Geese grazing grasslands
Managing the impact of geese on agricultural grassland
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Chapter 4

Timing and intensity of goose grazing: implications for grass height and first harvest

Nelleke H. Buitendijk, Bart A. Nolet

Abstract

Grazing birds like geese can have a big impact on agricultural land, potentially causing damage to crops. Their exploitation of agricultural land varies within and between seasons, and these temporal grazing patterns can be influenced by management. Furthermore, management practices using scaring and accommodation aim to influence local grazing pressures. To achieve efficient goose management we need a good understanding of effect of the timing and intensity of grazing on grass development and subsequent yield loss. We performed an exclosure study on twelve fields in Friesland (Fryslân), the Netherlands to study the effect of grazing on grass development and potential yield loss. Grazing was prevented either from November or from early April until farmers anticipated their first harvest. Every two weeks we measured grass height and calculated growth in exclosures and in ungrazed plots and performed dropping counts. The results show that grazing results in yield losses following both winter and spring grazing, and grazing into the growing season delays the start of grass growth. We also find that the difference in grass height between grazed and ungrazed plots increases as grazing pressure increases, but less so for higher grazing pressures. As a consequence the difference in grass height at the start of the growing season (i.e. mid spring) is nearly equal between fields that have been grazed with medium to high intensities. Overall these results show that the amount of yield loss depends on different aspects of grazing, most prominently the recovery time, duration and grazing intensity. We hypothesize that barnacle geese may select fields with denser swards and may stimulate sward density by frequent grazing throughout winter and early spring as well as across consecutive years. Future studies should look into the effect of harvest delays and sward density on the size and quality of yield across the season and especially at the last cut. Management with scaring and accommodation may be able to reduce overall yield losses, but the effect may depend on the timing and location of scaring.

Keywords: Grazing pressure; Yield loss; Agricultural damage; Grass growth; Herbivore farmer conflict; Goose management

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4.1 Introduction

Grazing on agricultural land by herbivorous waterfowl has greatly increased in the past decades, leading to increasing conflict with farmers (Fox et al., 2017; Fox & Madsen, 2017). Reducing this conflict can be challenging, as there are also conservation concerns. Many waterfowl species have recovered from low numbers in the last few decades, and several are still protected (Fox & Madsen, 2017). It is therefore important that management actions which may result in decreasing population sizes are well justified. Two such approaches are active population reduction (for species which are not protected) (Madsen et al., 2017), and active scaring or derogation shooting (shooting with the aim of chasing away, rather than culling) (Eythórsson et al., 2017; Koffijberg et al., 2017; Percival et al., 1997; Tombre et al., 2005; J. A. Vickery & Summers, 1992). While the first clearly aims to influence population size, the second aims to prevent damage by displacing birds out of a specific area (scaring areas). This can be combined with the presence of dedicated refuges, on agricultural land (hereafter called accommodation areas) or in nature reserves (Koffijberg et al., 2017; Percival et al., 1997; Tombre et al., 2005; J. A. Vickery & Summers, 1992). However, several studies show that when not enough refuge area is available, intensive scaring can have negative consequences for survival (Jensen et al., 2008; Nilsson, 2017; Vickery & Summers, 1992).

The intended effect of both management practices is to reduce waterfowl numbers in specific areas. Management which combines scaring and accommodation can also result in higher numbers inside the refuge areas. We therefore need to understand how the number of geese relates to the amount of agricultural damage. It has been well established that yield loss increases with numbers of herbivorous birds (Bedard et al., 1986; Bergjord Olsen et al., 2017; Colhoun & Day, 2002; Percival & Houston, 1992), but this increase may be non-linear. There may be a threshold grazing pressure, below which no damage occurs (Bergjord Olsen et al., 2017; Bjerke et al., 2021), while some studies suggest that damages increase at a decreasing rate with goose numbers, resulting in lower yield losses per goose (Buitendijk et al., 2022; Montràs-Janer et al., 2019). However, most of these studies look at cumulative grazing pressure, determined by repeatedly counting the number of birds or bird droppings over time. While this indicates the total amount of biomass removed by grazers, it does not reflect temporal patterns in grazing. It has been suggested that the temporal patterns hidden within cumulative grazing pressure may explain the non-linear relationship found in some studies (Buitendijk et al., 2022).

There are natural temporal patterns in the utilization of agricultural land by herbivorous waterfowl. Many are migratory species and spend only part of the year in certain areas. In wintering areas they can remain from autumn until spring, with habitat switches occurring within this period (Bos et al., 2008; Madsen et al., 2021; Mckay et al., 1994; Pot et al., 2019; Prins & Ydenberg, 1985), as well as changes in flock size and densities (Bos et al., 2004). In staging areas, they are present for only a short period, but this might be when the potential to inflict damage is highest (Fox et al., 2017). In addition, management practices involving shooting or scaring may influence temporal patterns of grazing when it is restricted to a specific period (Jensen et al., 2016; Madsen, 2001; Percival et al., 1997; Simonsen et al., 2016).
In addition to the management practices discussed above, there may be compensation schemes in place, to reimburse farmers for yield losses attributed to grazing waterfowl (Klaassen et al., 2008; Koffijberg et al., 2017; Montrás-Janer et al., 2019; Simonsen et al., 2017; J. A. Vickery et al., 1994). However, determining fair compensations can be challenging. Direct measurements of inflicted damage may be complicated when there is no ungrazed reference to compare with. Furthermore, the absolute amount of yield loss may decrease provided enough recovery time for the plants (Bedard et al., 1986; Colhoun & Day, 2002; Conover, 1988; Percival & Houston, 1992), therefore such measurements need to be well timed in relation to harvests. Alternatively, counting birds or bird droppings might be used as a basis for compensation. However, for this to result in fair compensation we need a clear understanding of the relationship between the cumulative grazing pressure and the amount of damage. Furthermore, we need to know whether this relationship changes with different temporal patterns in grazing. Yet despite decades of research, increasing farmer waterfowl conflict, and attempts at management, it is still unclear how yield reduction on agricultural grassland changes with grazing intensity and temporal patterns therein.

In the current study, we look at how time for recovery, timing of grazing and cumulative grazing pressure influence the effect of grazing on grass development and yield loss. We also look at the relationship between cumulative grazing pressure and potential yield loss, and how this changes with different temporal aspects of grazing. We use a number of terms to refer to different aspects of grazing, thought these are generally related. Throughout a period of time there can be multiple grazing events, which we refer to as the grazing period. The timing is the time of year the grazing period spans, the duration the length of the grazing period, and the frequency the frequency with which grazing occurs. The amount of time between the last grazing event and the first harvest is the recovery time. We also use the term grazing intensity, with which we refer to the amount of biomass removed by the grazers. This is measured by counting the number of droppings on a field, representing the amount of biomass consumed by the geese. This should give more insight into how management practices may reduce yield loss by influencing when, where and at what densities grazing occurs.

