken for the measurement of the bulk density.

Chemical analysis

The following parameters were determined:
- Mineral N extractable with 1 M KCl. Extracts were analysed with a Technicon autoanalyser (Traacs 800).
- Total soil N content according to Deijs (Deijs, 1961).
- Organic matter, defined as loss on ignition for the sandy soil and dichromate-oxidizable organic matter according to Kurmies for the loam (Mebius, 1960). For the sandy soil the amount of C was calculated as loss on ignition × 0.58.
- Organic N was calculated as the difference between total N and inorganic N.

Statistics

Measurements of the time course of soil N and C were statistically analysed with

Genstat (Genstat Manual, 1987). For each fertilizer treatment a separate curve was calculated for the relationship between the amount of organic N and the date of sampling. The slopes of the lines and the standard errors of the difference were calculated. Differences in the average amounts of soil organic N and C between mown and grazed grassland were also analysed with Genstat.

Results

Time course of the amounts of organic N and C and bulk density under grazing

In both soils, the level of fertilizer N did not significantly affect the bulk density and the N and C contents of the two soil layers. So the results for the different fertilizer levels obtained at the same sampling date have been pooled. The bulk density of the sandy soil changed little during the experimental period (Table 2). The bulk density of the loamy soil fluctuated more and tended to increase with time (Table 2). The C/N ratio of the organic matter of the sandy soil was higher than that of the loamy soil. There was not consistent change in the C/N ratio of the organic matter of both soils (Table 2).

In the sandy soil, fluctuations in the amount of organic N between sampling dates were considerable (Figure 1). The amount of organic N inreased by an average of 90 kg ha^{-1} yr^{-1} in the top 10 cm, but this increase was not significant at $P < 0.1$ (s.e.d. = 64). In the 10-30 cm layer there was a small but not significant ($P < 0.1$) annual decrease in the amount of organic N (30 kg ha^{-1} yr^{-1}, s.e.d. = 56). In the loamy soil the amount of organic N increased considerably in the top 10 cm by an average of 245 kg ha^{-1} yr^{-1} (s.e.d. = 44). In the 10-30 cm layer the average increase in

Table 2. Course of bulk density and C/N ratio of the organic matter in the 0-10 and 10-30 cm layers of the sandy and the loamy soil under grazing (average values of the four levels of N fertilizer). M = March, N = November.

Soil type	Soil layer (cm)	1986		1987		1988		1989	1990
		M	N	M	N	M	N	M	N
Bulk density (g cm^{-3})									
Sand	0-10	1.45	1.41	1.45	1.44	1.46	1.45	1.42	1.40
Sand	10-30	1.40	1.40	1.40	1.40	1.41	1.40		1.35
Loam	0-10	1.25	1.23	1.26	1.25	1.26	1.32	1.31	
Loam	10-30	1.32	1.38	1.33	1.33	1.33	1.39		
C/N ratio of organic matter									
Sand	0-10	15.6	16.1	16.2	15.5	15.0	15.9	15.9	16.0
Sand	10-30	16.6	17.8	17.3	17.2	15.7	17.3		17.0
Loam	0-10	11.9	11.5	12.1	11.7	11.6	11.3	11.6	
Loam	10-30	11.6	9.9	11.8	11.3	11.3	9.6		

the amount of organic N was 77 kg ha^{-1} yr^{-1} (s.e.d. = 91). This increase was not significant ($P < 0.1$) (Figure 2). For both soils the differences in amounts of N in replicate samples of a field at a certain sampling date were much smaller than the differences in amounts of N of a field between sampling dates.

