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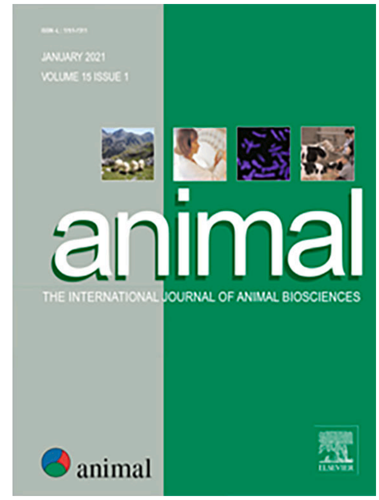

Animal and Pasture Responses in Contrasting Temperate Pasture-based Cattle Management Systems: Set-Stocking versus Cell Grazing

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Title: Animal and Pasture Responses in Contrasting Temperate Pasture-based Cattle Management Systems: Set-Stocking versus Cell Grazing

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Highlights:

- 4-year randomised trial comparing set-stocking and rotational cell grazing.
- Cell grazing boosted liveweight production per hectare by up to 44%.
- Rotational grazing improved pasture quality and increased herbage growth rates.
- Set-stocking yielded higher individual average daily gains in steers.
- Results endorse sustainable grazing practices for enhanced land efficiency.

Abstract

Grasslands cover a significant portion of the Earth's land and offer many benefits. In the UK, they constitute the largest agricultural area and support livestock production. Traditional set-stocking (**SS**) and continuous grazing methods allow animals to selectively graze more palatable and nutritious plant parts and species, boosting individual animal productivity in the short-term but can be detrimental to long-term pasture productivity. Cell grazing (**CG**), an intensive rotational system, is proposed as an alternative that can enhance system productivity and profitability through increased pasture production, utilization, and stocking rates; with potential to optimise natural resource use (e.g., land) and mitigate environmental impacts (e.g., soil carbon sequestration). A four-year study at Rothamsted Research's North Wyke site in southwest England compared animal and pasture responses under SS and CG stocking methods using a split-block design with three replicates (enclosures) per treatment. The SS enclosures (1.5-1.75 ha) were continuously grazed with fixed stocking rates and CG enclosures (1.0 ha) were rotationally grazed with flexible daily grazing area allocations and stocking rates. Grazing occurred spring to autumn, using two cohorts of autumn-born dairy × beef steers, each grazed for two years before slaughter. Measurements included standing herbage mass (weekly), herbage chemical composition (fortnightly), steer liveweight (monthly), and botanical composition (spring 2018 and 2022). Dry matter intake was estimated based on animal energy requirements. Significant interaction effects ($p<0.05$) were found for most variables, apart from metabolizable energy, ADF and NDF which were affected by treatment ($p<0.05$) and year ($p<0.001$), and DM content which was affected by year only ($p<0.001$). Average daily gain was higher in SS (0.77 kg/d) than CG (0.60 kg/d), linked to higher estimated DM intake (7.2 vs. 6.2 kg DM). However, annual liveweight (**LW**) production per hectare was greater in CG (687 vs. 476 kg LW/ha, respectively), due to higher total pasture production (6 053 vs. 3 667 kg DM/ha, respectively) and stocking rate (2 362 vs. 1 290 kg LW/ha, respectively). Herbage nutritional quality varied, with CG having higher metabolizable energy and water-soluble carbohydrates, and lower fibre (ADF and NDF) concentrations. Changes in botanical composition also varied between treatments. The proportion of perennial ryegrass increased under CG (42% to 69%, $p<0.001$) but declined under SS (36% to 16%, $p<0.01$). These results highlight that while SS can enhance individual animal gains, CG improves total system productivity and pasture composition. Long-term, replicated experiments like this are crucial for evaluating the long-term viability and sustainability of differing stocking methods and grazing management strategies.

Keywords: rotational stocking, continuous stocking, grazed pasture production, dairy x beef cattle, perennial ryegrass sward.

Implications

Grasslands dominate ruminant feed production, supporting livestock whilst providing ecosystem services. This study compared set-stocking and cell-grazing over four years. Overall, cell grazing achieved higher liveweight production per

hectare than set-stocking driven by greater pasture production and higher stocking rates. These findings suggest that cell grazing enhanced land-use efficiency, potentially reducing land required for grazing, and promoted better pasture nutritional quality with increased perennial ryegrass cover, aiding sustainable grazing management. Long-term evaluation showed variable trends in pasture production, botanical composition and animal performance, revealing the complexities of grazing systems and the need for extended studies to inform sustainable land use practices.

Introduction

Grasslands are the predominant type of land use globally, accounting for around 37% of Earth's ice-free land area (IPCC, 2022). Their primary agricultural use is to provide feed for ruminants, but they also provide other benefits to society by supporting biodiversity, recreation, hydrology, carbon stocks and sequestration, and biomass for bioenergy production (Hopkins and Wilkins, 2006; Prochnow *et al.*, 2009; O'Mara, 2012; Rui *et al.*, 2022). In the UK, grasslands represent approximately 60% of the total utilised agricultural area, equating to around 9.6 million ha of permanent grassland, 1.2 million ha of temporary grassland and 1.2 million ha of common grazing (DEFRA, 2022a). These grasslands helped support 9.6 million cattle and 33.0 million sheep in the UK in 2021, producing 15.2 billion litres of milk and 0.9 and 0.3 million tons of cattle and sheep meat, respectively (DEFRA, 2022b).

The stocking methods employed in grazed systems differ in their spatio-temporal arrangement to optimise animal, plant and soil responses *(Cox et al., 2017; Di Virgilio et al*., 2019). Temperate grasslands in the UK are typically managed using continuous or set-stocking (**SS**), where grazing livestock have prolonged and uninterrupted access to specific units of land throughout the grazing season/year without any periods of planned rest for the pasture (Earl and Jones, 1996; Allen *et al.*, 2011). However, this grazing management approach may lead to frequent defoliation of palatable and grazing-sensitive pasture species, particularly during peak growth periods (Teague and Dowhower, 2003; Briske *et al.*, 2008; Teague *et al.*, 2011; Norton *et al.*, 2013). In continuous stocking systems, defoliation frequencies can range from 7 to 15 days, depending on stocking rate, while rotational grazing typically involved defoliation intervals of 20 to 30 days (Gastal and Lemaire, 2015). This frequent defoliation can result in patchy or uneven grazing, as animals selectively graze more palatable and nutritious plant parts, leading to overgrazing of preferred species and under-grazing of less preferred ones (Adler *et al.*, 2001; Fuhlendorf and Engle, 2001). While this selectivity can enhance short-term animal productivity by providing higher-quality forage (Sollenberger and Vanzant, 2011), it can be detrimental to long-term pasture productivity. Frequent defoliation stresses plants, reducing their ability to regrow, especially for grazing-sensitive species, and can deplete carbohydrate reserves crucial for regrowth

(Fulkerson and Slack, 1995), leading to a decline in herbage DM production and future pasture re-growth potential (Cox *et al.*, 2017). Moreover, the structure of the sward influences animal intake patterns; swards with higher leaf-to-stem ratios allow for higher intake rates, but continuous stocking can lead to a decrease in leaf area index and an increase in steamy material, potentially reducing intake efficiency over time (Gastal and Lemaire, 2015; Parsons et al., 1988).

