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Klootwijk, C. W., Holshof, G., van den Pol-van Dasselaar, A., van Helvoort, K. L. M., Engel, B., de Boer, I. J. M., & van Middelaar, C. E.

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The rising plate meter is used to measure grass height, which subsequently is used in a calibration equation to estimate herbage mass, an important parameter to optimize feed management in grazing systems. Our results indicate that, despite relatively large differences in pre- and post-grazing heights and period of regrowth, one region-specific calibration equation can be used across grazing systems.

HERBAGE MASS ESTIMATES ACROSS GRAZING SYSTEMS

The effect of intensive grazing systems on the rising plate meter calibration for perennial ryegrass pastures

Cindy W. Klootwijk,*[1] Gertjan Holshof,† Agnes van den Pol-van Dasselaar,†‡ Koen L.M. van Helvoort,* Bas Engel,§ Imke J.M de Boer,* and Corina E. van Middelaar*

*Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands

†Wageningen Livestock Research, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands

‡Aeres University of Applied Sciences, De Drieslag 4, 8251 JZ Dronten, the Netherlands

§Biometris, Wageningen University & Research, P.O. Box 16, 6700 AA Wageningen, The Netherlands

[1]Corresponding author: cindy.klootwijk@wur.nl

ABSTRACT

The rising plate meter (RPM) is used to measure grass height, which subsequently is used in a calibration equation to estimate herbage mass (HM), an important parameter to optimize feed management in grazing systems. The RPM is placed on the sward and measures the resistance of the sward towards the plate, which depends not only on grass length, but also on sward structure. The accuracy of this calibration equation for the RPM to estimate HM across grazing systems, however, has not been evaluated yet. Therefore, our aim was to analyse the effect of intensive grazing systems on the rising plate meter calibration for perennial ryegrass pastures. To do so, we studied two grazing systems, i.e. compartmented continuous grazing (CCG) and strip grazing (SG), that differ in key grazing characteristics, such as pre- and post-grazing heights and period of regrowth, that may influence tiller density and vertical flexibility of the sward. The experiment was performed from April until October in 2016 and 2017 with 60 dairy cows at a fixed stocking rate of 7.5 cows ha^{-1}. To calibrate the RPM, 256 direct measurements of HM > 4 cm (i.e. above stubble) were collected by cutting and weighing plots of grass for CCG and SG. Our main interest was in the HM above stubble since this is consumed by the cows. Herbage mass < 4 cm is to represent the stubble left after grazing. Differences in HM < 4 cm may (partially) explain differences in HM > 4 cm between both grazing systems. Therefore, HM < 4 cm was additionally measured on four out of each eight plots per grazing system by cutting out quadrats until 0 cm with an electric grass trimmer. Our results showed an average error margin of our calibration equations of 25 – 31%, expressed as the RMSEP as a percentage of the observed HM > 4 cm. Differences between grazing systems were relatively small; and including grazing system as a factor in the regression model to explain the increase in HM per cm of grass did not reduce the RMSEP of the model to any relevant extent. On the other hand, the HM < 4 cm was significantly greater on CCG compared to SG, with 2042 kg

DM ha^{-1} for CCG and 1676 kg DM ha^{-1} for SG. The HM < 4 cm, however, is not used for grazing and this difference was not reflected in the HM > 4 cm. Our results indicate that we can use one region-specific calibration equation for perennial ryegrass pastures across intensive grazing systems, despite relatively large differences in pre- and post-grazing heights and period of regrowth.

Key words: intensive grazing, herbage mass, forage management, rising plate meter

INTRODUCTION

Several studies have shown that the economic benefit of grazing increases with an increase in grass intake (Evers *et al.*, 2008; Van den Pol-van Dasselaar *et al.*, 2014). An increase in grass intake results in a decrease in feed supplementation, leading to lower feeding costs (Sanderson *et al.*, 2001). Fresh grass intake is to a large extent determined by available herbage mass (**HM**). Accurate measurement of HM, therefore, is of utmost importance for a dairy farmer to optimize feed management. Sanderson *et al.* (2001), for example, concluded that measuring HM within a 10% error margin can improve forage budgeting by allocating an adequate amount of grass to the herd. They found this breakeven point by varying the percentage of under- or overestimation of forage yield in the dairy forage system model DAFOSYM (Rotz *et al.*, 1989). Accurately quantifying HM can increase grazing efficiency and, thereby, the economic benefit of grazing (Holshof *et al.*, 2015; McSweeney *et al.*, 2015). Allocating an adequate amount of grass to the herd may increase grazing efficiency and reduce variations in DMI and hence fluctuations in milk production (Hennessy *et al.*, 2015). To date, however, a considerable number of farmers still base grazing management decisions on intuitive decisions and visual assessments of standing biomass (McSweeney *et al.*, 2015).

Cutting and weighing grass is a direct and accurate method to estimate HM, but is also a time-intensive and destructive method and, therefore, is not always used in practice. Currently several tools are available to estimate HM in a non-destructive way. A common, non-destructive and easy to use tool is the rising plate meter (**RPM**), which measures grass height to estimate HM (Sanderson *et al.*, 2001). The RPM is placed on the sward and measures the resistance of the sward towards the plate, which depends not only on grass length, but also on sward structure ('t Mannetje, 2000; Fehmi and Stevens, 2009). Grass height is translated into HM in kg DM ha^{-1} using a calibration equation that includes a factor to represent the linear relation between grass height and biomass based on cutting and weighing. Rising plate meter readings can be incorporated into grassland management programmes like 'PastureBaseIreland' and 'Grip op Gras' (Stienezen *et al.*, 2018), that can assist in choosing which paddocks to use for grazing and which for cutting, and the exact timing of these activities.

For most RPMs, a standard calibration equation is provided by the manufacturer. When estimating HM with the RPM, however, it is important to use context-specific calibration equations, as standard calibration equations may under- or overestimate HM in practice. Sanderson *et al.* (2001), for example, found an error rate of 26% by comparing estimated HM calculated with a universal RPM equation developed in New Zealand with measured (i.e. cutting and weighing) HM in pastures in Pennsylvania, Maryland, and West Virginia (USA). Key factors that affect the relationship between RPM and HM are tiller density and vertical flexibility of the sward, which differ across climate, season, grass variety and soil type (Fehmi and Stevens, 2009; Ferraro *et al.*, 2012; Nakagami and Itano, 2013).

As the grazing system also affects tiller density and vertical flexibility of the grass, we hypothesise that the grazing system might also influence the relationship between RPM and HM (Fehmi and Stevens, 2009; Nakagami and Itano, 2013). To the authors knowledge, however, these effects of grazing system have not been studied so far. Therefore, our aim was to analyse the effect of grazing system on the RPM calibration for herbage mass.

