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Effect of grassland management on N mineralization potential, microbial biomass and N yield in the following year

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Abstract

The effect of mowing or grazing and mineral fertilizer level on N mineralization potential and microbial biomass N (N flush) was studied in 1988 on a sandy soil and a sedimentary calcareous silty loam (loam). On the loam the residual effect of the treatments on N yield and herbage dry matter accumulation in the following year was also studied. The different management practices were started in 1985 on the sandy soil and in 1986 on the loam. The amount of microbial biomass N was larger under grazing than under mowing. The increase in the amount of microbial biomass N due to grazing was larger for the loam than for the sandy soil. The N-mineralization rate was higher under grazing than under mowing. The difference in N-mineralization rates between grazed and mown fields was 20-30 % in April for both soils, but increased considerably in the sandy soil during the growing season. It was estimated that the difference in N-mineralization between mown and grazed plots under field conditions was 110 and 40 kg N ha^{-1} $year^{-1}$ in the sandy soil and the loam, respectively. Thus the optimus N fertilizer application rate should be considerably lower under grazing conditions than under mowing conditions, especially on sandy soil. Fertilizer level had no effect on the amount of microbial biomass and rates of N-mineralization. Both grazing compared to moving and increasing N fertilizer levels above 550 kg N ha^{-1} $year^{-1}$ affected the N yield and dry matter accumulation in the following year (= residual effects) on the loam. These effects were greater for N yield than for dry matter accumulation. The residual effect of previous fertilizer input was probably caused by the presence of different amounts of N in roots and stubble. The residual effect on N yield under grazing exceeded that under mowing by 28 %.

Keywords : grassland, management, microbial biomass, mineralization, residual effects

Introduction

To match fertilizer N supply with grass demand, the contribution of mineralization of soil organic N should be taken into account. It is known that cropping history and grassland management affect net mineralization (Hassink et al., 1990; Williams & Clement, 1966). Inputs of nitrogen into a grazed sward are usually larger than those into a mown sward due to the return of dung and urine and the larger utilization losses of herbage. The greater return of organic N should lead to a higher level of soil organic N under grazing than under mowing and to a gradually increasing level of net mineralization of N. It was recognized that quantitative data on this phenomenon are lacking (Lantinga et al., 1987).

Different methods have been used to estimate N mineralization. They include incubation of undisturbed soil cores in the laboratory or in the field (Raison et al., 1987; Hatch et al., 1990). Soil cores have also been incubated in sealed containers with acetylene to inhibit nitrification and minimize losses of N through denitrification (Hatch et al., 1990; Hatch et al., 1991). It was observed, however, that the addition of acetylene sometimes considerably reduced N mineralization rates (Hatch et al., 1990). Previous experiments with Dutch grassland soils have shown that in undisturbed samples N is immobilized during the first days of incubation due to dying roots, while in coarsely sieved field-moist soil samples N mineralization rates remain constant during a period of 12 weeks (Hassink, submitted). In the present study N mineralization was determined in coarsely sieved field-moist soil samples from which roots and plant parts had been removed.

It has been found that the amount of N in the microbial biomass increases considerably with increasing organic matter input (Adams & Laughlin, 1981; Hassink et al., 1991). In some experiments the size of the microbial biomass was a good indication of the amount of N that was mineralized (Paul & Voroney, 1984; Azam et al., 1986).

It is generally accepted that the accumulation of N is independent of the input of N (Clement & Williams, 1967; Hassink & Neeteson, 1991). The input of C rather than of N is the factor most commonly limiting organic matter and N accumulation below grassland (Ryden, 1984). Although the amount of total N is not influenced by fertilizer input, it has been observed that the amount of mineralizable N can increase considerably with increasing rates of fertilizer application. This was found both for arable soils (Glendining & Powlson, 1990) and grassland soils (Williams & Clement, 1966).

The residual effect of nitrogen on N yield and dry matter accumulation has been studied before (Prins & van Burg, 1977; Prins et al., 1981; Prins & Neeteson, 1982). The effects of previous grazing or mowing on the herbage dry matter accumulation and N yield in the following year have not yet received attention.

In the present study data were collected on the microbial biomass and N mineralization potential of grassland soils under mowing and grazing at various mineral fertilizer levels. For one soil the residual effect of the management system was measured. The effects of grazing, mowing and fertilizer level on the total amounts of C and N in the soils was described elsewhere (Hassink & Neeteson, 1991).

