

Annual and seasonal dry matter production, botanical species composition, and nutritive value of multispecies, permanent pasture, and perennial ryegrass swards managed under grazing

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Abstract

Reduced reliance on inputs such as fertilizer is fundamental to sustainable grazing systems. This two-year study compared four sward types, including multispecies swards (MSS), for herbage dry matter (DM) production, species contribution to DM, and herbage nutritive value under grazing. The systems were: (1) *Lolium perenne* L. monoculture (PRG; 170 kg N ha⁻¹ year⁻¹); (2) permanent pasture (PP; 135 kg N ha⁻¹ year⁻¹), (3) six species sward consisting of two grasses, two legumes and two herbs (6S; 70 kg N ha⁻¹ year⁻¹), (4) twelve species sward consisting of three grasses, four legumes and five herbs (12S; 70 kg N ha⁻¹ year⁻¹). Herbage samples were collected for DM yield, botanical composition, and nutritive value. Mean annual DM production for PRG, PP, 6S, and 12S was 11,374, 8526, 13,783, and 13,338 kg DM ha⁻¹ respectively. Herb proportions decreased in 6S and 12S from 2020 to 2021 while grass proportions increased. Mean crude protein levels were similar across all systems ($p > 0.05$), with higher ash content in 6S and 12S compared to PRG ($p < 0.001$). Organic matter digestibility was lowest in PP compared to PRG ($p < 0.001$) while neutral detergent fibre content of PP and PRG were greater than 6S and 12S ($p < 0.001$). Water soluble carbohydrate content was highest in PRG ($p < 0.0001$). Over 2 years, MSS delivered increased herbage DM yield and nutritive quality relative to PRG and PP swards, from reduced N inputs. However, maintenance of the herb component of MSS is a challenge.

KEYWORDS

grazing systems, legumes, multispecies swards, permanent pasture

1 | INTRODUCTION

In temperate grazing systems, grass accounts for the majority of the diet of ruminants (O'Mara, 2012). Improved grassland, which encompasses moderately and intensively managed pasture, accounts for 41% of the total national land area of Ireland (Lydon & Smith, 2018)

and reflects the suitability of the country's temperate climate to grass-based livestock production systems. Primarily, these grasslands consist of permanent pasture (PP), and where reseeding has occurred, perennial ryegrass (*Lolium perenne* L.) (PRG) is the species of choice (O'Donovan et al., 2021). Indeed, PRG accounts for approximately 95% of forage grass seed sales in Ireland (DAFM, 2023). However,

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national levels of reseeding are low ca. 2% annually (Shalloo et al., 2011; Teagasc, 2017). The economic cost and yield benefits associated with reseeding grassland are critical considerations for farmers and hinge on factors such as stocking rate, farming system, and performance of the existing sward (Creighton et al., 2011; Hopkins et al., 1990).

Perennial ryegrass can produce significant quantities of herbage dry matter (DM) (Finneran et al., 2012; O'Donovan et al., 2011) of excellent nutritive value (King et al., 2012) and responds well to frequent defoliation (Kemp et al., 2000; Shalloo et al., 2011). However, the performance of PRG is reliant on nitrogen (N) fertilizer application rates (King et al., 2012; Whitehead, 1995). The manufacture and application of N fertilizer is energy intensive and associated N losses can have environmental impacts including eutrophication of water, increased greenhouse gas emissions, and negative impacts on biodiversity (Crews & Peoples, 2004; Hoekstra et al., 2020; Vitousek et al., 1997; Von Blottnitz et al., 2006). Furthermore, the economic cost and supply security of inorganic N have been subject to increasing volatility over recent years (European Commission, 2022). Consequently, the European Union Farm to Fork Strategy includes a target of 20% reduction in fertilizer, use to be achieved by 2030 (European Commission, 2020).

Multispecies swards are improved agricultural grasslands (Fossitt, 2000) that are comprised of grass, legume, and herb species, specifically selected for inclusion due to perceived beneficial traits. Legume inclusion is particularly beneficial due to the biological N_2 fixation advantage of legumes over other functional groups (Peyraud et al., 2009) and may often result in increased herbage production, as observed in binary mixtures of PRG and *Trifolium repens* L. (Egan et al., 2018; Enriquez-Hidalgo et al., 2018; Guy et al., 2018) or PRG and *Trifolium pratense* L. (Clavin et al., 2016; Elgersma & Sørensen, 2016; Humphreys et al., 1998). Legumes can also increase herbage nutritive value and encourage higher intakes by livestock (Enriquez-Hidalgo et al., 2018; Lüscher et al., 2014; Phelan et al., 2015).

In addition to grasses and legumes, multispecies swards also include high-yielding forage herbs such as *Cichorium intybus* L. (chicory) and *Plantago lanceolata* L. (ribwort plantain) (Glasse et al., 2013; Li & Kemp, 2005). Herb inclusion can result in increased herbage DM yield relative to PRG monocultures or binary mixtures of PRG & *T. repens* (Baker et al., 2023a) and enhanced grazing animal performance (Grace, Boland, et al., 2019a; Handcock et al., 2015). They may also add to the nutritive value and mineral profile of the sward (Elgersma et al., 2014; Pirhofer-Walzl et al., 2011), resulting in reduced urinary N load into pasture (Bryant et al., 2017; Mangwe et al., 2019).

In comparison to PRG monocultures, MSS have demonstrated lower nitrous oxide (N_2O) emissions (Cummins et al., 2021) and greater yield stability and resilience during drought conditions (Grange et al., 2021; Haughey et al., 2018; Vogel et al., 2012). In addition, increasing plant diversity can benefit pollinator habitats (Cong et al., 2020; Ebeling et al., 2008), increase earthworm populations, enhance soil carbon storage (Fornara & Tilman, 2008; Lange

et al., 2023; Skinner & Dell, 2016) and increase water infiltration rates (Fischer et al., 2015).

While numerous benefits have been attributed to the use of MSS, much of the research has been undertaken at plot rather than paddock scale. Therefore, it is imperative to further investigate and better understand how MSS perform under grazing conditions. Where previous grazing research has been undertaken, it has generally focused on single species grazing systems e.g., beef (Baker et al., 2023a) or sheep (Grace, Boland, et al., 2018a), leaving a gap in our understanding of how these swards perform in a co-grazing (cattle and sheep) context. In addition, much of the existing MSS literature has been based on the inclusion of *C. intybus* and *P. lanceolata*, together with *T. repens* and *T. pratense*, *L. perenne* and *Phleum pratense* L. in seed mixtures. There is much more limited insight into the performance of MSS that are sown with a more diverse range of legume and herb species.

Addressing these knowledge gaps, the objectives of this experiment were to determine the impact of four grass based systems i.e., (1) permanent pasture – 135 kg N ha⁻¹ year⁻¹ (PP); (2) perennial ryegrass monoculture – 170 kg N ha⁻¹ year⁻¹ (PRG); (3) six species sward – 70 kg N ha⁻¹ year⁻¹ (6S); (4) twelve species sward – 70 kg N ha⁻¹ year⁻¹ (12S), managed under a cattle and sheep co-grazing system over 2 years in terms of: (1) annual and seasonal herbage dry matter production; (2) changes in the proportional contribution of individual species and functional groups to overall herbage dry matter production; (3) the nutritive value of herbage from each system.

2 | MATERIALS AND METHODS

2.1 | Experimental site and establishment

The study was conducted at the Devenish Lands at Dowth, County Meath, Ireland (Latitude 53°42'19.7" N, Longitude 6°26'24.7" W). The soil was a well-drained brown earth, with a sandy loam texture (Teagasc, 2016). Prior to the establishment of the experiment, soil tests were taken in January 2020 from each paddock and averaged as follows: Total N (%): 0.32; pH 6.2; P: 5.68, K: 52.18 and Mg: 122.06 mg l⁻¹; S: 3.12, Ca: 2401.71, Na: 36, Fe: 1062.11, Mn: 62.59, Zn: 6.22, Cu: 9.73, B: 1 and Mo: 0.13 mg kg⁻¹. Site grazing season (March to December) rainfall, air, and soil temperature (10 cm depth) was recorded daily throughout the establishment and experimental period. Prior to sowing, the site was sprayed with glyphosate herbicide at a total rate of 3.0 L ha⁻¹ (or 15 mL active ingredient l⁻¹) (Roundup, Monsanto) split between two occasions i.e., April and June 2019. The site was subsequently cultivated using a disc harrow, sown with a pneumatic seed drill (Lemken Solitair 9, Lemken GmbH & Co. KG, Alpen, Germany) on the 26th and 27th of June 2019, and press rolled following sowing. Seedbed fertilizer was applied according to pre-experimental soil tests at a rate of 25 kg N ha⁻¹, 25 kg P ha⁻¹, and 50 kg K ha⁻¹ in the form of 10-10-20 (Gouldings Chemicals Limited, Cork, Ireland). Ground limestone (CaCO₃) was spread in February 2019 following a variable rate programme.