To do so, we studied two grazing systems, i.e. compartmented continuous grazing (**CCG**) and strip grazing (**SG**), that differ in key grazing characteristics, such as pre- and post-grazing sward heights and period of regrowth, that may influence tiller density and vertical flexibility of the sward. Both CCG and SG are examples of daily rotational grazing systems suitable for intensive Dutch dairy farms with feed supplementation (Holshof *et al.*, 2018). Particularly in intensive grazing systems, accurate HM estimates are critical for feed budgeting as the balance between fresh grass allowance and feed supplementation needs to be correct.

MATERIALS AND METHODS

Experimental Set-up

The grazing experiment in which we conducted the measurements for this paper was performed at the Dairy Campus research facility in Leeuwarden during the grazing seasons of 2016 and 2017. Sixty dairy cows were allocated to two grazing systems, i.e. CCG and SG, in two replications. Cows were equally stratified based on parity (first, second and higher parity number), days in milk, milk constituent yield and fat- and protein-corrected milk yield to assure a balanced distribution of the cows. The cows were randomly allocated to the four treatment groups of 15 dairy cows, resulting in a randomized complete design. Cows had an average lactation number of 2.5 ± 1.2 (16 primiparous and 44 multiparous) in 2016 and 2.6 ± 1.4 (12 primiparous and 48 multiparous) in 2017. Body weight was on average 582 ± 67 kg in 2016 and 617 ± 73 kg in 2017.

All cows calved in the period December – March, prior to the grazing season. In total we used 8 ha of grassland, implying a fixed stocking rate of 7.5 cows per ha of grazing area (classified as intensive grazing). Standard grazing time was from 8:30 until 16:00 h. Cows had access to the pasture between morning and afternoon milking and were housed indoors in a cubicle barn during the rest of the time, where they were supplemented with roughage and concentrates. The botanical composition of the fields was 72% perennial ryegrass (*Lolium perenne* L.), 12% timothy-grass (*Phleum pratense* L.), 11% rough meadow-grass (*Poa trivialis* L.) and 5% other species.

Both CCG and SG are rotational grazing systems in which the cows receive a new grazing area daily. These systems, however, largely differ in pre- and post-grazing heights and period of regrowth, important factors that characterize grazing systems. The CCG system has been introduced in the Netherlands recently to balance between grassland utilization and labour intensity (Holshof *et al.*, 2018). The available grazing area in a CCG system is divided in blocks for continuous grazing, where each block is subdivided in compartments of a fixed size with a different compartment being grazed each day. Each CCG replicate was two ha and was divided into six 0.33 ha compartments (Figure 1). On a grazing day, therefore, each cow had access to 222 m^2 fresh grass allowance. Each compartment was grazed 30 times. Each SG replicate was two ha and was divided into 31 0.07 ha strips. On a grazing day, each cow had access to 43 m^2 fresh grass allowance and the strip of the previous day to provide more space to walk (in total 86 m^2). Each strip was grazed 6 times.

For CCG, five compartments were grazed and the sixth one was cut for silage to remove rejected patches (RP). After regrowth (on average 10 days) the sixth compartment was added to the rotation to provide fresh grass for grazing and the next compartment was selected to produce grass for silage. So the cows spent one day in each compartment and rotated around the compartments available for grazing over a 5 day period. Period of regrowth, i.e. days before cows returned to the same compartment, therefore, was four days for CCG. For SG, blocks of four strips were cut for silage and to remove RP after two grazing events. After regrowth, the cut strips were again added to the rotation. Period of regrowth was on average 20 days for SG.

The period of regrowth influenced the fresh grass allowance in CCG and SG, depending on the grass growth (influenced by weather conditions, see appendix I). Fresh grass allowance was measured by performing weekly grass height measurements in all compartments and strips. Per compartment or cluster of strips, about 60 measurements were performed while walking in a W-shape through the compartments and strips. The Jenquip EC10 (NZ Agriworks Ltd., NZ, diameter 36 cm, average pressure 0.47 g cm^{-2}) was used for grass height measurements in this study. The same RPM was also used for developing the Dutch standard equation for estimating HM of perennial ryegrass pastures (Holshof and Stienezen, 2016). The EC10 measures the grass height in clicks, with each click representing 0.5 cm (DairyNZ, 2008).

Based on the fresh grass allowance the amount of roughage supplementation was adjusted to provide sufficient feed for cows on pasture. Total DMI was set at 21 kg DM cow^{-1} day^{-1} and the concentrate allowance was fixed at 5.4 kg DM cow^{-1} day^{-1}. Roughage supplementation was at least 5.0 kg DM cow^{-1} day^{-1}, with a maximum of 8.0 kg maize silage supplemented with grass silage according to requirements. In addition to the adaptation in supplementary feeding, daily grazing time was reduced by two hours when total grass height was below 60 mm for CCG to assure sufficient grass growth for the next grazing. For SG, to match daily grazing time with grass allowance, grazing time was reduced by two hours when fresh grass allowance was below 4.0 kg DM cow^{-1} day^{-1}.

Calibration Measurements

To calibrate the RPM, we conducted direct measurements on HM by cutting and weighing plots of grass for CCG and SG. Similar to the methodology of Kennedy *et al.* (2007), as will be described in this section, we sampled plots with an average size of 12 m^2. For each plot, grass height was measured just before and after cutting, and HM was (directly) determined by weighing. In total there were eight measurement days in 2016 (i.e. 12-5, 19-5, 9-6, 7-7, 14-7, 9-8, 8-9, 15-9) and eight measurements days in 2017 (i.e. 9-5, 17-5, 8-6, 13-6, 11-7, 14-7, 8-8, 11-8). On each measuring day 16 plots were cut in the fields A or B (Figure 1), with eight plots per grazing system. For each grazing system, four plots with relatively high and four plots with relatively low grass heights were cut to maximize the range in grass height (which yields more accurate estimates in the regression calculations that will follow). The cutting height was set at 4 cm to simulate the stubble remaining after grazing (Kennedy *et al.*, 2007). Herbage mass > 4 cm, therefore, was assumed to represent the HM for grazing.

Within each of the 16 plots, we conducted 10 grass height measurements before and 10 grass height measurements after cutting. Using these data, we calculated the average grass height above stubble per plot by subtracting the average grass height after cutting from the average grass height before cutting. This average grass height > 4 cm was related to the HM > 4 cm per plot and subsequently expressed per hectare. We did this because we wanted to determine if a region-specific calibration equation is accurate across grazing systems above the stubble, since the stubble is not grazed.

HM > 4 cm was quantified by cutting plots with the Haldrup grass harvester (Haldrup Field research, DE, cutting table width 1510 mm), a method also described by 't Mannetje (2000). The precise length of the plots was measured with a measuring tape. The Haldrup automatically collects and weighs the harvested grass per plot. After weighing, a grass sample of about 1 kg was taken with a sample drilling cylinder. Grass samples were analysed for dry matter content by drying in a forced-air oven (UF1060 plus, Memmert GmbH & Co. KG, DE) at 105 °C for 24h.

