Impact of grazing on carbon and nutrient cycling in a grass-encroached Scots pine forest
Smit, A.

Citation for published version (APA):
Smit, A. (2000). Impact of grazing on carbon and nutrient cycling in a grass-encroached Scots pine forest
Amsterdam: Universiteit van Amsterdam

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
Grazing in Scots pine forests: synthesis.

In the Netherlands, grazing by large herbivores is increasingly used in nature conservation to counteract grass-encroachment and reduce the large stocks of soil organic matter. This may eventually result in increased species diversity and improved conditions for forest regeneration.

The main goal of this research was to investigate whether these aims of grazing could be achieved in Scots pine forests. The research was focussed on dynamics of both organic matter and nutrients and the following questions had to be answered:

- Is grazing effective in reducing stocks of soil organic matter, taking into account spatial variability in soil parameters?
- Can the nutrient status of the soil be reduced by grazing, through reduced input of litter and successive changes in the processes determining the availability of nutrients, such as decomposition and mineralisation?

In order to answer these questions, several approaches can be used, including comparison of (existing) long-term grazing projects with nearby non-grazed areas, or a fresh start with the initial situation clearly described, as was chosen for this study. The grazed and control sites were monitored simultaneously during the experiment. This enabled a constant comparison and therefore elimination of several external factors that would affect both grazed and non-grazed sites, such as seasonal and year-to-year fluctuations in biomass production and weather (temperature and precipitation), atmospheric deposition and the successional increase in soil organic matter (Emmer, 1994).

The experiment was performed in a first generation Scots pine forest ecosystem on nutrient-poor acid sandy soils. The undergrowth vegetation was dominated by Deschampsia flexuosa. In these forests, decomposition rates are retarded and a Mormodner humus form develops (Green et al., 1993). This means that most soil organic matter is concentrated in the organic horizons and possible
changes in the soil organic matter stocks may be relatively easy to detect. In addition, the nutrient-poor soils make it more likely that nutrient limitations due to grazing occur. Grazing usually results in a mosaic of patches that are grazed with various intensities (Bakker, 1989). These differences in grazing density are not always easy to detect and relations between grazing intensity and impacts of grazing therefore are hard to identify. In the experiment, grazing densities were very homogeneous within the sites and distinctly different between the sites. This situation could be established because the limited number of species in the undergrowth vegetation and the short but heavy grazing periods prevented preferential feeding. The homogeneity of grazing pressure and site conditions resulted in relatively homogenous effects of grazing.

**Impact of grazing on soil organic matter**

Based on the hypotheses of decreased litter input and increased decomposition rates, grazing was expected to cause a decrease in soil organic matter stocks. This part deals with the impact of grazing on litter input, decomposition rates and shows that soil organic matter stocks were not reduced by grazing. The spatial variability appeared to be very important for the interpretation of the measurements, but also gave valuable information on ecosystem functioning.

**Litter input**

Grazing reduced standing biomass and consequently litter input through the consumption of above ground biomass. However, after seven years of grazing the indirect effects, i.e. a 35% reduction in shoot biomass production and a 30% reduction in root biomass production, appeared to be more important (chapter 3). The study of the various types of litter input also showed that grass shoot litter input is only a small part of total litter input and that grass roots are much more important. As tree litter was not affected by grazing, the total litter input was reduced by 20%. In addition, the importance of tree litter increased from 30% of the total litter to 40% of the total litter input (chapter 3).