2.2 | Experimental design

The study area of 36 ha was arranged in a randomized block design comprised of four replicate blocks of 9 ha each (Figure 1). Each block was divided into 8 paddocks of 1.15 ha. The four systems investigated were: a pre-existing permanent pasture that received $135 \text{ kg N ha}^{-1} \text{ year}^{-1}$ (PP), a *Lolium perenne* L. monoculture that received $170 \text{ kg N ha}^{-1} \text{ year}^{-1}$ (PRG), six species sward (6S) (perennial ryegrass (*L. perenne*), timothy (*Phleum pratense* L.), white clover (*Trifolium repens* L.), red clover (*Trifolium pratense* L.), chicory (*Cichorium intybus* L.) and ribwort plantain (*Plantago lanceolata* L.)) that received $70 \text{ kg N ha}^{-1} \text{ year}^{-1}$ and a 12 species sward (12S) (6S plus cocksfoot (*Dactylis glomerata* L.), birdsfoot trefoil (*Lotus corniculatus* L.), yarrow (*Achillea millefolium* L.), sainfoin (*Onobrychis viciifolia* Scop.), salad burnet (*Sanguisorba minor* Scop.), sheep's parsley (*Petroselinum crispum* Mill.)) that also received $70 \text{ kg N ha}^{-1} \text{ year}^{-1}$. The proportion of overall seed that each species accounted for, corresponding seeding rate (g m^{-2} , seeds m^{-2}) and varieties of each species used in each system are shown in Table 1.

2.3 | Nutrient management

The $135 \text{ kg N ha}^{-1} \text{ year}^{-1}$ rate for PP was based on N requirements for a two livestock units (LU) ha^{-1} stocking rate. An additional allowance was applied to the newly sown PRG, resulting in a total application rate of $170 \text{ kg N ha}^{-1} \text{ year}^{-1}$ to these swards, as per Wall and Plunkett (2020). The N rate and application timing for both MSS was informed, in part, by previous research on legume containing swards (Enriquez-Hidalgo et al., 2018; Ledgard et al., 2001; Nyfeler et al., 2009) and on MSS in an Irish context (Grace, Lynch, et al., 2018b). Nitrogen fertilizer was spread in the form of protected urea (46% N) and protected urea + sulphur (38% N + 7% S) on a rotational basis after each defoliation with a total $20 \text{ kg S ha}^{-1} \text{ year}^{-1}$ target application as per recommendations in Wall and Plunkett (2020). Nitrogen was applied with an Amazone twin disc spreader at the following rates and timings to the PRG sward: 30 kg N ha^{-1} in March, 40 kg N ha^{-1} in April/May, 40 kg N ha^{-1} June, 40 kg N ha^{-1} in August, 15 kg N ha^{-1} September; PP: 30 kg N ha^{-1} in March, 40 kg N ha^{-1} in April/May, 25 kg N ha^{-1} June, 25 kg N ha^{-1} in

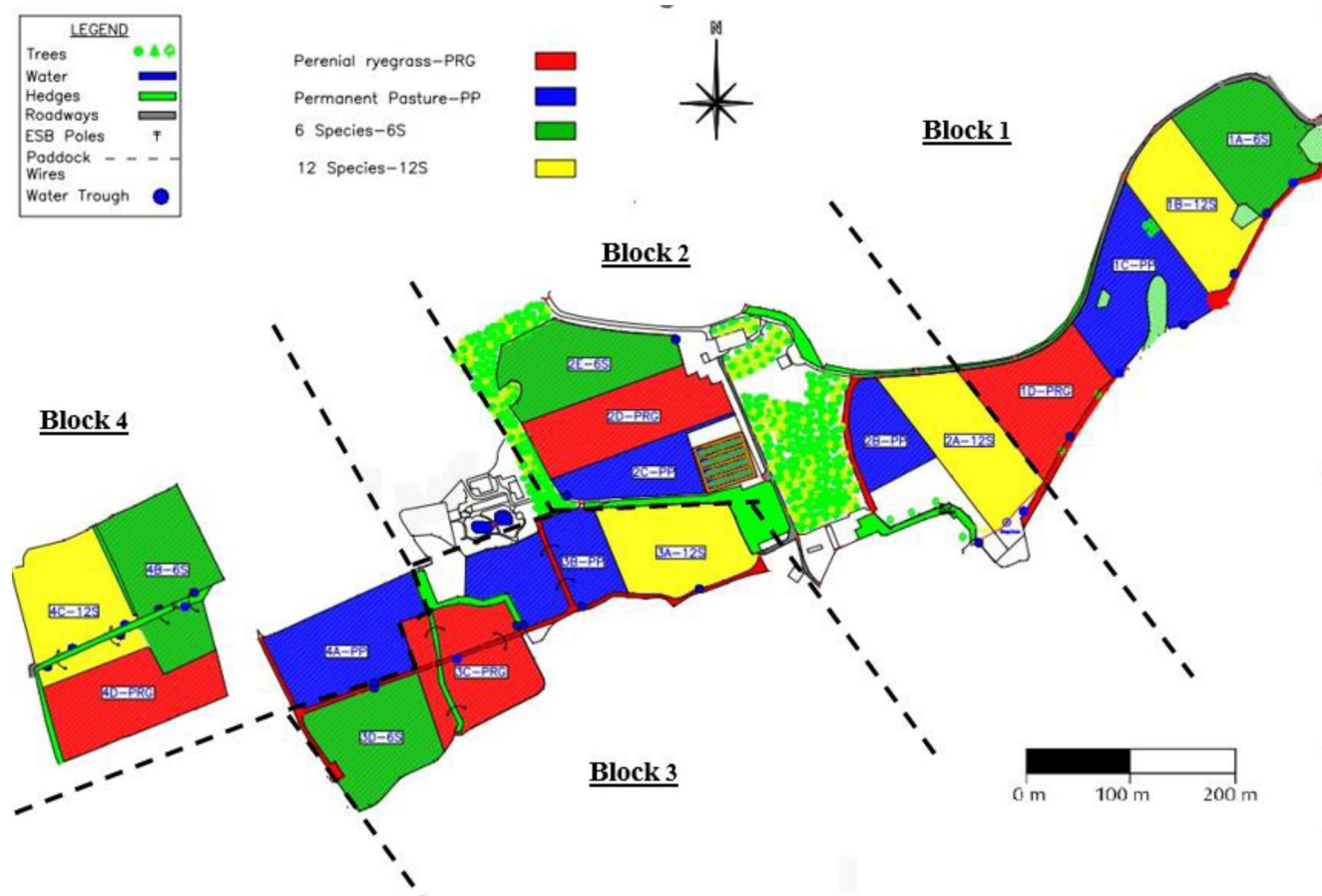


FIGURE 1 Experimental area (36 ha) divided into four randomized blocks, the four sward types randomly assigned within block and further subdivided into 1.15 ha paddocks. PRG: *L. perenne*, PP: Pre-existing permanent pasture, 6S: six species (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *C. intybus*, *P. lanceolata*). 12S: twelve species (*L. perenne*, *P. pratense*, *D. glomerata*, *T. repens*, *T. pratense*, *L. corniculatus*, *C. intybus*, *P. lanceolata*, *O. viciifolia*, *S. minor*, *P. crispum*, *A. millefolium*).

TABLE 1 The proportion (based on seed mass), seeding rates (g m^{-2} ; number of seeds m^{-2}) and varieties of each species per sown sward type.

