Correcting fresh grass allowance for rejected patches due to excreta in intensive grazing systems for dairy cows. *By Klootwijk et al.,*

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IMPROVING FRESH GRASS ALLOWANCE ESTIMATION

Correcting fresh grass allowance for rejected patches due to excreta in intensive grazing systems for dairy cows

C.W. Klootwijk,*[1] G. Holshof,† I.J.M de Boer,* A. Van den Pol-Van Dasselaar,†‡ B. Engel§ and C.E. Van Middelaar*

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

†Wageningen Livestock Research, Wageningen University & Research, PO 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

Dairy farms with intensive grazing systems combine grazing with supplemental feeding, which can be challenging since an incorrect balance between fresh grass allowance and feed supplementation results in inefficient use of the pasture, a lower feed-efficiency and potential decreases in animal production. When estimating fresh grass allowance, we currently do not correct for the formation of rejected patches (RP) surrounding excreta, which can lead to overestimation of the potential fresh grass intake and hampers optimal grazing. In this study, therefore, we aim to quantify the formation of RP in intensive grazing systems and improve the quantification of fresh grass allowance. To do so, we studied two grazing systems, i.e. compartmented continuous grazing and strip grazing, that differ in key grazing characteristics, such as pre- and post-grazing heights and period of regrowth. The experiment was performed from April to October in 2016 and 2017 with 60 dairy cows at a fixed stocking rate of 7.5 cows ha^{-1}. Average pre-grazing grass height was measured with a rising plate meter. To quantify the formation of RP after grazing, individual grass height measurements were conducted after grazing and classified as RP or not, based on visual assessment. Our analysis showed that the average percentage of grassland covered with RP increased from around 22% at the end of May to around 43% at the end of July/beginning of August, and these percentages do not differ across grazing systems. The percentage of grassland covered with RP should be subtracted from the total grazed area to better estimate true fresh grass allowance.

Key words: intensive grazing, fresh grass allowance, rejected patches, rising plate meter

INTRODUCTION

Grazing can be considered as a key component of the public opinion of the dairy sector. The Dutch society, for example, appreciates an open landscape with grazing cows (Van den Pol-van Dasselaar *et al.*, 2008; Boogaard *et al.*, 2010) and associates grazing with sustainable milk production and animal welfare (Blokland *et al.*, 2017). In addition to societal benefits, grazing can also have economic benefits. Various milk processors pay a higher milk price to farmers who graze their cows on pasture (Doornewaard *et al.*, 2017). Furthermore, several studies have shown that the economic benefit of grazing increases with an increase in fresh grass intake per cow, due to lower costs for supplementary feed and contract labour (Finneran *et al.*, 2012; Meul *et al.*, 2012; Van den Pol-van Dasselaar *et al.*, 2014).

A reliable prediction of the fresh grass allowance can increase farm profit by optimizing the grazing regime. In an optimum grazing regime, fresh grass allowance matches the requirements of the herd, which may increase grazing efficiency and reduce variations in DMI and hence fluctuations in milk production (Hennessy *et al.*, 2015). Fresh grass allowance is determined by stocking rate and available herbage mass (**HM**) on the grazing platform (Stockdale and King, 1983). The stocking rate on the grazing platform can be calculated by dividing the number of cows by the available hectares of grassland available and accessible for grazing. Herbage mass can be indirectly measured with the rising plate meter (**RPM**) (Sanderson *et al.*, 2001), which is used in practice to measure grass height before grazing and is subsequently translated to HM by using a prediction equation. Using this method, the fresh grass allowance can be estimated before grazing. The HM < 4 cm is not considered to be part of the fresh grass allowance since the cows do not graze the stubble (Kennedy *et al.*, 2007). In practice, however, the offered fresh grass is not homogenously grazed down due to selective grazing.

Excreta is the major cause of selective grazing as cows refuse to graze grass contaminated by dung due to the smell and taste, which results in the formation of rejected patches (**RP**) (Dohi *et al.*, 1991; Bosker *et al.*, 2002; Verwer *et al.*, 2016). Marten and Donker (1964) found that 93% of the non-grazed areas contained dung from previous grazing events. In addition, 81% of the dung patches, deposited three to four weeks before grazing, were rejected by dairy cows during grazing. Similarly, urine can result in rejected patches and persist for many months (Dennis *et al.*, 2011). When estimating fresh grass allowance, dairy farmers currently do not correct for the formation of RP. This overestimates the fresh grass allowance and, thereby, the potential fresh grass intake of dairy cows, which can undermine optimal grazing.

The excreta load and distribution in the field and, thereby, the formation of RP is shown to be influenced by stocking rate (Arnold and Holmes, 1958; Dennis *et al.*, 2011). The stocking rate on the grazing platform (i.e. the grassland accessible and available for grazing) is expected to increase in the Netherlands from 3.5 dairy cows ha^{-1} in 2013 to 4.5 in 2020 (Van den Pol-van Dasselaar *et al.*, 2015). This has resulted in reduced (daily) fresh grass allowance per cow and the need to increase feed supplementation. In this study, therefore, we aim to quantify the formation of RP in intensive grazing systems and improve the quantification of fresh grass allowance. 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. In addition, these two systems are examples of daily rotational grazing systems suitable for intensive Dutch dairy farms with feed supplementation (Holshof *et al.*, 2018).