An alternative to traditional, low-maintenance continuous or set-stocking is rotational stocking, where grazing livestock move between three or more subunits of land such that the pasture is subjected to alternating periods of grazing and rest (no grazing) during the grazing season/year (Allen *et al.*, 2011). Grazing management systems that use intensive rotational stocking include management intensive, high intensity-low frequency, adaptive multi-paddock, holistic planned, mob and cell grazing (**CG**), among others (Di Virgilio *et al.*, 2019). These rotational grazing regimes are believed to maintain or improve productivity per hectare by allowing pastures to rest and recover between grazing periods. They can also alter pasture botanical composition, shifting species proportions, and reduce bare ground area (Badgery *et al.*, 2012, 2017). The intensity of livestock grazing (i.e., stocking rate, grazing pressure), timing of grazing and grazing season duration further influence botanical composition (Pavlů et al., 2003). Additionally, intensively managed, rotationally grazed grassland, such as adaptive multi-paddock grazing, with short grazing periods, enhances sustainability by improving soil health, carbon sequestration, and biodiversity, minimising the need for expanding cultivated areas (Teague and Kreuter, 2020). However, the majority of studies that have directly compared continuous with intensive rotational stocking methods have either been carried out in rangeland or semi-arid regions (Briske *et al.*, 2008; Gosnell *et al.*, 2020; Teague and Kreuter, 2020) The few studies conducted in a temperate climate concluded that further investigation is needed to better understand the variables affecting the responses (Amaral *et al.*, 2013; Holshof *et al.*, 2018; Hoekstra *et al.*, 2020).

The objective of this study was to compare animal performance and pasture productivity under two contrasting stocking methods, SS and CG, in a long-term, replicated experiment under temperate climatic conditions. This paper focusses on animal liveweight production, average daily gain, pasture herbage DM production, nutritional quality, and botanical composition, contributing to the broader project evaluating soil-pasture-animal interactions and sustainability dimensions (economic, social, environmental). We hypothesise that CG will enhance pasture productivity, nutritional quality and land productivity, compared to SS, due to adaptive management and rest periods. Subsequent papers will address environmental impacts, carcass quality, and animal behaviour.

Material and methods

Experimental conditions and treatments

Experimental site

The study was carried out at Rothamsted Research, North Wyke, Devon, UK (50°46'38.9"N 3°55'10.0"W, 150 m – 174 m above sea level) across four consecutive grazing seasons between 2018 and 2021. Soil type was a brownish clay loam sitting over impermeable clay soil of the Hallsworth series, in a region of high annual rainfall (average annual precipitation of 1 043 mm for the period 1991-2020; Met Office, 2025). The study area was last ploughed and reseeded in 2013 with a perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) seed mix, composed of the following perennial ryegrass varieties: AberDart (14%), AberMagic (14%), AberStar (21%), Dunlace (24%), AberEve (24%), and the white clover Aran (3%). Prior to the start of the present study, the site was managed as two separate fields which were used for sheep or cattle grazing (under continuous stocking) and forage conservation (usually silage cuts). Table 1 summarises the conditions and main characteristics of the stocking methods evaluated in this study. Conditions and characteristics are described in more detail in the following sections. Weather data (air temperature and precipitation) for the duration of the experiment was sourced from the North Wyke Farm Platform Data Portal (https://nwfp.rothamsted.ac.uk/).

Experimental design

A grazing system study was established on the 11.5-ha site at the beginning of 2018. The study was arranged as a split-block design with three replicates per treatment, where the study site was divided into three blocks (taking into account variation in elevation, exposure and slope across the site) and each block divided into two grazing enclosures (experimental spatial units) using high-tensile semi-permanent electric fencing. One grazing enclosure per block was allocated to the CG treatment and the other grazing enclosure allocated to the SS treatment (Figure 1). Grazing enclosures for the CG treatment were each 1.0 ha in size, and enclosures for the SS treatment were 1.5 ha in 2018 and 1.75 ha in 2019, 2020 and 2021.

Soil nutrient management

At the beginning of the study, the average soil indexes and pH across treatments were index 1 for P, index 1 for K, index 2 for Mg, and soil pH of 6.1 (Supplementary Table S1). During the experimental period (2018 to 2021), inorganic fertiliser inputs were the same for both treatments applied uniformly to the study area as follows: 50 kg/ha of P in the form of triple superphosphate per year (all four years) and 30 kg/ha of K in the form of muriate of potash per year (except for 2021). No N was applied in 2018 due to it being an unusually dry summer. In 2019, 2020 and 2021, a total of 100 kg N/ha in the form of Nitram (290 kg/ha of Nitram) was applied to the area per year, split across three applications which were applied in late spring, mid-summer and early autumn. No lime was applied to the area throughout the study period.

Grazing and pasture management

The CG enclosures were divided into two parallel lanes and each lane was further sub-divided into 21 equally sized 'cells' marked out by fence posts. The CG enclosures were rotationally grazed, with daily grazing areas allocated in 0.25 increments of a cell (e.g. cattle may be allocated 1.75 cells on a particular day) allowing for precise control over the grazing frequency and stocking intensity. Cattle were confined to their allocated grazing area using a front and back temporary electric fence and were moved to new grazing allocations daily at approximately 09:00h. Grazing area allocations and stocking densities were reviewed and adjusted approximately fortnightly based on a combination of predicted pasture growth rate (based on local weather forecast and GrassCheckGB data for South-West England), current herbage DM availability (as determined by rising plate meter) and estimated feed DM demand (based on percentage body weight feeding to growing/*ad libitum* feed demand, i.e., 2.5 to 3.0% body weight). The average grazing area allocated per day across the four years of the study was 0.034ha (equivalent to 1.4 cells). Target pre-grazing herbage mass ranged between 3 000 and 3 500 kg DM/ha (depending on calculated feed demand and desired rotation length) and target post-grazing herbage mass was 1 800 kg DM/ha for all rotations (all measurements to ground level). Rotation length varied from 21 to 56 days depending on herbage availability, pasture growth rate and time of year (Figure 2). Pasture covers were controlled solely through animal grazing and no cutting/topping of pasture occurred during the study in the CG enclosures. Fresh water was provided to cattle in CG enclosures via a portable 'micro-trough' (KiwiTech International Ltd, New Zealand) which was able to move with the animals as they rotated around the enclosure.

The SS enclosures were continuously stocked at a target constant stocking rate of ca. 1 400 kg liveweight/ha throughout the grazing season (spring to autumn) with no active management of sward height (i.e., a fixed number of animals were free to graze wherever they chose within the SS enclosures and no cutting/topping of pasture was carried out). The minimum average pasture cover threshold for SS enclosures during the grazing season was 2 000 kg DM/ha (as determined by rising plate meter, measured to ground level), as pasture covers below this threshold would not be able to support a stocking rate of ca. 1 400 kg liveweight/ha without impinging on cattle performance and welfare (i.e., insufficient feed available to satisfy animal growth/maintenance). If average pasture cover reached below 2 000 kg DM/ha in an SS enclosure, all cattle were removed from the enclosure to allow the pasture to rest and recover and cattle were returned as soon as available herbage mass and predicted pasture growth allowed. Removal of cattle from SS within a grazing season due to insufficient pasture cover only occurred once, with cattle requiring to be removed from all three SS enclosures for 4 weeks in April-May 2019 (Figure 2) due to lower-than-expected pasture growth, driven by meteorological conditions, which was insufficient to meet feed demand at the time. During this time, SS cattle grazed the buffer area surrounding the study enclosures with comparable herbage availability, quality and composition to that within the study enclosures (Figure 1). Fresh water was provided via conventional water toughs (concrete or plastic) which were randomly situated at a fixed location in each SS enclosure.

Animal management

Autumn-born mixed breed dairy x beef steer calves (n = 41) were purchased in spring 2018 ('cohort 1'). Breeds consisted of dairy crosses with Aberdeen angus, British Blue, Hereford, Fleckvieh, Montbelliarde and Simmental. Calves were split into six equally sized groups, balanced for breed, categorised as either native (Aberdeen angus, British Blue, Hereford) or continental (Fleckvieh, Montbelliarde and Simmental), as well as age (206 ± 30.5 d) and liveweight (257 ± 39.3 kg). The groups were then randomly allocated to treatments. Cohort 1 steers grazed their allocated treatment enclosures from April to October 2018 (year 1 of the study) and April to October 2019 (year 2 of the study), after which they were either sent directly to slaughter or housed for further fattening and slaughtered later in 2019. During these grazing periods, cattle received no mineral, energy or protein-based supplementation. Between October 2018 and April 2019, the steers were housed as a single group and over-wintered on grass silage (bale or clamp) plus concentrates (2 kg molassed sugar beet (*Beta vulgaris*), 0.5 kg wheat (*Triticum aestivum*) distillers and 100 g minerals (GP Feeds, Shropshire, UK) per animal per day) with a target growth rate of 0.8 kg/day during this housed period.