Functional group Sward Type		Grass		Legume			Herb			Yarrow			
		PRG	Timothy	Cocksfoot	White clover	Red Clover	Birdsfoot trefoil	Sainfoin	Chicory		Plantain	Salad burnet	Sheep's parsley
PRG													
Proportion		1	0	0	0	0	0	0	0	0	0	0	0
Seeding rate (g m ⁻²)		3.7	0	0	0	0	0	0	0	0	0	0	0
¹ Number of seeds m ⁻²		1440	0	0	0	0	0	0	0	0	0	0	0
6S													
Proportion		0.32	0.08	0	0.13	0.26	0	0	0.12	0.1	0	0	0
Seeding rate (g m ⁻²)		1.25	0.3	0	0.5	1	0	0	0.48	0.38	0	0	0
Number of seeds m ⁻²		486	600	0	741	571	0	0	352	185	0	0	0
12S													
Proportion		0.14	0.11	0.07	0.1	0.2	0.01	0.11	0.11	0.09	0.03	0.01	0.01
Seeding rate (g m ⁻²)		0.63	0.5	0.25	0.44	0.88	0.06	0.5	0.48	0.38	0.13	0.06	0.06
Number of seeds m ⁻²		245	1000	250	651	503	75	33	352	185	19	39	400

Note: Sward types: PRG = perennial ryegrass only sward; 6S = six species sward containing perennial ryegrass, timothy, white clover, red clover, chicory, plantain; 12S = twelve species sward containing all species in 6S plus birdsfoot trefoil, sainfoin, salad burnet, sheep's parsley, and yarrow. Varieties: PRG: *L. perenne* (AberGain and AberChoice); Tim: *P. pratense* (Presto and Winnetou); Cocksfoot: *D. glomerata* (Intensiv and Donata); White clover: *T. repens* (Galway and Buddy); Red clover: *T. pratense* (AberChianti and AberClaret); Birdsfoot trefoil: *L. corniculatus* (Leo); Sainfoin: *O. viciifolia* (unnamed); Chicory: *C. intybus* (Puna II and Choice); Plantain: *P. lanceolata* (Tonic and AgriTonic); Salad burnet: *S. minor* (unnamed); Sheep's parsley: *P. crispum* (unnamed); Yarrow: *A. millefolium* (unnamed). ¹ Number of seeds m^{-2} were calculated from the 1000 seed weight of each species.

August, 15 kg N ha⁻¹ September; 6S and 12S: 30 kg N ha⁻¹ in March, 40 kg N ha⁻¹ in April/May. Lime, potassium (K), and phosphorous (P) applications were based on annual soil nutrient analysis from each individual paddock. A spring application of 0-10-20 (0 g N, 100 g P, 200 g K kg⁻¹) or muriate of potash (500 g kg⁻¹) was applied as required with a cap of 60 kg K ha⁻¹ to limit the risk of grass tetany in lactating ewes. Balances were applied in the late season and included additional applications depending on offtakes for silage (Wall & Plunkett, 2020).

2.4 | Pasture management

The four systems were rotationally co-grazed by 22 Suffolk cross ewes with lambs at foot and 20 heifers of Friesian x Angus or Hereford genetics. Heifers were approximately 13 months of age and 348 kg at turnout. This equated to an initial stocking rate of two LU ha⁻¹ at the beginning of each grazing year. Lambs were weaned at 16 weeks of age and were subsequently grazed in a leader-follower system whereby lambs grazed ahead of the ewes and heifers initially. Once the post grazing residual target +2 cm was achieved, the heifers were separated from the ewes and joined the lambs. Subsequently, when the ewes reached the post grazing residual target, the lambs moved forward again, and the leader-follower grazing system recommenced. Pre grazing herbage mass targets (PGHM) were 1500 kg DM ha⁻¹ ($\pm$ 300 kg DM ha⁻¹) above 4 cm for the PRG and PP swards and 2500 kg DM ha⁻¹ ($\pm$ 300 kg DM ha⁻¹) above 6 cm for 6S and 12S. Post grazing residual targets were 4 cm for PRG and PP and 6 cm for 6S and 12S. The targeted PGHM and post grazing residual for PRG and PP are commonly used to maximize forage quality at optimal forage maturity and to increase pasture utilization in rotational grazing systems (Chapman, 2016; Fulkerson & Donaghy, 2001; Lee et al., 2008; McEvoy et al., 2010). However, optimal grazing management of individual species within MSS often do not align and therefore necessitate compromise (Pembleton et al., 2015). Consequently, an alternative approach was adopted for the MSS based systems within the current study. This was characterized by higher pre and post grazing sward heights, which could potentially benefit less persistent species with higher growth points and upright growth habits such as *C. intybus*, *T. pratense* and *P. lanceolata* (Barreta et al., 2023; Cranston et al., 2015; Kemp et al., 2010). Herbage, in excess of grazing demand, was removed for silage by a rotary mower cutting to the target post grazing residual of 4 or 6 cm, depending on system, and wilted for a minimum of 48 h prior to baling as per recommendations by Moloney et al. (2020a).

2.5 | Herbage measurements

Pre and post grazing sward height was determined using a rising plate-meter (Jenquip, Fielding, New Zealand) by walking in a 'W' pattern across the paddock and measuring one hundred random heights per hectare. Pre grazing herbage mass (PGHM) and post grazing herbage

mass was determined by cutting herbage to the appropriate target height from five (0.25 m²) quadrats per paddock. A sub sample of 250 g was immediately dried to a constant weight at 55°C for 72 h in an air forced oven (UF750, Memmert GmbH and Co KG, Schwabach, Germany) to determine partial DM concentration prior to chemical composition analysis (Goering & Van Soest, 1970). The total DM content was calculated when the chemical composition of herbage was analysed (AOAC, 1995; method 930.15). Herbage daily growth rate (kg DM ha⁻¹ day⁻¹) was estimated weekly by cutting three (0.25 m²) quadrats per paddock, to the target post grazing sward height, weighing the herbage and drying to 105°C for 16 h to determine total DM concentration (AOAC, 1995; method 967.03). Paddock residency time was calculated as the number of days animals (leaders and followers) were resident in a paddock. The number of rotations was calculated as the number of times a paddock was either grazed or cut for silage within each year. Herbage accumulation was determined by calculating the number of residency days per paddock and multiplying by the daily herbage growth rate for that period as outlined by Doyle et al. (2021). Annual and seasonal DM production were determined by summing the pre grazing herbage mass at each defoliation event for each paddock in each year with the addition of the quantity of herbage accumulated. For analysis purposes the grazing season was divided into Early (March, April, May), Mid (June, July, August) and Late (September, October, November, December) seasonal periods. Herbage measurements were taken at all defoliation events in each seasonal period across two consecutive years.

2.6 | Botanical composition

A 250 g fresh weight sub sample of herbage (cut to the target post-grazing sward height) was taken prior to each defoliation from five 0.25 m² quadrats per paddock. This sample was separated into sown and unsown species and dried at 105°C for 16 h to determine the proportional contribution of each species to overall DM (AOAC, 1995; method 967.03).

2.7 | Herbage chemical composition

Samples were analysed for DM, ash content, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), organic matter digestibility (OMD) and water-soluble carbohydrate (WSC). The total DM content (g kg⁻¹ FW) of the herbage samples was determined by multiplying the partial DM content by the laboratory DM content at the time when other chemical constituents were determined (AOAC, 1995; method 930.15). Ash concentration (g kg⁻¹ DM) was determined by complete combustion in a muffle furnace (Nabertherm, GmbH, Lilienthal, Germany) at 550°C for 4.5 h (AOAC, 1995; method 942.05). Nitrogen concentration (g kg⁻¹ DM) was determined using a FOSS Kjeltac 8400 analyser (FOSS, 3400 Hillerød, Denmark) and multiplied by 6.25 to determine CP concentrations (g kg⁻¹ DM) (Kjeldahl, 1883). The NDF, ADF and ADL

concentrations (g kg^{-1} DM) were analysed using the ANKOM220 Fibre Analyser (ANKOM Technology, Macedon, NY) as per the methodologies outlined by Van Soest et al. (1991). Organic matter digestibility (g kg^{-1} OM) was estimated using the in vitro method as per Tilley and Terry (1963) using a Daisy II Incubator (ANKOM Technology, Macedon, NY). The concentration of WSC (g kg^{-1} DM) was determined using the anthrone method (Thomas, 1977).

2.8 | Meteorological data

Mean air temperature ($^{\circ}\text{C}$), mean rainfall (mm day^{-1}), total rainfall for the year and soil temperature ($^{\circ}\text{C}$) at 10 cm was recorded at the study site using a Davis Vantage Pro weather station (Davis Instruments, Hayward, CA, USA). Mean annual air temperature was higher than the 10-year average in both 2020 and 2021 by 0.2°C and 0.04°C respectively. Total annual rainfall was lower than the 10-year average in both 2020 and 2021 by 4% and 5% respectively, and mean soil temperature was 0.7°C higher in 2021 than in 2020 (Table 2).

2.9 | Statistical analysis

Herbage data was analysed using the linear mixed model procedure in SAS PROC MIXED (SAS, version 9.4, Inst. Inc., Cary, NC). Individual paddock within treatment was used as the experimental unit ($n = 8$). Measurements of herbage production and chemical composition were analysed using the fixed effects of system (sward type, N rate and grazing management), season, and year and their associated interactions. Botanical composition data was investigated within each system, with the effect of season and year and the interaction between season and year analysed. Differences between means were made using LSMEANS and adjusted by TUKEY for multiple comparisons.