**Decomposition rates**

Decomposition rates of fresh needles and grass shoot litter appeared unaffected by grazing (chapter 4). This means that potentially altered physical conditions are apparently not important for litter breakdown in this part of the organic matter cycle. It is therefore very unlikely that in underlying horizons (F and H) increased temperatures or altered moisture conditions will result in increased decomposition rates. In contrast, based on theoretical arguments it seems more likely that grazing leads to decreased decomposition rates. Firstly, the input of fresh, i.e. easily decomposable, litter decreases due to grazing, which leads to a shift in the ratio labile to refractory organic matter. Since at least some labile organic matter is needed for a further breakdown of the more refractory components, the latter will likely decrease. Secondly, due to the increasing significance of the pine litter compared to grass roots and shoots, the lignin rich organic material will become more important, possibly resulting in even lower decomposition rates. However, decomposition rates in older soil organic matter are already very low and the effect of changes therefore must also be relatively limited (chapter 5).
Soil organic matter stocks

The possible changes in soil organic matter stocks, resulting from decreased litter input and changes in decomposition rates, were modelled over a 25 year period (chapter 5). Model results showed that the soil organic matter stocks are very robust, and only small differences could be expected within the seven years of the experiment. Even after 25 years changes are probably too small to be detected, unless litter input or decomposition rates are such that they must be considered unrealistically.

Changes in soil organic matter stocks were also measured, through sequential sampling of the humus profile (chapter 5). The measurements showed that incidentally differences between the grazed and control sites were just significant, but the results were not consistent and in 1998, all statistical significant differences had disappeared. The inconsistencies in these results were attributed to the high variability in the soil organic matter stocks, which hampers accurate estimations of these stocks. It also explains why the small differences predicted by the model, could not be measured: given the observed variation, only differences larger than 1.9 kg.m can be measured in the field. Only when litter input and decomposition rates were unrealistically changed, the model predicted differences larger than this value.

Irrespective of spatial variability, a decrease in soil organic matter stocks is most unlikely. As mentioned above, there is not much reason to expect that decomposition rates will increase and despite the 30–35% decrease in the input of grass shoots and roots under grazed conditions, the soil organic matter stocks will increase in time, because the forest is still in an accretion phase (chapter 5). The strong reduction in the thickness of the organic horizons (chapter 2) must therefore be attributed to an increase in compactness, owing to the trampling by the cows.

It should be noticed that in other (forest) ecosystems the ratio between tree litter input and litter input of the undergrowth vegetation might be different. Consequently, the reduction in litter input may also differ, which may result in a different impact of grazing on soil organic matter stocks.

Spatial variability in soil organic matter stocks

Spatial variability hampered an accurate estimation of stocks of soil organic matter. However, it also gave valuable information on the functioning of the ecosystem. Spatial variability could not be explained by large-scale site conditions, such as slope angle, aspect or the presence of a buried podzol. Even the distance of the sample plot to the nearest tree was not correlated to soil organic matter stocks. These results were confirmed by the results of the small-scale spatial analyses revealing that most of the spatial variability was short distance variability (< 1.5 m). The scale of the spatial variability in soil organic matter was very much in accordance to the scale of the tussock structure of the grass (chapter 2).

The tussock structure may affect the variability in soil organic matter stocks by causing small-scale differences in litter input and decomposition. In the tussocks, root litter input may be much higher than between tussocks. Tussocks also affect the micro-topography of the soil and cause tree litter input, particularly pine cones, to accumulate between the tussocks, as was noticed in field observations. This may imply that spatial variability in tree litter input has a strong spatial correlation at very short distance. Spatial variability in decomposition rates was not measured but these rates
may vary spatially because of spatial differentiation in substrate quality. Unfortunately, the importance of these small-scale patterns became only apparent during the later years of the experiment. Measurements of litter input, decomposition and soil organic matter stocks were performed at different supports (spatial scales of the measurements). Therefore, the impact of small-scale patterns in input and decomposition on soil organic matter stocks could not be verified with field data. However, a conceptual model showed that spatial variability in input and decomposition rates may cause high variability in soil organic matter stocks, especially only when these spatial patterns are consistent in time (chapter 6).