A further fifty-three autumn-born dairy x beef steer calves were purchased in spring 2020 ('cohort 2'), consisting of dairy crosses with Hereford and Fleckvieh. Calves were split into six equally sized groups, balanced for breed, age (210 ± 17.2 d) and liveweight (202 ± 41.1 kg), with groups randomly allocated to treatments. Cohort 2 steers grazed their allocated treatment enclosures from April to October 2020 (year 3 of the study) and April to October 2021 (year 4 of the study) and were housed and over-wintered on grass silage plus concentrates between October 2020 and April 2021, as per cohort 1 steers. In response to increased herbage growth in the CG enclosures, some home-bred Stabiliser calves of similar age and liveweight to the dairy x beef calves were also used during summer 2020 to maintain control of pasture covers in CG enclosures. Cattle received no energy or protein-based supplementation during the grazing period in 2020 or 2021. Cattle were offered mineral supplementation in the form of a lick bucket (Cattle Tubby, Denis Brinicombe, Devon, UK) during the grazing period of 2020 and 2021, due to blood mineral analysis of cattle from the previous year showing mild Iodine deficiency. At the end of cohort 2's second grazing season, cattle were either sent directly to slaughter or housed for further fattening and slaughtered later in 2021.

A total of 41 cattle were used in the experiment during 2018, 38 cattle during 2019, 53 cattle during 2020 and 31 cattle during 2021 (Table 2). Any animals that were not grazing in the study enclosures (i.e., animals that were surplus to the required variable or fixed stocking rates on CG and SS, respectively) grazed a buffer area surrounding the study enclosures with comparable herbage availability, quality and composition to that within the study enclosures (Figure 1).

Pasture measurements

Average herbage mass of each enclosure was estimated by measuring compressed sward height using a rising plate meter (EC20, Jenquip, New Zealand) approximately weekly during the grazing season. Compressed sward height (cm) was converted to herbage mass (kg DM/ha) using the following equation:

$$Herbage\ mass\ (kg\ DM/ha) = (compressed\ sward\ height\ (cm) \times 125) + 640$$

Herbage samples were collected approximately fortnightly during the grazing season for chemical analysis. For the SS enclosures, the herbage was cut at two-thirds the sward surface height (to represent the portion of the canopy from which the animal would be grazing) and collected at nine random locations along a W-transect then bulked together to produce a representative herbage sample (Rook et al., 2004). For the CG enclosures, the average residual sward height was measured in the previous day´s allocated grazing area then herbage from the next day's grazing area was harvested at the measured residual sward height (to represent the portion of the canopy which the animals would be consuming), with nine herbage samples randomly collected and bulked together per enclosure. Samples were subsequently frozen at -20°C, freeze-dried and ground though a 1 mm sieve (CT 293 Cyclotec, Foss, Runcorn, UK) in preparation for chemical analysis.

Neutral detergent fibre, ADF and modified ADF concentrations (g/kg DM) in herbage were determined using an ANKOM 2 000 automated fibre analyser (ANKOM Technology, Macedon, NY, USA), following Ankom methods 1, 2, and 3, respectively. Water-soluble carbohydrates (**WSC**) concentration was determined by high-performance liquid chromatography (1 260 Infinity II, Agilent Technologies, Didcot, Oxfordshire, UK) according to Johansen et al. (1996). Crude protein concentration was determined by multiplying total N concentration by the constant 6.25, where total N was quantified using a Carlo Erba NA 2 000 element analyser (CE Instruments Ltc, Wigan, UK) linked with a Sercon 20:22 isotope ratio mass spectrometer (Sercon Ltd., Crewe, UK). Ash concentration was determined by burning 1 g of dried herbage in a muffle furnace (CWF 1 100, Carbolite Gero Ltd., Hope, Derbyshire, UK) at 550°C for 4 hours, modified ADF was used to calculate metabolizable energy concentration (**ME**, MJ/kg DM) as per the agricultural and food research council (AFRC, 1993) for perennial ryegrass:

$$ME\ (MJ) = 16.2 - (0.0185 * (modified\ ADF\ (\%\ DM) \times 10))$$

Botanical composition was estimated at the beginning (April 2018) and the end (April 2022) of the experimental period through a botanical survey. Surveys were carried out at five randomly selected locations along a W-transect per experimental spatial enclosure, with repeat surveys carried out at the same locations. Using 1-m^2 quadrats, the percentage of the soil covered with perennial ryegrass, forbs, other grasses and bare ground, was estimated at each location using the Domin scale of land cover (Bullock, 2006).

Animal measurements

Liveweights of animals were collected approximately monthly during the grazing season and when animals were introduced or removed from study enclosures (i.e., at the start and end of each grazing season, when CG stocking rates were adjusted, or when animals were removed from study enclosures due to lack of herbage DM availability or during adverse weather conditions such as extreme heat or water-logged soil conditions). Average daily gain (**ADG**) was calculated as the final live weight (**LW**) minus the initial LW, divided by the total number of days grazing in the study enclosures.

Total individual LW gained per animal per hectare was calculated as:

$$LWG\ per\ ha\ (kg/ha) = \frac{\sum_{n1}^{n}(\text{Average Daily Gain} \times \text{d})}{ha}$$

Due to variation in animal weight between the first and second grazing seasons of each cohort of animals, it was not appropriate to describe stocking rates in terms of number of animals or livestock units per hectare. Therefore, stocking rate was considered as the average LW that each hectare supported during each grazing season, and was calculated as:

$$Stocking\ rate\ (kg/ha) = \frac{\sum_{n=1}^{n}(Individual\ Average\ LW \times days\ present\ in\ study\ enclosures)}{days\ grazing\ season^{1} \times ha}$$

[1]Grazing season was considered as the longest value for days of grazing for each year

Calculations

Dry matter intake (**DMI**) was estimated using the following equation (AFRC, 1993):

$$DMI\ (kg\ DM/d) = \frac{(E_{mp} \times 1.05)}{E_{mp}\,feed}$$

Where E_{mp} = Energy for maintenance and production (MJ/d) and E_{mp} *feed* = Energy for maintenance and production of a feed (MJ/kg of digestible organic matter).

E_{mp} was calculated as:

$$E_{mp}\ (MJ/d) = E_m + E_g$$

The following equations were used to calculate E_m and E_g:

$$E_m\ (MJ/d) = \left(\mathrm{C1} \times (0.53 \times (\mathrm{LW}/1.08)^{0.67}\right) + (0.0071 \times \mathrm{LW})$$

$$E_g\ (MJ/d) = (\Delta LW \times [EV_g])$$

Where E_m = Energy for maintenance, E_g = Energy for production (energy retained/lost in daily weight change, MJ/d), LW = Liveweight, ΔLW = Liveweight change (kg/d), EV_g = The energy value of tissue lost or gained (MJ/kg), C1 = correction factor (bulls = 1.15, all other = 1).

EV_g was calculated as:

$$[EV_g](MJ/kg) = \frac{C2(4.1 + 0.0332LW - 0.000009LW^2)}{(1 - C3 \times 0.1475\Delta LW)}$$

Where *C2* = 1 (castrates males, of medium mature body size) and C3 = 1 (plane of nutrition above the level of maintenance).