Materials and methods

Site characteristics

Field trials were conducted on a sandy soil and on a young marine silty loam (loam). Both soils had been in grass for at least 20 years, but the latter soil was reseeded in 1985.

The soil characteristics of the two sites have been described elsewhere (Hassink & Neeteson, 1991). Parts of the fields were grazed and parts were mown only. The average number of grazing days was 1500 on the sandy soil and 600 on the loam. On the sandy soil steers were used, on the loam dairy cattle. The average amounts of excretal N returned to the soil under grazing were 421 kg N per ha on the sandy soil and 405 kg N per ha on the loam (approximately 20 % as dung and 80 % as urine; Deenen, 1990). At both locations the grazed fields were given four rates of mineral fertilizer annualy: 250, 400, 550 and 700 kg N per ha (Nl-N4), while the mown fields received 0, 250, 400, 550 and 700 kg N per ha (N0-N4) in six split dressings. Management and fertilizer practices were started in 1985 on the sandy soil and in 1986 on the loam.

The mown plots were laid out in duplicate and had an area of 25 m^2. The grazed fields were not replicated (size 0.2 ha on the sandy soil and 1.0 ha on the loam).

Sampling and analyses

In April, July and November 1988, samples were taken from the 0-25 cm depth for measurement of microbial biomass C, N flush, C respiration and N mineralization potential. At all sampling dates three mixed samples, each consisting of 10 cores, were taken from every plot. For the measurement of the microbial biomass C and the N flush the chloroform fumigation incubation technique was used (Jenkinson & Powlson, 1976).

C respiration and N mineralization were measured in sieved soil samples that were incubated at 25 °C. N mineralization potential was defined as the increase in anorganic N during 13 weeks of incubation; C respiration as the amount of CO_2 respired during 10 days of incubation. In April, C respiration was measured during 13 weeks of incubation. A more detailed description of the methods has been given elsewhere (Hassink et al., 1991). In April the N2 and N4 plots and in July and November the N2 plots of the sandy soil and loam were not sampled.

In 1989 the mown plots on the loam were no longer fertilized. On the grazed N1 and N3 plots, sections were marked out that were no longer grazed nor fertilized. In these sections three plots were laid out in such a way that visible urine and dung patches were excluded. The amount of anorganic N present in the top 40 cm was determined in February 1989. Nitrate and ammonium were extracted with 1 M KCl. Extracts were analyzed using a Technicon autoanalyzer. Herbage dry matter accumulation and N yield were measured in the mown and in the previously grazed plots. The N content in the herbage was determined according to the Kjeldahl method. In this way the residual effect of fertilizer level and grazing on N yield and herbage dry matter accumulation was determined. The residual effect is defined as the influence of management in the preceding years on the nitrogen and dry matter yield of the cuts in the current year (1989). The amount of N harvested in plots receiving no fertilizer N provides an indication of the amount of soil N that becomes available for herbage growth during the growing season.

Statistics

Differences between mown and grazed fields were analyzed with Genstat (1987). For the comparison of mown and grazed fields, the results of the N1-N4 plots were used.

Results

N-mineralization potential

In general, N mineralization rates were not influenced by the fertilizer level (Figure 1). Only in April were N mineralization rates in the mown fields on the sandy soil and loam receiving no fertilizer lower than N mineralization rates in the fertilized mown fields. In July and November, this difference had disappeared (Figure 1).

For the sandy soil, the N mineralization rate in April was on average 20 % higher in the grazed fields than in the mown fields. In July this difference increased to 80 % and in November to 100 % (Figure 1, top). In July and November the differences between mown and grazed fields were statistically significant ($P < 0.01$; average s.e.d. = 17 %). For the loam, the differences in N mineralization rate between mown and grazed fields averaged 30 % in April and July. In November the differences had increased, especially in the N3 and N4 plots, but were still much smaller than those in the sandy soil (Figure 1, bottom). The differences between mown and grazed fields on the loam were only statistically significant in November ($P < 0.05$; average s.e.d. = 13 %).

Microbial biomass (N flush)

In both soils, there was no clear effect of fertilization level on the N flush (Figure 2). In the sandy soil the N flush was generally higher on the grazed fields than on the mown fields, but the differences were not significant ($P < 0.1$; Figure 2, top). In the loam the N flush in the grazed fields in April was on average 40 % higher than in the mown fields; in July the difference was smaller (20 %) and in November it was 40 % again (Figure 2, bottom). The differences between mown and grazed fields were statistically significant for the loam on all dates ($P < 0.05$; average s.e.d. = 7 %).