Differences in HM < 4 cm may (partially) explain differences in HM > 4 cm between both grazing systems. Additional measurements were conducted, therefore, on four out of each eight plots per grazing system to quantify HM < 4 cm. Herbage mass < 4 cm was quantified per plot by clipping one 0.09 m^2 quadrat to bare ground (0 cm) with electric grass trimmer (HSA 25, Andreas Stihl ag & Co. KG, DE) and scissors. The quadrats were marked with a steel frame of

30 by 30 cm. All HM in the quadrat was carefully collected, weighed, and analysed for dry matter content by drying.

Statistical Analyses

We used linear regression to estimate HM based on grass height measurements with the RPM (i.e. build calibration equations). The sampled and cut plots served as the experimental units in this analysis. The average grass height per plot was the explanatory variable (x-variable), denoted by H, and expressed in cm. The response variable (y-variable) was HM, denoted by y, and expressed in kg DM ha^{-1}. Our first interest was the effect of grazing system on the relationship between HM and average grass height, so the model comprises effects for grazing system, making the intercept and slope (of height H) depending on the grazing system. In addition, seasonal effects were added, since existing literature shows effects of month and year on the relationship between HM and grass height (Ferraro *et al.*, 2012; Nakagami and Itano, 2013). To that end, the eight measurement days per year were classified into months May, June, July, August and September for 2016 and May, June, July and August for 2017.

Interactions between explanatory variable H and experimental factors for grazing system, month, and year were limited to two-factor interactions. This regression model will be referred to as the full model. Ideally, the full model would include year as a random effect, employing a mixed model analysis. This was not feasible, however, because the component of variance associated with the years cannot be estimated with acceptable accuracy based on two years data only. Year effects therefore were included as fixed effects. This full model was used as a benchmark to compare with a reduced and more practical model that did not include year effects, to see how much unexplained variation in the reduced model is due to years.

The full model reads as follows (Eq. 1):

$$y_{ijkl} = \mu + S_i + M_j + Yr_k + MYr_{jk} + \beta H_{ijkl} + \beta_{S,i} H_{ijkl} + \beta_{M,j} H_{ijkl} + \beta_{Yr,k} H_{ijkl} + \epsilon_{ijkl} \quad [1]$$

Here, y_{ijkl} is the HM > 4 cm of the l-th sampled plot of grazing system i, in month j, of year k, and H_{ijkl} is the corresponding average grass height. S_i, M_j, Yr_k are main effects of grazing systems, months, and years, respectively, and MYr_{jk} are interactions between months and years that affect the intercept. Terms like $\beta_{M,j} H_{ijkl}$ represent interaction between e.g. month and height and affect the slope of height H. The random error terms ϵ_{ijkl} were assumed to be independently normally distributed around 0 with constant variance σ^2. The so-called cornerstone representation, a common feature of statistical software, was used, implying that e.g. μ is the mean HM for system SG, in September in year 2, and effects in the intercept, like S_i, are relative to this reference combination. Similarly, β is the slope of height for SG in September of 2017 and effects in the slope, like $\beta_{S,i}$ are relative to this reference combination.

We looked at the effects of grazing system on HM < 4 cm, because such effects may (partially) explain differences in HM > 4 cm. Since height is more or less constant, attention was restricted to a comparison of means by the t-test.

To further disentangle the effects of grazing system and season on the relationship between grass height and HM > 4 cm, we analysed the effect of year by comparing the full model (Eq. 1) with a reduced model without year effects (Eq. 2). A similar interpretation of effects as in Eq. 1 holds for the reduced model, where year effects have been omitted.

$$y_{ijl} = \mu + S_i + M_j + \beta H_{ijl} + \beta_{S,i} H_{ijl} + \beta_{M,j} H_{ijl} + \epsilon_{ijl} \quad [2]$$

We compared the prediction accuracy of our fitted regression equations with the existing Dutch standard equation translated to HM > 4 cm (Eq. 3). Holshof and Stienezen (2016) developed this calibration equation for Dutch pasture conditions, based on cutting trials in the Netherlands during the growing season of 2014 and 2015. They found the following calibration equation for total HM (kg DM ha^{-1}): 845 + 210 × grass height (cm). Since the intercept (845) and the grass height until 4 cm represent the HM in the stubble, we translated the equation into HM > 4 cm as:

HM > 4 cm = 210 × grass height (cm) > 4 cm [3]

The prediction accuracy of the different regression models was expressed in terms of the root mean square error of prediction (RMSEP) (Eq. 4):

$$RMSEP = \sqrt{\frac{1}{n}\sum_{ijkl}\left(\hat{y}_{ijkl} - y_{ijkl}\right)^2} \quad [4]$$

Here, y_{ijkl} is the observed HM and $\hat{y}_{ijkl}$ the corresponding prediction (fitted value), and n is the total number of plots. Roughly, the prediction error is in between plus and minus twice the RMSEP. The RMSEP was determined by leave-one-out cross validation and was calculated from the squared deletion residuals (Montgomery and Peck, 1992).

The statistical program IBM SPSS Statistics for Windows, Version 22.0, was used to perform the regression calculations.

RESULTS

In Figure 2, HM > 4 cm is plotted against grass height > 4 cm and expressed per hectare, with one measurement representing one cut plot. We found a positive correlation between grass height > 4 cm and HM > 4 cm for CCG (r = 0.785; P < 0.001), SG (r = 0.911; P < 0.001) and the overall dataset (r = 0.900; P < 0.001). The lines for CCG and SG in Figure 2 represent lines of best fit with an R^2 of 0.62 for CCG and 0.83 for SG. The line of best fit without accounting for grazing system resulted in a R^2 of 0.81. Grass height > 4 cm varied from 0.4 to 14 cm, with an average of 3.1 ± 0.1 cm for CCG and 5.0 ± 0.3 cm for SG. Herbage mass > 4 cm varied from

62 to 3439 kg DM ha^{-1}, with an average of 671 ± 34 kg DM ha^{-1} for CCG and 1113 ± 63 kg DM ha^{-1} for SG. The actual height of the grass after cutting was on average 3.9 ± 0.0 cm. Figure 3a+b show the ratio between HM $>$ 4 cm and grass height $>$ 4 cm by month for the growing season of 2016 and 2017, respectively.

Using the full model, we see that the average increase in HM per cm of grass was smaller ($P < 0.001$; Table 1) for CCG than for SG (163 vs 223 kg DM ha^{-1} cm^{-1}, respectively). Using the reduced model, however, we no longer found evidence of differences in slope across grazing systems. In addition, excluding grazing system from the reduced model did not markedly affect the RMSEP. Differences between grazing systems in HM $>$ 4 cm were similar at grass heights $<$ 10 cm (Figure 2).

The HM $<$ 4 cm varied from 744 kg DM ha^{-1} to 3456 kg DM ha^{-1}, with an average of 2042 ± 70 kg DM ha^{-1} for CCG and 1676 ± 77 kg DM ha^{-1} for SG (Figure 4a+b). The t-test showed that the grazing system clearly affected the mean HM $<$ 4 cm ($P < 0.001$).

