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Nitrogen offset potential in a multiyear farmlet-scale study: Milk and herbage production from grazed perennial ryegrass–white clover swards

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ABSTRACT

The objective of this study was to quantify the farm gate nitrogen (N) offset potential of perennial ryegrass (*Lolium perenne* L.; PRG) white clover (*Trifolium repens* L.; WC) swards by comparing the herbage and milk production from dairy farmlets that were simulations of full farming systems. A study was established where 120 cows were randomly assigned to 4 farmlets of 10.9 ha (stocking rate: 2.75 cow/ha), composed of 20 paddocks each. Cows were fed 526 kg of DM of concentrate on average each year. The 4 grazing treatments were PRG-only at 150 or 250 kg of N/ha and PRG-WC at 150 or 250 kg of N/ha. Cows remained in their treatment group for an entire grazing season and were re-randomized as they calved across treatments each year. As cows calved in the spring as standard practice in Ireland, they were rotationally grazed from early February both day and night (weather permitting) to mid-November, to a target postgrazing sward height of 4.0 cm. Mean sward WC content was 18.1% and 15.4% for the 150 and 250 kg of N/ha PRG-WC treatments, respectively over the 3-yr period. When WC was included, lowering the N rate did not reduce pregrazing yield, pregrazing height, or herbage removed, but those factors decreased significantly when WC was absent. Total annual herbage DM production was 13,771, 15,242, 14,721, and 15,667 kg of DM/ha for PRG-only swards receiving 150 or 250 kg of N/ha and PRG-WC swards receiving 150 or 250 kg of N/ha, respectively. In addition, when WC was present, compressed postgrazing sward heights were lower (4.10 vs. 4.21 cm) and herbage allowance (approximately 17 kg/cow feed allocation per cow per day) higher than the high-N control (+ 0.7 kg of DM/cow per day). There

was a significant increase in milk production, both per cow and per hectare, when WC was included in PRG swards. Over the 3-yr study, cows grazing PRG-WC had greater milk (+304 kg) and milk solids (+31 kg of fat + protein) yields than cows grazing PRG-only swards. This significant increase in milk production suggests that the inclusion of WC in grazing systems can be effectively used to increase milk production per cow and per hectare and help offset nitrogen use. This result shows the potential to increase farm gate N use efficiency and reduce the N surplus compared with PRG-dominant sward grazing systems receiving 250 kg of N/ha, without negatively affecting milk solids yield or herbage production, thus increasing farm profit by €478/ha.

Key words: perennial ryegrass, white clover, milk production, nitrogen use efficiency

INTRODUCTION

In grass-based systems, the desire to reduce costs and environmental impact of inorganic nitrogen (N) use (Carran and Clough, 1995) and to increase farm gate N use efficiency (NUE), has led to renewed interest in the incorporation of legumes, and white clover (*Trifolium repens* L.; WC) in particular, in perennial ryegrass (*Lolium perenne* L.; PRG)-based production systems (Lüscher et al., 2014). Perennial ryegrass-based grazing systems are highly efficient and low cost but are ultimately dependent on high N fertilizer levels (>200 kg of N/ha) to achieve high levels of herbage production (Enriquez-Hidalgo et al., 2016). White clover is the predominant legume incorporated in swards in temperate regions (Rochon et al., 2004) and is a valuable natural resource that can increase herbage and animal production (Enriquez-Hidalgo et al., 2016; Egan et al., 2017; McClearn et al., 2019). White clover is able to biologically fix atmospheric N into a plant-usable form (i.e., nitrate) to facilitate PRG production (Crush, 1987). White clover is a nutritionally superior feed than PRG

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(McAuliffe et al., 2022; Egan et al., 2017; Dineen et al., 2018), and it promotes higher DMI due to its lower NDF levels, which can lead to higher milk production per cow (Ribeiro Filho et al., 2005; McClearn et al., 2020a). To avail these potential production benefits, it has been hypothesized that WC needs to be maintained within the sward at a minimum rate of 20% (Andrews et al., 2007). However, further investigation is required to quantify the capability of WC to offset N fertilizer inputs in intensive grazing systems.

There is increasing pressure for agricultural production to be achieved in a more sustainable manner (Hennessy et al., 2020). The Irish Government has recently announced a greenhouse gas (GHG) emissions ceiling for agriculture, which requires a 25% reduction in agricultural GHG by 2030 compared with 2018 levels (Government of Ireland, 2022). New Zealand has also committed to obtaining a net-zero target for their nitrous oxide and carbon dioxide emissions from agriculture by 2050 (Ministry for the Environment, 2016). One of the main avenues to achieve these emission reductions will be to reduce N fertilizer use, while avoiding any performance penalties, if possible. McClearn et al. (2019) evaluated milk production per cow and per hectare of spring-calving dairy cows grazing PRG-only and PRG-WC swards receiving 250 kg of N/ha and observed an increase in milk and herbage production from PRG-WC swards. However, a detailed analysis of the swards in that study observed a significant decrease in WC persistency, due in part to the high N input of 250 kg of N/ha these swards received (Murray et al., 2022). Egan et al. (2017) compared a PRG-only sward receiving 250 kg of N/ha with PRG-WC swards receiving 150 or 250 kg of N/ha and maintained an average sward WC content over 2 yr of 26.6% and 22.5%, respectively. Egan et al. (2017) observed similar herbage production for the PRG-WC treatment receiving 150 kg of N/ha and the PRG-only treatment receiving 250 kg of N/ha and increased milk production from the PRG-WC swards highlighting the potential of WC to facilitate a reduction in N fertilizer use without reducing herbage or milk production. However, Egan et al. (2017) made no comparison within their study to a low-N fertilizer PRG-only treatment and its effect on herbage and milk production. In the current study, a PRG-only treatment receiving 150 kg of N/ha was included, to make direct comparisons between sward type and fertilizer rate in terms of milk and herbage production, in addition to NUE and N surplus.

Consequently, the objective of this study was to quantify the extent to which a PRG-WC sward could be relied upon to maintain herbage and milk production over several years, within a sward that had previously contained high a WC content that had declined

when fertilizer N rate was reduced. The hypothesis was that herbage production and milk production would reduce when inorganic N fertilizer was lowered but that this reduction could be reliably offset by the inclusion of WC in the sward. Therefore, the current study investigated herbage and milk production over 3 full grazing seasons on PRG-only and PRG-WC swards at 2 fertilizer rates (150 and 250 kg of N/ha), while simultaneously monitoring sward WC contents.