Relative differences in total amounts of C and N and in biological parameters between mown and grazed fields

In Table 1 the amounts of C and N (see Hassink & Neeteson, 1991), the amounts of biomass C and N (N flush) and the amounts of C respired and N mineralized in the grazed fields divided by the corresponding values in the mown fields are presented. The average value for all of the fertilizer rates is given as no significant effect on total C and N, biomass C and N and the amounts of C respired and N

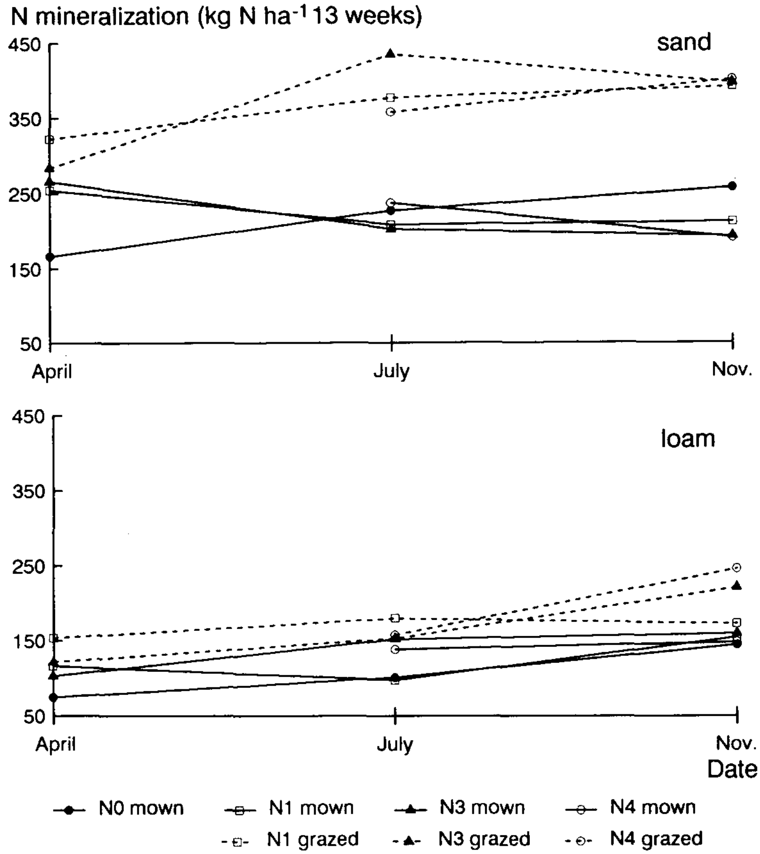

Fig. 1. N mineralization potential of mown and grazed plots on a sandy soil (top) and on a loam (bottom) with different N fertilizer inputs (see Materials and methods) in April, July and November 1988.

mineralized had been observed. In the sandy soil, grazing had the strongest effect on N mineralization rate. In the loam the effect of grazing on total N and C was larger, but the effect on N mineralization was smaller than in the sandy soil. In the loam the effect on the N flush was as large as the effect on N mineralization. Table 1 shows that the relative increase in N associated parameters was generally larger than the relative increase in C associated parameters.

Residual effects of grassland management on N yield and herbage dry matter accumulation

Previous management had very little effect on the amount of anorganic N in the top 40 cm in spring (Table 2). The amount varied from 9 to 16 kg N per ha. Five cuts were harvested in 1989. On the previously mown plots, N yield was lowest