### 4.2 Methods

#### 4.2.1 Study location

We performed our study in the province of Friesland (Fryslân), the Netherlands. This is an important wintering area for many goose species, with almost a third of the 2.4 million geese wintering in the Netherlands, residing in this province (Hornman et al., 2020). Friesland exists for a large part out of agricultural, rye-dominated grassland, maintained for cattle feed, through direct cattle grazing or harvest of silage in spring and summer. The landscape is generally flat and open. These fields can be heavily grazed by geese in winter and spring. The current management approach combines lethal scaring (under permit) in scaring areas with safe refuge in accommodation areas and nature reserves (BIJ12, 2019). Farmers are compensated for damages attributed to geese, with the total compensation paid increasing over time. In 2016 it amounted to € 8 million in Friesland (Fryske Guozzenoanpak-Evaluatie 2017, 2017).
The study was set up in two regions of the province, roughly 60 km apart, in the northeast (NE), and in the southwest (SW) (fig. 4.1). To ensure a gradient in grazing pressures, we included fields from both accommodation and scaring areas, creating four zones of three fields each: NE accommodation (field 1-3), NE scaring (4-6), SW accommodation (7-9) and SW scaring (10-12). Per zone we selected three fields of rye-dominated grassland, agriculturally managed for silage or cattle grazing. The soil type of the fields varies from loamy to heavy clay (except field 9, which was sandy, see 3.1) and groundwater level ranges from 0-40 cm in winter and from 40-120 cm in summer.

The study ran from November 2020 until June 2021. The winter period (Dec-Feb) was slightly warmer and wetter than usual (average temp 2020/21: 4.4 °C, long term average: 3.9 °C; average rainfall 2020/21: 223 mm, long term average: 204 mm; Koninklijk Nederlands Meteorologisch Instituut (KNMI)), with a week-long snowy period in the first half of February, followed by a cold spring from March-May (average temp 2021: 8.1 °C; long term average: 9.9 °C). Rainfall in spring followed normal patterns in March and April, but May was an exceptionally wet month (average rainfall May 2021: 90 mm, long term average for May: 55 mm).
4.2.2 Experimental set up

Between 2-20 November, we established 12 plots on each field, forming a 3x4 grid with 30 m between adjacent plots (fig. 4.2.A), resulting in a total of 144 plots across all fields. We had three treatments: plots with exclosures placed in November (full-exclusion), in early April (spring-exclusion), or with no exclosures (no-exclusion). Exclosures were left until shortly before the first harvest by the farmers, which varied among fields from late spring to early summer (table 4.1). Regular farming activities on the fields continued, including fertilization of all experimental plots in late winter (with the exception of field 2, which was fertilized in late spring). For more details see supplement 4.A.
Table 4.1 Field specific information ordered by cumulative dropping count. Period of measurement: the first and last week of measurement. Goose droppings: the first and last month (months) and the last week (last week) in which droppings were found, the number of measurement occasions with droppings (Times), and field average of the cumulative number of droppings m$^{-2}$ across the measurement period (Total m$^{-2}$). Vole activity: the number of plots (Plots) and the number of measurement occasions (Times) with one or more signs of vole activity.

<table>
<thead>
<tr>
<th>Field ID</th>
<th>Period of measurement</th>
<th>Goose droppings</th>
<th>Vole activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Months</td>
<td>Last week</td>
</tr>
<tr>
<td>1</td>
<td>47 - 22</td>
<td>Nov-May$^{1}$</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>45 - 24$^{3}$</td>
<td>Nov-May$^{1}$</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>45 - 22</td>
<td>Nov-May$^{1}$</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>45 - 22</td>
<td>Nov-May$^{1}$</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>45 - 20</td>
<td>Nov-Apr$^{1}$</td>
<td>16</td>
</tr>
<tr>
<td>9$^{6}$</td>
<td>45 - 24</td>
<td>Nov-May$^{1}$</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>45 - 20</td>
<td>Nov-Apr$^{1}$</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>45 - 18</td>
<td>Jan-Apr</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>45 - 18</td>
<td>Dec-Mar</td>
<td>10</td>
</tr>
<tr>
<td>11$^{7}$</td>
<td>45 - 18</td>
<td>Feb-Mar</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>45 - 22</td>
<td>Jan-Mar</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>45 - 18</td>
<td>Jan-Feb</td>
<td>8</td>
</tr>
</tbody>
</table>

$^{1}$Grazing started earlier, droppings were already present on the field when placing the set-up, two to four weeks before the start of dropping counts.
$^{2}$Droppings summed from week 49 onwards, as measurements started two weeks later on this field
$^{3}$Week 22 excluded from all analyses due to fertilizing activity (see supplement 4.A)
$^{4}$Vole activity mainly on full-exclusion plot B, excluded from all analyses (see supplement 4.B)
$^{5}$Vole activity mainly in row D (3 plots), excluded from all analyses (see supplement 4.B)
$^{6}$Field with less intensive agricultural management (not excluded)
$^{7}$Row D excluded from all analyses due to deviating management (see supplement 4.A)

Each row of three plots followed the direction in which the field was usually mowed and fertilized, and contained one of each treatment. We ensured that two adjacent plots never received the same treatment. Within these rules, treatments were assigned randomly. The set-up was placed along the edge of a field or in a corner, ensuring at least 5 m between the set-up and the edge of the field. This allowed enough space for agricultural machinery to pass, limiting edge effects on grass growth. To minimize effects of disturbance on goose grazing, the set-up was placed on the end of the field furthest from public roads or farm buildings, though most fields did not border a public road directly.

As exclosures we used 50x50 cm cages, made of reinforcing rods surrounded by chicken wire (fig. 4.2.B). The height of these cages could be adjusted between 20 and 50 cm by pushing the legs further into the ground. The no-exclusion plots were marked with unobtrusive brown beads, placed in the ground using metal pins (fig. 4.2.C), which could be found either by eye or using a metal detector.
On each field, we placed an overview camera at a height of 1-1.5 m, facing a corner of the set-up, which took a picture every 30 min during daylight. On the fields in accommodation area (1-3, 7-9), we also placed two motion-triggered cameras near two randomly chosen no-exclusion plots, at roughly 0.5 m distance and 0.3 m height. After placing the setup, the exact location of the plots and the overview camera were determined with an accuracy of 10 cm using a Differential Global Positioning System (DGPS; Spectra Promark 800 with a Spectra Precision Mobile Mapper 120).

4.2.3 Measurements
A number of different measurements took place every two weeks from November until shortly before the farmers anticipated their first harvest, except in week 6 (February 8-14) when we were unable to take measurements due to a temporary snow cover. We took measurements on all fields in the same week, within a period of 1-3 days.

At the no-exclusion plots we performed dropping counts. We used a 1x1 m detachable frame that could be positioned using the brown beads, which marked the two opposing corners (fig. 4.2.C). During each measurement, all droppings within the frame were counted and removed, with the exception of the first week, in which droppings were only removed but not counted. During each visit, droppings within a 10 cm rim outside the frame were also removed, but not counted, to ensure they would not be accidentally included during the next visit. In three instances, we found one or more piles of droppings, indicating geese spent some time resting there. We counted these as one dropping per pile. When clearly distinguishable, we counted droppings belonging to geese or wigeon (*Anas penelope*) separately, but this was a regular occurrence only on field 5.