MATERIALS AND METHODS

Experimental Site and Design

The experiment was conducted under the approval of the Health Products and Regulatory Authority (Dublin, Ireland) through the project authorization AE19132/P076. The experiment was established at Clonakilty Agricultural College, Clonakilty, Co. Cork, Ireland (51°63' N, 08°85' E; 25–70 m above sea level), from February 2019 to November 2021. The experiment was a 2 × 2 factorial design of 2 sward types at 2 fertilizer rates giving 4 separate grazing treatments: PRG-only swards receiving 150 kg of N/ha (**GO-150**) or 250 kg of N/ha (**GO-250**) and PRG-WC swards receiving 150 kg of N/ha (**GC-150**) or 250 kg of N/ha (**GC-250**). The total grazing area used was 43.6 ha, of which 75% was reseeded in 2012 and the remaining 25% in 2013. In keeping with a full farm system approach, swards were maintained in similar good condition by reseeding as necessary. This resulted in 20%, 15%, and 5% of the area being reseeded in 2019, 2020, and 2021, respectively. Each treatment was randomly assigned to a separate farmlet of 10.9 ha subdivided into 20 paddocks. The farmlets were balanced for location, topography, soil type, and sward age, and each carried 30 cows at a stocking rate (**SR**) of 2.75 cow/ha. Four breeds or crossbreeds were used: Holstein-Friesian (**HF**), Jersey × HF, Norwegian Red × (Jersey × HF), and HF × (Norwegian Red × [Jersey × HF]), equally distributed across the 4 farmlets and balanced for parity, calving date, pre-experimental milk yield (mean d 7 and 8 milk yield postcalving), and economic breeding index within each breed. Cows had a mean calving date of February 8 and an average lactation length of 284 d and were on a silage-only diet over the winter dry period (December and January). Cows remained in their treatment group for an entire grazing season and were re-randomized across treatments each year to have cows in treatments for early February and to allow for equal groups each year. Therefore, there is no carryover effect between years for treatments, as each grazing year accounts for variability among cows for milk production.

Grazing Management

As cows calved in the spring, they were rotationally grazed from early February both day and night (weather permitting) to mid-November. Cows were fed 4 kg/d of concentrate postcalving, which was gradually reduced to a minimum of 1 kg/d as herbage growth met demand, typically in mid-April.

Nitrogen fertilizer applications were similar for all treatments in late January, mid-March, and April (Table 1). Thereafter, the 150 kg of N/ha treatments received 40% of the 250 kg of N/ha treatment rate for each subsequent rotation and received 50% for the final rotation. If paddocks were selected to be closed for first-cut silage, they received an elevated level of N of 50 kg of N/ha and 112 kg of N/ha for the 150 kg of N/ha and 250 kg of N/ha treatments, respectively, after the preceding grazing. Based on yearly soil tests, inorganic phosphorus (P) and potassium (K) were applied across all swards, averaging 7 kg of P/ha per year and 29 kg of K/ha per year. Sulfur (S) was also applied during the main growing season (mean 16 kg of S/ha per year). Actual N fertilizer applied was 152, 250, 152, and 250 kg of N/ha for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively.

Each farmlet was managed independently to achieve the best performance from the herbage grown. Each farmlet was walked weekly to monitor average farm cover using the online application PastureBase Ireland (PBI; Hanrahan et al., 2017), which was the main decision support tool used to manage grazing. When herbage surplus to demand was identified for treatments through PBI, they were removed in the form of baled silage. If a feed deficit (growth less than demand) occurred in an individual treatment, then cows were supplemented with conserved silage produced from within that treatment. If a feed deficit occurred across all treatments, then all treatments were supplemented with concentrate. On average, 526 kg of DM concentrate was fed per year per cow across all treatments.

Target pregrazing herbage yield (**PrGHY**) was calculated separately for each treatment using the formula as found in the Teagasc Dairy Manual:

$$\text{Target PrGHY} = (\text{stocking rate on grazing platform} \\ \times \text{ideal rotation length} \times \text{daily pasture allowance per} \\ \text{cow}) + \text{residual pasture mass},$$

where ideal rotation length during the main grazing season (April to July) = 21 d and daily pasture allowance (>4.0 cm) = 17 to 18 kg of DM/cow per day (O'Donovan and McEvoy, 2016). Residency time within paddocks was dictated by a target postgrazing sward

Table 1. Nitrogen fertilizer application strategy

Date and rotation	Treatment	
	250 kg of N/ha (kg)	150 kg of N/ha (kg)
Mid-late January	28	28
Mid March	32	28
April 15 (second rotation)	30	24
May 6 (third rotation)	30	15
May 27 (fourth rotation)	20	8
June 17 (fifth rotation)	20	8
July 8 (sixth rotation)	20	8
July 29 (seventh rotation)	20	8
August 19 (eighth rotation)	20	8
Mid September	30	15
Total	250	150

height (**PoGSH**), measured using a rising plate meter (Jenquip, New Zealand), of 3.5 to 4.0 cm for the first and last grazing rotation and 4.0 to 4.5 cm during the main grazing season. When this target PoGSH was reached, cows were moved to the next paddock. In times of inclement grazing conditions, the target PoGSH may not have been reached; nonetheless, PoGSH was always below 5.0 cm.

Herbage Measurements

The PrGHY was determined twice weekly by harvesting 2 strips (approximately 10 m × 1.2 m) to a postheight of 4.0 cm using an Etesia mower (Etesia UK Ltd., Warwick, UK). These were weighed, and a 100-g subsample from each strip was dried at 90°C for 16 h in a forced-air convection oven (Parsons Lane, Hope Valley, UK) to determine DM content. A bulked herbage subsample from the 2 harvested strips was frozen, freeze-dried, bowl chopped, and milled through a 1-mm screen using a Cyclotech 1093 Sample Mill (Foss, DK-3400 Hillerød, Denmark). These samples were further combined into bulk samples by treatment by fortnight across the year and analyzed for DM content, ash content, ADF, NDF (Van Soest, 1963), CP (Association of Official Analytical Chemists, 1990), and organic matter digestibility (**OMD**; Garry et al., 2018). Ten sward heights were taken before and after each strip of herbage was harvested, using a rising platometer (Jenquip, Feilding, New Zealand). This was used to calculate sward density as

$$\text{sward density} = \text{PrGHY} / (\text{precutting height} \\ - \text{postcutting height}) \text{ as kg of DM/cm per ha.}$$

Pregrazing sward height (**PrGSH**) and PoGSH were measured daily across whole paddocks using a rising plate meter (Jenquip) at 30 and 50 vertical drops in the

sward respectively. Pregrazing herbage yield above 4.0 cm was calculated using sward density according to the following equation (Delaby et al., 1998):

$$\text{Pregrazing herbage yield} > 4.0 \text{ cm} = (\text{PrGSH} - 4 \text{ cm}) \\ \times \text{sward density (kg of DM/ha)}.$$

Herbage removed was calculated as follows:

$$\text{herbage removed} = (\text{PrGSH} - \text{PoGSH}) \\ \times \text{sward density (kg of DM/ha)}.$$

Daily herbage allowance and daily herbage removed were then calculated based on the PrGHY and herbage removed, respectively, and the number of cows and residency time within each paddock.

All herbage production was recorded and calculated using the PBI application. Total annual herbage production per paddock was subdivided into either grazed or silage production. Silage yields were measured by quadrat cuts using Gardena hand shears (Accu 60; Gardena International GmbH, Ulm, Germany) and sward WC content was not measured from paddocks when silage was harvested.

White Clover Content

Sward WC content was measured before each grazing by cutting 15 random grab samples to 4.0 cm with a Gardena hand shears across the paddock. This was mixed and two 70-g cut samples were weighed, separated into PRG and WC, and dried at 90°C for 16 h to determine proportions on a DM basis.