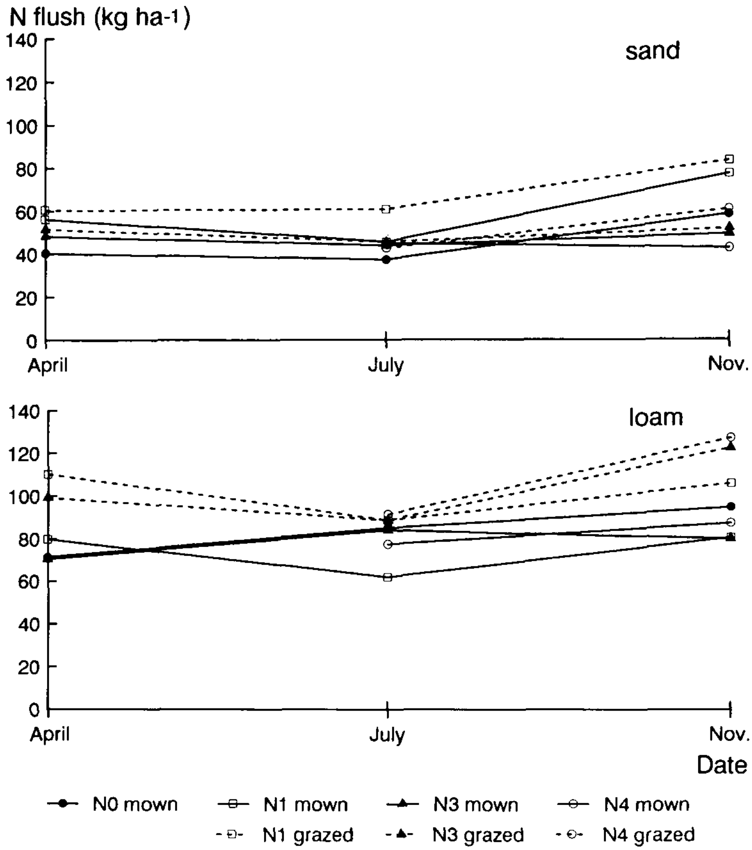

Fig. 2. Microbial mass (N flush) in mown and grazed plots on a sandy soil (top) and on a loam (bottom) with different N fertilizer inputs (see Materials and methods) in April, July and November 1988.

Table 1. Amounts (kg ha^{-1}) of total C (C-t), total N (N-t), microbial biomass C, N flush, respiration and N mineralization in the top 25 cm of the grazed fields divided by the amounts (kg ha^{-1}) of the same parameters in the mown fields. Average of the fertilizer levels.

	Sand			Loam		
	April	July	Nov.	April	July	Nov.
C-t	1.12			1.17		
N-t	1.13			1.18		
Biomass-C	1.1	1.1	1.0	1.0	1.0	1.1
N flush	1.1	1.1	1.2	1.4	1.2	1.4
Respiration	0.9	1.0	1.2	1.1	1.2	1.2
N mineralization	1.2	1.8	2.0	1.3	1.3	1.4

Table 2. Amount of anorganic N in the top 40 cm of the soil in spring 1989 of previously mown and grazed fields with various levels of fertilizer input in 1986-1988.

Grassland management 1986-1988	N fertilizer application rate (kg ha^{-1}) 1986-1988	Soil anorganic N (kg ha^{-1}) in spring 1989
Mowing	0	9.1
	250	10.1
	400	11.3
	550	11.8
	700	14.3
Grazing	250	16.0
	550	16.0

on the N0 plot and increased with increasing amounts of fertilizer applied previously (Table 3). The effect of previous fertilization was the most apparent in the N4 plots. The residual effects of grazing were more pronounced than the residual effects of fertilization level (Table 3). The respective N yield in the N1 and N3 plots that were previously mown were 88 and 95 kg per ha, and in the plots that were previously grazed 108 and 130 kg per ha. For both the Nl and N3 plots the difference in N yield between previously mown and grazed plots was statistically significant at $P < 0.1$. (s.e.d. = 9.2 for the Nl plots and 4.6 for the N3 plots). The difference in N yield between previously mown and grazed fields was apparant throughout the growing season in the N3 plots, but was only clear in the last cut in the Nl plots (Figure 3). The residual effects on N yield were larger than the residual effects on herbage dry matter accumulation (Table 3).

Table 3. Dry matter yield and total N yield in 1989 of previously mown and grazed fields with various levels of fertilizer input in 1986-1988.

Grassland management in 1986-1988	N fertilizer application rate (kg ha^{-1}) 1986-1988	1989	
		dry matter yield (t ha^{-1})	N yield (kg ha^{-1})
Mowing	0	5.14	80.6
	250	5.27	87.5
	400	5.79	93.5
	550	5.88	94.9
	700	6.74	110.7
Grazing	250	6.06	108.1
	550	7.01	130.1