Data distributions were analysed to fit the assumption of normality using the UNIVARIATE procedure. The data were considered statistically significant when $p < 0.05$ and is expressed as least square means $\pm$ SEM.

3 | RESULTS

3.1 | Herbage production

3.1.1 | Dry matter production

Over the two-year experimental period, both multispecies systems (6S and 12S) produced significantly more herbage DM than PP ($p < 0.01$), while 6S alone outperformed PRG ($p < 0.01$). Significantly more herbage DM was produced by PP, PRG and 6S in 2021 compared to 2020 ($p < 0.05$). In early season, DM production was greater from both MSS compared to PP ($p < 0.05$), while 6S produced significantly more than all other systems in mid-season ($p < 0.01$; Table 3).

3.1.2 | Herbage masses, residency periods and rotations

Annually, the mean pre-grazing herbage masses for PRG and PP were lower compared to both MSS ($p < 0.0001$) which aligned with the different target pre-grazing herbage mass for different systems. When compared across season a similar relationship was found, aside from in late season, when there was no treatment difference in pre-grazing herbage mass ($p > 0.05$; Table 3). In late season, when averaged across both years, PRG had a longer paddock residency time than any other system ($p < 0.05$). Overall, there were more rotations in 2021 compared to 2020 ($p < 0.05$; Table 3).

TABLE 2 Total monthly rainfall (mm), average daily temperature ($^{\circ}\text{C}$), and average soil temperature ($^{\circ}\text{C}$) at the experimental site for 2020 and 2021 compared to the 10-year average (yr; 2012–2022) at Ardcaif station, County Meath, Ireland.

Month	Total monthly rainfall (mm) 2020	Total monthly rainfall (mm) 2021	Total monthly rainfall (mm) 10-year average (Ardcaif)	Average air temperature ($^{\circ}\text{C}$) 2020	Average air temperature ($^{\circ}\text{C}$) 2021	Average air temperature ($^{\circ}\text{C}$) 10-year average (Ardcaif)	Average 10 cm soil temperature ($^{\circ}\text{C}$) 2020	Average 10 cm soil temperature ($^{\circ}\text{C}$) 2021
January	36	115	70	6	4	5	5	3
February	135	88	71	6	6	5	4	5
March	37	53	62	6	7	6	5	7
April	19	30	44	9	6	8	9	8
May	14	86	58	12	9	11	13	10
June	101	15	67	14	14	14	14	15
July	120	57	76	14	17	15	15	18
August	91	95	97	15	15	15	14	16
September	60	43	66	13	15	13	13	15
October	91	96	90	9	12	10	9	11
November	61	29	92	8	8	7	7	7
December	84	133	88	5	7	5	4	6

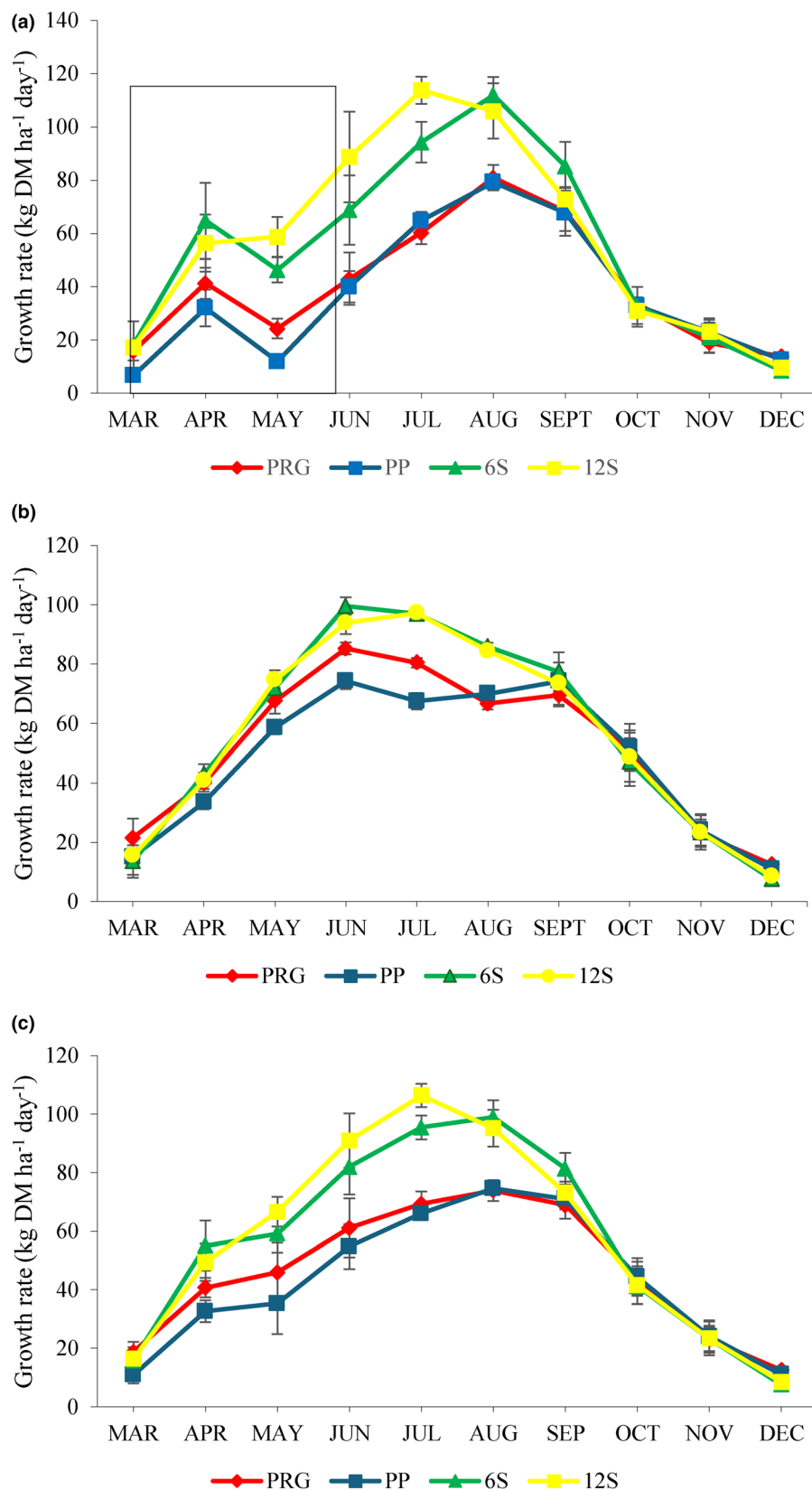
TABLE 3 The effect of sward type on annual and seasonal herbage production, grazed and silage herbage production, pre-grazing and pre-silage cutting herbage masses, residency period (days) and number of rotations in 2020, 2021 and as an average of both years (data are least square means and SEM).