Animal Production Measurements

Cows were milked twice daily for the full lactation at approximately 0700 and 1530 h. Milk yield (kg) was recorded daily (Dairymaster, Causeway, Co. Kerry, Ireland) and milk composition (fat, protein, and lactose) weekly by taking milk samples for each individual cow from a consecutive p.m. and a.m. milking and testing using infrared spectrophotometry (Milkoscan 203 [DK-3400], Foss Electric, Hillerød, Denmark). Milk solids (MSo; kg of fat + protein) per cow were calculated from these measurements. Cows were weighed fortnightly during lactation upon departure from the milking parlor using electronic weighing scales, (Tru-Test Ltd., Auckland, New Zealand). Body condition score was simultaneously recorded fortnightly by the same trained individual throughout the lactation on a scale of 1 to 5 in increments of 0.25 (where 1 = emaciated, 5 = extremely fat; Edmonson et al., 1989).

Milk, fat, protein, lactose, and MSo yield per hectare were calculated by determining the total milk and MSo production from each paddock within each treatment and dividing by the area of the paddock to give the yield per ha as outlined by McCarthy et al. (2013). Similarly, cow grazing days (GD) per hectare was determined for each paddock by calculating the total number of cow GD in each paddock and dividing by the area of the paddock. Also, effective SR by system was obtained by dividing GD per hectare by the grazing season length of 250 d. Silage supplement-corrected SR was calculated by subtracting the silage supplemented, converted to GD (16 kg equivalent to 1 GD) from the GD per hectare and then dividing the adjusted GD per hectare by the grazing season length of 250 d.

Nitrogen use efficiency and N surplus were estimated by entering the production data (N fertilizer spread, concentrate fed, silage imported [due to winter feed deficits] and milk protein yield/cow) into an N balance model (Ryan et al., 2011), similar to Hennessey et al. (2019). The same level of concentrate was fed to all treatments and was accounted for as the same for N inputs in the model (37 kg of N/ha). As SR was the same in all treatments, it was assumed that culling rate and calves sold from the treatments were the same (i.e., it was assumed that N inputs were approximately 7 kg of N/ha for in-calf heifers entering the treatments, and N outputs were approximately 7 kg of N/ha and 4 kg of N/ha for cull cows and calves leaving the treatments). Nitrogen from atmospheric deposition and N fixation by WC was not accounted for in the farm gate model.

Weather Data

A weather station 7 km away at Timoleague, Ireland (Agricultural Catchments Program, Teagasc), was used to record daily rainfall (mm), mean air temperature (°C), and soil temperature (°C at 10 cm depth), with soil moisture deficit calculated according to the equations of Schulte et al. (2005).

COVID-19 Implications

Due to the COVID-19 pandemic, strict lockdowns occurred in 2020 and 2021 in Ireland during the experiment. This led to reduced sampling of herbage for 6 wk when the initial lockdown occurred in 2020, and only subsampling of paddocks occurred during these weeks. Thereafter, herbage samples were collected from all paddocks pregrazing, and minimal disruptions were incurred, as research was by then deemed an essential activity. However, due to social distancing implications enforced on the farm in 2020, PrGHY was estimated using quadrat cuts rather than Etesia cuts for the ma-

Table 2. Weather data means for experimental period 2019–2021

Time period	Mean air temperature (°C)	Mean soil temperature (°C)	Total rainfall (mm)	Mean soil moisture deficit (mm)
2019	10.5	11.4	1,022	11.7
2020	10.6	11.5	1,060	15.2
2021	10.7	11.6	1,204	15.4
2019–2021 means	10.6	11.5	1,095	14.1
10-yr mean (2009–2018)	9.9	10.8	1,046	11.8

jority of the year. Therefore, full grazing season data were not collected in 2020, and only results from 2019 and 2021 are presented for herbage allowance.

Statistical Analysis

Grazing characteristics such as PrGHY, PrGSH, PoGSH, density, herbage DM, weekly growth rate, and sward WC content were analyzed using PROC MIXED in SAS (SAS 9.4, SAS Institute Inc., Cary, NC). Terms included in the model were year, block, rotation, WC treatment, fertilizer rate, and their interactions. Individual paddock was the experimental unit, with paddock included as a random factor and rotation as a repeated measure. A compound symmetry covariance structure among records within paddock was used. Sward nutritive value was analyzed using PROC GLM, with year, time point, WC treatment, and fertilizer rate included in the model. Concentrate and silage supplementation was analyzed by PROC MIXED at group level measurements expressed by cow, taking into account the effects of year, fertilizer rate, WC treatment, parity, and their subsequent interactions. Tukey's test was used to determine differences between treatment means. Significance was declared at $P < 0.05$ and a tendency at $P > 0.05$ and $P < 0.10$.

Data for 360 lactation records from 212 cows were available for analysis. Milk data such as daily milk yield, milk fat, protein, and lactose content, daily MSo, cumulative milk and MSo yield, BW, and BCS were also analyzed using PROC MIXED. Terms included in the model were year, WC treatment, fertilizer rate treatment, parity, breed, and their interactions. The experimental unit was the individual cow. Tukey's test was used to determine differences between treatment means. Significance was declared at $P < 0.05$ and a tendency at $P > 0.05$ and $P < 0.10$.

Paddock was the experimental unit for milk, fat, protein, lactose, MSo yield, and GD per hectare, and variables were analyzed individually using PROC MIXED, with the effect of year, block, fertilizer rate, WC treatment, number of silage cuts, and their interactions included in the model. Corresponding milk yield to paddock and residency time was used by allocating 40% of the daily milk yield for an a.m. grazing (after

morning milking) in a paddock and 60% of the daily milk yield for a p.m. grazing (after evening grazing) in a paddock. Tukey's test was used to determine differences between treatment means. Significance was declared at $P < 0.05$ and a tendency at $P > 0.05$ and $P < 0.10$.

RESULTS

Weather Conditions

The weather conditions among the 3 yr did not fluctuate majorly from each other or the 10-yr means (Table 2). However, 2021 did experience nearly 200 mm more rainfall than 2019 and 2020 (+13.6%).

Grazing Characteristics and Herbage Production

Several interactions were recorded between treatments for the grazing parameters, which largely showed that adding WC could reduce some of the effects of reducing N fertilizer rate (Table 3). When WC was present, lowering the N rate did not reduce pregrazing yield, pregrazing height, or herbage removed (GO-250 vs. GC-150), but those variables were significantly reduced when WC was absent (GO-250 vs. GO-150). In addition, when WC was present (GC-150 and GC-250), postgrazing sward heights were lower (4.10 vs. 4.21 cm, respectively) and herbage allowance higher than GO-250 (+0.7 kg of DM/cow), though similar to GO-150. When N rate was increased, the DM content of the sward reduced, but when WC was included, the DM content remained unchanged, even when the N rate was increased. Sward density was unaffected when WC was included, regardless of the N rate. Finally, of note, although the WC content at high N (GC-250) was numerically lower (15.4%) than at low N (GC-150; 18.1%), the difference was not statistically significant, although there was a tendency ($P = 0.086$) for the GC-250 to be lower than the GC-150. Figure 1 shows the sward white clover content for the GC-150 and GC-250 kg of N/ha treatments from January to November.