MATERIALS AND METHODS

Grazing Systems

The grazing experiment in which we conducted our measurements was performed at the Dairy Campus research facility in Leeuwarden in 2016 and 2017. Sixty dairy cows were allocated to two different grazing systems, i.e. CCG and SG, in two replicates (Figure 1). Cows were 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, 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 key grazing characteristics, such as pre- and post-grazing sward heights and period of regrowth. Each CCG replicate was two ha and was divided into six 0.33 ha compartments. On a grazing day, therefore, each cow had access to 222 m^2 of fresh grass. Each SG replicate was also two ha and was divided into 31 strips of 0.07 ha each. On a grazing day, each cow had access to 43 m^2 of fresh grass and the strip of the previous day to provide more space to walk (in total 86 m^2).

For CCG, five compartments were grazed and (random) the sixth one was cut for silage to remove RP. After regrowth (on average ten 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 during the whole season, five of the six compartments were grazed in a five day rotation. Period of regrowth for the five compartments in the rotation, 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. Cutting for silage in between grazing events is common practice on Dutch dairy farms and reduces seasonal buildup of RP.

The period of regrowth influenced the fresh grass allowance in CCG and SG, depending on the grass growth (influenced by weather conditions). Fresh grass allowance was measured by performing weekly grass height measurements in all compartments and strips. Per compartment or cluster of four strips, about 60 measurements were performed while walking in a W-shape through the compartments and strips.

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 DM of maize silage supplemented with grass silage according to requirements. In addition to the adjustment of 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}.

Quantifying Fresh Grass Allowance with RP Correction

Since the formation of RP occurs during grazing, we analyzed the percentage of grassland covered with RP after grazing to correct fresh grass allowance before grazing. We recorded grass heights in recently grazed fields and indicated for each individual measurement whether or not it corresponded to an RP (yes/no) based on visual assessment. An RP was identified as an ungrazed spot due to excreta (Bao *et al.* (1998). The percentage of grassland measurements related to a RP was determined by the mean proportion of RP and non-RP according to the visual assessment. In total we analysed nine fields for CCG and eight fields for SG. Proportions of RP per field were analysed with a logistic regression model. This model was comprised of main effects and interactions for the two systems and for three time periods (1 = May, 2 = July and 3 = August) on the logit scale. A multiplicative overdispersion parameter was included in the binomial variance function. Parameters on the logit scale were estimated by maximum quasi-likelihood (MCcullagh and Nelder, 1989). The overdispersion parameter was estimated by Pearson's chi-square statistic divided by its degrees of freedom. A test for interaction and tests for main effects (within the additive model without interaction) were based on the quasi-likelihood ratio test. P-values were derived from an approximation with an F-distribution (with denominator degrees of freedom associated with Pearson's chi-square from the largest model). Pairwise comparisons between time points, within the additive model, were based on quasi-Wald tests, with P-values derived from an approximation with the t-distribution. Calculations were performed with generalized linear model facilities of Genstat (VSN International, 2017).

Grass Height Measurements

To assure a reliable representation of the RP formation per field we used the following protocol. The fields served as experimental units and were either a compartment of CCG or two adjacent strips of SG. For CCG, one compartment measured 26.7 by 125 meters (3333 m^2). In this compartment, we marked the long side at about every 15 meters with a stick and walked through the compartment in a W-pattern, taking 30 measurements in each of the four W-shapes covering

30 meters (Figure 2A), resulting in 120 measurements. Measurements were triplicated to have a total of 360 measurements per compartment. For SG, two adjacent strips measured a total size of 10 by 125 meters. In these strips, we marked the long side in between the two strips at about every 15 meters with a stick and walked through the middle of each strip straight from the beginning until the end, taking about 15 measurements per 30 meter (Figure 2B). Measurements were triplicated to have a total of 360 measurements per two strips.

In total we conducted 6,120 grass height measurements in 17 recently grazed fields, from the end of May until the beginning of August in 2017. We calculated the average grass height for RP and non-RP for in total nine fields for CCG and eight fields for SG and performed a Wilcoxon's signed rank test to compare the grass height of RP and non-RP for CCG and SG separately. All grass height measurements were conducted by the same operator using the Jenquip EC20 (NZ Agriworks Ltd., NZ) RPM, which was developed in New Zealand. This RPM enables the operator to record each individual grass height measurement in mm and was connected with an Android Pasture Meter App via a Bluetooth connection.

Quantifying the Required Number of Grass Height Measurements per Field

The current advice in practice is to take 30 measurements per field before grazing to estimate fresh grass allowance. To determine whether 30 measurements is sufficiently accurate to estimate HM in intensive grazing systems, we analysed the effect of number of grass height measurements on the accuracy of estimating the average grass height in the field. Eq. 1 was used to quantify the effect of within-field variance on the number of measurements needed per field to estimate the average grass height with a predefined, accepted accuracy (i.e. error). Since the accepted error in mm depends on the average grass height and the aim of measuring, we varied the accepted error from 1 to 20 mm.

$$n = \frac{1.96^2 \times \sigma^2}{E^2} \quad [1]$$

Here, σ^2 is the within-field variance between measurements and E is the error margin in grass height.