Sward type ^a	2020					2021					2-year average					SEM	sig.	
	PRG	PP	6S	12S	SEM	sig	PRG	PP	6S	12S	SEM	sig	PRG	PP	6S			12S
Total herbage production (kg DM ha ⁻¹)	10,546 ^b	7741 ^a	13,643 ^c	13,432 ^c	640	*	12,195 ^{ab}	10,055 ^a	13,849 ^b	13,203 ^b	737	*	11,374 ^b	8526 ^a	13,783 ^c	13,338 ^{bc}	731	**
Grazed	6049	5749	8585	7991	1056	ns	6694	5623	8565	7823	1037	ns	6372 ^a	5486 ^a	8536 ^b	7907 ^{ab}	733	(*)
Silage	4497	1960	5049	5455	1260	ns	5507	4434	5296	5406	978	ns	5002	3197	5172	5431	891	ns
Early	3602 ^{ab}	1659 ^a	4288 ^{ab}	4476 ^b	476	*	4525 ^a	3624 ^a	4466 ^a	6440 ^b	539	(*)	4063 ^{ab}	2542 ^a	4377 ^b	5458 ^b	507	*
Mid	3892	3563	6112	5939	691	ns	4753 ^a	3514 ^a	6731 ^b	3488 ^a	652	**	4323 ^a	3539 ^a	6429 ^b	4689 ^a	671	**
Late	2781	2094	3178	2793	323	ns	3084	2918	2643	3115	379	ns	2932	2446	2885	2889	377	ns
Pre-grazing herbage mass (kg DM ha ⁻¹)																		
Annual	1939 ^a	1846 ^a	2732 ^b	2483 ^b	179	**	1609 ^a	1703 ^a	2406 ^b	2408 ^b	166	**	1757 ^a	1770 ^a	2555 ^b	2419 ^b	122	****
Early	2226 ^a	1886 ^a	3027 ^b	3273 ^b	260	(*)	1744 ^a	1845 ^{ab}	2722 ^{ab}	2779 ^b	225	(*)	1985 ^a	1866 ^a	2874 ^b	3026 ^{bx}	172	**
Mid	1704 ^a	1773 ^{ab}	2622 ^b	2365 ^b	191	(*)	1537 ^a	1655 ^a	2393 ^b	2291 ^b	179	(*)	1620 ^a	1714 ^a	2508 ^b	2328 ^{by}	132	*
Late	2047	1931	2649	2238	205	ns	1565	1610	2104	2101	235	ns	1806	1771	2376	2169 ^y	156	ns
Residency (days)																		
Annual	17.5	15.1	16.6	14.1	2.2	ns	20.1	19.8	13.9	15	2.2	ns	18.8	17.5	15.3	14.6	2.2	ns
Early	21.1	18.5	19.1	19.1	1.9	ns	12.1	16.2	12.8	11.7	1.7	ns	16.6	17.4	15.9	15.4	1.8	ns
Mid	15.1	10.9	16.0	10.3	2.0	ns	14.7	16.2	13.1	13.6	2.1	ns	14.9	13.5	14.6	12.0	2.1	ns
Late	18.5	18.4	14.9	14.0	3.2	ns	37.7 ^b	30.8 ^{ab}	16.5 ^a	19.8 ^a	5.9	*	28.3 ^b	24.6 ^a	15.7 ^a	17.1 ^a	4.6	*
Number of rotations	3.9	3.5	4.3	4.5	0.3	ns	5.0	4.4	4.5	4.6	0.35	ns	4.4	3.9	4.4	4.6	0.3	ns

Note: Within rows, means with differing superscripts (ab) differ significantly ($P < 0.05$). Within rows, means with differing superscripts with a tendency to differ ($P < 0.1$). Within columns for pre-grazing herbage mass seasonal means with differing superscript symbols (*) differ significantly ($P < 0.05$). (Sig.) significance levels P: ns > 0.1, (*) < 0.1, * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001.

^aPP: Permanent pasture, PRG: L. perenne only, 6S: six species sward (L. perenne, P. pratense, T. repens, T. pratense, C. intybus, P. lanceolata), 12S: twelve species sward (L. perenne, P. pratense, D. glomerata, T. repens, T. pratense, L. comiculatus, P. lanceolata, C. intybus, O. viciifolia, S. minor, P. crispum, A. millefolium).

FIGURE 2 The effect of sward type on herbage growth rate ($\text{kg DM ha}^{-1} \text{ day}^{-1}$) per sward type in (a) 2020 (period of below average rainfall (March–June 2020) highlighted by boxed area), (b) 2021 and (c) as an average of both years Error bars represent $\pm$ SEM. PRG: *L. perenne* only, PP, permanent pasture, 6S, six species sward, 12S: Twelve species sward.



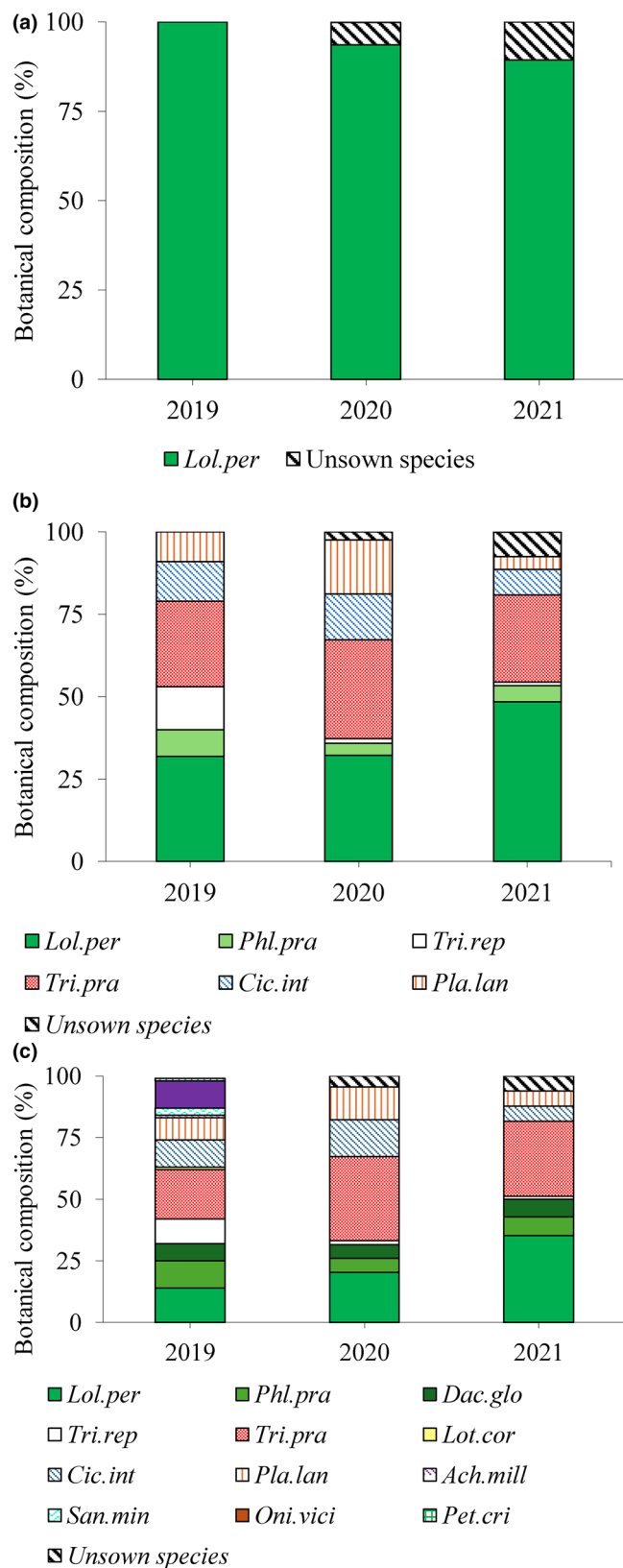
3.1.3 | Herbage daily growth rates

In early season 2020, there was a period of below average rainfall from March to June (Table 2) and herbage daily growth rates (kg DM

$\text{ha}^{-1} \text{ day}^{-1}$) for this period are highlighted in Figure 2a. It was noted that both PP and PRG had significantly lower growth rates than either MSS ($p < 0.0001$). The daily herbage growth rate for PP, PRG and 6S peaked in August 2020 (Figure 2a) and in June 2021 (Figure 2b), while

across both years, the mean daily herbage growth rate for 12S was highest in July (Figure 2c). Overall, 6S and 12S had higher daily herbage growth rates than PP and PRG ($p < 0.0001$; Figure 2c). In early

season, PP had lower daily herbage growth rates than either MSS ($p < 0.0001$) while in mid-season, both PP and PRG had lower daily herbage growth rates compared to 6S and 12S ($p < 0.0001$).



3.1.4 | Botanical composition

In PRG, the percentage contribution of *L. perenne* to herbage DM tended to decrease ($p < 0.1$), while that of the unsown grasses increased from 2020 to 2021 ($p < 0.05$; Figure 3). The botanical composition of PP remained unchanged across the two experimental years (Table 4).

The contribution of *L. perenne* to herbage DM in the 6S increased from 2020 to 2021 ($p < 0.0001$; Table 4, Figure 3). Across both years, the contribution of *L. perenne* increased in mid ($p < 0.05$) and late season ($p < 0.01$; Table 5). The contribution of both *C. intybus* and *P. lanceolata* to herbage DM decreased from 2020 to 2021 ($p < 0.05$; $p < 0.0001$ respectively). Early and late season percentage contribution of *P. lanceolata* to herbage DM were greater than mid-season ($p < 0.05$). The contribution of *T. pratense* to herbage DM was greatest in mid compared to early and late season ($p < 0.001$), while that of the unsown herb species increased from 2020 to 2021 ($p < 0.01$; Table 5).