Figure 2 shows the average daily grass growth profile in kilograms of DM per hectare for the 4 treatments over the 3 yr. The profiles overlap through the early

Table 3. Effect of sward type (ST) and N fertilizer rate (FR) on grazing characteristics, grazing efficiencies, herbage allowance, herbage removed, and silage supplementation fed

Item	Treatment ¹				SEM	P-value		
	GO-150 ¹	GO-250	GC-150	GC-250		ST	FR	ST × FR
Pregrazing yield (kg of DM/ha)	1,612 ^a	1,793 ^b	1,725 ^b	1,806 ^b	20.5	<0.01	<0.001	<0.05
Pregrazing height (cm)	8.71 ^a	9.45 ^b	9.11 ^b	9.51 ^b	0.065	<0.001	<0.001	<0.01
Postgrazing height (cm)	4.13 ^a	4.25 ^b	4.06 ^a	4.16 ^{ab}	0.028	<0.01	<0.001	0.851
Density (kg of DM/ha/cm)	324	316	324	313	3.8	0.669	<0.05	0.712
Herbage removed (kg of DM/ha)	1,580 ^a	1,714 ^b	1,714 ^b	1,756 ^b	17.9	<0.001	<0.001	<0.05
Herbage allowance (kg of DM/cow)	16.4 ^a	16.7 ^{ab}	17.2 ^b	17.3 ^b	0.02	<0.05	0.071	0.993
DM (%)	18.8 ^b	18.0 ^a	17.5 ^a	17.5 ^a	0.21	<0.001	<0.05	<0.05
Clover content (%)	—	—	18.1	15.4	1.03	—	0.086	—
Silage supplementation ² (kg of DM/cow)								
Total	336 ^d	222 ^a	317 ^c	242 ^b	3.9	0.923	<0.001	<0.001
Spring	105	107	105	104	3.7	0.899	0.681	0.574
Summer	24 ^b	0 ^a	0 ^a	0 ^a	0.5	<0.001	<0.001	<0.001
Autumn	207 ^b	115 ^a	212 ^b	138 ^a	1.9	<0.001	<0.001	<0.001

^{a-d}Different superscripts indicate a significant difference ($P < 0.05$).

¹GO-150 = perennial ryegrass (PRG)-only sward receiving 150 kg of N/ha; GO-250 = PRG-only sward receiving 250 kg of N/ha; GC-150 = PRG-WC sward receiving 150 kg of N/ha; GC-250 = PRG-WC sward receiving 250 kg of N/ha.

²Spring = January 1 to April 7; summer = April 8 to August 31; autumn = September 1 to December 31.

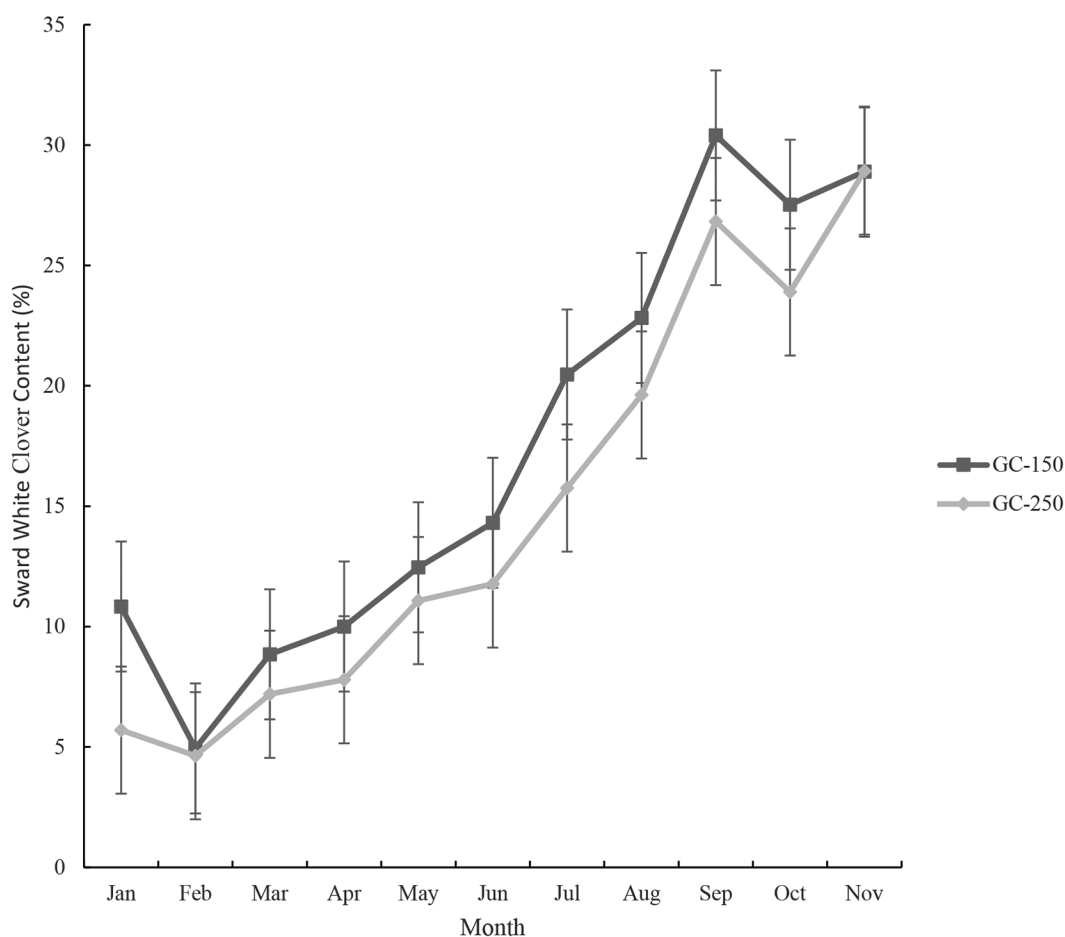
**Figure 1.** Sward white clover content for perennial ryegrass-white clover swards receiving 150 kg of N/ha per year (GC-150) and 250 kg of N/ha per year (GC-250) for the grazing season from late January to November.

Table 4. Effect of sward type (ST) and N fertilizer rate (FR) on sward nutritive value (mean of 2019–2020)

Item	Treatment ¹				SEM	P-value		
	GO-150	GO-250	GC-150	GC-250		ST	FR	ST × FR
CP (g/kg of DM)	195 ^a	207 ^b	211 ^b	215 ^b	3.4	<0.001	<0.05	0.206
OM digestibility (g/kg of DM)	807 ^a	807 ^a	821 ^b	817 ^b	3.7	<0.01	0.533	0.561
DM digestibility (g/kg of DM)	898	897	898	895	0.9	0.296	0.152	0.447
NDF (g/kg of DM)	419 ^a	419 ^a	401 ^b	408 ^{ab}	4.9	<0.01	0.215	0.475
ADF (g/kg of DM)	236	235	230	234	3.0	0.237	0.732	0.373
Ash (g/kg of DM)	106	103	106	107	2.9	0.478	0.792	0.615

^{a,b}Different superscripts indicate a significant difference ($P < 0.05$).