Several vegetation measurements took place inside the permanent cages at the exclusion plots, and inside a transportable cage at the no-exclusion plots (fig. 4.2B, C). The transportable cage was always placed in the same location, 10 cm from the edge of the 1x1 m square, where droppings had not been removed. This prevented accidental exclusion of a mitigating effect of droppings on grass growth. Both frame and transportable cage were removed again after measurements were completed.

To determine the effect of grazing on grass development and yield we used the grass height. We measured this using a rising plate meter, with a styrofoam disc of 20 cm diameter, weighing 32 g. At each exclosure-cage we took the average of four grass height measurements, rounded to the nearest full cm. We calculated the two weekly change in grass height (hereafter referred to as apparent growth), by subtracting the height at the previous measurement from the current height. This excludes potential new growth which was removed through grazing in between measurement periods (and thus unmeasured). In addition to grass height and growth, we visually estimated the percentage cover by grasses and by herbs at each plot, using the lattice work on top of the cages as a guide (fig. 4.2B, C). We also counted the number of herb species and looked for signs of vole activity.

4.2.4 Statistical analysis
We analysed the data using R version 4.0.3 (R Core Team, 2020) within the R-studio platform (RStudio Team, 2022).
We compared both grass height and apparent growth between the different treatments in the weeks following placement of the spring-exclusion cages (week 14-22 for grass height, and 16-22 for apparent growth). Using the ‘lmer’ function from the package ‘lme4’ (Bates et al., 2015), we fitted linear mixed effect models with grass height and apparent growth as response variables. The combination of treatment and week of measurement was included as explanatory variable. Since we did not include any numerical explanatory variables, we also did not include an intercept. We added Field nested in Region as random factors. This also accounted for between-field variation in grazing intensity. We used the ‘glht’ function from the package ‘multcomp’ (Hothorn et al., 2008) to perform a post-hoc test, comparing treatments within a week with t-tests and a Bonferroni-correction. Model assumptions were tested by a visual inspection of the residuals. To ensure the spring-exclusion treatment represented a true release from grazing pressure, we excluded fields with little grazing (<5 droppings m\(^{-2}\) across the entire study period) from this analysis.

To study the effect of grazing on apparent grass growth, we performed a segmented regression on the relationship between grass height and time (in weeks since first measurement) for each full-exclusion and no-exclusion plot. We used the segmented function from the package of the same name (Muggeo, 2008, 2017) to estimate a breakpoint. This breakpoint represents the moment when apparent growth increases in spring, while the slope represents the subsequent average apparent growth. We calculated the difference in breakpoint between each no-exclusion plot and the field-average of the full-exclusion plots, indicating the delay in apparent growth. This delay was used as response variable in a linear mixed effect model, with the last week in which droppings were counted at the plot as explanatory variable, and Field nested in Region as random factors. Plots where no droppings were found during the entire study period also did not have a last week with droppings, and were therefore excluded.

Finally, we studied the effect of cumulative grazing pressure on potential yield in different weeks, again using linear mixed effect models. For each no- and spring-exclusion plot, we determined the absolute difference in grass height compared to the field-average of the full-exclusion plots (referred to hereafter as ‘difference in grass height’) which we used as response variable. As explanatory variables for the no-exclusion plots, we used Week (as factor), cumulative dropping density per plot, counted across the measurement period (\(d_1\)) and its square root (\(\sqrt{d_1}\)), and the interaction of Week with \(d_1\) and \(\sqrt{d_1}\). For the spring exclusion plots, we calculated cumulative dropping density from the first week until week 14 (\(d_2\)), as grazing was prevented from week 14 onwards. Furthermore, we used the average dropping density per field, rather than per plot, as droppings were not counted directly adjacent to spring-exclusion plots. As this reduced the variation and explanatory power of \(d_2\), we tested only the linear relationship between dropping density and grazing effect, as well as the effect of Week, and the interaction between Week and \(d_2\). In all models we again included Field, nested within Region, as random factor.

For all our models we determined the significance of the different parameters with an ANOVA with Satterthwaite’s method, using ‘anova’ and ‘step’ from the ‘lmerTest’ package.
Timing and intensity of goose grazing

(Kuznetsova et al., 2017). We used the ‘predictInterval’ function from ‘Multcomp’ (Hothorn et al., 2008) to determine the 95% confidence interval of the relationship. Marginal and conditional R² values were calculated using ‘r.squaredGLMM’ from ‘MuMIn’ (Barton, 2020; Nakagawa et al., 2017) and some supporting packages (Campitelli, 2021; Guan, 2021; Kassambara, 2020; Ooms, 2022). Week numbers for the week of measurement were determined using the ‘isoweek’ function from ‘lubridate’ (Grolemund & Wickham, 2011).

4.3 Results

Grass cover on the experimental plots was generally high, with little presence of herb species. Camera data indicates that grazing occurred mainly by barnacle geese, though some grazing also occurred by grey goose species (Anser spp.) and wigeon. For more details on the grass cover and the different types of grazers see supplement 4.B.

4.3.1 Field use over time

Grazing pressures differed greatly between fields (table 4.1). The field average of cumulative droppings from first until last measurement ranged from 1.8 to 119.8 m⁻². Fields were either grazed for a short period at the end of winter (fields 4, 6, 10-12), or throughout the season (1-3, 5, 7-8), with the exception of field 9 which was grazed only in autumn and spring (table 4.1, fig. S4.1). From early April onwards, the number of droppings per measurement decreased on some fields (5, 7-9), but increased on others (1-3), with up to 31.8 droppings m⁻² on field 1 in week 18 (early May) (fig. S4.1). This coincides with an increase in grass height in full-exclusion plots, and in all plots on fields with only winter grazing (fig. 4.4, fig. S4.1).

4.3.2 Comparisons between treatments

In total there were three fields with fewer than 5 droppings m⁻² (field 6, 11 and 12; table 4.1), leaving a total of nine fields for week 14-18, falling to eight and four fields in week 20 and 22 respectively for the comparison between treatments. A few observations were excluded for various reasons (see table 4.1 and supplement 4.A and 4.B for details), resulting in 447 observations of grass height, and 342 of apparent grass growth, with 424 and 322 degrees of freedom in the respective models. The random factor Field explained around 22% and 17% of the variation in height and apparent growth respectively. Nesting it within Region did not increase the amount of variation explained. We therefore continued with only Field as random factor.