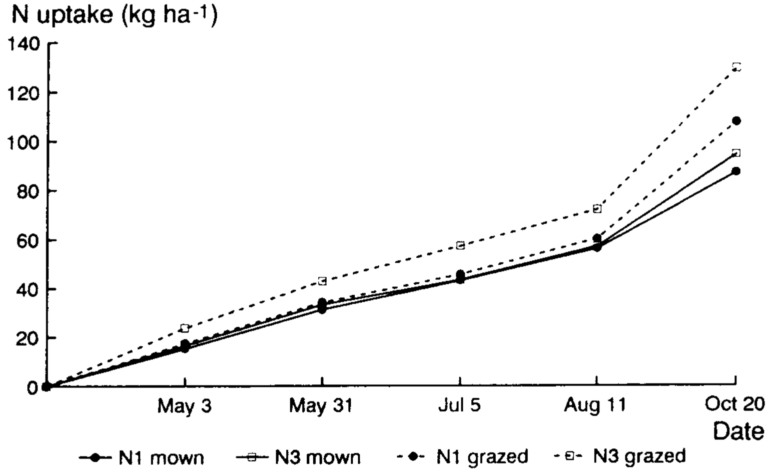

Fig. 3. N yield by grass in 1989 from previously mown and grazed plots on the loam with two different fertilizer inputs in the preceding years.

Discussion

Influence of grazing on microbial biomass C and N, and N mineralization potential

In April only relatively small differences in N mineralization potential were observed between mown and grazed plots. The greater input of organic materials into the soil under grazing takes place only during the grazing period.

Grass and root residues contain a considerable fraction that is easily decomposed (Jenkinson, 1977; Muller et al., 1988). The decomposition rate of cow dung is usually lower than that of grass. When incubated under field conditions, 20-35 % of cow manure N was mineralized after one growing season (van Faassen & van Dijk, 1987). In spring only the most resistant part of the residues incorporated in previous years is still present in the soil. This material contributes far less to mineralization than the active fractions. Later in the season there was a large increase in the potential N mineralization rate in the sandy soil. The increase in the loam was much smaller. It has been observed and described that mineralization processes are much slower in loams and in clay soils than in sandy soils (Jenkinson, 1977; van Faassen & van Dijk, 1987; Verberne et al., 1990). It is postulated that clay minerals have a protective capacity due to adsorption or to entrapment of organic residues in pores where the residues are not susceptible to decomposition (van Veen, 1987). So the direct effect of incorporation of residues on N mineralization will be greater in sandy soils than in clay soils. As a higher proportion of incorporated organic material is retained in soils of heavier texture, the increase in total N and microbial biomass (N flush) should be larger in clay soils than in sandy soils. So the present results which indicated that grazing had a greater positive effect on the N flush in the loam than in the sandy soil are in agreement with the present ideas about the protection of organic residues that occurs in loams and in clay soils. The increased input of organic material under grazing thus had a larger effect on the N mineralization potential in the sandy soil than in the loam, whereas the effect on N flush was greatest in the loam. This has consequences for the amount of N fertilizer that should be applied to satisfy plant demand and keep N losses to the environment low. The average amount of N mineralized in soil from the mown plots during an incubation period of 13 weeks in the laboratory at 25 °C was 215 kg N ha^{-1} in the sandy soil and 142 kg N ha^{-1} in the loam. Assuming that the average soil temperature was approximately 10 °C and that Q10 was 2 (Stanford et al., 1973), the amount of N mineralized in the field in the mown plots should be approximately 189 kg N ha^{-1} yr^{-1} in the sandy soil and 125 kg N ha^{-1} yr^{-1} in the loam (during a period of 200 days).

In the grazed plots the average mineralization rate was 1.6 and 1.3 times as high as in the mown plots in the sandy soil and the loam, respectively. The mineralization in the grazed plots under field conditions should be approximately 300 kg N ha^{-1} in the sandy soil and 165 kg N ha^{-1} in the loam. So, due to grazing management, N mineralization under field conditions would increase with approximately 110 and 40 kg N ha^{-1} $year^{-1}$ in the sandy soil and the loam, respectively. The optimum N fertilizer application rate should be considerably lower under grazing conditions than under mowing conditions, especially on the sandy soil.

This is in agreement with data from Deenen (1990), who showed that on the sandy soil there was no response of N yield to fertilizer N under grazing conditions above an application rate of 250 kg N ha^{-1} $year^{-1}$, while on the mown plots, N yield increased up to an application rate of 550 kg N ha^{-1} $year^{-1}$. On the loam, both under mowing and grazing conditions, there was a response of N yield to fertilizer N up to an application rate of 550 kg N ha^{-1} $year^{-1}$ (Deenen, 1990). In the future more frequent sampling of mown and grazed fields will be performed to obtain more accurate estimations of the differences in N mineralization.

On the loam the difference in mineralization between mown and grazed fields was small during the first years. However, also on this type of soil will the differences in mineralization increase in later years due to the buildup of total N and N in microbial biomass, which will eventually lead to higher mineralization rates during the whole growing season.