¹GO-150 = perennial ryegrass (PRG)-only sward receiving 150 kg of N/ha; GO-250 = PRG-only sward receiving 250 kg of N/ha; GC-150 = PRG-WC sward receiving 150 kg of N/ha; GC-250 = PRG-WC sward receiving 250 kg of N/ha.

and late seasonal periods, separating during the main growing period of May to October. Total annual herbage DM production was reduced when N fertilizer rate was reduced but increased when WC was included ($P < 0.05$). Total annual herbage DM production was 13,771^a, 15,242^{bc}, 14,721^{ab}, and 15,667^c kg of DM/ha, for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively, where different superscripts indicate a significant difference ($P < 0.05$). The difference in growth between the treatments necessitated additional supplementation for individual treatments at certain times of the year or required excess herbage to be removed as baled silage when average farm cover was greater than target in certain treatments. When surpluses occurred for all groups, silage was harvested for all groups. If surpluses occurred from one or more groups, silage was harvested from those groups, but not for treatments where no surplus herbage occurred; this allowed rotation length to remain the same for treatments. This resulted in a significant interaction between treatments for the total amount of silage fed, as adding WC at low N reduced the amount fed (336 vs. 317 kg of DM/cow for GO-150 vs. GC-150), but increased it at high N (222 vs. 242 kg of DM/cow for GO-250 vs. GC-250). The spring period had equal silage supplementation for all treatments. The GO-150 treatment was the only treatment that received silage supplementation in the summer period. During the autumn period, silage supplementation was 83 kg of DM higher per cow for the 150 kg of N/ha treatments compared with the 250 kg of N/ha treatments.

When the reduced annual herbage production and the silage fed during lactation were accounted for (i.e., the silage fed during lactation was subtracted from the silage harvested) winter feed production was below target (1,200 kg of DM/cow) for all treatments but to a greater or lesser extent depending on the treatment. Winter feed produced was 500, 851, 689, and 1,009 kg of DM/cow for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively.

Lowering the N rate reduced the CP content (203 vs. 211 g/kg for 150 kg of N/ha and 250 kg of N/ha, respectively) but did not change any of the other sward nutritive values, and there were no treatment interactions (Table 4). Including WC significantly increased CP content (213 vs. 201 g/kg DM for PRG-WC and PRG-only, respectively) and OMD (819 vs. 807 g/kg DM for PRG-WC and PRG-only, respectively), and reduced NDF content (405 vs. 419 g/kg DM for PRG-WC and PRG-only, respectively) but did not change the DM digestibility or the ADF and ash concentrations of the swards compared with the PRG-only swards.

Milk Production

When the average milk production figures per cow for the 3 yr were compared (Table 5), there were no significant differences between swards of the same composition when the N rate was lowered (GO-250 vs. GO-150 and GC-250 vs. GC-150), and there were no treatment interactions. However, including WC did significantly increase several milk performance parameters (daily milk yield, daily MSo, cumulative milk yield, and cumulative MSo), when N rates were the same (GC-150 vs. GO-150 and GC-250 vs. GO-250). Over the 3 yr, cows grazing PRG-only swards produced, on average, 5,500 kg cumulative milk yield and 468 kg cumulative MSo/cow per year, in comparison with cows grazing PRG-WC swards that produced 5,859 kg of milk and 499 kg of MSo/cow per year. Figure 3 illustrates the lactation profile of the 4 treatments and illustrates that the differences between the PRG-only and PRG-WC swards occurred from May to September, coinciding with the growth curves in Figure 2. Body condition score did not differ between sward types or N rates at any point during lactation.

When the milk production parameters were compared on a per-hectare basis, decreasing N rate significantly reduced GD, effective SR, and silage supplement-corrected SR, with no significant change induced by

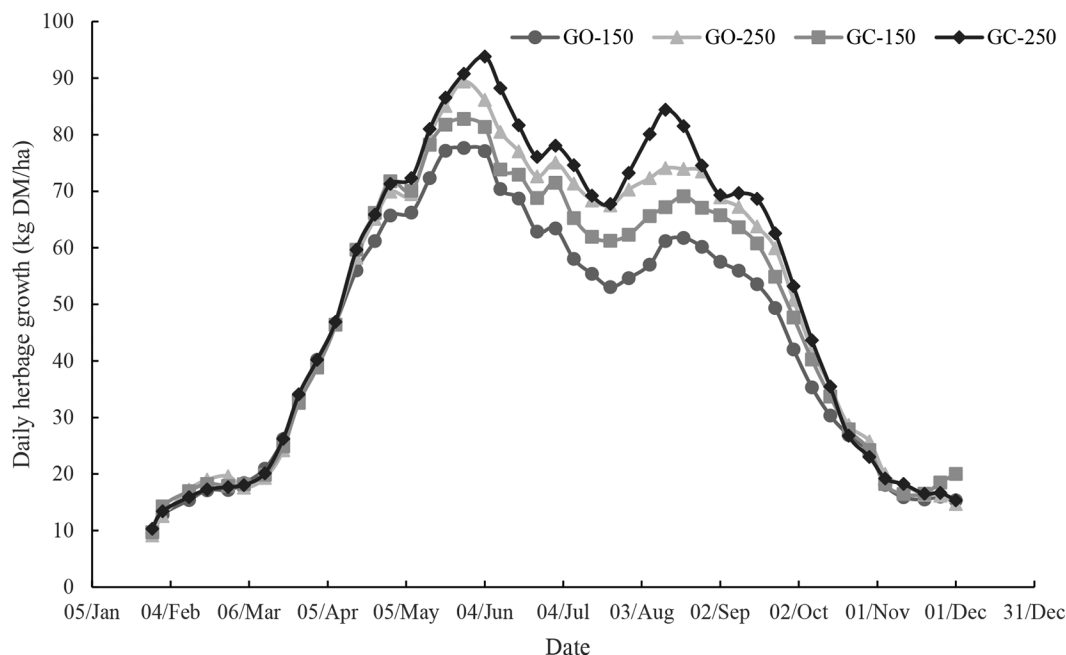


Figure 2. Comparison of daily herbage growth (kg of DM/ha) for nitrogen fertilizer rate and sward type from 2019 to 2021 for perennial ryegrass (PRG)-only swards receiving 150 kg of N/ha (GO-150) or 250 kg of N/ha (GO-250) and a PRG-white clover sward receiving 150 kg of N/ha (GC-150) or 250 kg of N/ha (GC-250).

adding WC (Table 6). The number of cow GD/ha increased by 40 d when the N rate was increased by 100 kg of N/ha (506 and 546 GD/ha for 150 kg of N/ha and 250 kg of N/ha, respectively). Even when silage, used as supplementation, was accounted for as GD (1 GD was equivalent to 16 kg of DM of silage), giving a SR corrected for silage supplement, the higher fertilizer rate still had the highest value (2.13 vs. 1.95 cow/ha),

whereas sward types still did not differ. In contrast, MSo yield (+132 kg MSo yield/ha), along with fat, protein, and lactose yield (+72, 62, and 77 kg/ha, respectively) all increased significantly when WC was added but had no significant response to N rate. Total milk yield per hectare was greater when WC was in the sward (+1,482 kg) and also when the higher N rate was applied (+1,073 kg; $P < 0.001$).