Grass height in the full-exclusion plots differed significantly from the other two treatments in all weeks (t>3.23, p<0.02). As was to be expected, grass height did not differ between spring-exclusion and no-exclusion plots in week 14, when the spring-exclusion cages were first placed (t=0.93, p=1; fig. 4.3.A). This did not change in the next two weeks (t=0.207, p=0.59), but from week 18 onwards grass in spring-exclusion plots was taller (t>4.75, p<0.001). All treatments showed equal apparent growth in almost all weeks (t<2.77, p>0.072), with only in week 16-18 a lower apparent growth rate for the no-exclusion plots (Full-exclusion: t=4.07,
Figure 4.3 Boxplots showing A) grass height (cm) per treatment and week, and B) grass growth (cm two weeks-1) per treatment and each two-week period. The grey plots in B are added for reference, but the difference was not tested. Non-significant differences are indicated by black lines and corresponding p-values. Remaining differences are all significant (A) P < 0.02, B) P<0.002). Dates of week 14-22 in 2021: April 5-11, April 19-25, May 3-9, May 17-23 and May 31-June 6.

p<0.001; Spring-exclusion: t=3.76, p=0.002; fig. 4.3.B). However, we see a trend towards higher growth rates when comparing the spring- and full-exclusion plots.

4.3.3 Time of last grazing and start of apparent grass growth
A visual inspection of the segmented regression per plot shows that the breakpoints appear logical (fig. S4.3, S4.4), and the field average of the segmented regressions fits well with average measurements (fig. 4.4).

We see that there is little overall apparent growth in winter, either in full-exclusion or no-exclusion plots. From week 45 to week 14 both increases and decreases occur, average two-weekly apparent growth in this period was 0.28 cm in full-exclusion plots (sd 1.79) and -0.19 in no-exclusion plots (sd 1.36). The small average difference between the treatments stems mainly from grazing in the first few weeks, when most full-exclusion and ungrazed plots show apparent growth, while no-exclusion plots with grazing show decreasing grass heights (fig. S4.1).

Apparent grass growth starts later on those fields which have been most intensively grazed, both in full-exclusion and no-exclusion plots (fig. 4.4). In the full-exclusion plots where growth starts later, we see that the subsequent slope is steeper, indicating faster growth, and ultimately resulting in similar grass heights in week 20. In the no-exclusion plots this is not the case, with a similar slope for most fields. On fields where grazing continues longer, apparent growth generally starts in the period before the last week in which we found droppings (fig. 4.4).

Comparing the difference in the start of apparent grass growth within fields, we find that later grazing indeed relates to a longer delay in apparent growth (estimate: 0.14, SE 0.06; ANOVA: df=1, F=6.21, p=0.023, fig. S4.2). In this model, the random factor Region again did not explain any additional variation, therefore only Field was included. In total we excluded 5 plots
Figure 4.4 Development of grass per treatment. Lines indicate A) average segmented regression per field and B) average grass height measurements per field, in full- and no-exclusion plots. Colour indicates the last week in which droppings were encountered on that field.

where no droppings had been found, as well as a few other observations (see table 4.1 and supplement 4.A and 4.B for details), leaving 41 no-exclusion plots on 12 fields.

4.3.4 Relating differences in grass height to grazing pressure
In these last analyses we included all fields, though some individual plots and measurements were excluded for various reasons (see table 4.1 and supplement 4.A and 4.B for details). This
left us with 12 fields in week 14-18, falling to nine and five fields in week 20 and 22 respectively, adding up to 192 observations for all three models. The random factor Region did not explain any additional variation in any of these models, we therefore included only Field in all three.

The model explaining differences in grass height between full- and no-exclusion plots shows a significant effect of √d₁ and Week, as well as an interaction effect of Week with both d₁ and √d₁ (table 4.2). Overall variation explained by the model was high, and was mostly due to the fixed factors (marginal $R^2 = 0.65$, conditional $R^2 = 0.72$). This indicates that a non-linear relationship exists between the difference in grass height and cumulative droppings, with intercept, slope and curve changing over time (table 4.3, fig. 4.5).

The first three weeks do not differ much in terms of slope or curve, but in week 20 the relationship increases more steeply and nearly linearly within the measured range. This appears to be caused by the change in the difference in grass height from week 18 to week 20. The difference decreases for fields grazed until week 14, but increases for fields grazed past week 18 (fig. 4.5). Furthermore, in week 20 we find that plots with a grazing pressure of around 50 droppings m$^{-2}$ vary greatly in the difference in grass height, which appears to correlate to variation in the last week with droppings (i.e., recovery time). In week 22 the curvature is stronger, potentially due to the decrease in sample size and loss of fields with medium grazing pressures. From week 14 to 22, the maximal difference in grass height increases from 12 to 27 cm.

**Table 4.2** Significance of the parameters explaining the difference in grass height between the field average of full-exclusion plots and individual no-exclusion plots. Cumulative droppings were summed per plot across the measurement period.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DF</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>4</td>
<td>2.47</td>
<td>0.047</td>
</tr>
<tr>
<td>Cumulative droppings</td>
<td>1</td>
<td>0.16</td>
<td>0.691</td>
</tr>
<tr>
<td>(Cumulative droppings)$^{1/2}$</td>
<td>1</td>
<td>14.03</td>
<td>&lt;0.000</td>
</tr>
<tr>
<td>Week*Cumulative droppings</td>
<td>4</td>
<td>3.49</td>
<td>0.009</td>
</tr>
<tr>
<td>Week*(Cumulative droppings)$^{1/2}$</td>
<td>4</td>
<td>4.18</td>
<td>0.003</td>
</tr>
</tbody>
</table>

**Table 4.3** Model estimate of the intercept, slope and curve of the relationship between difference in grass height and cumulative droppings per week, with standard error.

<table>
<thead>
<tr>
<th>Week</th>
<th>Intercept Estimate (±SE)</th>
<th>Slope Estimate (±SE)</th>
<th>Curve Estimate (±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>2.00 (1.55)</td>
<td>-0.01 (0.06)</td>
<td>0.74 (0.62)</td>
</tr>
<tr>
<td>16</td>
<td>3.21 (1.78)</td>
<td>-0.02 (0.08)</td>
<td>0.87 (0.78)</td>
</tr>
<tr>
<td>18</td>
<td>3.55 (1.76)</td>
<td>-0.01 (0.07)</td>
<td>1.17 (0.74)</td>
</tr>
<tr>
<td>20</td>
<td>2.94 (2.49)</td>
<td>0.13 (0.08)</td>
<td>0.19 (0.88)</td>
</tr>
<tr>
<td>22</td>
<td>-4.36 (2.69)</td>
<td>-0.15 (0.08)</td>
<td>3.92 (0.96)</td>
</tr>
</tbody>
</table>
For the spring-exclusion plots we also found a significant effect of dropping density on the difference in grass height compared to the field average of the full-exclusion treatment (estimate: 0.1, SE 0.022; table 4.4, fig. 4.6). Corresponding to the comparison between treatments, we see that the difference in grass height persists over time, resulting in no effect of Week, either in the intercept or the slope. The fixed factor still explained over a third of the variation in the response variable, with an additional 20% explained by variation between fields (marginal $R^2 = 0.38$, conditional $R^2 = 0.56$).