To better understand the effects of grazing system and season on the relationship between grass height and HM $>$ 4 cm, we analysed the effect of year by comparing the full model (Eq. 1) with a reduced model without year effects (Eq. 2). Table 1 shows results of the full model with a RMSEP of 231 kg DM ha^{-1}. By comparing the years 2016 and 2017, we found that the average intercept was greater ($P < 0.001$) for 2016 than for 2017 (185 vs 19 kg DM ha^{-1}, respectively), whereas the average increase in HM per cm was not shown to be affected by year ($P = 0.273$). Differences between months were not the same in the two years ($P < 0.001$).

The RMSEP of the reduced model excluding year effects increased from 231 to 274 kg DM ha^{-1} (Table 1). This leads to an increased prediction error of ± 86 kg DM ha^{-1}, which is 10% of the average observed HM $>$ 4 cm (i.e. 892 ± 38 kg DM ha^{-1}). When plotting the deletion residuals from the reduced model against the deletion residuals from the full model we found that the increase in prediction accuracy of the full model is mainly attributable to June estimates (Figure 5a+b).

Since June was so influential in the model for HM > 4 cm and was known to give inaccurate results with the RPM due to the reproductive stage of grass in this month (Michell and Large, 1983), the reduced model without year effects was analysed again after excluding all June measurements. This model, therefore, cannot be used to translate grass height measurements during the reproductive stage into HM. Table 1 shows the results of this analysis. The RMSEP decreased from 274 to 226 kg DM ha^{-1} compared to the reduced model including June measurements. Although the average increase in HM per cm of grass showed an interaction with grazing system ($P = 0.036$), excluding grazing system from the model did not affect the RMSEP to any great extent.

To improve the accuracy of estimating HM in restricted rotational grazing systems in the Netherlands, we compared the RMSEP of the full and the reduced model with the standard Dutch calibration equation (Eq. 3). The RMSEP of the full model, i.e. 231 kg DM ha^{-1}, was lower compared to the standard Dutch calibration equation, i.e. 271 kg DM ha^{-1}. The reduction in RMSEP, however, was mainly observed around June, which was during the reproductive stage. The RMSEP of the reduced model, i.e. 274 kg DM ha^{-1}, was comparable to the RMSEP of the Dutch calibration equation, suggesting that accounting for month and grazing system is not increasing prediction accuracy to a particularly relevant extent. When we excluded June measurements, however, we found an RMSEP of 226 kg DM ha^{-1} with the reduced model, which is lower compared to the RMSEP of the Dutch calibration equation, i.e. 271 kg DM ha^{-1}.

DISCUSSION

Using the full model, we found that the average increase in HM per cm of grass was smaller for CCG than for SG. The lower slope for CCG might potentially be explained by a higher leaf proportion and a lower dead material proportion in the HM > 4 cm compared to SG, which can be explained by differences in pre- and post-grazing sward height and period of regrowth. Curran *et al.* (2010) found a higher leaf proportion (< and > 4 cm) and a lower dead proportion (> 4 cm) for a low pre-grazing HM (HM > 0 cm: 1600 kg DM ha^{-1}) compared to a high pre-grazing HM (HM > 0 cm: 2400 kg DM ha^{-1}), resulting in a lower HM density in kg DM ha^{-1} cm^{-1} for the low pre-grazing HM. Differences between grazing systems, however, were relatively small; and including grazing system as a factor in the regression model to explain the increase in HM per cm of grass did not reduce the RMSEP of the model to any important extent.

In contrast, the HM < 4 cm was clearly affected by grazing system. The larger HM < 4 cm for CCG might be explained by a higher tiller density for CCG compared to SG. From November 2016 onwards, tiller density indeed was higher for CCG than for SG ($P < 0.05$) (N. J. Hoekstra, Louis Bolk Institute, Bunnik, The Netherlands, personal communication). This finding is in line with literature, showing an increased tiller density at increasing grazing pressure per grazing event to compensate for a loss in leaf area index (Matthew *et al.*, 1996; Hernández Garay *et al.*, 1999). This difference in HM < 4 cm between grazing systems, however, was not expressed in HM > 4 cm.

By comparing the full model (Eq. 1) with the reduced model (Eq. 2), we found a year effect on the absolute level of HM, but not on the average increase in HM per cm. This suggests that the seasonal pattern may be largely similar for different years, although coefficients are likely to differ to some extent across years. These findings are in line with literature describing year effects (Braga *et al.*, 2009; Ferraro *et al.*, 2012; Nakagami, 2016). Differences between years could easily be explained by differences in weather conditions since they influence the proportion of leaf, stem and dead material in the sward and, thereby, the density in kg DM per cm of grass height (Curran *et al.*, 2010). In principle, e.g. covariates for past weather conditions, could be included when working on a monthly basis.

When further analysing month effects with the full model (Eq. 1), we found a clear seasonal pattern with a marked decrease in average HM per cm of grass height for June compared to May, July, August and September. This seasonal pattern is in line with findings in literature for cool-season grass swards (Michell and Large, 1983; Ferraro *et al.*, 2012; Nakagami and Itano, 2013). The decrease in slope in June can be explained by the onset of the reproductive stage of perennial ryegrass in the Northern hemisphere (Michell and Large, 1983; Nakagami and Itano, 2013). Reproductive tillers contribute to increasing grass height but without an equivalent increase in HM, since the density of these tillers is low. Compared to vegetative tillers, reproductive tillers contain a larger proportion of stem and dead material, which is generally more heavy and contains a higher DM%, and a smaller proportion of leaf material (Curran *et al.*, 2010). We indeed observed an increase in tall rejected grass in the flowering stage in June, especially in the CCG system in 2016. In line with these findings, we found a positive correlation between DM% and intercept ($r = 0.642$; $P = 0.004$) and a negative correlation between DM% and slope ($r = -0.556$; $P = 0.017$). Dry matter content was greatest in June 2016, both for CCG (23%) and SG (19.2%).

We observed during May that the whole field was equally grazed, resulting in a relatively low abundance of rejected patches. In line with perennial ryegrass, however, timothy-grass was more often rejected by the cows in June. Compared to perennial ryegrass, timothy-grass might even be more stiff and is expected to result in equal or higher resistance to the plate meter, especially in June. This might also contribute to the decrease in slope of the calibration equation in June. Rough meadow-grass, on the other hand, bends easily and is expected to result in equal or lower resistance to the plate meter. With the grass species being equally distributed in the field we do not expect an effect of the botanical composition on the relationship between grass height > 4 cm and HM > 4 cm. This study can serve as a valuable guide for other researchers to investigate the forage mass estimations of different forage species in different regions of the world.

Our comparison of calibration equations showed that the (modified) Dutch standard equation (Eq. 3) is suitable to estimate HM > 4 cm in CCG and SG, considering both accuracy and feasibility. Including grazing system in the model did not result in a higher prediction accuracy compared to the Dutch calibration equation. Since these systems largely differ in pre- and post-grazing heights, our results indicate that a region-specific calibration equation is accurate across grazing systems. Overall, the calibration equations analysed in this study, however, showed an average error margin of 25 – 31%, expressing the RMSEP as a percentage of the observed HM > 4 cm. This exceeds the 10% that Sanderson *et al.* (2001) proposed as a maximum error margin for estimating fresh grass availability to increase economic benefits of improved forage budgeting. To obtain more a higher prediction accuracy with the Dutch calibration equation, we suggest to include random year effects in the model with data based on a long-term study and to exclude measurements in tall rejected grass during the reproductive stage.