To determine the number of measurements needed to estimate grass height before grazing (eq. 1), we need an estimate of the within-field variance in grass height for both CCG and SG. Since the average grass height to quantify HM is measured before grazing in practice, we needed a representative within-field variance for before grazing. For both systems, therefore, we conducted additional measurements in three fields that were not grazed since the last mowing activity, with 360 measurements per field. For CCG, the within-field variation in grass height before and after grazing is not so different, because the period of regrowth is only four days. In addition, the within-field variation in grass height increases as the number of grazing events increases. Therefore, we also included the within-field variation of the fields after grazing providing an average within-field variance after 0 to 18 grazing events for CCG. Since we argue that the fresh grass allowance should be corrected for RP, we excluded RP from this analysis.

RESULTS AND DISCUSSION

Fresh Grass Allowance with RP Correction

Figure 3 shows the variation in grass height per recently grazed field for non-RP and RP, for each grazing system separately. For non-RP, average grass height per field was 65 ± 18 mm for CCG and 64 ± 18 mm for SG. For RP, average grass height per field after grazing was higher than for non RP ($P < 0.001$), i.e. 142 ± 34 mm for CCG and 106 ± 23 mm for SG. The large contrast in grass height between non-RP and RP supports that we could distinguish them based on visual assessment. The contrast we found in grass height of non-RP and RP is comparable with results of Bao *et al.* (1998), who showed an average post-grazing grass height of 60 mm for non-RP and 100 mm for RP in a 20-day rotational system with a stocking rate of 4.9 cows ha^{-1}. Schwinning and Parsons (1999) argued that instead of having two alternative stable states (i.e. predominantly shorter or taller patches), a grazing system in which there is preference for short patches (non-RP) is likely to result in a bimodal frequency distribution with short (non-RP) and tall (RP) patches. In line with this, Bao *et al.* (1998) mention that the extent to which tall patches are defoliated seems likely to be influenced by the grazing pressure. Cows first tend to graze on non-RP, but then turn to RP gradually in proportion to the availability when the sward is further grazed down (Bao *et al.*, 1998). The shift towards RP is likely dependent on the proportion of available leaf to stem material, since cows prefer leaf over stem material. The RP in CCG likely contain more stem material since they are refused for multiple grazing events without mowing in between.

Our analysis showed that the average percentage of grassland (predominantly perennial ryegrass) covered with RP increased from around 22% at the end of May to around 43% at the end of July/beginning of August (Figure 4). The logistic regression model showed that the development of proportion of RP in time did not differ across grazing systems ($P = 0.33$). Time showed an effect on the proportion of RP ($P < 0.001$), while grazing system did not ($P = 0.33$). Pairwise comparisons between time points revealed that the proportion of RP was lower in May compared to both July and August ($P < 0.001$), but that the difference between July and August was not significant ($P = 0.37$). These results suggest that the percentage of grassland covered with RP is not influenced by grazing system under intensive grazing. In addition, after a period of increase in grassland covered with RP, in both systems a maximum seems to be reached in July. MacLusky (1960) also described an equilibrium state after an increase in RP formation, which can be explained by a balance between formation of RP and reduction of RP due to breakdown of dung.

It takes on average about three months before the dung patches have visually disappeared from the pasture (Lantinga *et al.*, 1987). It may take about two years, however, before the affected areas are fully recolonized with the original grass species and grazed normally again (Castle and MacDaid, 1972). The time of disappearance of dung patches depends on weather conditions, the activity of the soil fauna, feeding strategy and mechanic treatment (Lantinga *et al.*, 1987; Bosker *et al.*, 2002; Vadas *et al.*, 2011; Van Schooten *et al.*, 2014). The time to reach equilibrium in the percentage of grassland covered with RP as well as the level of this equilibrium, therefore, will likely depend on these factors. Grass species might also influence the area covered with RP. We observed that in early spring the whole field was equally grazed. In line with perennial ryegrass, however, timothy-grass was more often rejected by the cows in June. With the grass species being equally distributed in the field we do not expect a marked effect of the botanical composition of the fields in this study on the proportion of grassland covered with RP.

Sanderson *et al.* (2001) concluded that measuring within 10% error margin can improve forage budgeting by allocating an adequate amount of grass to the herd. An error margin of 22-43% in predicting fresh grass allowance is substantial and can result in an imbalance with the rest of the ration and subsequently a reduction in milk production. If the fresh grass allowance is insufficient in the CCG system the grass height will decrease below the intended 60 mm, which will result in an insufficient grass growth. This means that there will be less grass left for the next grazing and this will increase the need for supplementary feeding. The SG system is even less flexible because there will be insufficient grass available to feed the cows requiring an immediate increase in supplementary feeding. Therefore, it is necessary to correct fresh grass allowance for RP formation under intensive grazing. The fresh grass allowance can be corrected by subtracting the surface covered with RP from the total grazed area. If the RP can be visually distinguished before grazing, they should be excluded from the grass height measurements to get a reliable estimate of the remaining grazing area without RP. This is more relevant for grazing systems with a short grazing interval (i.e. CCG) since the contrast in grass height between non-RP and RP reduces with an increase in the number of days since grazing. For grazing systems with a long grazing interval (i.e. SG), the contrast between non-RP and RP will be small if the RP cannot be visually distinguished and, therefore, will not substantially affect the average grass height. In this case, the surface correction will be sufficient to correct fresh grass allowance for the formation of RP.