We also observe that when the cumulative dropping count on a plot stops increasing (i.e. after grazing had stopped), both increases and decreases in the difference in grass height can still occur. This is the case both for the no-exclusion plots (fig. 4.5) and the spring exclusion plots (fig. 4.6). Within one week, some plots show an increase in grass height while others show a decrease.

![Figure 4.5](image)

**Figure 4.5** Difference in grass height (cm) between the field average of full-exclusion plots and individual no-exclusion plots, set out against the cumulative dropping density (nr m$^{-2}$), summed from first measurement until the relevant week. Line and shaded area give the estimated relationship and its 95% confidence interval. Points represent the individual plots, with colour indicating the change in the difference in grass height and shape the change in the number of droppings compared to the previous measurement. To account for potential accumulation of measurement errors, differences smaller than 1.5 cm are shown as No change.
Table 4.4 Significance of different parameters explaining the difference in grass height between the field average of full-exclusion plots and individual spring-exclusion plots. Cumulative droppings were summed per plot from first measurement until week 14.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DF</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>4</td>
<td>1.24</td>
<td>0.296</td>
</tr>
<tr>
<td>Cumulative droppings</td>
<td>1</td>
<td>24.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Week*Cumulative droppings</td>
<td>4</td>
<td>1.27</td>
<td>0.283</td>
</tr>
</tbody>
</table>

Figure 4.6 Estimated relationship between the difference in grass height between field potential and spring exclusion plots (cm), and the cumulative dropping density (number m$^{-2}$) per field from week 49 (Nov 30 to Dec 6) until week 14 (April 5-11). Shaded area indicates the 95% confidence interval, points represent individual plots, with colour and shape indicating whether the difference in grass height increased or decreased compared to the previous measurement.

4.4 Discussion

Corresponding with earlier studies, we find that grazing by geese has a negative effect on grassland yields (Bedard et al., 1986; Bjerke et al., 2021; Buitendijk et al., 2022; Colhoun & Day, 2002; Conover, 1988; Fox et al., 1998; Groot Bruinderink, 1989; Mayhew & Houston, 1999; Montràs-Janer et al., 2019; Olsen et al., 2017; Patton & Frame, 1981; Percival & Houston, 1992; Summers & Stansfield, 1991). Furthermore, we see that the effect of grazing on grass development and subsequent agricultural yield depends on interactions between different temporal aspects of grazing.
4.4.1 Recovery time

Our results suggest a potential effect of recovery time on the amount of yield loss. We observe that when grazing continues into spring, apparent growth is depressed, resulting in larger yield losses in late spring. Furthermore, by late spring we see a trend towards a decreased difference in grass height in the spring- compared to full-exclusion plots (fig. S4.1), and we observe a potential correlation between the last week of grazing (i.e. recovery time) and the difference in grass height for the no-exclusion plots. A recent study in north-west Germany, close to our research area, also suggests that prolonged grazing into spring, and thus shorter recovery times before harvest, is an important factor affecting yield loss (Düttmann et al., 2023).

Our data further shows that both increases and decreases in the difference in grass height are possible after grazing ends. Also in previous studies we see both increases (Colhoun & Day, 2002; Conover, 1988; Groot Bruinderink, 1989; Percival & Houston, 1992) and decreases (Conover, 1988; Groot Bruinderink, 1989; Summers & Stansfield, 1991) in absolute yield loss, following recovery times of 4 to 8 weeks. An explanation for this is can be found in findings from Groot Bruinderink (1989), where grazed grass initially grew slower than ungrazed grass, but after two weeks achieved a higher absolute growth rate. This indicates that the effect of grazing on yield loss may be partially caused by a change in growth rate. When grazing ends, lowered growth rates cause an initial increase in yield loss, followed by a decrease after a certain recovery period, which can vary between 2 to 8 weeks based on these previous studies.

Is recovery on time?

This raises the question whether a full recovery of yield is possible without delaying the first harvest. Based on the measured increase in growth rate, Groot Bruinderink (1989) estimated that the effect of grazing should disappear by early June at the latest (week 24). That study was conducted in the same region as our study, but goose numbers have since increased nearly five-fold (Hornman et al., 2022). The grazing pressures and period of grazing correspond to those on our five least grazed fields. It is indeed likely that the effect of grazing would have disappeared on these fields by early June (fig. S4.1). However, first harvests generally takes place late April or early May, and thus the difference in grass height does not disappear early enough. With heavier grazing pressures, a delay in first harvest is likely inevitable. Several other studies also indicate that first harvests may be delayed due to goose grazing (Colhoun & Day, 2002; Conover, 1988; Olsen et al., 2017; Patton & Frame, 1981; Summders & Stansfield, 1991).

Delaying the first harvest will also result in later subsequent harvests. This could shift the last harvest of the season into less favourable conditions and reduce its yield, as has indeed been shown in Norway (Bergjord Olsen et al., 2017). This is especially problematic in northern regions, where the harvest season is short and only two or three cuts take place each year (Bergjord Olsen et al., 2017; Bjerke et al., 2021). However, also in lower latitudes it may be worthwhile to study the effects of a delayed first harvest on the size and quality of the last harvest, or on the total yield across the season.

In order to optimize both the amount and the quality of silage, agricultural grasslands are preferably harvested when production of biomass slows down, shortly before flowering. This ensures optimal digestibility (Groot & Neuteboom, 1997; Valente et al., 2000), protein content
(Tuñon, 2013) and continued high production (Ferraro & Oesterheld, 2002; Lee et al., 2010). Especially for the first cut of the year this is important, as spring grass has a higher protein content than summer grass. Previous studies have suggested that grazing may delay the maturation of grass (Bedard et al., 1986; Bjerke et al., 2013). However, looking at our camera-trap pictures we see that grass started flowering by late spring, despite large variation in grass height. In many grass species the transition from a vegetative to the reproductive stage is dictated by photoperiod (Pautler et al., 2013), limiting how long the flowering stage can be postponed. Since little growth occurs after flowering, this imposes a limit on the amount of recovery time which is available. Furthermore, if harvests are delayed to long and flowering starts, the quality of the silage will likely decrease.

To conclude, increased recovery time may allow yield losses to decrease, but only if enough time is available prior to harvest in the ungrazed situation. Recovery time may be extended by delaying the first harvest, but future studies should address how this will impact the last harvest and yield across the season. Furthermore, the switch from vegetative to reproductive growth may limit how long harvests can be postponed, which may also merit further study. Such studies could further improve the basis for determining fair compensation payments. Overall, we find that differences in grass height following limited winter grazing persist until the moment when grass started flowering, and a full recovery of yield thus does not occur on time.

4.4.2 Cumulative grazing pressure

Corresponding to previous studies (Buitendijk et al., 2022; Montràs-Janer et al., 2019) we find a non-linear relationship between cumulative grazing pressure and yield loss, where the difference in grass height increases at a decreasing rate with grazing pressure. However, these earlier studies looked at estimated grazing pressure across the season, either per year (Montràs-Janer et al., 2019) or per field (Buitendijk et al., 2022). In this study we directly determined the grazing pressure through repeated dropping counts throughout the grazing period. This ensures a more accurate relationship between the grazing pressure and the effect on grass height. Furthermore, we can look at how this relationship changes with temporal aspects of grazing.