CONCLUSIONS

The HM < 4 cm was significantly greater on compartmented continuous grazing (CCG) compared to strip grazing (SG), with 2042 kg DM ha^{-1} for CCG and 1676 kg DM ha^{-1} for SG. The HM < 4 cm, however, is not used for grazing and this difference was not reflected in the HM > 4 cm. Our results indicate that we can use one region-specific calibration equation for perennial ryegrass pastures across intensive grazing systems, despite relatively large differences in pre- and post-grazing heights and period of regrowth. The average error margin of our calibration equations, however, appeared 25 – 31%, expressed as the RMSEP as a percentage of the observed HM > 4 cm. To obtain more reliable results with the Dutch calibration equation, we suggest to include random year effects in the model with data based on a long-term study and to exclude measurements in tall rejected grass during the reproductive stage.

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APPENDIX

Appendix I. Average temperature and cumulative rainfall surplus (rainfall - evaporation) per month for 2016 and 2017.

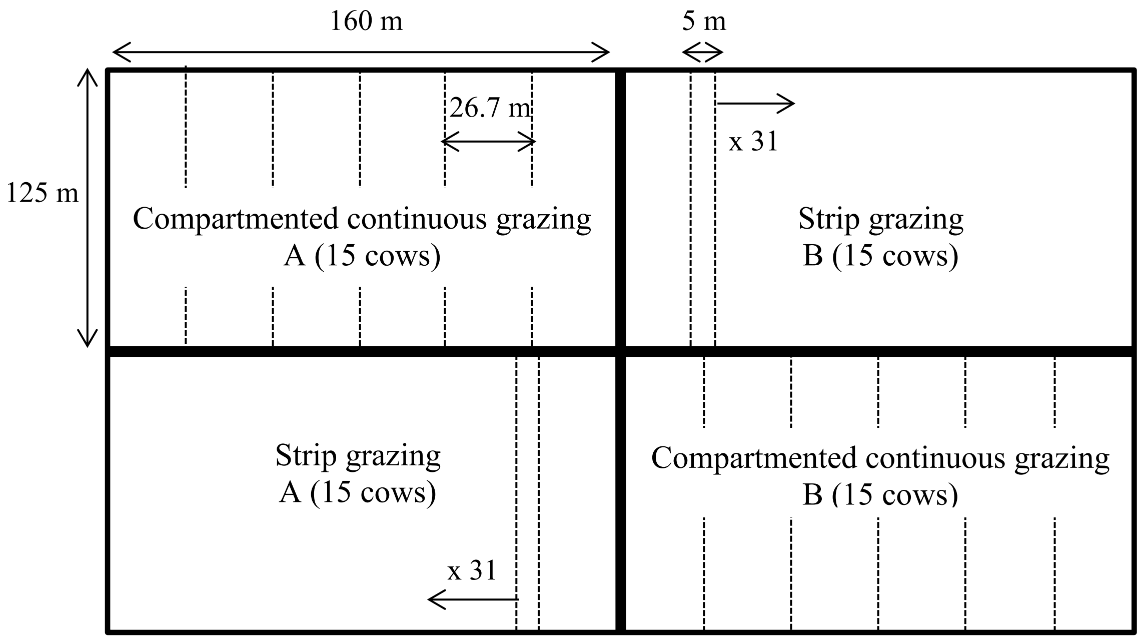
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean temperature (°C)	2016	3.3	4.2	4.8	7.8	13.7	15.6	17.5	17.2	17.5	9.8	5.3	5
	2017	1.6	4.1	7.5	7.8	13.6	16.5	17.1	16.8	13.8	13	7.2	4.6
Rainfall surplus (mm) (cumulative)	2016	30	93	125	120	78	37	46	33	10	-3	48	85
	2017	26	52	104	74	25	-29	-40	-46	25	75	121	193

TABLES

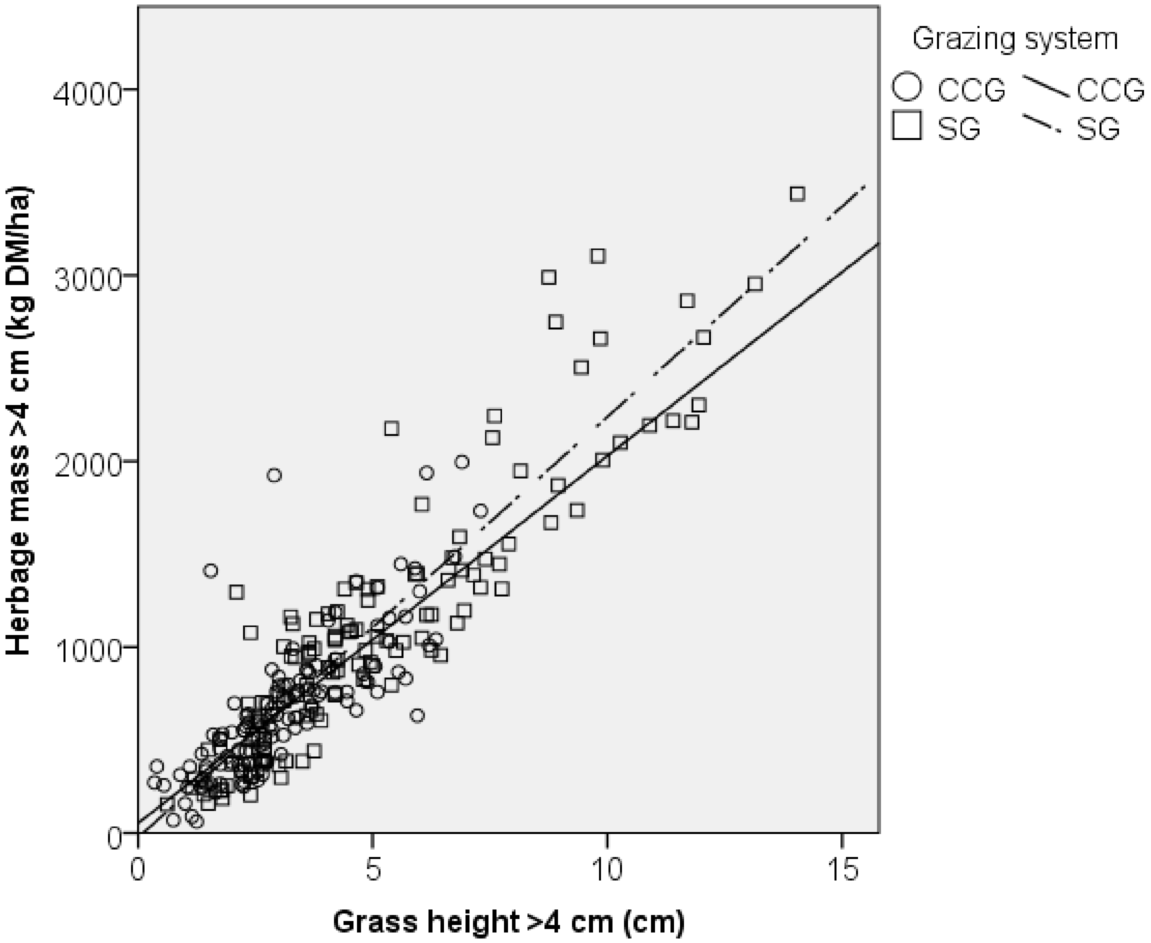
Table 1. P-values and the root of the mean square error of prediction (RMSEP) for the full regression model with year effects, the reduced regression model without year effects and the reduced regression model without year effects and excluding the June measurements.