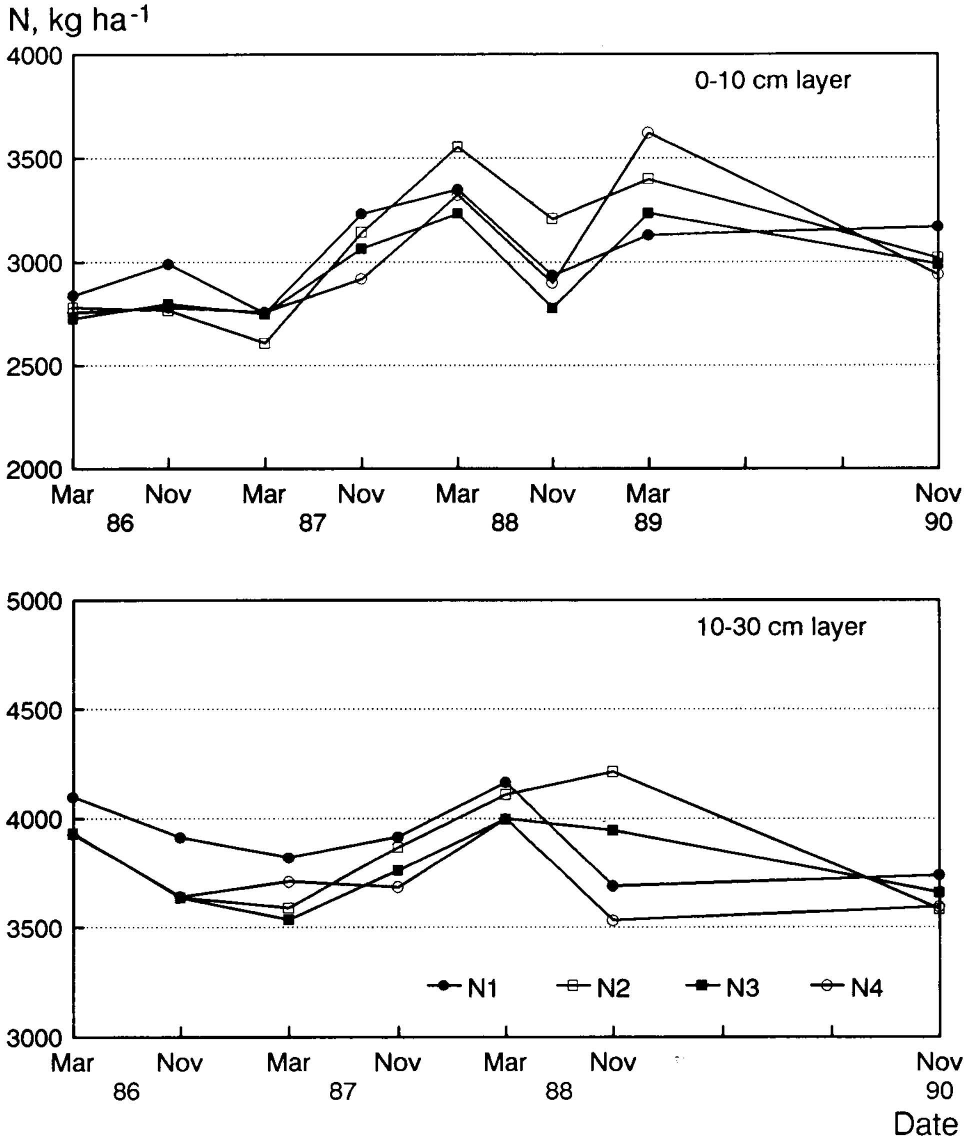

Fig. 1. Course of the amount of organic N in grazed plots of the sandy soil during the period March 1986-November 1990 in the 0-10 cm soil layer (top) and the 10-30 cm soil layer (bottom).