Quantifying the surface covered with RP can be done during the grass height measurements with the RPM. This requires scoring the number of measurements that corresponds with an RP (yes/no) based on visual assessment, as in this study. Due to the increase in RP during the season it is advisable to do this in spring and summer in a representative subset of the field. In addition, rejected patches should be excluded from the weekly grass height measurements if they can be visually distinguished to get a more accurate average grass height. Since this method is labour-intensive it might be more practical to explore less labour-intensive methods, for example the potential of multispectral images to correct fresh grass allowance for selective grazing.

The Required Number of Grass Height Measurements per Field

Table 1 shows the effect of number of grass height measurements on the accuracy of average grass height estimates per field for CCG and SG. The number of necessary grass height measurements reduces with a decrease in within-field variance and with an increase in accepted error. The within-field variance in grass height before grazing was 544 mm^2 for CCG and 618 mm^2 for SG. The current advice in practice is to take 30 measurements per field before grazing to estimate fresh grass allowance (Holshof and Stienezen, 2016). The corresponding errors in estimations of the average grass height per field are 8-9 mm for both CCG and SG. The error in estimating the average grass height should in general be as small as possible since the calculation from average grass height to HM already comes with an error margin of 25-31% under CCG and SG (C. W. Klootwijk, unpublished data). Since most of the RPMs measure grass height in clicks, which corresponds with 5 mm, this might be accepted as a maximal error. To achieve a maximal error of 5 mm, our results indicate that we need to take minimally 84 measurements per field in CCG, when excluding visible RP, and 95 measurements per field in SG.

CONCLUSIONS

Our analysis showed that the average percentage of grassland (predominantly perennial ryegrass) covered with RP increased from around 22% at the end of May to around 43% at the end of July/beginning of August at a fixed stocking rate of 7.5 cow^{-1} ha^{-1}. After a period of increase in grassland covered with RP an equilibrium state was reached, which can be explained by a balance between formation of RP due to excreta and reduction of RP due to breakdown of dung. We found no difference between grazing systems in average proportion of RP and development of RP over the season. Our finding that on average 22% to 43% of the grassland is covered with RP indicates that estimates of grass height should be corrected for RP formation in intensive grazing systems when estimating potential fresh grass allowance. This can be done by subtracting the percentage of grassland covered with RP from the total grazed area. Our results suggest that the percentage of grassland covered with RP is not influenced by grazing system under intensive grazing in perennial ryegrass pastures and, therefore, the surface correction can be used across grazing systems. If the RP can be visually distinguished before grazing, they should be excluded from the grass height measurements to get a reliable estimate of the remaining grazing area without RP. This is more relevant for grazing systems with a short grazing interval (i.e. CCG) since the contrast in grass height between non-RP and RP reduces with an increased period of regrowth. For grazing systems with a long grazing interval (i.e. SG), the contrast between non-RP and RP will be small if the RP cannot be visually distinguished and, therefore, will not substantially affect the average grass height. The current advice in practice is to take 30 measurements per field before grazing to estimate fresh grass allowance.

To achieve a maximal error of 5 mm, our results indicate to take a minimum of 90 measurements per field in intensive grazing systems.

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REFERENCES

Arnold, G. W. and W. Holmes. 1958. Studies in grazing management. VII. The influence of strip grazing versus controlled free grazing on milk yield, milk composition, and pasture utilization. J Agric Sci 51:248-256. doi.org/10.1017/S0021859600034250.

Bao, J., P. S. Giller, and G. Stakelum. 1998. Selective grazing by dairy cows in the presence of dung and the defoliation of tall grass dung patches. Animal Science 66:65-73. doi.org/10.1017/S1357729800008845.

Blokland, P. W., A. Van den Pol-Dasselaar, C. Rougoor, F. Van der Schans, and L. Sebek. 2017. Maatregelen om weidegang te bevorderen; Inventarisatie en analyse (Measures to stimulate grazing; Inventarisation and analysis). Wageningen University & Research, report 071, Wageningen, the Netherlands. Pages: 60.

Boogaard, B., B. Bock, S. Oosting, and E. Krogh. 2010. Visiting a farm: An exploratory study of the social construction of animal farming in Norway and the Netherlands based on sensory perception. Int. Jrnl. of Soc. of Agr. & Food 17:24-50.

Bosker, W. T. E., N. J. Hoekstra, and E. A. Lantinga. 2002. The influence of feeding strategy on growth and rejection of herbage around dung pats and their decomposition. J Agric Sci 139:213-221. doi.org/10.1017/S0021859602002472.

Castle, M. E. and E. MacDaid. 1972. The decomposition of cattle dung and its effect on pasture. Grass Forage Sci. 27:133-138. doi.org/10.1111/j.1365-2494.1972.tb00700.x.

Dennis, S. J., J. L. Moir, K. C. Cameron, H. J. Di, D. Hennessy, and K. G. Richards. 2011. Urine patch distribution under dairy grazing at three stocking rates in Ireland. IJAFR 50:149-160.

Dohi, H., A. Yamada, and S. Entsu. 1991. Cattle feeding deterrents emitted from cattle feces. J. Chem. Ecol. 17:1197-1203. doi.org/10.1007/BF01402943.