Table 5. Effect of sward type (ST) and N fertilizer rates (FR) on full-lactation milk production per cow

Item	Treatment ¹				SEM	P-value		
	GO-150	GO-250	GC-150	GC-250		ST	FR	ST × FR
Daily milk yield (kg/cow)	18.9 ^a	19.2 ^a	20.3 ^b	20.4 ^b	0.21	<0.001	0.372	0.541
Milk fat (%)	4.78	4.79	4.76	4.74	0.050	0.503	0.898	0.734
Milk protein (%)	3.82	3.85	3.87	3.82	0.023	0.522	0.575	<0.05
Milk lactose (%)	4.64	4.63	4.63	4.64	0.012	0.779	0.782	0.450
Daily milk solids (kg)	1.59 ^a	1.62 ^a	1.72 ^b	1.72 ^b	0.016	<0.001	0.310	0.309
Cumulative milk yield (kg/cow)	5,503 ^a	5,596 ^a	5,909 ^b	5,809 ^b	60.7	<0.001	0.295	0.526
Cumulative milk solids yield (kg/cow)	463 ^a	472 ^a	499 ^b	499 ^b	4.8	<0.001	0.309	0.352
Average BW (kg)	512	510	509	508	4.5	0.609	0.742	0.896
Minimum BW during lactation (kg)	476	475	461	469	4.4	<0.001	0.399	0.301
BW at calving (kg)	506	504	506	508	4.7	0.926	0.484	0.7892
BW at drying off (kg)	534	533	522	528	4.9	0.090	0.130	0.605
Average BCS	2.92	2.95	2.97	2.97	0.017	0.083	0.462	0.407
Minimum BCS during lactation	2.76	2.77	2.74	2.76	0.020	0.331	0.436	0.626
BCS at calving	3.13	3.15	3.12	3.14	0.015	0.158	0.169	0.717
BCS at drying off	2.88	2.87	2.90	2.89	0.021	0.355	0.309	0.352

^{a,b}Different superscripts indicate a significant difference ($P < 0.05$).

¹GO-150 = perennial ryegrass (PRG)-only sward receiving 150 kg of N/ha; GO-250 = PRG-only sward receiving 250 kg of N/ha; GC-150 = PRG-WC sward receiving 150 kg of N/ha; GC-250 = PRG-WC sward receiving 250 kg of N/ha.

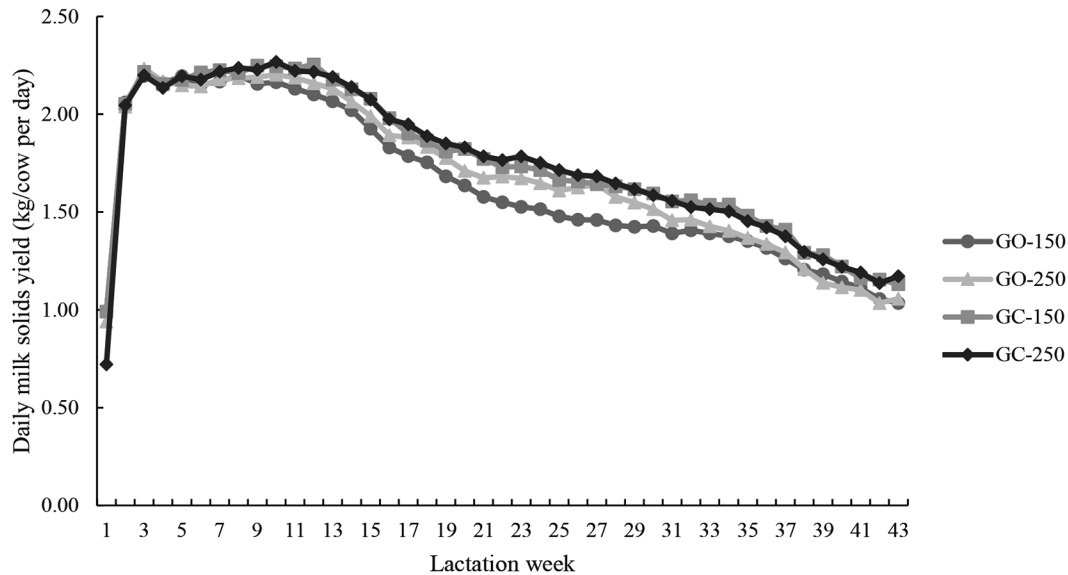


Figure 3. Daily milk solids yield per cow by lactation week for perennial ryegrass (PRG)-only swards receiving 150 kg of N/ha (GO-150) or 250 kg of N/ha (GO-250) and a PRG-white clover sward receiving 150 kg of N/ha (GC-150) or 250 kg of N/ha (GC-250).

Nitrogen inputs in the farm gate NUE model differed among treatments in terms of N fertilizer applied and silage imported for the system as no system was self-sufficient in terms of producing adequate silage for the winter period (Table 7). Silage imported was 40, 20, 37, and 11 kg of N/ha for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively. Nitrogen outputs differed for milk production among treatments. Milk production N outputs were 92, 95, 101, and 98 kg of N/ha for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively. Nitrogen use efficiency was 46%, 33%, 51%, and 36% for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively. Nitrogen surplus

was 115, 201, 102, and 191 kg of N/ha for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively.

DISCUSSION

Multiple studies have compared PRG-only swards receiving various levels of N fertilizer to PRG-WC swards receiving lower levels of N fertilizer (Egan et al., 2017; Humphreys et al., 2012; Ledgard et al., 2009). However, a unique aspect of this study was the comparison of PRG-only and PRG-WC swards at 2 levels of N fertilizer, allowing the quantification of the effect of reducing N fertilizer on both PRG-only and PRG-

Table 6. Responses to adding white clover (WC) to sward type (ST) at 2 nitrogen fertilizer rates (FR) on full-lactation milk production per hectare from grazing and herbage harvested per hectare (mean of 2019–2021)

Item	Treatment ¹				SEM	P-value		
	GO-150	GO-250	GC-150	GC-250		ST	FR	ST × FR
Cow grazing days (d/ha)	485 ^a	541 ^b	526 ^{ab}	550 ^b	31.5	0.198	<0.05	0.410
Effective SR (cows/ha)	1.94 ^a	2.16 ^b	2.10 ^{ab}	2.20 ^b	0.100	0.195	<0.05	0.408
Silage supplement-corrected SR (cows/ha)	1.86 ^a	2.11 ^b	2.03 ^{ab}	2.14 ^b	0.109	0.199	<0.05	0.380
Milk yield (kg)	9,555 ^a	10,919 ^a	11,328 ^b	12,110 ^b	818	<0.01	<0.05	0.560
Milk solids yield (kg)	841 ^a	959 ^b	1,013 ^b	1,052 ^b	65.2	<0.01	0.051	0.349
Fat yield (kg)	483 ^a	548 ^{ab}	573 ^{bc}	602 ^c	38.0	<0.01	<0.05	0.451
Protein yield (kg)	355 ^a	409 ^b	437 ^b	450 ^b	27.8	<0.001	0.055	0.237
Lactose yield (kg)	442 ^a	505 ^{ab}	538 ^b	563 ^b	36.7	<0.001	0.056	0.395
Silage harvested (kg of DM/cow)	836 ^a	1,073 ^b	1,006 ^b	1,251 ^c	230.5	<0.05	<0.01	0.956

^{a-c}Different superscripts indicate a significant difference ($P < 0.05$).

¹GO-150 = perennial ryegrass (PRG)-only sward receiving 150 kg of N/ha; GO-250 = PRG-only sward receiving 250 kg of N/ha; GC-150 = PRG-WC sward receiving 150 kg of N/ha; GC-250 = PRG-WC sward receiving 250 kg of N/ha. SR = stocking rate.