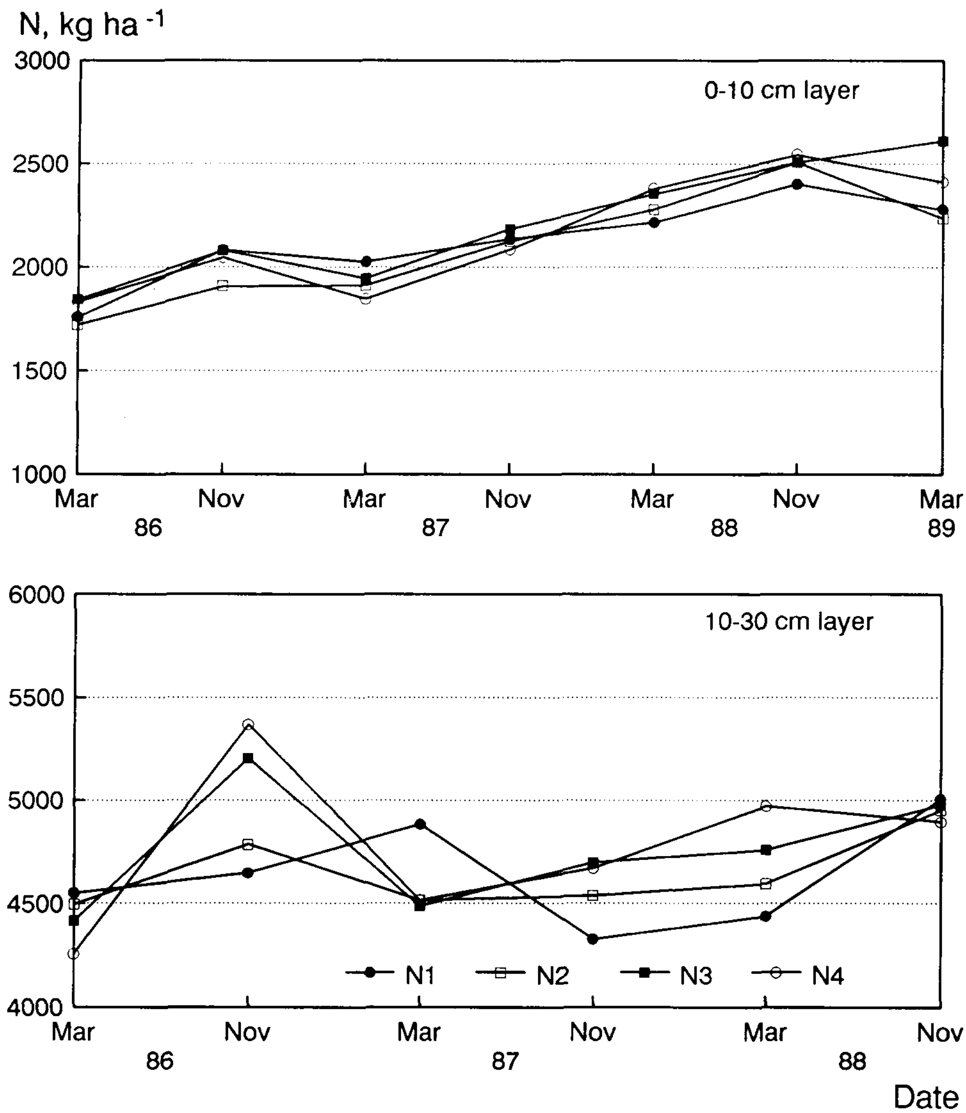

Fig. 2. Course of the amount of organic N in grazed plots of the loamy soil during the period March 1986-March 1989 in the 0-10 cm soil layer (top) and the 10-30 cm soil layer (bottom).

Effect of fertilizer level on the amounts of organic C and N in the soil under mowing and grazing

Under the mowing as well as the grazing regime, the level of fertilization had no clear effect on the amount of organic C and N present in the top 25 cm of the soil in the spring of 1989 (Table 3).

In both soils the C/N ratio of the organic matter of the unfertilized mown plots was significantly ($P < 0.05$) higher than the C/N ratio of the organic matter of the mown plots which received 250-700 kg N ha^{-1} yr^{-1} (Table 4).