Doornewaard, G. J., J. W. Reijs, A. C. G. Beldman, J. H. Jager, and M. W. Hoogeveen. 2017. Sectorrapportage Duurzame Zuivelketen; Prestaties 2016 in perspectief (Sector report Duurzame Zuivelketen; Achievements 2016 in perspective). Wageningen Economic Research, report 087, Wageningen, the Netherlands. Pages: 200.

Finneran, E., P. Crosson, P. O'Kiely, and L. Shalloo. 2012. Stochastic simulation of the cost of home-produced feeds for ruminant livestock systems. J Agric Sci 150:123-139. doi.org/10.1017/S002185961100061X.

Hennessy, D., L. Delaby, A. Van den Pol-Dasselaar, and L. Shalloo. 2015. Possibilities and contraints for grazing in high output dairy systems. Pages 151-162 in Proc. Grassland Science in Europe 20.

Holshof, G. and M. W. J. Stienezen. 2016. Grasgroei meten met de grashoogtemeter. Wageningen University & Research, Livestock Research, Report 925, Wageningen, The Netherlands.

Holshof, G., R. L. G. Zom, A. P. Philipsen, A. Van Den Pol-Van Dasselaar, and C. W. Klootwijk. 2018. Amazing grazing: substantial fresh grass intake in restricted grazing systems with high stocking rates. Pages 234-236 in Proc. Grassland Science in Europe 23.

Kennedy, E., M. O'Donovan, J. P. Murphy, L. Delaby, and F. P. O'Mara. 2007. Effect of Spring Grazing Date and Stocking Rate on Sward Characteristics and Dairy Cow Production During Midlactation. J. Dairy Sci. 90:2035-2046. doi.org/10.3168/jds.2006-368.

Lantinga, E., J. Keuning, J. Groenwold, and P. Deenen. 1987. Distribution of excreted nitrogen by grazing cattle and its effects on sward quality, herbage production and utilization. Pages 103-117 in Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste? Springer.

MacLusky, D. S. 1960. Some estimates of the areas of pasture fouled by the excreta of dairy cows. Grass Forage Sci. 15:181-188. doi.org/10.1111/j.1365-2494.1960.tb00176.x.

Marten, G. C. and J. D. Donker. 1964. Selective Grazing Induced by Animal Excreta I. Evidence of Occurrence and Superficial Remedy. J. Dairy Sci. 47:773-776. doi.org/10.3168/jds.S0022-0302(64)88762-2.

MCcullagh, P. and J. A. Nelder. 1989. Generalized Linear Models. 2nd ed. Chapman & Hall, London, England.

Meul, M., S. Van Passel, D. Fremaut, and G. Haesaert. 2012. Higher sustainability performance of intensive grazing versus zero-grazing dairy systems. Agron Sustain Dev 32:629-638. doi.org/10.1007/s13593-011-0074-5.