P-values	Full model	Reduced model	Reduced model without June
Grazing system	0.005	0.141	0.055
Year	< 0.001		
Month	< 0.001	0.351	0.586
Year × Month	< 0.001		
Grass height > 4 cm	< 0.001	< 0.001	< 0.001
Grazing system × Grass height > 4 cm	< 0.001	0.059	0.036
Year × Grass height > 4 cm	0.273		
Month × Grass height > 4 cm	0.018	0.877	0.707
RMSEP	231	274	226

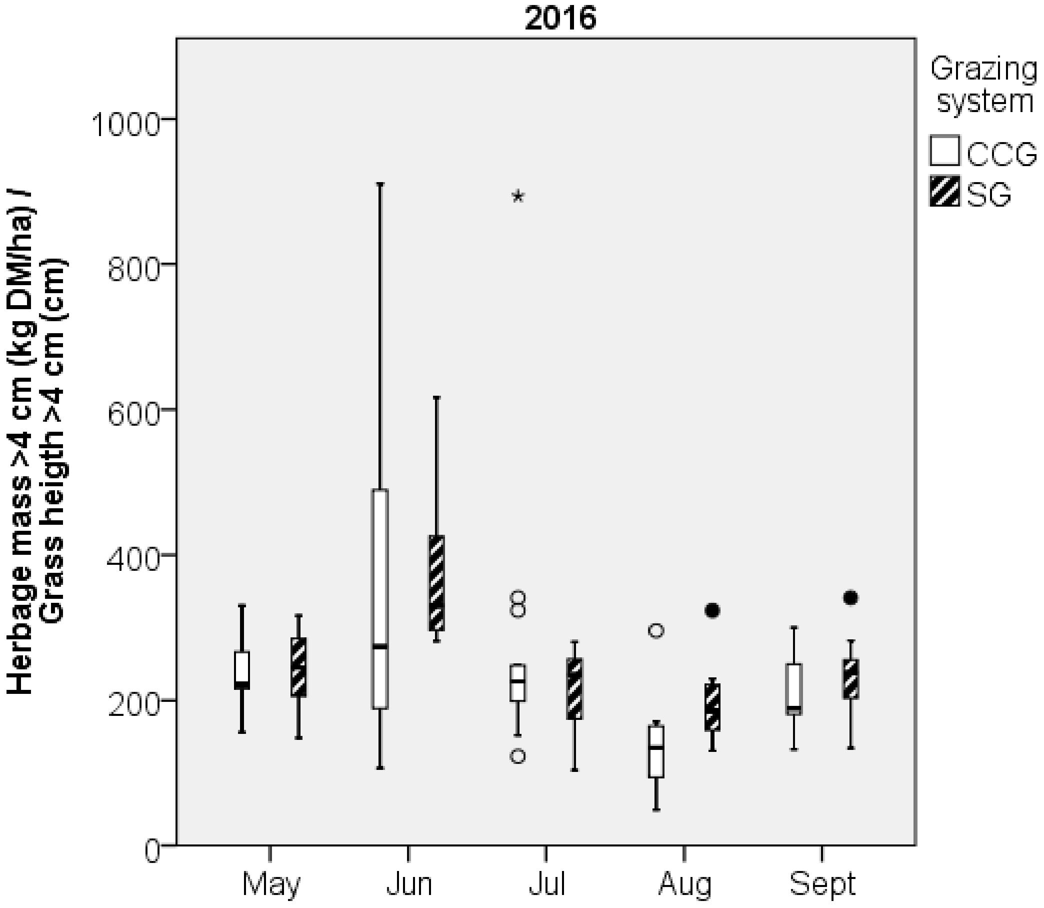