Table 3. Total N (N_{tot}, kg ha^{-1}) and C (C_{tot}, kg ha^{-1}) in grassland soils (0-25 cm) at different mineral fertilizer levels under mowing and grazing in March 1989. N0, N1, N2, N3, N4 = fertilizer N application rates of 0, 250, 400, 550 and 700 kg ha^{-1}, respectively.

Fertilizer N application	Mowing		Grazing	
	N_{tot}	C_{tot}	N_{tot}	C_{tot}
Sand				
N0	5360	93 383		
N1	5442	88 925	5677	97 631
N2	5470	87 424	6563	108 512
N3	5364	90 072	6125	98 195
N4	5465	92 501	6839	110 902
Average (N1-N4)	5435	89 731	6301	103 810
Loam				
N0	4985	59 178		
N1	4942	55 620	5612	63 306
N2	4557	53 466	5388	61 537
N3	4556	51 668	5829	65 729
N4	5162	58 105	5897	64 084
Average (N1-N4)	4805	54 715	5682	63 664

Table 4. C/N ratio of organic matter in mown and grazed plots with (= N1-N4) and without (= N0) mineral fertilizer application in March 1989.

Soil layer (cm)	Sand			Loam		
	mown		grazed	mown		grazed
	N0	N1-N4	N1-N4	N0	N1-N4	N1-N4
0-5	18.9	16.9	15.6	12.9	11.9	11.7
5-10	16.5	16.3	16.4	11.7	11.4	11.2
10-25	17.2	16.3	17.1	11.5	11.2	11.0

Differences in amounts of soil organic C and N and in bulk density between mown and grazed fields

As no significant effect of fertilizer level on the amounts of organic C and total N was observed, average values of the N1-N4 plots are presented for comparison of the effects of mowing and grazing on the amounts of C and N in the sandy and the loamy soil.

The respective differences in the amounts of organic C and organic N between grazed and mown fields were 14 079 kg ha^{-1} (s.e.d. = 3568) and 866 kg ha^{-1} (s.e.d. = 256) for the sandy soil, and 8950 kg ha^{-1} (s.e.d. = 1623) and 877 kg ha^{-1} (s.e.d. = 189) for the loamy soil (Table 3). The amounts were larger on the grazed fields. The differences were statistically significant ($P < 0.02$).

In the sandy soil, grazing significantly ($P < 0.05$) increased the bulk density and the percentages of organic C and N in the top 5 cm (Table 5). In deeper layers no significant differences between mown and grazed fields were found. In the loamy soil, the increases in bulk density and the percentages of organic C and N in the top 5 cm were smaller than those in the sandy soil, but the differences extended to a greater depth (Table 5). The increases in the amounts of soil N and C due to grazing were significant ($P < 0.1$) in all soil layers investigated.

In both soil types, the increase in the amount of organic N due to grazing was larger than the increase in organic C in the top 5 cm of the soil. Therefore, the C/N ratio of the organic matter was lower under grazing than under mowing in this soil layer (Table 4).

Discussion

Development of organic N under grazing conditions in time

Soil N increases in soils recently resown to grass. According to Ryden (1984), increases between 50 and 150 kg ha^{-1} are usually found. Model predictions indicated

Table 5. Measured bulk density and C and N contents and amounts in the top 25 cm of the grazed fields divided by the same values in the corresponding mown fields.

Soil type	Soil layer (cm)	Bulk density (g cm^{-3})	Ratio of grazed/mown fields			
			C_{tot}%	N_{tot}%	C_{tot}	N_{tot}
Sand	0-5	1.19*	1.21*	1.32*	1.45*	1.57*
	5-10	1.03	0.97	0.98	1.01	1.01
	10-25	1.03	1.02	0.99	1.06	1.02
Loam	0-5	1.09*	1.03	1.06	1.14*	1.16*
	5-10	1.08*	1.09	1.10	1.18*	1.19*
	10-25	1.06	1.09	1.12	1.17*	1.19*

* = Difference between mown and grazed fields statistically significant ($P < 0.1$).

that the increase in soil N after reseeding would be larger in loam and clay soils than in sandy soils (Hassink et al., 1990). It is assumed that the increase in soil N decreases with time and that an equilibrium is reached, but it is uncertain when this equilibrium is reached. According to Jenkinson (1988) it takes 100 years, but according to Garwood et al. (1977) only 10-12 years of consistent management are needed. Amounts of soil N are usually higher in loam and clay soils than in sandy soils (Verberne et al., 1990).