Effect of rate of fertilizer application on total N and C, potential N mineralization rate and microbial biomass

In a previous study it was observed that increasing the rates of fertilizer application from 250 to 700 kg N per ha per year did not affect the amount of soil C and N (Hassink & Neeteson, 1991). The N flush and the potential N mineralization rate were also unaffected by the level of fertilizer input. In long-term experiments with arable crops it was found that an increase in fertilizer rate had only a small effect on total soil N, but a considerable effect on mineralizable N

(Glendining & Powlson, 1990). It was assumed that the amount of organic N incorporated increased with increasing fertilizer application rate. Apparently this was not the case in the grassland soils studied here during the first years after the differences in fertilizer input were introduced. Although the amount of grass produced and the N content of grass and root residues will be increased by higher N fertilizer levels, the amount of incorporated organic material does not necessarily increase. It has been observed that the amount of roots decreases at high fertilizer levels (Ennik et al., 1980). So the increase in return of herbage material to the soil may be counteracted by a decrease in the amount of root material incorporated.

It can be concluded that, compared with mowing, grazing had a much stronger impact on the amount and quality of soil organic matter than the amount of N fertilizer applied.

Relative differences in total amounts of C and N and in biological parameters between mown and grazed plots

In a previous study on a loam it was found that an increase in organic matter input had an equally strong effect on N flush and N mineralization, but the effect on total N was smaller (Hassink et al., 1991). In the present study the same pattern was found for the loam, but on the sandy soil the relative increase in N mineralization was larger than the increase in N flush during the growing season. Present data suggest that the relative increase in N flush and N mineralization in grazed grassland soils depends on soil type and time of sampling.

Residual effect of grazing and fertilizer management on N yield

The difference in residual effect between grazing and mowing on N yield on the loam was of the same order as the differences in mineralization potential between grazed and mown fields (around 30 %) in the preceding year. The average amount of N mineralized in soil from the N0 plot during an incubation period of 13 weeks in the laboratory at 25 °C was 110 kg N ha^{-1}. Assuming an average soil temperature of 10 °C and a Q10 of 2, the amount of N mineralized in the N0 plot under field conditions in the loam should be approximately 97 kg N ha^{-1} (during a period of 200 days). The N yield on the N0 plot was 81 kg ha^{-1} when no fertilizer N was applied. Taking into account that approximately 80 % of the amount of N mineralized in the soil will be harvested (Hatch et al., 1991), the amount of N mineralized in the field was close to the amount estimated from the laboratory incubations. This indicates that N mineralization potential is a good indicator of the amount of N that mineralizes in the field.

According to Prins et al. (1981), considerable residual effects due to differences in fertilizer input in the preceding season can be expected only when anorganic N accumulates in the soil due to high fertilizer N applications. They observed large differences in amounts of anorganic N in spring between fields that had received low and high fertilizer N applications in the preceding year. In one experiment also the residual effect in the second year was measured (Prins, 1981). Although no differences in amount of anorganic N in spring were found, there was still a residual effect of 21 kg N per ha. A satisfactory explanation for this effect could not be given. In the present study, although little anorganic N was present in the top 40 cm of the soil in spring, there were differences in N yield.

Although N yield was higher on the N4 plot that was previously mown than on the other plots that were previously mown no effect on total N, N mineralization potential and N flush was observed. This may be explained by the fact that the previously higher fertilizer level resulted in a higher N content of stubble and roots. This larger reserve resulted in a higher N yield. In the incubation studies in which potential N mineralization and N flush were determined, roots and stubble were removed from the sample. Then N was mineralized only from the soil organic matter. Williams & Clement (1966), who found a large effect of fertilizer level on N mineralization, did not remove roots and stubble from their samples. According to Whitehead et al. (1990), the amount of N present in stubble and roots is approximately 85 kg N per ha for the N0 treatment and 115 kg for the N3 treatment. These differences in N reserve are large enough to account for the observed differences in N yield in the following season.

The difference in residual effect between grazing and mowing was larger than the differences in residual effect due to the fertilization level. This may be due to the return of dung and urine-N which may have resulted in a larger increase in N reserves in roots, stubble and soil organic matter than a high fertilization level. This has also been observed by Whitehead et al. (1990).

The residual effects measured have implications for the amounts of fertilizer N recommended to meet crop demand. If the effects of previous mowing or grazing are taken into account, the recommendations for grassland under a 550 N regime could be adjusted by as much as 50 kg N per ha per year, assuming a recovery of 80 % of the applied nitrogen.

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