Klootwijk Figure 1



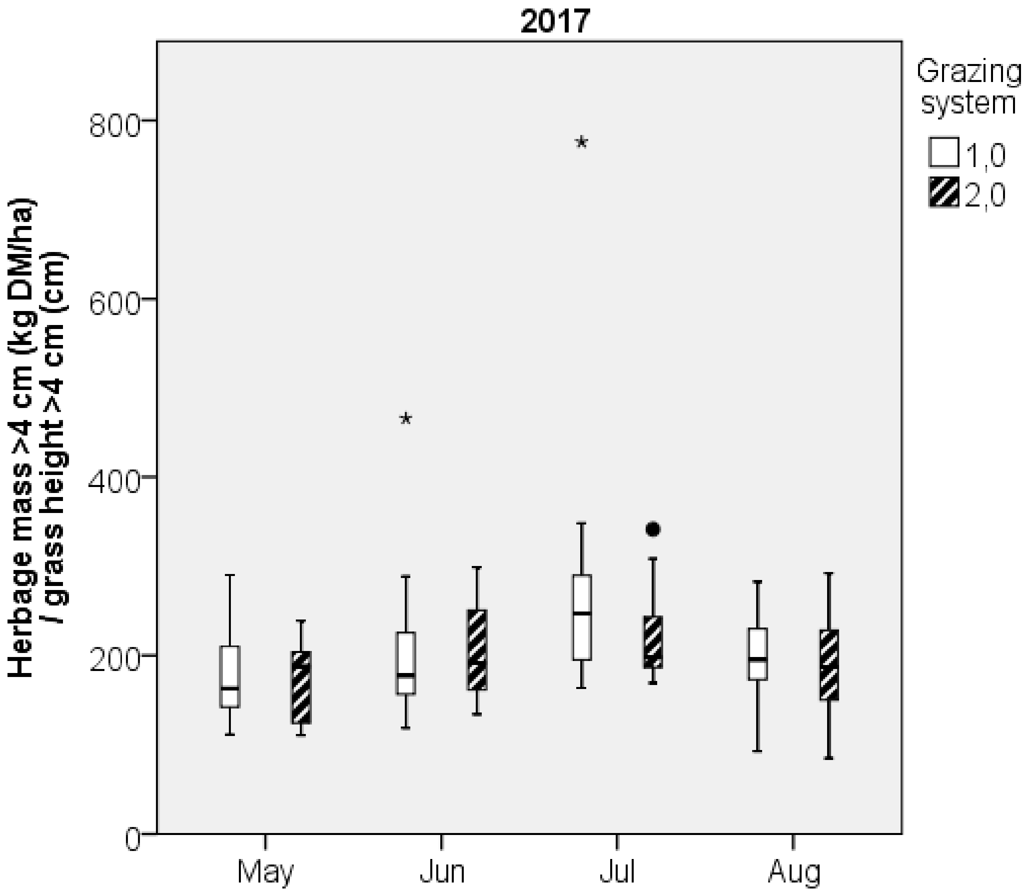
Klootwijk Figure 2



Klootwijk Figure 3A



Klootwijk Figure 3B



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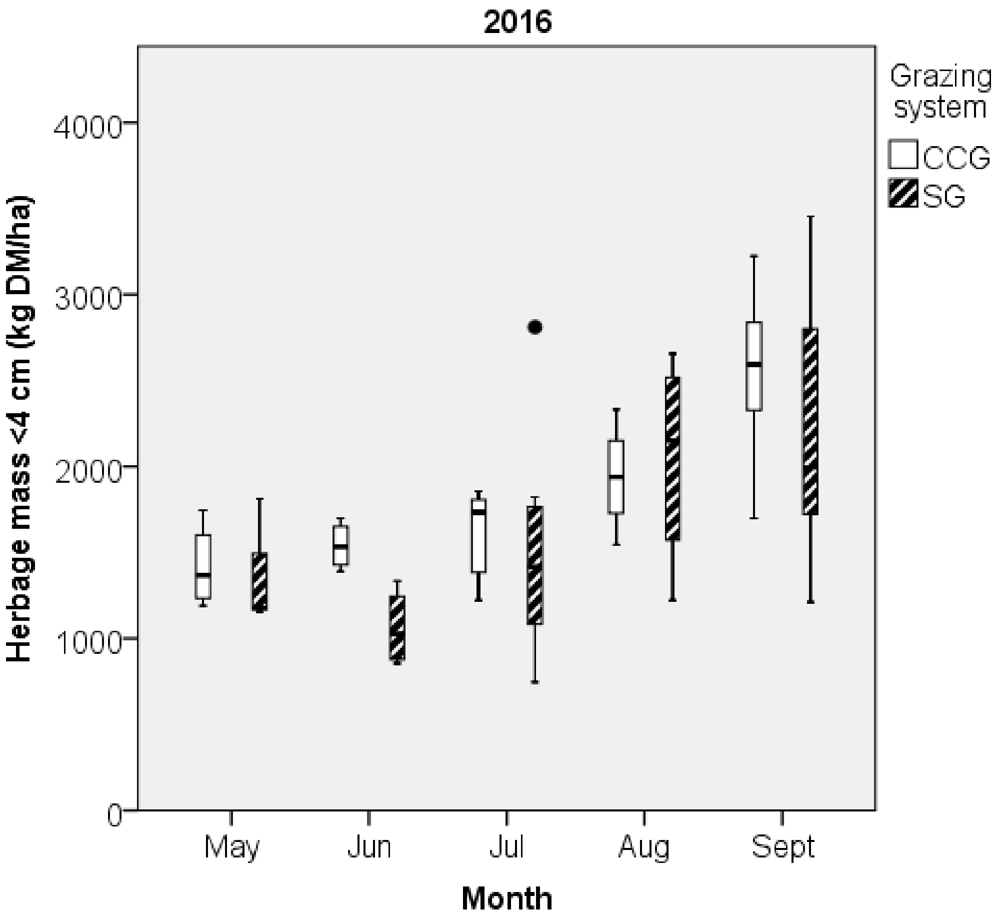

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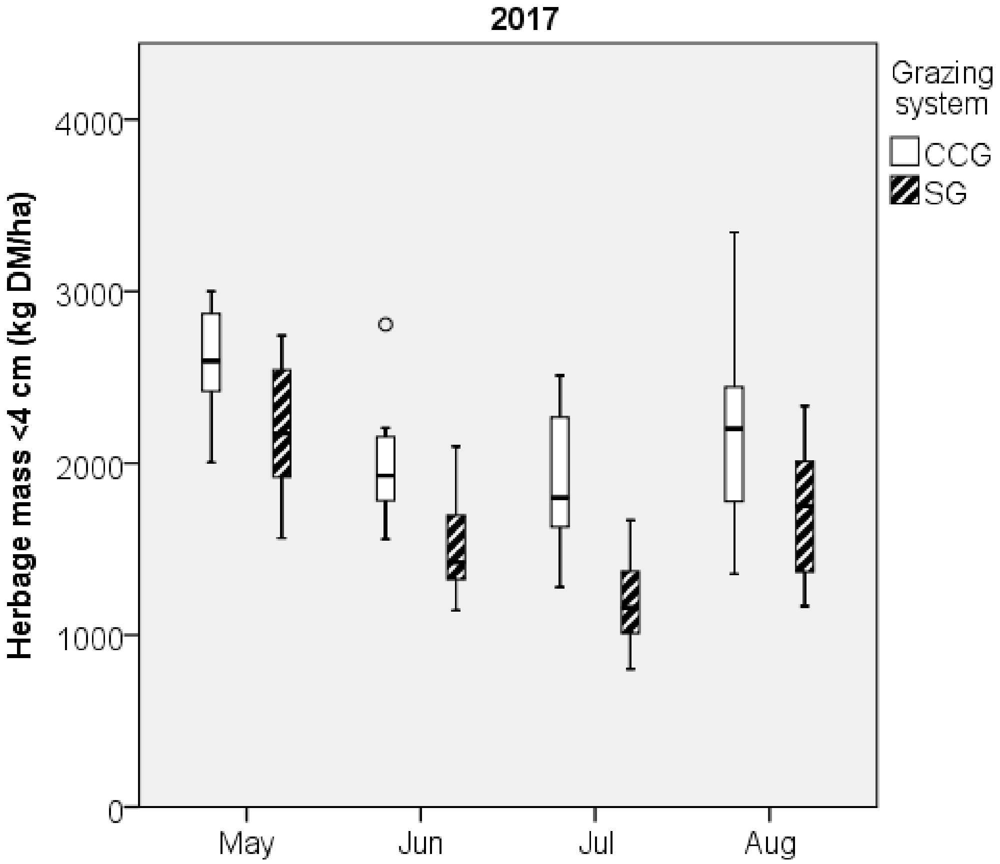
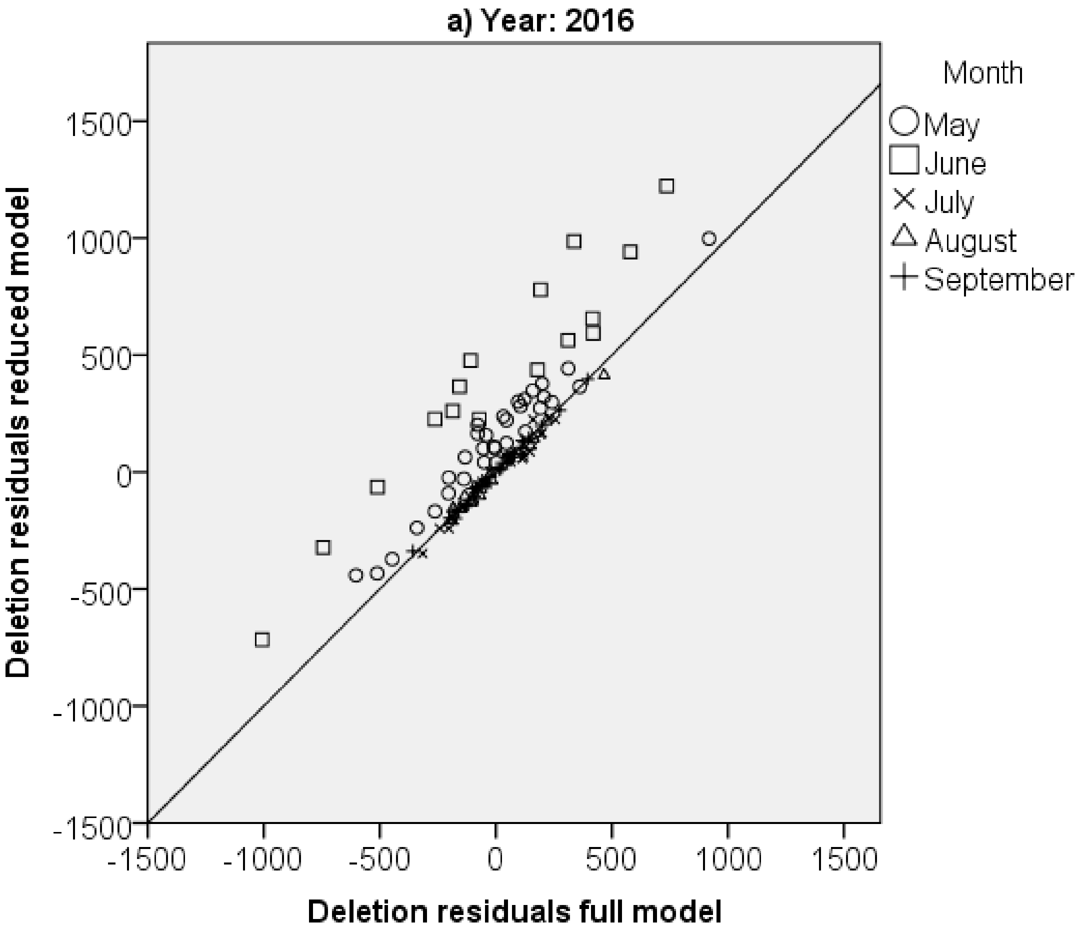