E_{mp} *feed* was calculated as:

$$E_{mp}feed = ME * K_{mp}$$

Where *ME* = metabolizable energy concentration of the feed (MJ/kg DM) and K_{mp} = efficiency of utilization of dietary ME for maintenance and production. The calculation of K_{mp} included a correction factor (*qm*) that was calculated for each treatment and year which depended on the modified ADF content of the feed, since the amount of modified ADF influences the utilization efficiency of that feed by the animal for growth and maintenance.

Average LW (initial LW plus half LW gain) and ADG for all the grazing season for each animal and each year were used for the DMI calculations.

Dry matter intake per hectare was estimated using the equation:

$$DMI\ per\ ha\ (kg\ DM/ha) = \frac{\sum_{n1}^{n}(\text{individual DMI} \times \text{days grazing})}{ha}$$

Daily herbage growth per study enclosure was estimated by summing the change in herbage mass measured approximately weekly during the grazing season (using a rising plate meter), adding the total DMI/ha, and then dividing by the number of grazing days for each season.

$$Growth\ Rate\ (kg\ DM/ha/day) = \frac{\sum_i(Herbage\ mass_i - Herbage\ mass_{i-1}) + DMI/ha_i}{Grazing\ days_i}$$

Statistical Analyses

The experimental unit was the steer for variables expressed on an individual animal basis (i.e. ADG and DMI per head) and the study enclosure (experimental spatial unit) for variables expressed per hectare (i.e. pasture production, pasture growth rate, herbage chemical composition, botanical composition, liveweight production, stocking rate and DMI per ha). All data were initially tested for normality and homogeneity of variance and 160 steers out of 163 were used for the analysis; three animals were removed due to inconsistent data with just one or two observations (i.e., animals that had only grazed the study enclosures for a short period of time).

Variables were analysed via generalized linear mixed model with repeated measures in time using the GLIMMIX procedure of SAS (2024). The model included the fixed effects of treatment, year, treatment by year interaction effect and the residual error for pasture production, pasture growth rate, herbage chemical composition, botanical composition, DMI per ha and LW production per ha. The model for individual DMI and ADG included the fixed effects of treatment, cohort, year, treatment by cohort(year) interaction and the residual error.

Block was treated as a random effect. Least square means were separated using Tukey-Kramer tests and significant differences were declared at $p \leq 0.05$ with tendencies toward significance declared at $0.05 < p \leq 0.10$. Normality was assessed using the UNIVARIATE procedure, and no outliers were identified. The model's (co)variance structure was selected based on the lowest Bayesian information criterion value. Year was the main time factor and was treated as a repeated measure.

Results

A summary of the F-statistics, degrees of freedom, and *p*-values for the main and interaction effects tested across all variables are presented in Supplementary Table S2 and S3. Treatment by year interactions were found for most variables, apart from ME, DM, ADF and NDF concentrations. Detailed results for each variable are provided in the subsequent sections.

Weather conditions

Average air temperature and precipitation varied across years (Figure 3) with 2020 having the highest average air temperature and the highest rainfall accumulation (10.8°C and 1 132 mm, for average air temperature and precipitation accumulated across the year, respectively). Conversely, 2021 had the lowest average air temperature (9.7 °C) and 2019 the lowest total rainfall accumulated (988 mm) across the year. The driest month (lowest rainfall) during the experiment was June 2018 with 1 mm of rainfall recorded while the wettest month (highest rainfall) was 197 mm recorded in February 2020. The month with the lowest recorded average air temperature was February 2018 (3.1 °C) and the month with the highest recorded average air temperature was July 2018 (18.0 °C).

Pasture variables

Pasture productivity

Length of grazing season for each treatment and each year, determined by the minimum herbage mass availability, differed between years (Figure 2), with a minimum of 161 and a maximum of 225 grazing days. Standing herbage mass, measured as the average standing crop in each plot with the rising plate meter, did not differ between treatments within grazing seasons (2 796 ± 67.8 and 2 644 ± 69.2 kg/ha of DM, for CG and SS respectively, p = 0.274); however, it varied between years and months with no treatment by year interaction effect (p = 0.533), or treatment by month (year) interaction effect (p = 0.226) (Figure 4).

Estimation of total herbage production per hectare showed a year by treatment interaction effect with the maximum difference between treatments in 2021, in which CG produced 3 743 kg DM/ha more than SS (Figure 5a). Estimated herbage growth rate (kg DM/ha/day) also showed a year by treatment interaction effect where the maximum difference between treatments was in 2021 when CG herbage growth rate was, on average, 20.8 kg DM/ha per day higher than for SS (p <0.0001, Figure 5b).

Chemical composition of herbage

The average chemical composition of pasture for the variables that did not show a treatment by year interaction is presented in Table 3 for CG and SS over the four years. The CG pasture had a higher metabolizable energy concentration than SS (11.2 *vs.* 11.0 ± 0.03 MJ ME/kg of digestible organic matter, respectively, p = 0.0002), lower NDF concentration, (474 *vs.* 499 ± 39.0 g/kg DM, respectively, p = 0.003) and a lower ADF concentration (248 ± 0.8 *vs.* 260 ± 1.0 g/kg DM, respectively, p < 0.0001). A year by treatment interaction effect was found for CP and WSC concentrations. Crude protein concentration increased for both treatments from 2018 to 2020 and decreased for both in 2021, and it was higher for SS than CG in 2020 and 2021 (Figure 5c). Water-soluble carbohydrates concentration increased each year for both treatments except for 2020 where it decreased for SS (Figure 5d).

Botanical composition

Botanical composition on the study enclosures varied across years and treatments (Figure 6); the cover of perennial ryegrass increased in CG treatment (from 42% to 69% ± 1.7% of cover for 2018 and 2022 respectively, p = 0.0004) and bare ground and other grasses decreased (17% to 5% ± 2.0% of bare ground and

35% to 20% ± 4.2% of other grasses, for 2018 and 2022 respectively, $p < 0.05$) while forbs and white clover remined constant (mean 4.6% ± 1.4% of cover for forbs, $p = 0.875$; mean 1.9% ± 0.68% of cover for white clover, $p = 0.514$). Conversely, in SS treatment, perennial ryegrass cover decreased (from 36% to 16% ± 4.7% of cover for 2018 and 2022 respectively, $p = 0.0055$) and other grasses increased (from 41% to 75% ± 4.2% for 2018 and 2022 respectively, p<.0001) while forbs covers did not differ between years (6% ± 0.9%, $p = 0.3$). Nonetheless, bare ground decreased in a similar extent than that of the CG treatment (from 18% to 3% ± 2.1% of cover for 2018 and 2022 respectively, $p < 0.0001$) and white clover decreased from 3% to 0% ±0.9% ($p = 0.02$).

Animal variables

Animal productivity

Average daily gain (kg/d per animal) showed a treatment by year (cohort) interaction effect as in cohort 1 steers of SS treatment had a higher ADG than CG only in their first year of production (2018); in cohort 2, SS had a higher ADG than CG in both years ($p < 0.05$, Figure 5e).

Liveweight production per hectare (kg/ha) showed a treatment by year interaction effect, with CG resulting in higher LW production per hectare than SS in three of the four years of the study (2019, 2020 and 2021), while no difference was observed in 2018 (Figure 5f). A treatment by year interaction effect was found for estimated stocking rate, increasing yearly for CG while remaining constant for SS (Figure 5g). When LW production per hectare (kg/ha) was analysed with stocking rate as a co-variable, no differences were found between treatments (582 and 580 ± 48.2 kg/ha, for CG and SS respectively, $p = 0.989$), but differences between years remained with a maximum average difference of 979 kg/ha in 2020 and a minimum of 405 kg/ha in 2021.

Dry matter intake

A treatment x year(cohort) interaction effect was found for DMI; in cohort 1 steers on SS treatment tended to show a higher DMI than CG on the first year of the growing cycle, whist in cohort 2 the SS had a higher individual DMI than CG in both years (Figure 5h). Estimated individual DMI on SS was on average 16% higher (p < 0.0001) compared with that achieved under CG. Values of DMI/ha differed between years for both treatments; however, DMI/ha was higher for CG treatment in three of the four years (Figure 5i).