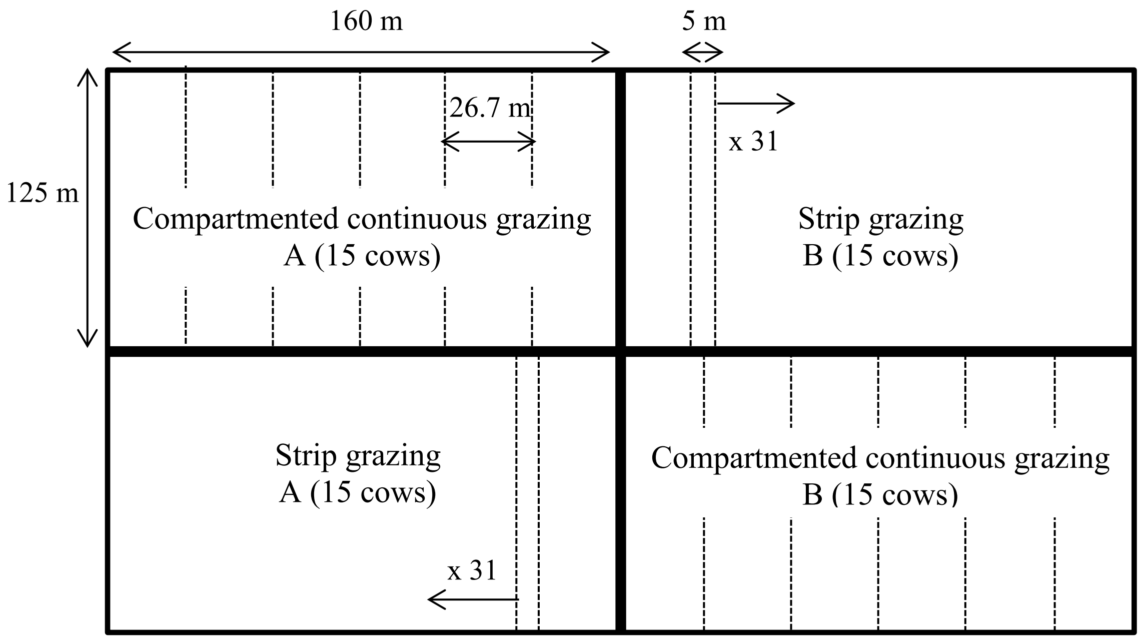
Sanderson, M. A., C. A. Rotz, S. W. Fultz, and E. B. Rayburn. 2001. Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. Agron. J. 93:1281-1286. doi.org/10.2134/agronj2001.1281.
Schwinning, S. and A. J. Parsons. 1999. The stability of grazing systems revisited: spatial models and the role of heterogeneity. Funct. Ecol. 13:737-747. doi.org/10.1046/j.1365-2435.1999.00382.x.
Stockdale, C. R. and K. R. King. 1983. Effect of stocking rate on the grazing behaviour and faecal output of lactating dairy cows. Grass Forage Sci. 38:215-218. doi.org/10.1111/j.1365-2494.1983.tb01642.x.
Vadas, P., S. Aarons, D. Butler, and W. Dougherty. 2011. A new model for dung decomposition and phosphorus transformations and loss in runoff. Soil research 49:367-375. doi.org/10.1071/SR10195.
Van den Pol-van Dasselaar, A., P. W. Blokland, T. J. A. Gies, G. Holshof, M. H. A. D. Haan, H. S. D. Naeff, and P. Philipsen. 2015. Beweidbare oppervlakte en weidegang op melkveebedrijven in Nederland (Grazing platform and grazing on dairy farms in the Netherlands). Wageningen UR (University & Research centre) Livestock Research, Livestock Research, Wageningen.
Van den Pol-van Dasselaar, A., A. P. Philipsen, and M. H. A. De Haan. 2014. Economics of grazing. Pages 662-664 in Proc. Grassland Science in Europe 19.
Van den Pol-van Dasselaar, A., T. V. Vellinga, A. Johansen, and E. Kennedy. 2008. To graze or not to graze, that's the question. Pages 706-716 in Proc. Grassland Science in Europe 13.
Van Schooten, H. A., K. M. Van Houwelingen, A. P. Philipsen, N. J. M. Van Eekeren, and F. A. J. Lenssinck. 2014. Amazing Grazing deelproject: De Weidewasser 2013 : innovatievraag: Hogere opbrengst en lagere verliezen van grasland? : opgave: Negatief effect van mestflatten omzetten in positief effect. Wageningen UR Livestock Research, Lelystad.
Verwer, C., H. Van Schooten, B. Philipsen, F. Lennsinck, K. Van Houwelingen, and N. Van Eekeren. 2016. Rejection of grass around dung pats; influence of smell, taste or both? Pages 430-432 in Proc. Grassland Science in Europe 21.
VSN International. 2017. Genstat for Windows 19th ed. VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk.

TABLES

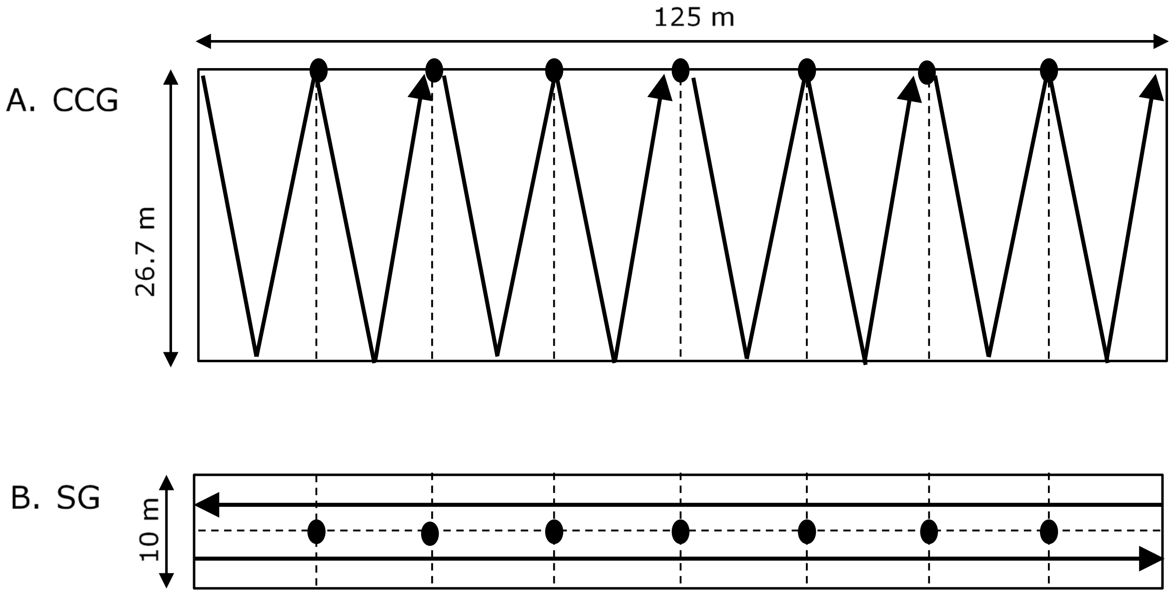
Table 1. Number of grass height measurements needed in fields for compartmented continuous grazing (CCG) and strip grazing (SG) systems to reach various levels of accepted error when estimating average grass height.