**Impact of grazing on nutrient cycling**

In the previous section, it became clear that soil organic matter stocks are very robust and grazing does not lead to major reductions. In contrast, nutrient availability was clearly affected by grazing

**Input of nutrients to the soil**

The input of nutrients to the soil compartment decreases with the input of litter, but not uniformly since different nutrients appeared to be affected differently (chapter 3). Plant macronutrients such as N, P and K were affected most, and with 23% (N and P) and 30% (K) the decrease was higher than expected from the total decrease in litter input. This is partly due to the large decrease in input of grass roots, which have relatively high N and P concentrations. Also, the decrease in input of N and P via grass shoot litter was relatively large due to increased retranslocation of nutrients from the dying leaves under grazed conditions. The decrease in K input was mainly caused by the 50% reduction in the input of grass shoots, which had high concentrations of K. Input of K is particularly through leaching from the vegetation and to a lesser extent through shoot litter input, as evidenced by large differences in K concentrations between living and dead grass shoots. The input of Ca in litter was only reduced with 10%, because of the high contribution of tree litter with high Ca concentrations (chapter 3).

**Nutrient availability**

There were not only differences between nutrients in input reduction, but also in turnover rates. This may be important as to which nutrient becomes (the most) limiting factor for *Deschampsia flexuosa* The release of N and P from decaying litter is relatively slow and may take 1 to 1.5 years (chapter 4). This means that it may take a few years before a reduction in N and/or P availability due to grazing will occur. The N mineralisation study and the ammonium levels indeed suggest a decrease in N availability, but only after seven years of grazing. Whether N becomes a limiting nutrient to plant growth is not clear. The N concentration in living grass did not differ, but retranslocation was higher under grazed conditions, which suggests that some limitation occurs. On the other hand, the N:P ratios of grass shoots, ranging from 14 to 17, suggest that N and P are in balanced supply. Also, the input of N via atmospheric deposition could more or less balance the decrease due to grazing, which may make the decrease less important in a relative sense. Nevertheless, it is still possible that the availability of both N and P (not measured), decrease and lead to a lower production of biomass.
In contrast to N, K is a relatively mobile ion. The input of K was mainly through leaching from dying needles and grass shoots and the remaining K was released from litter almost completely within 10 weeks. Potassium levels in the soil seemed to decrease after a few years of grazing already and after seven years of grazing they were significantly reduced by 30%. Apart from the mobility of K, the reduced levels of K at the cation exchange complex may be due to interactions with the divalent cations Ca and to a lesser extent Mg, which are preferentially bound to the soil exchange complex. As pointed out above, Ca levels in pine litter were twice as high as in grass litter, and further increase in importance because pine litter was not reduced by grazing, while grass litter input was. Potassium may be exchanged and since root biomass and thus uptake are also much lower under grazed conditions, subsequently leaches to deeper horizons. Because K-levels in living grass are relatively high and amount to 15 mg.g⁻¹, compared to 6 mg.g⁻¹ in pine needles, this decrease in K-availability in the soil may impose serious problems upon the productivity of Deschampsia flexuosa.

Thus, the availability of both N and K is clearly reduced. It is not known which of these two is the main limiting nutrient. However, the latter may be more likely since it takes at least a few years before N availability will be reduced, while the reduction of K may start immediately and also because K levels are much higher in the grass than in the pine needles.

**Decreased biomass production**

The results clearly indicate that biomass production of Deschampsia flexuosa was reduced upon grazing (chapter 3). It seems likely that the above-described decrease in nutrient availability in the soil explains at least some of this lower plant productivity. However, a reduced productivity may also be caused by direct effects of grazing on the plants (Hulme et al., 1999). The repeated removal of shoot biomass leads to export of nutrients and potentially to a decrease of amounts retranslocated and stored in the plant (Lambers et al., 1998). Moreover, the removal of shoots results in a decreased photosynthetic apparatus (Crawley, 1983). The amounts of carbohydrates may become too small to maintain a large root system, which is supported by the strong decrease in root biomass found in this study. This implies that the nutrient uptake capacity has decreased. Combined with the nutrient availability in the soil, this very likely results in reduced nutrient uptake by the plants. Together with the lower retranslocation and storage this means a clear reduction of the amount of nutrients available for biomass production. Such a decrease in productivity may become even stronger when differences in nutrient turnover rates in the soil lead to a situation where a particular nutrient becomes more limiting than others.