Discussion

According to Allen et al. (2011) the manipulation of grazing through different stocking methods in pursuit of a specific objective is what defines different types of grazing management, and in combination with soil, plant, animal, social and economic features, defines grazing systems. While SS goes through a specific, non-variable number of animals on a specific, non-variable area of land, CG system recurs to an intensively-managed rotational system with a variable number of animals and a variable daily allocation of area. Both strategies were compared through four years of experiment with natural variable weather conditions that affected the performance of each system.

Overall, average standing herbage mass did not differ between treatments across the four-year period, but did differ between years and months. Variability between years was expected, as weather conditions (temperature and precipitation) are key drivers of herbage growth rate. In the SS treatment, variability between months was also anticipated due to the use of a fixed stocking rate and the absence of active sward height management, either by varying the stocking rate or cutting excess grass. This meant that in spring, when grass growth was high, feed supply would exceed feed demand, while in autumn, as grass growth slowed, available feed would better align with feed demand. Conversely, herbage mass in CG were expected to remain more consistent between months, given that the premise of this stocking method is to closely match estimated feed demand with feed supply by varying the stocking rate, thereby maximising forage mass utilization. However, variability in pasture cover did occur between months for CG, particularly in 2018 and 2020, which also had higher average pasture covers compared to SS. This suggests that the carrying capacity of the CG enclosures may have been underestimated during the study and that feed supply and demand could have been better matched by using higher stocking rates, especially during the 2018 and 2020 grazing seasons; however, all calves available for the study were already grazing the enclosures during these times.

Predictably, weather conditions had a large impact on herbage growth and availability during the study, with some years being more favourable than others. The year with the highest average temperature and precipitation (2020) also saw the highest herbage production per hectare and growth rate for both treatments. In contrast, the lowest herbage production for both treatments occurred in 2018, which had more variable weather conditions compared to other years, starting with an unusually cold February and a very wet March that delayed cattle turnout to grass, resulting in high pasture covers early in 2018. This was followed by a severe drought during the summer, during which cattle continued to graze the study enclosures, supported by the excess pasture accumulated earlier in 2018, without the need for supplementary forage during the drought. The impact of drought on pasture production aligns with observations by Laidlaw (2009), which indicated that drought imposed on perennial ryegrass during May and June reduced herbage growth rate, leaf extension rate, and tillering rate, underscoring the importance of soil moisture in pasture production. Additionally, it has been reported that temperature influences herbage growth rate; for example, increases from 10 to 20°C reduced the number of days between successive leaves and increased the lamina expansion rate, both of which affect herbage growth rate (Duru and Ducrocq, 2000).

Herbage production (kg DM/ha) varied between treatments, with differences increasing over the years. On average, CG produced 38% more forage during the grazing season than SS throughout the four-year study period. This superiority of CG over SS was also evident in winter, where CG exhibited a higher herbage growth rate and accumulated more herbage mass during three of the four study years (Rivero et al., 2023). This finding aligns with previous studies measuring forage quantity responses under rotational and continuous stocking. A review by Sollenberger et al (2012) found that 85% of studies comparing the two stocking methods reported higher forage quantity under rotational stocking, with differences ranging from 9% to 68%, and averaging 30%. The results of the present study are consistent with these findings. The beneficial impact of rotational stocking on herbage production is attributed to either or both greater herbage growth/accumulation and improved forage mass use efficiency (Sollenberger et al., 2012). Long-term canopy photosynthesis rates of perennial ryegrass have been reported to be higher in rotationally stocked pastures (Parsons et al, 1988), resulting in a greater proportion of young leaves in the pasture, which may support more rapid regrowth and increased herbage production compared to continuously stocked pastures. Similarly, estimated herbage growth rates were higher for CG than for SS in three of the four years of the present study.

Differences in forage nutritive value were found between years for all measured chemical components and between stocking methods for energy, NDF, ADF, and WSC, with CG pasture showing a preferential nutritive value compared to SS pasture. Similarly, a study by Bertelsen et al. (1993), involving beef cattle in continuous, 6-paddock rotational, or 11-paddock rotational systems reported lower NDF and ADF and higher CP concentrations in forage from the rotationally grazed systems compared to the continuously grazed system when analysing pre-graze pasture samples. However, according to a review by Sollenberger et al. (2012), the effects of continuous versus rotational stocking on forage nutritive value are largely inconclusive in the academic literature, with 70% of studies reporting no difference in forage nutritive value between continuously and rotationally stocked pastures. They also note that making comparisons between different studies is difficult due to inconsistencies in sample collection methods and species diversity.

The difference in forage nutritive value between CG and SS observed in the present study is likely explained, at least in part, by the changes in botanical composition during the study. In SS, the cover of sown productive species (namely perennial ryegrass and white clover) decreased, while forbs and other grasses (i.e., invasion of unsown 'weed' species of poorer nutritive value) increased. In contrast, CG showed an increase of 27 percentage points in perennial ryegrass cover over the years, while white clover remained constant in the pasture. The limited body of literature on botanical composition under different stocking methods suggests that, while stocking method influences botanical composition and plant species persistence, numerous other factors also play a role, making it difficult to compare and generalise results across studies (Sollenberger et al., 2012). The change in botanical composition observed in the present study likely results from the combined effects of stocking method and stocking rate (grazing intensity), as these factors differed between treatments. At higher stocking rates, animals have less opportunity to select what they graze, leading to a greater persistence of grazing-tolerant plant species (e.g., grasses) compared to less grazing-tolerant species (e.g., clover). While a substantial increase in the cover of perennial ryegrass was observed between 2018 and 2022 for CG, the perennial ryegrass cover of SS decreased by 20 percentage points, suggesting that the CG method is more favourable for maintaining and enhancing the proportion of sown species within the sward over time compared to SS. If sown species persist longer in the pasture there is less necessity for frequent re-seeding to maintain pasture productivity, thereby lowering input costs associated with purchasing seed and minimising negative soil and environmental impacts associated with soil tillage (especially if soil is ploughed). The change in botanical composition may also have contributed to the difference in pasture production observed between stocking methods, due to the changes in perennial ryegrass cover, which is a more productive grass species.

Despite the greater productivity, nutritive value, and botanical composition of pasture under CG stocking, individual ADG was higher in the SS treatment, with an overall average difference of 0.170 kg/d per animal. According to Sollenberger and Vanzant (2011), the nutritive value of forage sets the upper limit for ADG, while forage quantity determines the proportion of achievable ADG. Forage nutritive value also influences the slope of the regression between ADG and stocking rate and establishes the forage mass at which ADG plateaus. When there are no constraints on forage quantity (i.e., under continuous stocking at low to moderate rates), animals can achieve the upper limit of ADG dictated by forage nutritive value. However, if forage quantity is restricted beyond the point at which ADG plateaus for a given level of nutritive value, the achievable proportion of ADG will decline relative to the level of forage restriction. Although the nutritive value of the CG pasture was more favourable and could theoretically support a higher ADG than SS pasture, confining animals to a predefined grazing area per day (calculated based on an estimated intake of 2.5-3% body weight) limited the available forage per animal per day to a level where maximal ADG was not achievable. This is reflected in the estimated individual DMI results, with estimated DMI being overall 1 kg less per day for CG compared to SS across the four years of the study. It is however acknowledged that while these DMI estimates provide useful comparative insights across treatments and years, caution is warranted when interpreting the absolute values as the method used in this study to estimate DMI does not consider pasture structural characteristics such as sward height, herbage mass, leaf- to-stem ratio, and proportion of senescence material, which are known to influence bite size, grazing time, and overall ingestive behaviour, affecting actual DMI (Forbes, 1988). More precise methods are available (e.g. observation-based, sward-based, or marker-based techniques) to more accurately determine DMI, however their application was impractical in the present study due to the large number of animals involved (n = 163) and the spatial scale of the experimental enclosures. Estimating

DMI based on energy requirements is considered the most practical method for large-scale experiments involving large numbers of animals or many treatments (Hodgson, 2004). Accordingly, this method was adopted in the present study.