In the experiment presented here a considerable increase in organic N under rotational grazing conditions was found in the loamy soil (245 kg ha^{-1} yr^{-1}). Due to the marine history and the ploughing down of the sward in 1985, the top soil had a low N content in comparison with other loamy grassland soils in the Netherlands. The data suggest that the soil organic matter content of the soil is still far from equilibrium. The N accumulation rate agrees with data from Hoogerkamp (1974). This large buildup of soil organic N decreases the availability of N to the herbage and consequently increases the optimum application rate of fertilizer N. In agreement with this, Deenen (1990) observed that N uptake by the herbage in these plots increased substantially in response to fertilizer N even at the highest level of fertilization. In the sandy soil, the soil organic N pool was in equilibrium under grazing conditions. Because this soil was used as grassland since 1981, a large change in organic N could not be expected. In contrast to the loamy soil, the increase in N uptake by the herbage in response to an increase in N fertilizer application was small in these plots at high levels of fertilizer application (Deenen, 1990).

In the loamy soil, a large amount of the N is incorporated in the soil organic matter. So the soil serves as a sink. At first the risk of N losses is low due to the large net immobilization, but the soil organic matter content will move towards equilibrium and the amount of N that is immobilized will decrease in the future. In the sandy soil, no net immobilization does occur. So the N that is not accounted for in the balance for this soil can be regarded as being lost to the environment.

Effect of fertilization level on soil characteristics

The results presented here showed that increasing levels of fertilizer N from 250 to 700 kg ha^{-1} did not affect the amount of organic N found in the top 25 cm of the soil. It has been shown before that accumulation of N is independent of the input of N (Clement & Williams, 1967). The input of C rather than N is the factor most commonly limiting organic matter and N accumulation under grassland (Ryden, 1984). The return of grass residues to the soil will be larger at the high fertilizer levels. It has been observed, however, that the amount of roots decreases with increasing fertilizer levels (Ennik et al., 1980). So the total amount of organic residues returned to the soil might be independent of the fertilizer level.

The C/N ratio of the organic matter was higher without than with application of N fertilizer, especially in the top 5 cm. This was also observed by Adams & Laughlin (1981). The amount and quality of dying roots and grass residues may have a strong impact on the accumulation rate of soil organic matter. It was found that grass grown without N fertilizer had a lower N content than grass grown with fertilizer

(Lantinga, 1988). The return of material with a higher C/N ratio will gradually increase the average C/N ratio of the soil organic matter. This may eventually slow down the average decomposition rate of the soil organic matter.