The percentage contribution of *L. perenne* to herbage DM in 12S increased from 2020 to 2021 ($p < 0.01$; Table 4). This increase was most pronounced between the early season of 2020 (19%) versus early season 2021 (44%) (SEM 5; $p < 0.05$). The contribution of *P. pratense* in early season was greater than in late season ($p < 0.05$). Similar to 6S, a significant decrease in the contribution of *C. intybus* and *P. lanceolata* to herbage DM was observed from 2020 to 2021 ($p < 0.001$; $p < 0.001$ respectively; Table 4, Figure 3). There was a significant reduction from mid-season 2020 (16%) to 2021 (5%) in the contribution of *C. intybus* to herbage DM (SEM 3; $p < 0.05$), while the contribution of *P. lanceolata* significantly decreased from late season 2020 (19%) to 2021 (8%) (SEM 2; $p < 0.01$). *L. corniculatus*, *A. millefolium*, *O. viciifolia*, *S. minor* and *P. crispum* did not contribute to herbage DM at a level that could be quantified.

3.1.5 | Annual nutritive value of herbage

In terms of the two-year average, DM content was influenced by system, with higher content in PRG and PP relative to both MSS

FIGURE 3 Development of the annual sown and unsown species proportion (%) in 2020 and 2021 compared to the actual sowing rate of species in 2019. (a) *L. perenne* only sward (b) six species sward (c) twelve species sward. *Lol.per*: *L. perenne*, *Phl.pra*: *P. pratense*, *Dac.glo*: *D. glomerata*, *Tri.rep*: *T. repens*, *Tri.pra*: *T. pratense*, *Lot.cor*: *L. corniculatus*, *Cic.int*: *C. intybus*, *Pla.lan*: *P. lanceolata*, *Ach.mill*: *A. millefolium*, *San.min*: *S. minor*, *Oni.vici*: *O. viciifolia*, *Pet.cri*: *P. crispum*.

TABLE 4 The annual percentage contribution of each sown species, unsown species and dead material to overall herbage DM produced per sward type in 2020, 2021, and as averaged across the 2 years (data are least square means and SEM).

Sward type ^a	2020	2021	2-year-average	SEM	Sig.
PRG					
<i>Lolium perenne</i>	94	89	91	3	(*)
Unsown grass spp.	3	8	6	2	*
Unsown herb spp.	2	2	2	1	ns
Dead material	1	1	1	1	ns
PP					
<i>Lolium perenne</i>	41	43	42	5	ns
<i>Holcus lanatus</i>	14	15	15	1	ns
<i>Phleum pratense</i>	7	6	8	2	ns
<i>Dactylis glomerata</i>	6	6	6	2	ns
<i>Poa</i> spp.	5	7	5	1	ns
<i>Elymus repens</i>	3	3	3	1	ns
<i>Agrostis</i> spp.	3	4	3	1	ns
<i>Festuca</i> spp.	0	2	1	0	*
Other grass spp. (<1%)	8	2	5	5	ns
<i>Ranunculus</i> spp.	3	3	3	1	ns
<i>Cirsium</i> spp.	1	1	1	1	ns
<i>Rumex obtusifolius</i>	1	1	1	1	ns
<i>Taraxacum</i> spp.	1	3	2	1	ns
Other herb spp. (<1%)	1	0	1	0	ns
<i>Trifolium repens</i>	1	3	2	1	ns
Dead material	5	2	3	2	ns
6S					
<i>Lolium perenne</i>	32	49	41	4	****
<i>Phleum pratense</i>	4	5	4	2	ns
<i>Cichorium intybus</i>	14	8	11	3	*
<i>Plantago lanceolata</i>	16	4	10	2	****
<i>Trifolium repens</i>	1	1	1	0	ns
<i>Trifolium pratense</i>	30	27	29	5	ns
Unsown grass spp.	1	3	2	1	ns
Unsown herb spp.	1	5	3	2	*
Dead material	1	1	1	1	ns
12S					
<i>Lolium perenne</i>	20	35	28	5	**
<i>Phleum pratense</i>	6	8	7	2	ns
<i>Dactylis glomerata</i>	5	7	6	2	ns
<i>Trifolium repens</i>	2	1	2	0	ns
<i>Trifolium pratense</i>	33	30	32	5	ns
<i>Cichorium intybus</i>	15	6	11	2	***
<i>Plantago lanceolata</i>	13	6	10	2	***
Unsown grass spp.	1	2	2	1	ns
Unsown herb spp.	3	4	4	1	ns
Dead material	2	1	1	1	ns

^aPRG: *L. perenne* only, PP: permanent pasture, 6S: six species sward (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *C. intybus*, *P. lanceolata*), 12S: twelve species sward (*L. perenne*, *P. pratense*, *D. glomerata*, *T. repens*, *T. pratense*, *L. corniculatus*, *P. lanceolata*, *C. intybus*, *O. viciifolia*, *S. minor*, *P. crispum*, *A. millefolium*). (Sig.) significance levels: ns > 0.1, (*) < 0.1, * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001. Species within PP which accounted for <1% of total DM are presented by functional group. Where sown species were not recorded, they were omitted from the table.

TABLE 5 The percentage contribution of sown and unsown species and dead material to overall herbage DM produced per sward type in each season (data are least square means and SEM).

Sward type ^a	Early	Mid	Late	SEM	Sig.
PRG					
<i>Lolium perenne</i>	93	93	89	3	ns
Unsown grass	5	4	8	3	ns
Unsown herb	2	1	3	1	ns
Dead material	1	1	1	1	ns
PP					
<i>Lolium perenne</i>	42	37	45	4	ns
<i>Holcus lanatus</i>	13	18	12	2	ns
<i>Festuca</i> spp.	1	2	0	1	ns
<i>Dactylis glomerata</i>	5	10	6	2	ns
<i>Phleum pratense</i>	8	9	8	2	ns
<i>Elymus repens</i>	1	2	2	1	ns
<i>Poa</i> spp.	6	3	4	2	ns
<i>Agrostis</i> spp.	4	2	2	1	ns
Other grass spp. (<1%)	9	5	3	4	ns
<i>Ranunculus</i> spp.	4	3	3	1	ns
<i>Taraxacum officinale</i> spp.	1	2	2	1	ns
<i>Cirsium</i> spp.	0	2	1	1	ns
<i>Rumex obtusifolius</i>	1	1	1	1	ns
Other herb spp. (<1%)	1	1	1	1	ns
<i>Trifolium repens</i>	1	2	3	1	ns
Dead material	3	2	6	3	ns
6S					
<i>Lolium perenne</i>	45	35	42	5	ns
<i>Phleum pratense</i>	7	3	3	2	ns
<i>Trifolium repens</i>	1	1	1	0	ns
<i>Trifolium pratense</i>	22 ^a	43 ^b	21 ^a	7	**
<i>Cichorium intybus</i>	9	8	15	3	ns
<i>Plantago lanceolata</i>	12 ^a	5 ^b	13 ^a	2	*
Unsown grass spp.	2	1	3	1	ns
Unsown herb spp.	3	3	3	2	ns
Dead material	1	1	1	1	ns
12S					
<i>Lolium perenne</i>	30	27	25	6	ns
<i>Phleum pratense</i>	12 ^a	6 ^{ab}	2 ^b	3	**
<i>Dactylis glomerata</i>	6	5	8	3	ns
<i>Trifolium repens</i>	2	2	1	1	ns
<i>Trifolium pratense</i>	24	39	32	7	(*)
<i>Cichorium intybus</i>	10	10	12	3	ns
<i>Plantago lanceolata</i>	11 ^{ab}	6 ^a	12 ^b	2	**
Unsown grass spp.	3	1	1	1	ns
Unsown herb spp.	2	4	5	1	ns
Dead material	1	0	2	1	ns

^aPRG: *L. perenne* only, PP: permanent pasture, 6S: six species sward (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *C. intybus*, *P. lanceolata*), 12S:

twelve species sward (*L. perenne*, *P. pratense*, *D. glomerata*, *T. repens*, *T. pratense*, *L. corniculatus*, *P. lanceolata*, *C. intybus*, *O. viciifolia*, *S. minor*, *P. crispum*, *A. millefolium*). (Sig.) significance levels P: ns >0.1, (*) < 0.1, * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001. Species within PP which accounted for <1% of total DM are presented by functional group. Where sown species were not recorded, they were omitted from the table.