In addition to the effects of forage nutritive value and quantity on ADG potential, the magnitude of diet selection opportunity is also believed to contribute to the observed lower ADG on rotationally versus continuously stocked pastures. For example, Badgery et al. (2012, 2017), working with lamb grazing systems, showed that continuous stocking allowed the selection of more palatable species, resulting in a higher-quality diet; while intensive rotational grazing systems encourage animals to consume all the forage allocated to them within a defined time period, forcing them to consume lower nutritive value pasture species (e.g., unsown 'weed' species) or plant parts (e.g., stemmy material). It is likely that SS stocking allowed animals to select a relatively higher quality diet, leading to higher individual intake and, subsequently, a higher individual ADG. Dietary selection behaviour may have also contributed to changes in botanical composition, where the proportions of perennial ryegrass and white clover declined in the SS pasture, possibly due to animals selectively grazing these palatable and higher nutritive value species, resulting in overgrazing and reduced persistence of these species. In contrast, the opportunity for diet selectivity was much lower in CG, preventing overgrazing of particular plant species.

Conversely, animal LW production per hectare was similar between stocking methods for 2018 and higher in the CG treatment for the remaining three years of the study. Based on the overall mean LW production per hectare per year (687 kg for CG; 476 kg for SS), the estimated land area required to produce 1 000 kg of LW annually would be 1.46 ha under the CG treatment compared to 2.07 ha under the SS treatment. This represents a ~30% reduction in the land area required for equivalent total LW production, signifying improved land use efficiency under CG management and opening up opportunities for other land uses such as green energy, biodiversity conservation, and carbon sequestration. While the findings of this study demonstrate a substantial increase in system productivity and land use efficiency under controlled conditions, caution is warranted in extrapolating these outcomes beyond the context of this study. The scalability of CG as a routine management practice and the long-term stability of these productivity gains may be constrained by variability in climate, soil type, pasture composition, labour and resource availability, and infrastructure costs, among other factors. Equally, although increased per-hectare productivity theoretically frees up land for alternative uses such as biodiversity conservation or carbon sequestration, the viability and value of these alternative uses are dependent on site-specific ecological and socioeconomic context. Quantifying these benefits and trade-offs more deeply across a wider range of environments and contexts is a relevant area for future research.

It is important to emphasise that many advantages of the CG treatment were cumulative over time, as evidenced by the treatment-by-year interaction effects observed for many varaibles presented in this paper. This trend underscores the importance and value of long-term, replicated experiments conducted over several years for drawing robust conclusions about stocking methods and grazing management strategies, as recently highlighted by Rouquette et al (2023). While short-term studies may show certain trends, they might not accurately reflect the long-term impacts of specific stocking methods on factors such as forage productivity and nutritive value, pasture botanical composition, carrying capacity, and soil health attributes. The value of long-term experiments has been widely demonstrated in Rothamsted Research field experiments, where, for example, changes in soil organic matter and acidity required several years of evaluation (Poulton and Johnston, 2021). Only through long-term, replicated experiments can the long-term viability and impact of differing stocking methods and grazing management strategies on various ecological, economic, and social factors be fully evaluated.

Conclusion

A 4-year study comparing SS and CG demonstrated that CG achieved higher LW production per hectare, driven by increased stocking rates supported by greater herbage DM production and maintained herbage quality. These outcomes enhanced land-use efficiency by maximising livestock output on existing pasture. The 4-year duration was crucial for capturing annual and seasonal variations in pasture productivity, botanical composition, DMI, and ADG, highlighting the importance of long-term evaluations for understanding grazing system dynamics.

Ethics approval

This study was approved by the Ethical Review Committee of Rothamsted Research (North Wyke, United Kingdom) under Project License number P592D2677 and was conducted in accordance with the Animal Scientific Procedures Act (1986) Amendment Regulations (2012).

Data and model availability statement

The datasets were deposited in a repository and are available at DOI: https://doi.org/10.23637/rothamsted.991v9. Information can be made available from the authors upon request.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

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Declaration of interest

All authors declare that they have no real or potential conflict of interest that could affect their ability to objectively present the data of this research.

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Table 1. Summary of environmental conditions and key management characteristics of the two stocking methods to manage dairy × beef cattle investigated in this study.

Condition/Characteristic	Treatment	
	Cell grazing	Set-stocking
Climatic region	Temperate oceanic (South-West UK)	
Soil type	Clay loam (Hallsworth series)	

Grassland type	Permanent pasture (>5 years old)	
Sown pasture species	Perennial ryegrass, white clover	
Grazing season (annual)	April (Spring) to October (Autumn)	
Total annual Inorganic N fertiliser	100 kg N ha/year[1]	
Total annual Inorganic P fertiliser	50 kg P ha/year	
Total annual Inorganic K fertiliser	30 kg K ha/year[2]	
Stocking method	Rotational	Continuous
Stocking rate (within grazing season)	Variable	Fixed
Study spatial enclosure size	1.0 ha	1.5 ha / 1.75 ha
Average daily grazing area allocation	0.034 ha	1.5 ha / 1.75 ha
Minimum / post-grazing herbage mass	1800 kg DM/ha	2000 kg DM/ha

[1] Except in 2018 where no N fertilizer was applied; [2] Except in 2021 where no K fertilizer was applied.

Table 2. Number of dairy × beef cattle used per stocking method (cell grazing and set-stocking) per year (2018 to 2021).

Cohort	Year	Treatment	
		Cell Grazing	Set-stocking
1	2018	20	21
	2019	17	21
2	2020	29	24
	2021	18	13

Table 3. Effect of stocking method, cell grazing (CG) or set-stocking (SS), on herbage chemical composition, of pasture grazed by dairy × beef cattle, across four grazing seasons (2018 to 2021).

	Treatment		Year				SEM	p-value		
Variable	CG	SS	2018	2019	2020	2021		T	Y	T × Y
ME (MJ/kg DOM)	11.2^{a}	11.0^{b}	10.5^{a}	11.4^{b}	11.4^{b}	11.2^{b}	0.03	0.0002	<.0001	0.707
DM (g/kg)	262	271	338^{a}	257^{b}	235^{c}	240^{bc}	05.1	0.1287	<.0001	0.861
NDF (g/kg DM)	474^{b}	499^{a}	544^{a}	471^{b}	474^{b}	458^{b}	39.0	0.003	<.0001	0.149
ADF (g/kg DM)	248^{b}	260^{a}	273^{a}	246^{b}	242^{b}	255^{b}	13.0	<.0001	<.0001	0.658

[a,b] Values within a row with different superscripts differ significantly between treatments or between years.

ME, metabolizable energy; DOM, digestible organic matter; T, treatment; Y, Year; T × Y, Treatment by year interaction effect.

Figure captions

Figure 1. Satellite view of the experimental area with three grazing enclosures (experimental spatial units) per stocking method (treatment), grazed by dairy × beef cattle. Solid lines mark the perimeter of the grazing enclosures using high-tensile semi-permanent electric fencing. Dotted lines in the cell grazing enclosure represent the use of temporary elasticated electric fencing to confine cattle to their allocated daily grazing area; arrows denote the direction of rotation within the cell grazing enclosures. Dashed lines in the set-stocking enclosures mark where a temporary polywire electric fence was situated in 2018 to reduce the size of the enclosure to 1.5 ha. Source: Google Maps (2025) accessed 11/06/2025.

Figure 2. Timeline of the study showing when dairy × beef cattle grazing began and ended for each stocking method (cell grazing and set-stocking) each year (2018 to 2021). The timeline for cell grazing is further broken down into the average duration of each grazing rotation within each grazing season (year).