Klootwijk Figure 5A



Klootwijk Figure 5B

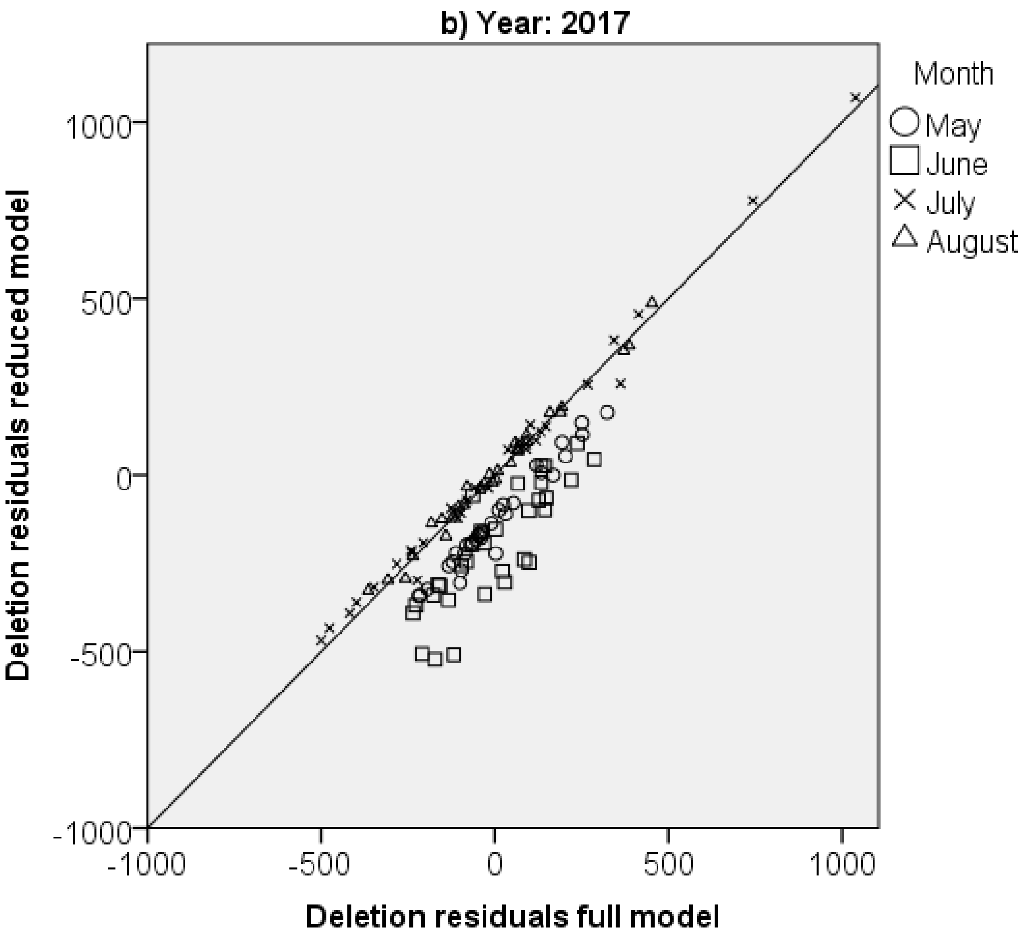


Figure 1. Overview of the grazing experiment with two grazing systems, i.e. compartmented continuous grazing (CCG) and strip grazing (SG) in two replications (A and B). Both CCG and SG are rotational grazing systems in which the cows receive a new grazing area daily. In our experiment cows rotated across six compartments in the CCG system and across 31 strips in the SG system.

Figure 2. Herbage mass > 4 cm plotted against grass height > 4 cm by grazing system. The lines for CCG and SG represent lines of best fit with an R^2 of 0.62 for CCG and 0.83 for SG.

Figure 3a+b. Ratio between herbage mass > 4 cm and grass height > 4 cm for compartmented continuous grazing (CCG) and strip grazing (SG) by month for 2016 (a) and 2017 (b).

Figure 4a+b. Herbage mass < 4 cm for compartmented continuous grazing (CCG) and strip grazing (SG) by month for 2016 (a) and 2017 (b).

Figure 5a+b. Deletion residuals of the reduced model with year effects plotted against the full model by month for 2016 (a) and 2017 (b). The data is presented in kg DM ha^{-1}.