($p < 0.05$; Table 6), while WSC was highest in PRG compared to the other systems ($p < 0.0001$). The NDF difference between systems was also highly significant, with PP higher than PRG which in turn was higher than both 6S and 12S ($p < 0.001$). The two-year average ADF concentration of PP was significantly higher than both PRG and 6S ($p < 0.05$) but similar to 12S ($p > 0.05$), while it was similar for PRG, 6S and 12S ($p > 0.05$). Year influenced the ADL concentration across all systems, with lower levels in 2020 compared to 2021 ($p < 0.0001$). When averaged across both experimental years, 12S herbage had a significantly higher ADL concentration compared to PRG ($p < 0.05$) but was similar to PP and 6S ($p > 0.05$). While higher OMD was recorded across all systems in 2021 compared to 2020 ($p < 0.01$), when averaged across both years, PRG had higher OMD relative to PP ($p < 0.001$) but was similar to 6S and 12S ($p > 0.05$). Both MSS had higher ash content than PRG ($p < 0.001$) but were similar to PP (Table 6).

3.1.6 | Seasonal nutritive value of herbage

On average in early season, PRG had significantly higher DM content compared to all other treatments ($p > 0.01$), while in mid-season, DM content was higher in herbage from both PRG and PP compared to the two MSS ($p < 0.05$; Table 7). Across all systems, lowest DM content of the herbage was in late season compared to early and mid-season ($p < 0.001$). The CP levels in the late season were significantly higher than in either early and mid-season in all systems (PRG: $p < 0.001$; PP: $p < 0.05$; 6S: $p < 0.01$; 12S: $p < 0.05$; Table 7).

There was an interaction between system and season ($p < 0.01$) whereby the WSC content of PRG in early season and mid-season was significantly higher than PP, 6S and 12S ($p < 0.0001$) but in late season all systems were similar ($p > 0.05$). Across all systems, WSC was highest in the early compared to mid and late seasons ($p < 0.001$). The NDF content of the herbage was also influenced by an interaction between system and season ($p < 0.05$). In this instance, early and mid-season PP herbage had the highest NDF compared to all other systems ($p < 0.05$). By late season, the NDF content of PP was significantly higher than 12S only ($p < 0.05$) and similar to the other systems (Table 7). In PRG, 6S and 12S, early season had the lowest NDF content compared to mid and late seasons (PRG: $p < 0.001$; 6S: $p < 0.001$; 12S: $p < 0.01$) while PP had lower NDF content in early and late season compared to mid-season PP ($p < 0.001$; $p < 0.05$).

Across all systems lowest levels of ADF were recorded in early season compared to mid and late season (PRG: $p < 0.0001$; PP:

TABLE 6 The effect of sward type on mean annual herbage chemical composition in 2020, 2021 and averaged over the two experimental years (data are least square means and SEM).

Sward type ^a	2020					2021					2- year average							
	PRG	PP	6S	12S	SEM	Sig	PRG	PP	6S	12S	SEM	Sig	PRG	PP	6S	12S	SEM	Sig
	199 ^a	202 ^a	155 ^b	153 ^b	13	*	185 ^a	172 ^{ab}	148 ^b	155 ^{ab}	12	*	191 ^a	187 ^a	152 ^b	154 ^b	8	*
Composition (g kg ⁻¹ DM)																		
Crude Protein (CP)	131 ^b	142 ^a	148 ^a	160 ^a	9	*	153	148	151	150	8	ns	142	145	149	155	6	ns
Water soluble carbohydrate (WSC)	298 ^a	192 ^b	175 ^b	165 ^b	18	****	252 ^a	168 ^b	171 ^b	170 ^b	16	****	275 ^a	180 ^b	173 ^b	168 ^b	12	****
Neutral detergent fibre (NDF)	401 ^b	449 ^a	347 ^c	347 ^c	11	*	401 ^{ab}	439 ^a	364 ^b	384 ^b	10	***	401 ^b	444 ^a	356 ^c	362 ^c	11	***
Acid detergent fibre (ADF)	214 ^b	240 ^a	217 ^{ab}	220 ^{ab}	8	*	214	233	221	231	8	ns	214 ^b	237 ^a	219 ^b	225 ^{ab}	6	*
Acid detergent lignin (ADL)	20	24	34	44	9	ns	45	67	66	70	8	ns	33 ^b	45 ^{ab}	50 ^{ab}	57 ^a	9	*
Organic matter digestibility (OMD) (g kg ⁻¹ OM)	854 ^a	801 ^b	849 ^{ab}	833 ^{ab}	16	*	877	840	841	843	15	ns	865 ^a	821 ^b	845 ^{ab}	838 ^{ab}	11	***
Ash content	73 ^b	81 ^{ab}	91 ^a	89 ^a	4	***	82	88	92	86	4	ns	77 ^b	85 ^{ab}	92 ^a	88 ^a	3	***

Note: Dry matter content expressed as grams per kilogram of fresh weight (g kg⁻¹ FW). Organic matter digestibility expressed as grams per kilogram of organic matter (g kg⁻¹ OM). All other variables are expressed as grams per kilogram of dry matter (g kg⁻¹ DM). Within rows, means with differing superscripts (a-c) differ significantly. (Sig.) significance levels P: ns >0.05, * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001.

^aSward Type = PRG: *L. perenne* only, PP: permanent pasture, 6S: six species sward (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *C. intybus*, *P. lanceolata*), 12S: twelve species sward (*L. perenne*, *P. pratense*, *D. glomerata*, *T. repens*, *T. pratense*, *L. corniculatus*, *P. lanceolata*, *C. intybus*, *O. viciifolia*, *S. minor*, *P. crispum*, *A. millefolium*).

TABLE 7 The effect of sward type on mean seasonal herbage chemical composition (data are least square means and SEM).

Sward Type ^a	PRG	PP	6S	12S	SEM	Sig
Early (March–May)						
Dry matter content (g kg ⁻¹ FW)	227 ^a	199 ^b	164 ^b	166 ^b	16	**
Composition (g kg ⁻¹ DM)						
Crude Protein (CP)	124	140	144	152	12	ns
Water soluble carbohydrate (WSC)	404 ^a	246 ^b	259 ^b	243 ^b	23	****
Neutral detergent fibre (NDF)	340 ^b	409 ^a	293 ^b	320 ^b	19	*
Acid detergent fibre (ADF)	181	207	173	193	18	ns
Acid detergent lignin (ADL)	33	46	44	45	17	ns
Organic matter digestibility (OMD) (g kg ⁻¹ OM)	881	834	892	867	20	ns
Ash content	66	78	85	81	4	ns
Mid (June–August); g kg DM ⁻¹)						
Dry matter content (g kg ⁻¹ FW)	195 ^a	204 ^a	160 ^b	157 ^b	15	*
Composition (g kg ⁻¹ DM)						
Crude Protein (CP)	140	128	144	148	9	ns
Water soluble carbohydrate (WSC)	238 ^a	158 ^b	137 ^b	129 ^b	18	****
Neutral detergent fibre (NDF)	428 ^b	478 ^a	372 ^c	391 ^{bc}	15	*
Acid detergent fibre (ADF)	232 ^b	261 ^a	240 ^{ab}	243 ^{ab}	8	*
Acid detergent lignin (ADL)	28	42	43	54	13	ns
Organic matter digestibility (OMD) (g kg ⁻¹ OM)	845	796	822	819	16	ns
Ash content	79	80	87	86	3	ns
Late (September–December)						
Dry matter content (g kg ⁻¹ FW)	152	158	132	142	12	ns
Composition (g kg ⁻¹ DM)						
Crude Protein (CP)	162	166	160	164	10	ns
Water soluble carbohydrate (WSC)	183	136	123	131	20	ns
Neutral detergent fibre (NDF)	435 ^{ab}	446 ^a	403 ^{ab}	386 ^b	17	*
Acid detergent fibre (ADF)	229	243	243	238	9	ns
Acid detergent lignin (ADL)	36	48	63	72	15	ns
Organic matter digestibility (OMD) (g kg ⁻¹ OM)	870	832	822	829	18	ns
Ash content	87 ^b	95 ^b	103 ^a	96 ^{ab}	3	*

^aSward Type = PRG: *L. perenne* only, PP: permanent pasture, 6S: six species sward (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *C. intybus*, *P. lanceolata*), 12S: twelve species sward (*L. perenne*, *P. pratense*, *D. glomerata*, *T. repens*, *T. pratense*, *L. corniculatus*, *P. lanceolata*, *C. intybus*, *O. viciifolia*, *S. minor*, *P. crispum*, *A. millefolium*). Dry matter content expressed as grams per kilogram of fresh weight (g kg⁻¹ FW). Organic matter digestibility expressed as grams per kilogram of organic matter (g kg⁻¹ OM). All other variables expressed as grams per kilogram of dry matter (g kg⁻¹ DM). Within rows, means with differing superscripts (^{a-c}) differ significantly. (Sig.) significance levels P: ns >0.05, * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001.