Table 7. Responses to adding white clover (WC) to sward type (ST) at 2 nitrogen fertilizer rates (FR) on farm gate nitrogen use efficiency (NUE) of the system (mean of 2019–2021)

Item	Treatment ¹				SEM	P-value		
	GO-150	GO-250	GC-150	GC-250		ST	FR	ST × FR
N input (kg)	234 ^a	313 ^b	223 ^a	304 ^b	42.1	<0.001	<0.001	0.489
N output (kg)	103	106	112	109	3.5	<0.01	0.533	0.561
N surplus (kg)	115 ^a	201 ^c	102 ^a	191 ^b	47.4	<0.001	<0.001	0.403
NUE (%)	46.0 ^b	33.3 ^a	51.0 ^c	35.7 ^a	8.0	<0.01	<0.001	0.089

^{a–c}Different superscripts indicate a significant difference ($P < 0.05$).

¹GO-150 = perennial ryegrass (PRG)-only sward receiving 150 kg of N/ha; GO-250 = PRG-only sward receiving 250 kg of N/ha; GC-150 = PRG-WC sward receiving 150 kg of N/ha; GC-250 = PRG-WC sward receiving 250 kg of N/ha.

WC swards. Importantly, the work was conducted on a farmlet scale, to make it as relevant as possible to commercial dairy farming and to contribute to one of the industry's current critical knowledge needs (i.e., how a reduction in N fertilizer use will affect productivity in PRG-only and PRG-WC grazing systems).

Herbage Production

Nitrogen fertilizer is required in PRG-only systems to produce high levels of high nutritive value herbage reliably. The previous experiment in Clonakilty (McCleary et al., 2019, 2020a) had demonstrated the benefits of including WC into PRG swards at high levels of N fertilizer but at a cost to WC persistency. In this study, when WC was introduced into a low-N system (GC-150), herbage production increased significantly, yielding an additional 950 kg of DM/ha compared with the low-N PRG-only system (GO-150), despite the relatively low annual WC content (18.1%) of the GC-150 sward. Although the GC-150 treatment did not fully offset the reduction of 100 kg of N fertilizer/ha imposed in terms of herbage production compared with the GO-250 treatment, the reduction in herbage production for the GC-150 treatment was not significant (−521 kg of DM/ha). This implies that even at the reduced levels of 20% inclusion rate (Andrews et al., 2007), there is a production benefit from including WC into the sward. If the WC content of the swards did reach the optimum level of 20%, it is likely that the GC-150 treatment would have fully offset or offset up to 90% of the N inputs in terms of herbage production compared with the GO-250 treatment (Egan et al., 2017; Humphreys et al., 2012). At the higher N application rate there was a reduced production benefit of 425 kg of DM/ha for the PRG-WC swards compared with the PRG-only swards. This may be due to the combined effect of the lower WC contents of the swards (15.1%) and due to the high levels of inorganic N application available for herbage production. In the 250 kg of N/ha swards the addition of WC increased cow GD per hectare by only 9

d. In contrast, for the 150 kg of N/ha swards including WC increased cow GD per hectare by 41 d. Therefore, applying high levels of inorganic N to PRG-WC swards cannot be justified, as the extra 100 kg of N/ha applied to the GC-250 treatment only yielded an extra 2.8% herbage production compared with the GO-250 treatment, and there was a tendency for the GC-250 treatment to have a lower sward WC content ($P = 0.086$) compared with the GC-150 treatment. The greater reduction in WC content with increased N application has previously been documented by Enriquez-Hidalgo et al. (2016), who observed under intensive grazing, that the maximum applied N rate that optimized herbage production with minimal effect on WC content was up to 120 kg of N/ha. Similarly, McDonagh et al. (2017) found that the WC contribution to sward productivity declined under a higher N input when PRG-only grazing plots were compared with PRG-WC at 2 fertilizer rates (100 and 250 kg of N/ha per year). Nitrogen fixation by WC was also reduced under high N fertilizer application rates (Harris and Clark, 1996; Enriquez-Hidalgo et al., 2016), and reduced N fixation by the WC in the GC-250 treatment may have also contributed to the small increase in herbage production observed on the GC-250 treatment. Total herbage production is a key factor in the productivity of grazing systems to support moderate to high SR. However, even more fundamental to herbage production is the quality and utilization of the herbage grown with regards to milk production.

Milk Production

White clover inclusion increased milk production on both an individual cow basis and on a per-hectare production level. This further strengthens previous studies that observed a milk production benefit with WC inclusion (McCleary et al., 2019; Loza et al., 2021; McAuliffe et al., 2022). Similarly, this study detected that higher MSo production arose due to higher overall milk volume rather than an increase in milk fat and protein content. It is widely accepted that the increase

in milk production per cow grazing PRG-WC swards versus PRG-only swards is due to greater DMI as a result of the lower NDF content and higher feeding value (Harris and Clark, 1996; Dineen et al., 2018; Egan et al., 2017; McClearn et al., 2019). Herbage allowance and herbage removed in the current experiment align with these previous findings. White clover swards had higher herbage allowances (4.1%) and herbage removed (5.1%) compared with PRG-only swards, which infers a greater DMI by cows grazing these swards. This equated to 0.7 kg of DM/cow greater herbage allowance per day for cows grazing PRG-WC compared with PRG-only swards. This finding agrees with McClearn et al. (2019), who reported a similar 0.8 kg of DM/cow per day greater herbage allowance for cows grazing PRG-WC compared with PRG-only swards and supports previous research that has shown greater DMI for cows grazing PRG-WC swards compared with PRG-only swards (Ribeiro Fihlo et al., 2005; Egan et al., 2017; McClearn et al., 2020a). The nutritive value of the PRG-WC swards was greater than the PRG-only swards in the current study, as they had significantly greater CP content and OMD paired with lower NDF content, which made it a superior diet for lactating dairy cows compared with the PRG-only swards (Bargo et al., 2003). Both these factors would justify the increase in milk production on both per-cow and per-hectare basis observed in the current study.

Egan et al. (2017) previously found that incorporating WC into PRG swards increased MSo yield by 91 (7.1%) and 85 (6.6%) kg/ha from the PRG-WC 150 kg of N/ha and PRG-WC 250 kg of N/ha treatments, respectively, compared with PRG-only treatment receiving 250 kg of N/ha per year. When the same comparisons are made for the current experiment, WC similarly increased MSo yield by 54 (5.3%) and 93 (8.8%) kg/ha in the GC-150 and GC-250 treatments, respectively, compared with GO-250 treatment. Furthermore, in the current study, an additional side-by-side comparison can be made at 2 fertilizer rates for the 150 kg of N/ha fertilizer rate when WC is incorporated into PRG swards. There was an additional 172 kg of MSo per hectare for the GC-150 treatment compared with the GO-150 treatment equating to a 16.9% increase in MSo produced per ha with the same N inputs into the system at farm gate level. This is a substantial increase in MSo from the same N input that is both critical for the environment and economically important to the farmer, 2 major issues affecting the industry at present (Horan and Roche, 2020). Milk solids produced per hectare, per kilogram of N applied were 5.6, 3.8, 6.7, and 4.2 kg for GO-150, GO-250, GC-150, and GC-250 treatments, respectively. This illustrates the efficiency of the GC-150 treatments on a farm gate N input per unit of output basis, producing

1.1 kg of MSo more per hectare, per kilogram of N, than the PRG-only treatment receiving the same N inputs.