Thus, the lower biomass production under a grazing regime is probably regulated by reduced amounts of available nutrients, but in a complex way, via reduced availability in the soil, plant responses and possibly shifts in the relative importance of particular nutrients.
Implications for biodiversity and forest regeneration

Grass-encroached ecosystems generally have low light levels at the soil surface due to the dense grass carpet, and the biodiversity has strongly decreased (Veer and Kooijman, 1997). In more open ecosystems such as dune grasslands, the reduction in biomass due to grazing clearly leads to improved light conditions. The chances for small species thus increase and biodiversity accordingly (Kooijman and De Haan, 1995). In the pine forest of this study, light levels are much lower than dune grasslands, but here too the reduction of biomass probably leads to improved light conditions at the soil surface. The species potentially occurring were the same, but the number of species has increased from 4 per m² in the non-grazed site to 7 per m² in the heavily grazed site. At the landscape scale, the effect of increased light availability may be enhanced because light is spatially differentiated in a situation of differing grazing intensities, such as the non-grazed, moderately and heavily grazed sites of the study. Also, grazing probably leads to spatial differentiation in nutrient availability.

Grazing has been reported to redistribute nutrients from large grazing areas to small manured areas near shade or drinkwater locations (Mathews et al., 1994; McIntosh, 1997). However, it should be kept in mind that in the heavily grazed site, nutrient availability was clearly reduced, but especially as a result of reduced production of grass shoots and roots rather than the amount of nutrients exported (chapter 4).

The focus of this study was the improvement of conditions for forest regeneration. The actual establishment of tree species was not measured, because during the grazing period seedlings were supposedly eaten by the cows. This has been shown, for instance, in the long term investigations in the New Forest, where under continuous grazing forest regeneration remained absent (Putman, 1986), or in long term model results of Jorritsma et al. (1999). Nevertheless, an incidental survey of the species composition in the gridpoints revealed that the establishment of tree species, such as *Rhamnus frangula*, *Sorbus aucuparia*, *Pinus sylvestris* and *Quercus robur* was 2 to 6 times higher in the heavily grazed site. The mentioned species occurred there in 12-61% of the plots.

As soon as grazing is abandoned, the changes in site conditions due to grazing suggest that regeneration may improve even more. The thick organic layers, which were supposed to inhibit germination, did not disappear. It is, however, questionable whether regeneration is really hampered by these thick organic layers. There are literature reports suggesting that establishment of trees is not entirely impossible in thick organic layers (Emmer, 1995a; Fanta, 1986; Kooijman et al., in press). Oak and beech trees appeared to establish in pine forests a little older than those of the study, and birch trees occurred in spruce forests in middle mountain areas.

While changes in the organic matter stocks were basically absent, above ground biomass of the grass layer and as such light conditions were clearly affected by grazing. The improved availability of light at the soil surface very likely lead to better chances for seedling establishment. The decreased availability of nutrients may hamper growth of the seedlings. However, while the decreased levels of K may be a key factor to the decreased grass growth, the tree seedlings may be less affected by K limitation, because their leaf concentrations are generally lower and their K need as well. Moreover, their roots may exploit deeper soil layers, where they can catch K leached from the organic horizons and from weatherable minerals.
Concluding remarks

This study shows that it is extremely difficult to reduce stocks of soil organic matter by grazing. In grass-encroached Scots pine forests, even after 25 years, stocks of soil organic matter are expected to be only 20\% lower than under non-grazed conditions. Grazing applied as nature management of such stands is thus not very effective in reducing stocks of organic matter. In the light of the present day discussion about climate change and carbon sequestration, this can however hardly be seen as a negative result.

In terms of biodiversity, grazing also seems a positive measure. Although the stocks of N in the soil were not affected, the availability of mineral N to the vegetation was clearly reduced. Perhaps even more important is the reduction in both stocks and availability of K. Even if this does not lead to improved forest regeneration, it at least results in a decreased production of *Deschampsia flexuosa* and increased biodiversity.