Rotn, rotation number.

*Average pasture cover reached below the threshold of 2 000 kg DM/ha; therefore, cattle were temporarily removed from the set-stocking enclosures to allow pasture recovery.

Figure 3. Monthly recorded (2018-2021) and long-term (1991-2000) average temperatures and accumulated precipitation recorded at the met station near the dairy × beef cattle grazing study.

*Recorded data (2018-2021) obtained from North Wyke Farm Platform data portal (https://nwfp.rothamsted.ac.uk); Long-term average data (1991-2000) obtained from Met Office (2025). W, winter; SP, spring; SU, summer; AU, autumn. Letters J to D within each year in the x-axis represent the months (January to December, respectively).

Figure 4. Standing herbage mass estimated as the average standing crop using a rising plate meter for an improved permanent pasture (sown with perennial ryegrass and white clover) grazed under a cell grazing (CG) and a set-stocking (SS) method, by dairy × beef cattle, during the grazing season (April to November) of 2018, 2019, 2020 and 2021.

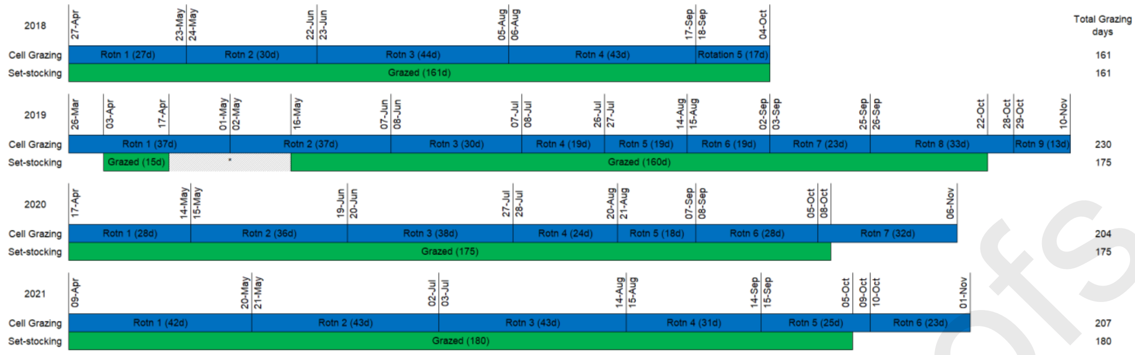
SP, spring; SU, summer; AU, autumn. Letters A to N within each year in the x-axis represent the months (April to November, respectively).

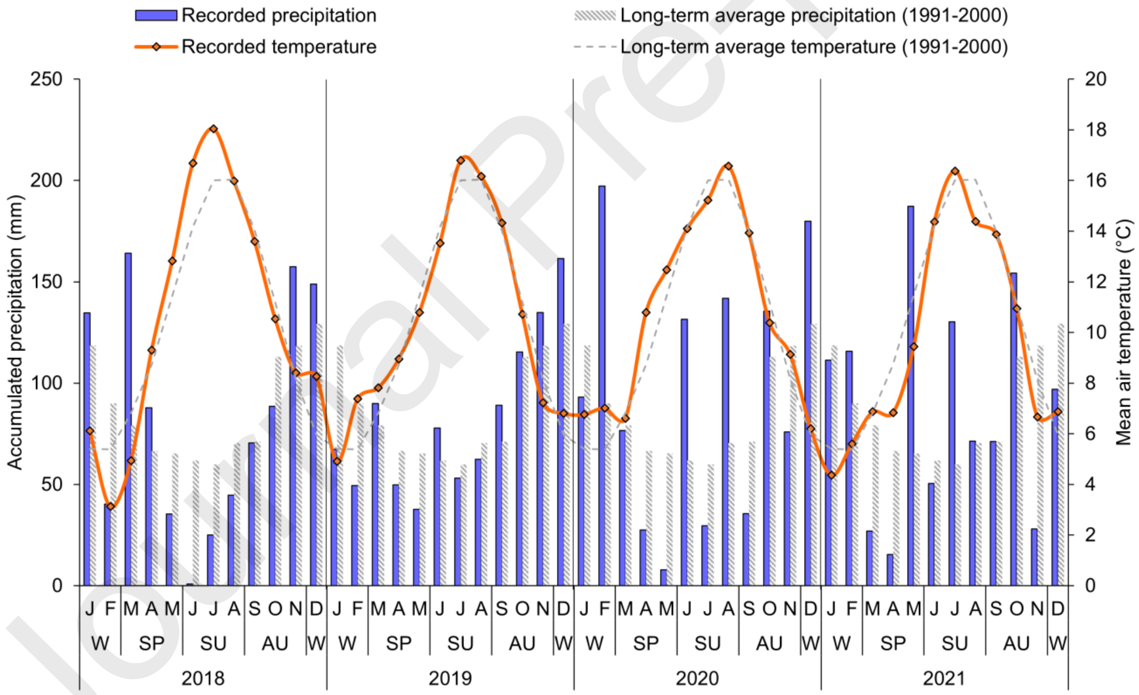
Figure 5. Effect of stocking method (cell grazing, CG, or set-stocking, SS) and year (2018 to 2021) on pasture and animal (dairy × beef cattle) responses: (a) pasture production; (b) pasture growth rate; (c) pasture CP concentration; (d) pasture water-soluble carbohydrates concentration; (e) animal average daily gain; (f) total liveweight (LW) production per hectare; (g) animal stocking rate; (h) estimated DM intake (DMI) per animal; (i) estimated DMI per hectare.

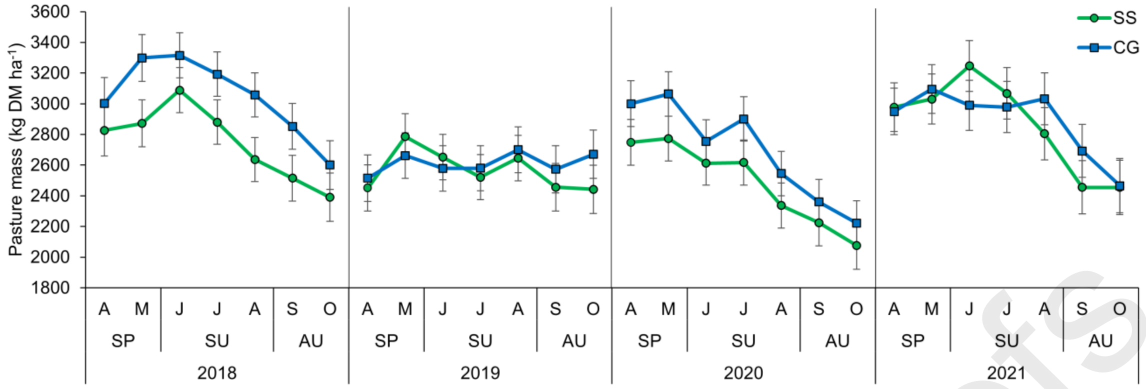
[a,b]Different letters indicate significant differences among treatment × year least square means (p<0.05).