Fertilizer rate had no effect on milk production on a per-cow production level. However, milk production per hectare was affected by fertilizer rate, as observed, for example, by Delaby et al. (1998). The lack of difference in milk production per cow by fertilizer rate is perhaps concealed for 2 reasons. First, due to the fact that the low-N fertilizer rate treatments, and in particular, the GO-150 treatment, received higher levels of silage supplementation during lactation to offset the reduction in cow GD per hectare. The profile of this supplementation by season is presented in Table 3. All treatments received similar supplementation in the spring period, with the GO-150 treatment requiring higher supplementation in the summer period than the other 3 treatments and the autumn period requiring differing levels of silage supplementation for all treatments. The GC-150 treatment received 75 kg of DM/cow more silage during lactation compared with the GC-250 treatment. This agrees with Egan et al. (2017), who supplemented cows with an extra 93 kg of DM/cow of silage during lactation for their GC-150 treatment compared with their GC-250 treatment with no fertilizer effect on milk production observed between these 2 treatments. Second, the nutritive value of the low-N treatments was not significantly different than the high-N treatments, except for the CP content, which was significantly lower for the GO-150 compared with the other treatments. This is not particularly surprising for the GC-150 treatment, as WC increases the nutritive value of the sward (Guy et al., 2018). However, it is noteworthy that the nutritive value of the GO-150 treatment did not differ greatly from the GO-250 treatment, despite receiving 100 kg less N per hectare. It had been expected that nutritive value of the GO-150 sward would be reduced (Peyraud and Astigarraga, 1998), but in this case, only the CP content of the GO-150 treatment was slightly reduced compared with the GO-250, but it was still over the minimum requirement of 16% to 17% for dairy cows (Olmos Colmenero and Broderick, 2006). This agrees with Peyraud and Astigarraga (1998) and Peyraud et al., (1997) who observed no reduction in herbage DMI, digestion, or milk production on low-N fertilized swards. Therefore, reducing N fertilizer level without utilizing WC will likely require a lower SR due to less herbage produced, or more silage supplementation, which is evident from the reduced effective SR and silage supplementation-corrected SR with the low-N treatments.

Farm Gate NUE and N Surplus

In this study, farm gate NUE increased slightly when WC was included in the sward (+4%), but there was

a large increase in farm gate NUE (+14%) when 100 kg of N/ha less fertilizer was used. The greatest NUE and lowest N surplus achieved was with the GC-150 treatment (51% and 102 kg of N/ha), which combined reduced-N fertilizer use and WC to offset the reduction in N fertilizer through biological N fixation (**BNF**) and increase N output through increased MSo yield from cows grazing PRG-WC swards, compared with the GO-250 treatment that had the lowest NUE (33.3%) and greatest N surplus (201 kg of N/ha). These results support Chapman et al. (2020), who stated that including WC in the sward and reducing N fertilizer application rates will increase farm gate NUE and reduce the N surplus compared with PRG-dominant swards receiving high rates of N fertilizer, without negatively affecting MSo yield or herbage production, as supported by Hennessy et al., 2019. The results of this study highlight that lower N input grazing systems should be promoted to increase farm gate NUE, and in turn, the sustainability of the grass-based dairy production systems (Herron et al., 2021).

Although BNF was not measured in this study, estimates for BNF of 52 kg of N/ha per tonne of annual WC DM produced (kg of DM/ha) can be made based on measurements according to Enriquez-Hidalgo et al. (2016) for the 2 WC treatments, based on the amount of WC herbage DM produced. Therefore, the estimated BNF was 139 and 125 kg BNF/ha for GC-150 and GC-250 treatments, respectively. This would enable a system NUE calculation excluding N leaching to be carried out, changing the systems' NUE figures to 46%, 33%, 32%, and 25% for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively, and N surplus to 115, 201, 242, and 320 kg of N/ha for the GO-150, GO-250, GC-150, and GC-250 treatments, respectively. However, these figures also support Chapman et al. (2020), who stated that including WC increases the farm gate NUE, but if BNF is included, system NUE is decreased. This would subsequently favor the GO-150 treatment as the superior treatment in terms of total organic and inorganic N inputs and N surpluses of the system. However, when you consider the economics of adding WC into the system, there is a substantial benefit for the farmer and environmental benefit in terms of the carbon footprint in the production and land spreading of inorganic N (Herron et al., 2021).

Practical Implications

Andrews et al. (2007) had previously stated that a minimum WC sward content of 20% was required to achieve the production benefits of WC in the sward. However, overall sward WC contributions in this study did not reach that threshold level, but a significant

milk response was achieved. Therefore, it should be promoted that even beginning at relatively low sward contents, WC can make a positive impact in terms of both herbage and milk production. This can also help to insulate farmers from dramatic price fluxes in a volatile market (Kelly et al., 2020). This should be reassuring for farmers and at the industry level to promote WC inclusion in swards when the decision is made as a long-term goal to convert whole-farm grazing systems from PRG-only swards to PRG-WC swards. This is because is not practical to reseed or over-sow a whole farm simultaneously to incorporate WC without affecting the farm SR. There may also be benefits for including herbs in addition to WC, which is being explored in other studies (McCarthy et al., 2020; Hearn et al., 2022).

A partial modeling exercise on the economic performance of the grazing treatments was undertaken. The economic performance was modeled similarly to McClearn et al. (2020b) using the Moorepark Dairy Systems Model (Shalloo et al., 2004), based on a 40-ha farm with a SR of 2.75 cow/ha. The main variables used were MSo yield/cow, N fertilizer input, and silage supplemented input for each treatment. Milk solids yield and silage supplemented were converted to a per-hectare basis by multiplying the per-cow figure by the SR of 2.75 cow/ha, and all other inputs and outputs were assumed to be equal. The cost of N fertilizer and silage was included at €1.41/kg of N applied and €240/t of silage fed. Milk solids were included at €5.09/kg MSo. The GO-150 treatment had a reduced profit of €93/ha compared with the GO-250 despite the reduction in fertilizer inputs due to reduced milk output and increased silage supplementation. Both WC treatments had increased profit compared with the GO-250 treatment of €478/ha and €185/ha for the GC-150 and GC-250 treatments, respectively. The reduction in fertilizer cost in the GC-150 treatment resulted in an increased farm profit of €293/ha compared with the GC-250, despite requiring additional silage supplementation. When bloat oil was included at 20 cents/d for 100 d in the WC treatments, as recommended to prevent incidences of bloat in WC grazing systems, profit reduced to €423/ha and €130/ha for the GC-150 and GC-250 treatments, respectively. The GC-150 treatment was the most profitable treatment.

CONCLUSIONS

White clover incorporation into PRG swards is crucial for temperate grazing systems, both in terms of achieving environmental targets and financial reward for farmers in a volatile market. The inclusion of WC in PRG swards significantly increased milk yield and MSo production both per cow and per hectare. Reducing

N fertilizer rate from 250 to 150 kg of N/ha successfully offset N inputs in terms of milk production but reduced herbage production and GD per hectare, and in turn, required greater silage supplementation during lactation. As land availability and environmental constraints are 2 of the main limiting factors affecting production on farms, WC inclusion into PRG swards is a key grassland and management strategy that should be incorporated to overcome this challenge. White clover included within the sward will increase farm gate NUE and reduce the N surplus compared with PRG-dominant swards receiving high rates of N fertilizer (250 kg of N/ha) while increasing profit by €478/ha.

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