Spring grazing pressures

It has been suggested that the tendency of barnacle geese to aggregate in large flocks in spring may explain the shape of the non-linear relationship between yield loss and grazing pressure (Buitendijk et al., 2022; Montràs-Janer et al., 2019). The highest densities would coincide with the period with highest potential for growth. However, this does not seem likely based on our results. We do find that barnacle geese aggregate in spring on those fields with the highest cumulative dropping densities (fig. S4.1). However, we also find higher grazing pressures on these fields throughout the winter. In addition, the non-linear relationship is already present when grass growth is only just starting. Furthermore, we find that the difference in grass height increases with shorter recovery time, corresponding to previous findings that spring grazing results in higher damages than winter grazing (Fox et al., 2017). Overall we would thus expect comparatively higher damages following spring grazing, suggesting that the non-linear relationship is the result of a grazing effect prior to the start of the growing season.
Grazing prior to the growing season

The suggestion of a grazing effect prior to the growing season is reinforced when looking at intermediate to high grazing pressures. Despite large variation in the cumulative grazing pressure, indicating a range of biomass removed, we find a nearly equal difference in grass height in mid-spring, when grass growth is just starting. This suggests that plots with a high grazing pressure may have produced more (unmeasured) biomass compared to those with an intermediate grazing pressure. Considering the low absolute growth measured during winter in the ungrazed situation, it might seem likely that this increased growth occurred mainly in autumn. However, we see higher dropping densities in autumn on fields with overall intermediate grazing compared to the most heavily grazed fields (fig. S4.1). This suggests that there may have been increased growth in winter or early spring. Indeed, previous studies in temperate regions do suggest that geese and wigeon may be able to increase their own harvest in winter and early spring (Fox et al., 1998; Mayhew & Houston, 1999; van der Graaf et al., 2005; Ydenberg & Prins, 1981), supporting this suggestion.

Implications for yield loss and management

It thus appears that the non-linear relationship between grazing pressure and yield loss may stem from increased growth due to frequent grazing prior to the growing season. However, since the new growth is continuously removed by the geese, this does not benefit the individual farmer. Furthermore, we find that higher winter grazing pressures coincide with longer grazing in spring, counteracting any potential beneficial effects with shorter recovery times. Still, there might be a positive consequence on a larger scale. If grazing pressure on a field can be higher with an equal amount of damage, there may be merit to management practices that aim to concentrate geese in specific regions. However, to properly understand what this non-linear relationship means for management, we need to understand how a grazing effect can occur. If this is due to certain field characteristics, the location of accommodation areas needs to be chosen carefully.

4.4.3 Hypotheses on increased growth

Previous studies have shown that grazers may be able to increase the total biomass production of grass by optimizing their grazing frequency and intensity (Cargill & Jefferies, 1984; Fox et al., 1998; Hik & Jefferies, 1990b; Mayhew & Houston, 1999; McNaughton, 1979; Prins et al., 1980; van der Graaf et al., 2005; Ydenberg & Prins, 1981). The total biomass production in these studies refers to the combination of the standing biomass, which can be measured and harvested, and the biomass removed through grazing, estimated from droppings or short term exclosures. When reported, the same studies generally find a decrease in standing biomass (Cargill & Jefferies, 1984; Mayhew & Houston, 1999; Prins et al., 1980; van der Graaf et al., 2005; Ydenberg & Prins, 1981), though there are exceptions (Hik & Jefferies, 1990b). Different mechanisms have been suggested to explain the increased production of grazed grass. Some are likely not applicable in temperate, agricultural systems, such as improved nutrient cycling (Mayhew & Houston, 1999; van der Graaf et al., 2005), but others may play an important role in this system.
**Relationship between grass height and growth rate**

As the leaf area of a plant increases, it produces comparatively more energy, and growth rates increase (Byrne et al., 2005; Groot Bruinderink, 1989). However, when a certain height is reached, shadow effects decrease the amount of light intercepted by lower leaves, comparatively less energy comes in and growth rates decrease. The plant reabsorbs nitrogen from shaded lower leaves, which subsequently senesce and die (Schapendonk et al. 1998). There should thus be an optimal grass height for growth. With our data, we could compare the initial grass height with subsequent two weekly growth in exclosures plots. This does suggest that an optimal height may exist (Buitendijk et al. unpublished data), though a more detailed analysis of this pattern was beyond the scope of this study.

An optimal grass height for growth can explain why grass growth rates are initially lower after grazing ends, increasing after a period that can vary from 2 to 8 weeks. The time needed for growth rates in the grazed situation to exceed those in the ungrazed situation depends on their respective grass heights in relation to the optimal grass height. A study with sheep grazing in winter already found that yield reduction in spring could be explained by the date on which grazing ended and the photosynthetic tissue left at that moment (Wilman & Griffiths, 1978). Here we suggest that both the grass height before and after grazing may be an important factor in the effect of grazing on grass land yield loss, as this affects the subsequent difference in growth rate.

If grass growth slows down due to shadow effects on lower leaves, we might expect that the optimal height for growth would change with the sun-angle. A lower sun-angle would cause shadows to occur at a lower height compared to a higher sun-angle. Such a shift in the optimal height for growth could be beneficial to plants, as it potentially allows continuous peak production. Furthermore, there may be an interacting effect of temperature and incident light intensity on photosynthetic efficiency (Schapendonk et al., 1998): the optimal temperature for photosynthesis changes with the incident light intensity. In spring and summer this is mainly influenced by the leaf area index (LAI). Across the harvest season this is counteracted by increasing respiration costs as it gets warmer, causing the temperature effect to be disregarded when modelling spring and summer growth (Schapendonk et al., 1998). However, with lower temperatures in winter and early spring the changes in respiration costs may be more limited, while the incident light intensity changes not only with LAI, but also with the sun angle. Our comparison of grass height and two weekly growth inside exclosures does suggest that the optimal height for growth may increase over time.

**Autumn grass height**

Based on this discussion, we would expect that the effect of winter grazing depends on the temperature, sun angle and grass height before and after grazing. It also suggests a possible role for the grass height after the last autumn harvest on the effect of winter grazing. This height may influence whether senescence occurs in the ungrazed situation, and whether grazing will bring the grass height closer to the optimal height for growth. We indeed see a decrease in the height of taller ungrazed grass during winter in our study, but not in shorter ungrazed grass, suggesting senescence may depend on grass height. Farmers have a preferred height with which
Timing and intensity of goose grazing

grass should enter the winter (Schils, 1998), with a larger percentage of dead material resulting in lower spring harvests (Thompson et al., 2017). The higher amount of dead material in taller grass could contribute to a later start of growth in early spring, as we also observed in the full-exclusion plots in our study (fig. 4.4). Finally, we see that our most heavily grazed fields do appear to have slightly taller grass in November than the medium grazed fields. However, further research is required to truly understand if and how autumn grass height influences the potential winter grazing pressure, and to translate this to actual management advice.