Difference in total soil N and C under grazing and mowing

Under grazing, the total amounts of C and N were larger than under mowing. In the sandy soil the differences were restricted to the top 5 cm, while in the loam the increase due to grazing was found to a depth of at least 25 cm (Table 5). In 1989 the differences in total N in the top 25 cm between grazing and mowing were 866 and 877 kg ha^{-1} for the sandy and the loamy soil, respectively. In comparison with the mowing management, the grazing management resulted in accumulations of N of 217 kg ha^{-1} yr^{-1} on the sandy soil and 292 kg ha^{-1} yr^{-1} on the loamy soil. A part of this difference was not a real accumulation caused by the increase in bulk density under the grazing conditions. In the sandy and loamy soil the bulk densities in the grazed fields were 6 and 7 % higher than those in the mown fields. For the top 25 cm this corresponds with a soil layer of 1.5 and 1.75 cm, respectively. The effect of the higher bulk density in the grazed fields on the amount of organic N can be excluded when it is assumed that the N content of the 1.5 and 1.75 cm layers was the same as that of the 10-25 cm layer (this may be an overestimation) and when the amount of N found in this layer is added to the amount found in the top 25 cm. In this way the difference in total amount of organic N between grazed and mown fields is reduced to 570 kg ha^{-1} for the sandy soil and 492 kg ha^{-1} for the loamy soil. On an annual basis the increase in soil organic N due to grazing in comparison with mowing was 143 kg ha^{-1} for the sandy soil and 164 kg ha^{-1} for the loamy soil. This increase is considerable. Data in the literature concerning the difference in soil N and C under different grassland management systems are scarce. Williams & Clement (1966) and Ryden (1984) found an extra annual increase in soil N of only 30-50 kg ha^{-1} yr^{-1} due to grazing. However, no information was given about the grazing conditions in these papers. The increase in soil N will also increase the rate of N mineralization. This must be taken into consideration in order to attune fertilizer N supply to crop demand.

Time course of the amount of organic N under mowing

The difference in soil organic N between grazed and mown fields on the sandy and loamy soil increased by 143 and 164 kg ha^{-1} yr^{-1}, respectively. As the amount of organic N was in equilibrium in the sandy soil under grazing, the amount of organic N decreased annually by about 140 kg ha^{-1}. In the loamy soil the amount of organic N increased by about 80 kg ha^{-1} yr^{-1} under mowing conditions. It seems strange that the amount of organic N would increase under mowing conditions. Deenen (1990) found that the amount of N that was removed in the harvest on these plots was larger than the amount of fertilizer N that was applied at low fertilization levels. This indicates that either the grass is able to take up nutrients from greater depth or that the calculated accumulation of organic N is an overestimation. The last would be the case when the effect of the difference in bulk density between mown and grazed plots on the amount of soil organic N was overestimated for the loamy soil. Then the real difference in the accumulation of soil organic N between mown and grazed plots would be larger than the calculated 164 kg ha^{-1} yr^{-1}, and the accumulation of organic N in the mown plots would be smaller than 80 kg ha^{-1} yr^{-1} or even negative.

Difference in input of organic matter into the soil under grazing and mowing

Generally, under grazing conditions more organic material returns to the soil than under mowing conditions. Under grazing, dung and urine are returned to the soil. Grazing also increases the amount of herbage that is incorporated into the soil, because grazing losses will occur. In 1986 and 1987 Deenen (1990) measured the amounts of organic N in manure and urine. The average annual amounts in the 250 and 550 fertilizer N treatments were 405 kg ha^{-1} on the sandy soil and 305 kg ha^{-1} on the loamy soil. When it is assumed that under grazing the percentage of the herbage produced that is incorporated into the soils was 20 % higher than under mowing conditions, the amount of N of grass residues returned to the soil was about 80 kg ha^{-1} yr^{-1} higher under grazing than under mowing. So the total difference in annual input of organic N between mown and grazed fields was 485 kg ha^{-1} for the sandy soil and 385 kg ha^{-1} for the loamy soil. As the difference in amounts of soil N between grazed and mown fields increased by 143 and 164 kg ha^{-1} yr^{-1} in the sandy and loamy soil, respectively, in the sandy soil 29 % and in the loamy soil 43 % of the annual extra input of organic N was found in the top 25 cm of the soil. So on the loamy soil a higher percentage of the organic N incorporated contributed to the increase in soil organic N than on the sandy soil. This is in agreement with the assumption in simulation models that in heavier soils a larger part of the soil organic matter is physically protected against decomposition than in sandy soils (van Veen et al., 1985; Verberne et al., 1990; Hassink et al., 1990). Under grazing conditions a large percentage of the input of organic N circulates in the plant-soil system. As only 29 and 43 % of the extra N returned is retained in the soil-plant system, the losses of N should be considerably heavier under grazing management than under mowing management.

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