	Number of grass height measurements	
Accepted error (mm grass)	**CCG**	**SG**
1	2089	2375
2	522	594
3	232	264
4	131	148
5	84	95
6	58	66
7	43	48
8	33	37
9	26	29
10	21	24
11	17	20
12	15	16
13	12	14
14	11	12
15	9	11

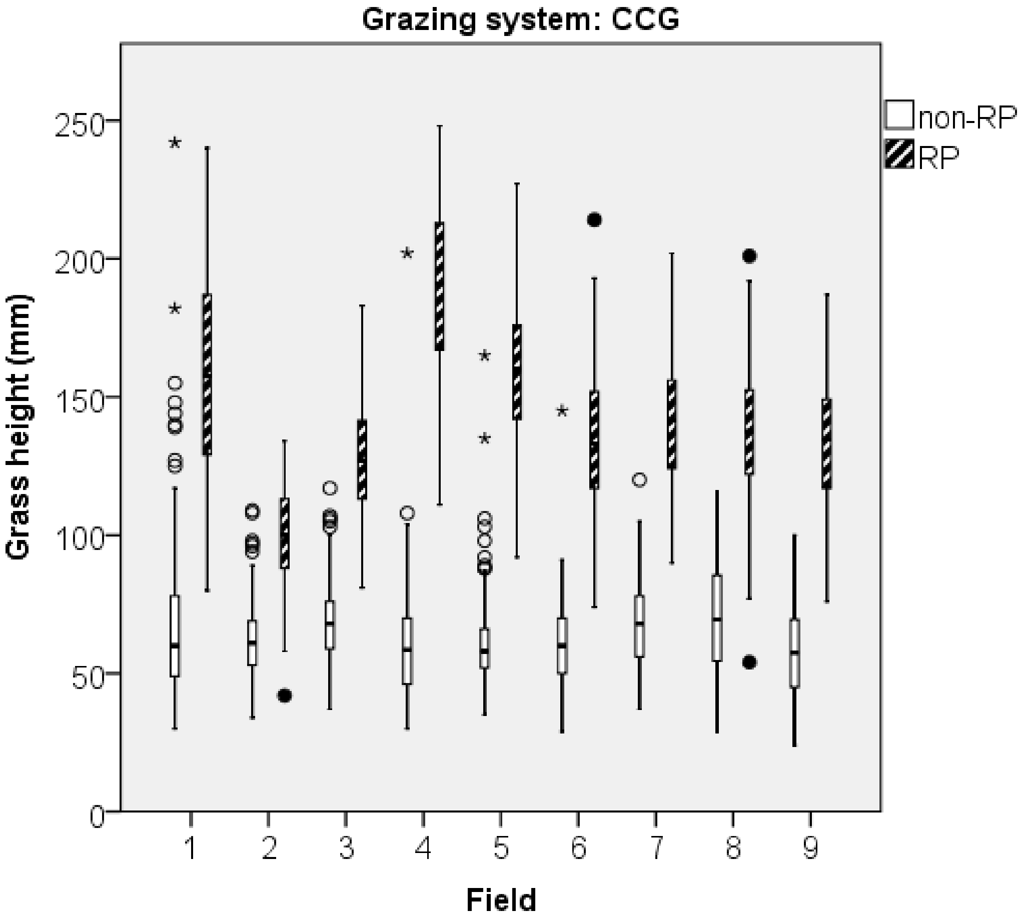
Klootwijk Figure 1



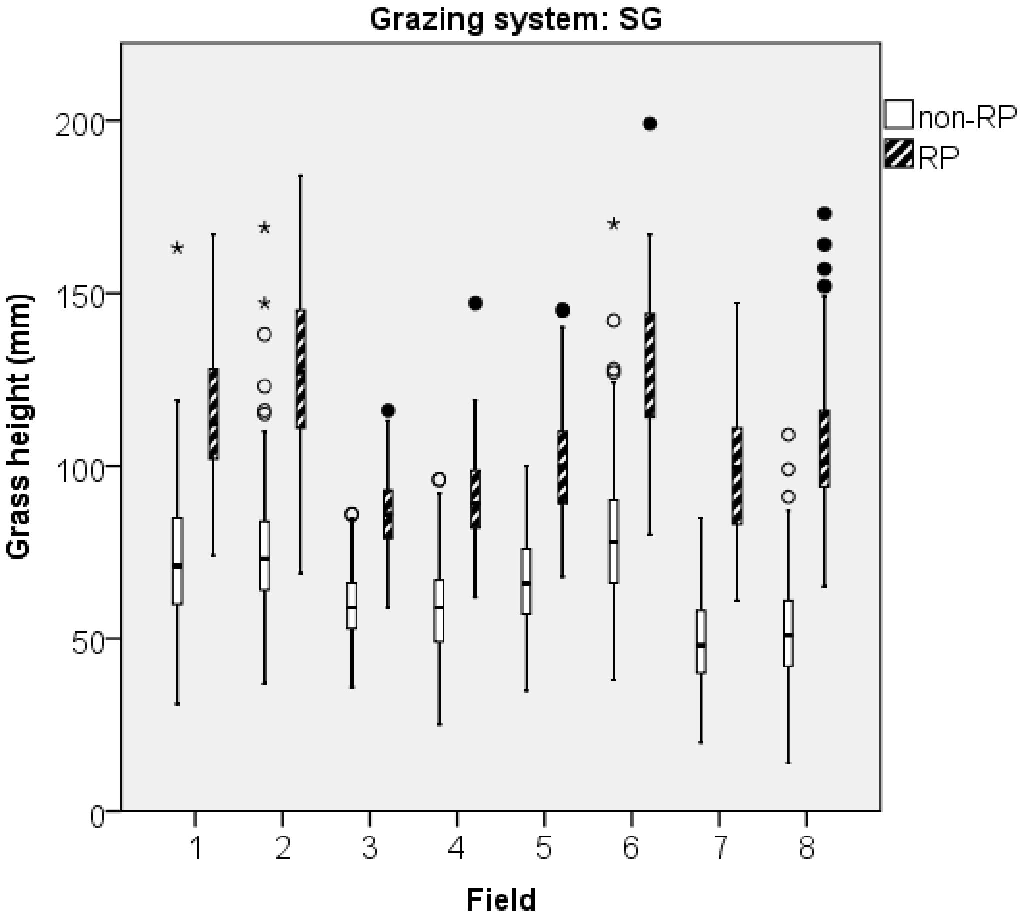
Klootwijk Figure 2 A+B



Klootwijk Figure 3 CCG



Klootwijk Figure 3 SG



Klootwijk Figure 4

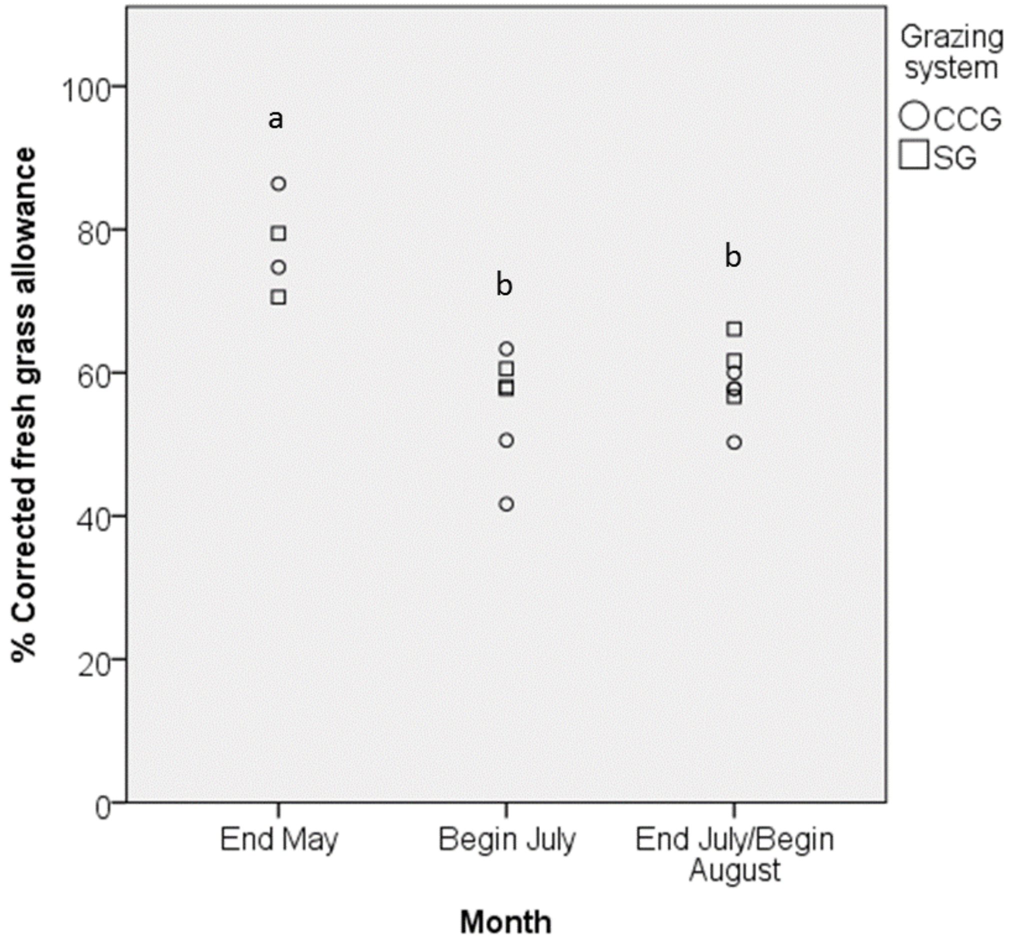


Figure 1. Overview of the grazing experiment with two contrasting grazing systems, i.e. compartmented continuous grazing (CCG) and strip grazing (SG) in two replicates (A and B). Both CCG and SG are rotational grazing systems in which the cows receive a new grazing area daily. In our experiment cows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

Figure 2. Sampling technique for representative grass height measurements in two grazing systems, A) CCG = compartmented continuous grazing and B) SG = strip grazing, with the black dots indicating the sticks as reference points.

Figure 3. Range in grass height (mm) per recently grazed field distinguishing between non-rejected patches (non-RP) and rejected patches (RP) split up for 2 grazing systems, i.e. CCG = compartmented continuous grazing and SG = strip grazing. The average grass height per field after grazing was higher for RP than for non RP ($P < 0.001$).

Figure 4. The percentage of fresh grass allowance remaining after correction for (i.e. excluding) rejected patches (RP) at the end of May, beginning of July and end of July/beginning of August for continuous compartmented grazing (CCG) and strip grazing (SG). Different letters indicate significant differences ($P<0.001$).