Rejuvenation and long term effects

It has been suggested in previous studies that increased biomass production might be the consequence of plant rejuvenation, with removal of biomass resetting it to an earlier growing stage (van der Graaf et al., 2005). Reducing the height of grass plants appears to change gene expression and subsequent physiological processes (Lee et al., 2010). Furthermore, tiller production has been found to increase after defoliation (S. A. Grant et al., 1981, 1983; Hunt & Field, 1978; Martins et al., 2019), though not when grass has entered the reproductive stage (S. A. Grant et al., 1983). In defoliation studies tiller densities were highest in the treatment with shortest grass, at 2-3 cm (S. A. Grant et al., 1981, 1983) or 4 cm (Martins et al., 2019), with a subsequent decrease in tiller density as height increased. This appears to be mainly a consequence of increased competition for light (Schapendonk et al., 1998). In our study barnacle goose grazing resulted in a constant height between 1 and 5 cm, suggesting that they may optimize tiller density. The result could be denser swards, with a subsequent higher food availability per m², allowing a larger number of geese to graze on the field. Furthermore, it increases biomass in the top 2 cm of the grass, resulting in larger bite sizes and more efficient foraging for the geese. Another study looking into barnacle goose grazing on grasslands indeed found that grazed plots had a higher sward density (van der Graaf et al., 2005).

Geese have been found to select greener fields with higher biomass production (Bedard et al., 1986; Bjerke et al., 2021; Colhoun & Day, 2002), but this suggests that their foraging behaviour could also result in more suitable fields. This might even be a long term process. Studies in natural grassland grazed by mammals and birds suggest that repeated, heavy grazing for consecutive years may result in selection for shorter plants and grazing lawns (Person et al., 2003), with plants with more horizontal growth (Detling & Painter, 1983), as well as higher tiller densities (Anderson & Frank, 2003; Detling & Painter, 1983). Repeated intensive grazing during spring might reduce the fitness of plants which do not invest sufficiently in increased leaf area shortly after defoliation, as this prevents them from replenishing stored nutrients before a subsequent defoliation event. Plants that invest more strongly in lateral growth would be at a competitive advantage compared to plants that do not, by intercepting more light. This might also play a role in permanent agricultural grasslands where little reseeding takes place.

Implications for yield loss

It thus seems that the effect of grazing depends on the grass heights before and after grazing, and how these relate to the optimal height for growth. This in turn depends on temperature, and possibly on the sun angle and light intensity. The amount of biomass removed may be of less importance. Furthermore, geese may increase their own food supply by keeping grass short
and stimulating lateral growth. We hypothesise that this might result in denser swards, especially when fields are grazed repeatedly over many consecutive years, leading to fields which may support a larger number of geese. However, this requires further field studies to prove. It should also be noted that these denser swards do not benefit the farmer, since most of the lateral growth will senesce and die as the plant grows taller. Farmers might even prefer a less dense sward, as this would result in less dead material in the silage, and thus better quality food. However, when fields are kept for livestock grazing rather than harvesting, the denser swards might be useful, provided grazing starts before grass gets too tall.

4.4.4 Management implications
In line with many previous studies, our results show that both winter and spring grazing can reduce grassland yields (Bedard et al., 1986; Bergjord Olsen et al., 2017; Bjerke et al., 2021; Buitendijk et al., 2022; Colhoun & Day, 2002; Conover, 1988; Fox et al., 1998; Groot Bruinderink, 1989; Mayhew & Houston, 1999; Montrás-Janer et al., 2019; Patton & Frame, 1981; Percival & Houston, 1992; Summers & Stansfield, 1991). We find that the amount of yield loss depends on different aspects of grazing, most prominently the recovery time, duration and grazing intensity. Which factor(s) are most relevant appears to depend on whether grazing is limited to a short period in late winter, or occurs throughout winter and extends into the growing season. In the first case, the amount of biomass removed appears most important, while the recovery time plays an increasingly important role when grazing extends into the growing season.

We also find that grazing can change the growth rate of grass, which is an important influence on the amount of yield loss. It appears that even after the last grazing event, the difference in grass height will initially increase, which would result in yield losses exceeding the amount of biomass removed by the geese. How long it takes before it starts decreasing again, may depend on an interaction between the grass height before and after grazing and growing conditions such as temperature and sun angle. Furthermore, we hypothesise that barnacle geese may select for fields that allow a larger grazing pressure during winter. This may be related to the grass height in autumn, but could also be due to the density of the sward, which the geese might influence through repeated grazing, both within and across years. These are hypotheses which should be further tested in future studies, measuring not only the change in grass height, but also the amount of standing biomass.

Our study also gives some further insight on how yield loss may be accurately estimated. This cannot achieved by only counting the number of geese or droppings, since yield losses can be greater or smaller than the amount of biomass removed. When determining yield losses, not only the difference in grass height with a reference plot should be taken into account, but also the delay in harvest time, the subsequent loss at the end of the season, and decreases in silage quality, both due to the advancing reproductive stage of the plant and the percentage of dead material present.

The non-linear relationship between barnacle goose grazing pressure and yield loss suggests that concentrating geese in accommodation areas might result in lower yield losses on a regional scale. However, considering the low food availability in mid to late winter, it may not be possible to concentrate geese in a smaller area at this time. Scaring at this time of year may
Timing and intensity of goose grazing

increase overall yield loss rather than lower it, since it causes geese to spend additional energy which they need to compensate (Béchet, Giroux, & Gauthier, 2004; Bélanger & Bédard, 1990; Nolet et al., 2016). In contrast, we find a natural aggregation of geese in early spring, and to a lesser extent in autumn. Similar patterns have also been noted in GPS- and count-data, though not extensively analysed (Buitendijk et al., 2022). If it is possible to stimulate or steer these aggregations, scaring could become more targeted and efficient. However, this requires more knowledge on why geese forage and aggregate on specific fields. An in-depth study of movement patterns of geese throughout winter and site-fidelity within and between winters may give more insight into this. Furthermore, to optimize management with accommodation and scaring we need to better understand the mechanisms that allow a larger amount of biomass removal across the winter to result in an equal difference in grass height in spring. This requires measurements of standing biomass at regular intervals throughout the year, and accurate estimates of the amount of biomass removed through grazing. Furthermore, to determine the role of senescence, the percentage dead material should be established.

Acknowledgements

We are grateful to all farmers who allowed us to use their fields for our measurements and provided us with useful practical insights. Furthermore, we would like to thank all the interns and assistants who helped make this field work possible. We benefited from many discussions with our colleagues, in particular, Chiel Boom, Melanie Lindner, Kees van Oers and Henk van der Jeugd, as well as Gertjan Holshof and Hans Baveco from Wageningen Environmental Research.