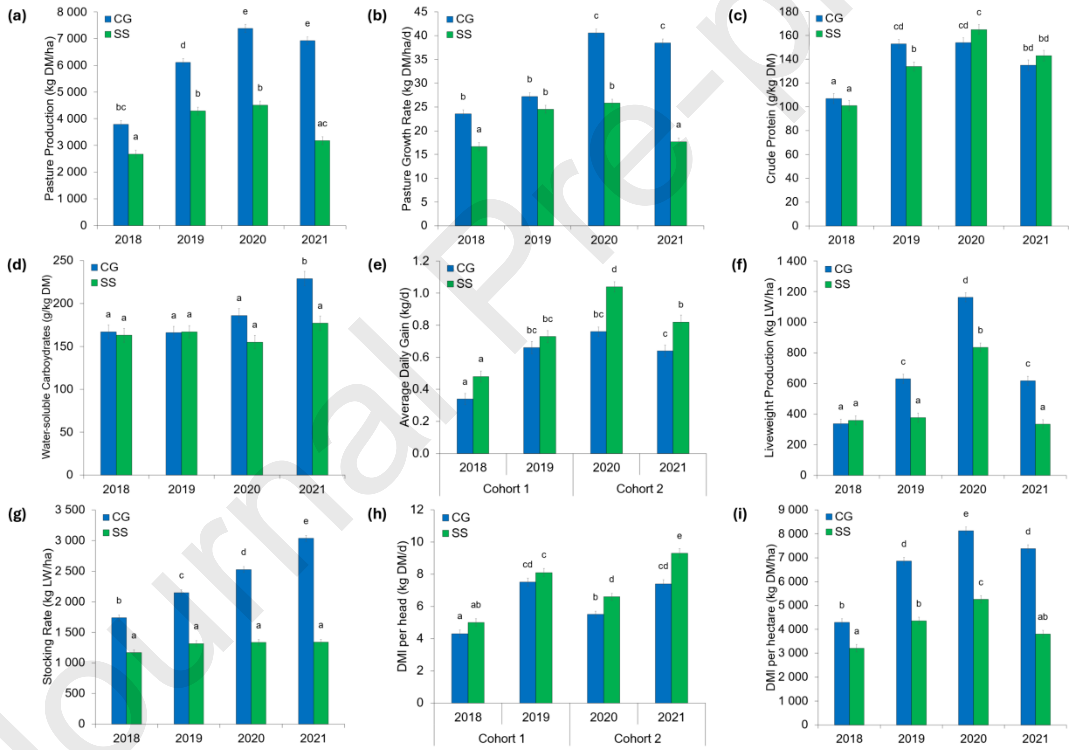
Figure 6. Evolution of the principal botanical groups in an improved permanent pasture (sown with perennial ryegrass and white clover) grazed by dairy × beef cattle under cell grazing (CG) and set-stocking (SS) methods, at the beginning (April 2018) and the end (April 2022) of the experimental period.

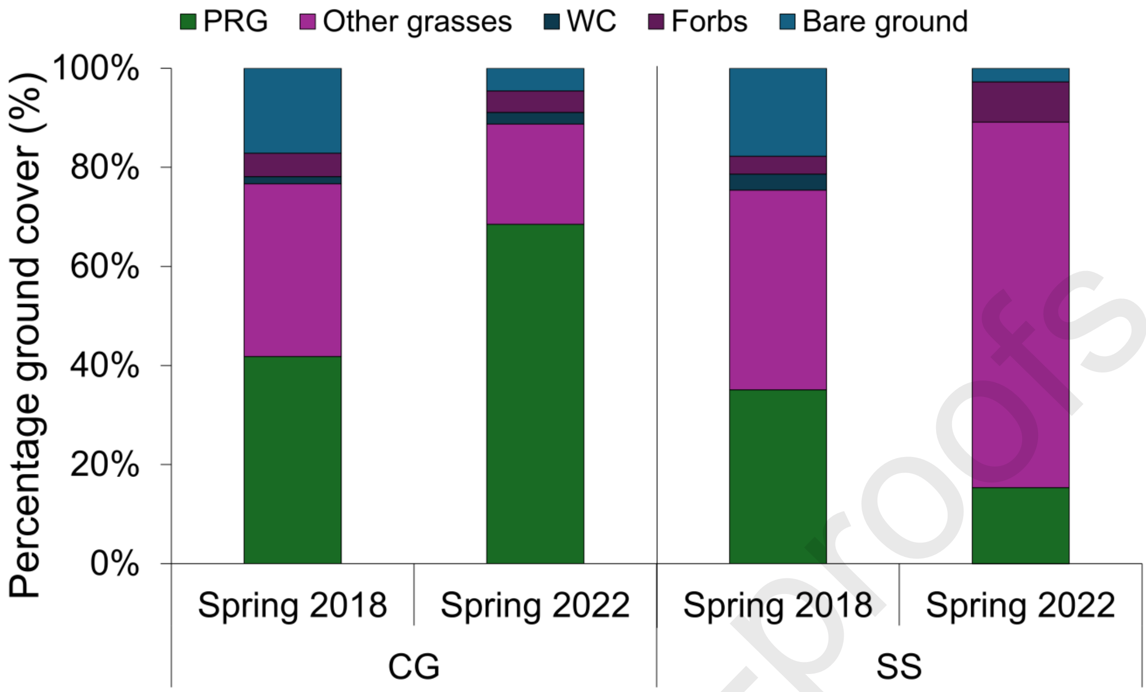
PRG, perennial ryegrass, WC, white clover.


2018
27-Apr
23-May
24-May
22-Jun
23-Jun
05-Aug
06-Aug
17-Sep
18-Sep
04-Oct
Total Grazing days
Cell Grazing
Rotn 1 (27d)
Rotn 2 (30d)
Rotn 3 (44d)
Rotn 4 (43d)
Rotation 5 (17d)
161
Set-stocking
Grazed (161d)
161
2019
26-Mar
03-Apr
17-Apr
01-May
02-May
16-May
07-Jun
08-Jun
07-Jul
08-Jul
26-Jul
27-Jul
14-Aug
15-Aug
02-Sep
03-Sep
25-Sep
26-Sep
22-Oct
28-Oct
29-Oct
10-Nov
Cell Grazing
Rotn 1 (37d)
Rotn 2 (37d)
Rotn 3 (30d)
Rotn 4 (19d)
Rotn 5 (19d)
Rotn 6 (19d)
Rotn 7 (23d)
Rotn 8 (33d)
Rotn 9 (13d)
230
Set-stocking
Grazed (15d)
*
Grazed (160d)
175
2020
17-Apr
14-May
15-May
19-Jun
20-Jun
27-Jul
28-Jul
20-Aug
21-Aug
07-Sep
08-Sep
05-Oct
08-Oct
06-Nov
Cell Grazing
Rotn 1 (28d)
Rotn 2 (36d)
Rotn 3 (38d)
Rotn 4 (24d)
Rotn 5 (18d)
Rotn 6 (28d)
Rotn 7 (32d)
204
Set-stocking
Grazed (175)
175
2021
09-Apr
20-May
21-May
02-Jul
03-Jul
14-Aug
15-Aug
14-Sep
15-Sep
05-Oct
09-Oct
10-Oct
01-Nov
Cell Grazing
Rotn 1 (42d)
Rotn 2 (43d)
Rotn 3 (43d)
Rotn 4 (31d)
Rotn 5 (25d)
Rotn 6 (23d)
207
Set-stocking
Grazed (180)
180


Recorded precipitation
Recorded temperature
Long-term average precipitation (1991-2000)
Long-term average temperature (1991-2000)
Accumulated precipitation (mm)
Mean air temperature (°C)
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
20
J F M A M J J A S O N D
W SP SU AU W
2018
2019
2020
2021


Pasture mass (kg DM ha-1)
SS
CG
A M J J A S O
SP SU AU
2018
2019
2020
2021


(a)
Pasture Production (kg DM/ha)
CG
SS
(b)
Pasture Growth Rate (kg DM/ha/d)
(c)
Crude Protein (g/kg DM)
(d)
Water-soluble Carbohydrates (g/kg DM)
(e)
Average Daily Gain (kg/d)
Cohort 1
Cohort 2
(f)
Liveweight Production (kg LW/ha)
(g)
Stocking Rate (kg LW/ha)
(h)
DMI per head (kg DM/d)
(i)
DMI per hectare (kg DM/ha)
2018
2019
2020
2021


PRG
Other grasses
WC
Forbs
Bare ground
Percentage ground cover (%)
100%
80%
60%
40%
20%
0%
Spring 2018
Spring 2022
Spring 2018
Spring 2022
CG
SS