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Conflict of Interest: The authors declare no conflict of interest
Supplementary material

Supplement 4.A: Farming activities

Here we discuss the different farming activities that occurred during our study period and potentially affected our measurements. The timing of these activities is indicated in fig. S4.1.

**Sheep grazing**

Fields 4, 6 and 9 were grazed by sheep for two to four weeks in November and/or December. The sheep showed a great interest in the set-up, damaging the cages and the surrounding grass. We took no measurements while they were present, and moved all plots 2 m after sheep were removed, excluding and effect on grass height due to sheep grazing. Because no droppings were counted on these fields in the weeks prior to the period with sheep, and no droppings were seen on the field while the sheep were present, we do not expect that we missed any goose grazing during this period. We were thus still able to measure the difference in grass height due to goose grazing.

**Fertilisation**

In early spring, the setup was removed for some time from each field, allowing fertilising by farmers. On fields with frequent grazing, the exclosures were removed shortly before fertilising (field 1-3, 5, and 7-9). Due to the grazing activity, the location of the exclusion plots was clearly visible after fertilising, and farmers were able to replace the exclosures directly after. These fields were without exclosures for at most a few days, usually less.

On fields with little to no grazing, the setup was removed and replaced by us during the regular measurements. Using the DGPS, the set up could be replaced in the exact same position. This resulted in a period of up to two weeks without exclosures (field 4, 6, 11, 12). Of these fields, only field 4 contained droppings in the week following fertilisation (on average 4.75 m$^2$).

On field 10 we were unable to determine the exact position of the plots due to technical failure of the DGPS, therefore these were replaced in roughly the same location. On this field we counted on average 3.25 droppings m$^2$ when replacing the set-up, which may have included older droppings as well.

Farmers in this study generally used a combination of rough and liquid manure and/or artificial fertiliser, with the exception of field 9 and row D of field 11, which were fertilized only with rough manure. For field 11, this added within-field variation between rows, which was not present on any of the other fields. We therefore excluded row D from all analyses. Most fields were fertilized between week 8 and 14, with the exception of field 2, where fertilisation was delayed until week 20. The different types of manure were applied in two batches, but usually within the same period of two weeks. For the rough manure and artificial fertiliser we did not need to remove the setup.

The machinery and fertilizer caused a temporary flattening of the grass, leading to a slight underestimate of grass height when measurements followed within a few days. On the fields where fertilising occurred prior to week 14, this effect was small, and we expect this did not influence our results. However, field 2 was fertilized only in week 21, causing a much larger
decrease in grass height, especially in the exclusion treatments. For this field we therefore excluded all measurements from week 22 from the analyses (fig. S4.3, S4.4).

**Harvest**
When farmers indicated that they expected their first cut within the next two weeks, based on the grass height on the field, we took our last measurements and removed the setup. This did not happen at the same time on all fields, causing some fields to remain in the study for a longer period than others (table 4.1). From week 18 onwards the number of fields with measurements decreased, with 9 left in week 20, 5 in week 22 and 2 in week 24. Harvest usually occurred within two weeks after our last measurements, but on a few occasions this period was longer. This was mainly due to the consistent rain in late April, which made the land too wet for the heavy harvest machinery.
Supplement 4.B: Grass cover and grazers

There was generally little variation in grass cover among plots, especially in later weeks. Field 9 was the exception, with only on average 48% (range 22-70% per plot) grass cover averaged across all weeks. On the other fields, the average per treatment ranged from 88-100% (taking together all weeks and fields), with at least 80% cover per plot. Corresponding to the high grass cover, the number of herb species on most fields was also low, ranging from 0-2 species per plot, regardless of treatment. Field 9 was again the only exception, with 4 or more species in most plots, though also with no difference between treatments.

Vole (*Microtus arvalis*) activity was low in this winter (also noted in an unrelated study in the same area (Wymenga et al., 2021)). Over the entire period, we encountered signs of voles at 15% of the plots, but most were incidental. When we found evidence of vole grazing on more than 5 occasions at the same plot or after week 14 (4 out of 144 plots, 2.8%) we excluded the plot from the analyses (table 4.1, fig. S4.3, S4.4).

In addition to vole activity, we twice encountered clear signs that an animal had slept inside an exclosure-cage (once because a hare *Lepus europeaus* fled as we approached), which resulted in depressed grass height in that week. We excluded these measurements from the analysis as well (field 1, full-exclusion B, week 22 and field 7, full-exclusion A, week 16, fig. S4.3).

Camera data showed that most grazing was done by barnacle geese. On occasion, we also saw grey goose species (*Anser* spp.), most frequently white-fronted geese (*Anser albifrons*), followed by greylag geese (*Anser anser*). The triggered cameras also captured night time grazing by wigeon a few times on field 8 and 9, and droppings clearly belonging to wigeon were found regularly on field 5. We also observed occasional visits by hares and rarely by roe deer (*Capreolus capreolus*), but we expect these contributed little to the overall grazing effect.
Supplement 4.C: supplementary figures

Field 1 - Cum. dr. 120
Field 2 - Cum. dr. 90
Field 3 - Cum. dr. 87
Field 8 - Cum. dr. 62
Field 5 - Cum. dr. 56
Field 9 - Cum. dr. 44
Field 7 - Cum. dr. 28
Field 4 - Cum. dr. 14
Field 10 - Cum. dr. 11
Field 11 - Cum. dr. 3
Field 6 - Cum. dr. 2
Field 12 - Cum. dr. 2

Droppings (nr/m²) / Grass height (cm)

Temperature (°C)

Treatment
- Full exclusion
- Droppings
- Temperature
- extra measurements
- Spring exclusion
- Missing measurements
- No exclusion
Figure S4.1 (*left page*) Data per week of measurement. Brown bars indicate the field average of the dropping count per 2 weeks, with the lines indicating the highest count in the corresponding period. Green lines follow the average of the grass height per treatment. Sudden dips around March are the consequence of fertilizing, with the machinery and the weight of fertilizer temporarily depressing the height of the sward. Tractors indicate the moment of fertilization, sheep indicate that sheep grazing occurred until that week. Red dots give the mean of 8 measurements taken after the set-up had been removed on field 10 and 12. Blue lines indicate the average weekly temperature. In week 6 no measurements were taken, indicated with the red star. Graphs have been ordered by cumulative number of droppings m$^{-2}$ from week 47 until last measurement in descending order. Note that the count at the end of February includes droppings from a 4 week period, as we did not perform measurements in week 6.

Figure S4.2 The y-axis gives the start of grass growth for each no-exclusion plot relative to the field average in the full-exclusion plots. The x-axis shows the last time droppings were found on the corresponding plot. The line and shaded area give the linear mixed effects model and the 95% confidence interval ($y = -1.59 + 0.14x$).
Figure S4.3  Segmented regression on grass height for each full-exclusion plot. Grey points indicate individual measurements excluded from analysis. When the entire plot was excluded, the line is grey as well.
Figure S4.4 Segmented regression on grass height for each no-exclusion plot. Grey points indicate individual measurements excluded from analysis. When the entire plot was excluded, the line is grey as well.