$p < 0.01$, 6S: $p < 0.0001$, 12S: $p < 0.0001$). The OMD of early season herbage from 6S was greater than that from 6S herbage in mid and late season ($p < 0.001$). Late season 6S had higher ash content compared to PRG and PP ($p < 0.05$). Across all systems, the highest levels of ash were recorded in late season compared to early and mid-seasons (PRG: $p < 0.001$; PP: $p < 0.05$; 6S: $p < 0.01$; 12S: $p < 0.05$).

4 | DISCUSSION

4.1 | Dry matter production

In the context of mounting pressures to enhance the sustainability of ruminant systems, the current study demonstrates the ability of MSS

to produce more herbage DM of high nutritional value from lower fertilizer N inputs relative to PRG monocultures and PP swards. The 6S produced 17% and 38% more herbage DM while receiving 59% and 21% less fertilizer N than the PRG and PP systems respectively. High DM production from MSS has been well documented at plot scale (Finn et al., 2013; Grace, Boland, et al., 2019; Kirwan et al., 2007). While fewer studies have investigated MSS performance under grazing livestock, Grace, Boland, et al. (2018a) found comparable DM production from MSS fertilized with 90 kg N ha⁻¹ year⁻¹ and PRG fertilized with 163 kg N ha⁻¹ year⁻¹, while Baker et al. (2023a) reported a 21% increase in DM production from MSS fertilized with 90 kg N ha⁻¹ year⁻¹ compared to a PRG monoculture fertilized with 205 kg N ha⁻¹ year⁻¹ in a beef grazing system. The findings from the current study are therefore, in line with previous MSS

studies, albeit managed under different systems. No yield advantage was found from increasing the sown species richness of the multispecies swards from six to twelve. Both MSS produced statistically similar herbage DM yields, but on average the 12S produced almost 0.5 t DM ha⁻¹ year⁻¹ less than 6S. Similarly, Grace, Boland, et al. (2018a) and Sanderson et al. (2005) found no significant yield benefit from increasing sown species richness of mixtures from six to nine species. This likely indicates a saturation point in terms of the yield benefit accrued from increased species inclusion in MSS. Jing et al. (2017) reported an increase in herbage DM yield associated with a modest increase in sown species richness from ten to twelve species which was attributed to the dominance of *Medicago sativa* L. which accounted for most of the yield increase. The DM production of MSS in the current study was unaffected by the botanical changes within sward from 2020 to 2021 (see 4.1.4). During this time, *T. pratense*, a high-yielding legume, accounted for approximately 30% of herbage DM and by 2021 it should be noted that the grass and legume components contributed to the majority of herbage DM produced by the MSS. Indeed, binary mixtures of grass and legume species are well-documented in their ability to improve herbage DM production and nutritive values (Egan et al., 2018; Elgersma & Søegaard, 2016; Guy et al., 2018). While the inclusion of a binary mix would perhaps would have represented a valuable comparison in the present study, findings by Baker et al. (2023a) showed a significant DM yield advantage of a six species MSS over a perennial ryegrass – white clover-based system grazed by dairy calf to beef. However, it should be acknowledged that longer term observation of the different systems is necessary to fully appreciate the potential for DM yield differences between MSS and binary mixtures.

In general, reseeding is known to result in an initial increase in herbage production (Shalloo et al., 2011). In the current study, all resown treatments (PRG, 6S, 12S) produced greater herbage DM yield compared to PP in 2020. However, in 2021, the herbage DM yield from PP increased by 23%, relative to its 2020 performance i.e., similar to the PRG system, despite receiving ca. 21% less fertilizer N. However, the yield from PP was significantly lower than that produced from either of the MSS systems, despite the fact that they received ca. 52% less fertilizer N. Despite the yield benefits, reseeding should be given very careful consideration prior to its implementation. The decision to undertake it should not be solely determined by biomass production as a number of other factors also warrant consideration e.g., herbage nutritive value (see 5.3), costs, and the potential yield loss in the establishment year (Hopkins et al., 1990; Teagasc, 2017). Indeed, Humphreys and Casey (2002) recommend that reseeding of permanent pasture should only be considered when the proportional contribution of *L. perenne* to herbage DM falls below 20%, which is much lower than the observed *L. perenne* contribution to PP herbage in the current study.

Availability of herbage throughout the year is another important consideration for farmers, with early season herbage availability being of particular economic value (McEvoy et al., 2011). Early spring turnout of animals from winter housing can improve animal performance (Dillon et al., 2002) and herbage quality (O'Donovan & Delaby, 2008)

whilst also reducing the requirement for costly silage and concentrate supplementation (Crosson et al., 2014; Finneran et al., 2012). Similarly, extending grazing later into the year and thereby delaying animal housing (where ground conditions allow) improves overall farm profitability (Hanrahan et al., 2018). Consequently, perceived low growth rates of legumes relative to grasses during early and late season, due to their higher soil temperature requirement (Egan et al., 2018), raises concerns regarding the potential implications of their inclusion in swards on herbage availability during these periods (Humphreys et al., 2009). However, the current study found similar herbage growth rates for both MSS and PRG swards in both early and late season. Similar findings were reported by Baker et al. (2023a). This can likely be attributed to the front loading of N application to MSS in the early season, when the contribution of the legume component to herbage DM was at its lowest. In addition, the rate of N fixation in response to temperature can vary between legume species, with lower temperatures tolerated by *T. pratense* compared to *T. repens* (Liu et al., 2011). Therefore, the dominance of high yielding *T. pratense* in both MSS could explain why the herbage growth rates associated with both MSS were comparable to PRG. The lower herbage growth rates observed in PP compared to the sown swards is likely due to sward age and botanical composition, thus reflecting the reduced response of PP to nutrients such as N compared to PRG (Teagasc, 2017).

Environmental perturbations such as increased frequency of summer drought and changes to precipitation patterns experienced due to climate change (Nolan, 2015) necessitate the development of enhanced sward resilience to ensure consistent supply of herbage from grasslands (Vogel et al., 2012). Plants with deeper rooting systems, which allow them to access moisture resources in lower levels of the soil profile, such as *C. intybus*, and *T. pratense* are generally thought to tolerate extended periods of low rainfall better than shallower rooting species such as *L. perenne* (Chaves et al., 2003; Hoekstra et al., 2015). Indeed, Grange et al. (2021) have reported similar herbage DM yields from mixtures of comparable composition to the 6S under drought conditions, compared with PRG monocultures under rainfed conditions. In the present study, there was a period of reduced rainfall in early 2020, during which a higher herbage growth rate was observed in both MSS compared to either PRG or PP. This demonstrates the capacity of swards containing a mixture of species with varied rooting depths, to help alleviate risks to herbage production under periods of below average rainfall, thus enhancing resilience of herbage supply for farmers.

4.2 | Botanical composition

Findings from the current and previous studies (e.g., Baker, Lynch, Godwin, Boland, Kelly, et al., 2023; Grace, Boland, et al., 2018a) demonstrate that MSS are dynamic in terms of the proportional contribution of individual species and indeed, functional groups to herbage DM production over the grazing season. On the other hand, PRG and PP remained relatively constant in terms of their botanical

composition over the duration of the experimental period. Promoting persistence of the two main herb species – *C. intybus* and *P. lanceolata*, was key to the determination of the grazing rules applied to both MSS. For example, the post grazing sward height of 6 cm aimed to support herb species through the protection of their growing points (Cranston et al., 2015; Li et al., 1997), while the higher pre grazing herbage mass aimed to reduce the frequency of defoliation and mitigate tap root damage via the recovery of root reserves (Kemp et al., 2010). However, despite these accommodations, the contribution of both species to herbage DM decreased significantly between 2020 and 2021. Similar findings, albeit under differing grazing management rules and systems, have been reported by Baker et al. (2023a); Grace, Boland, et al. (2018a) and Jing et al. (2017). This is likely due to challenges such as grazing pressure, treading and autumn grazing (Li et al., 1997). However, *C. intybus* in particular, is regarded as a relatively short-lived perennial, irrespective of the grazing management approaches (Grace, Boland, et al., 2019a; Kemp et al., 2010). Indeed, in the current study its decrease in contribution to herbage DM may have been further exacerbated by the competitive dynamics inherent in co-grazing systems (Nolan & Connolly, 1989). The impact of the grazing pressure associated with each ruminant species, namely cattle and sheep, could not be conclusively differentiated in the current study. However, both cattle and sheep exhibit distinct plant selection behaviours. Sheep, with their narrow, small mouths, are more selective feeder compared to cattle (Rook & Yarrow, 2002), enabling them to choose a higher quality diet than what is generally available (Gregorini et al., 2017). In contrast, cattle are less selective herbivores (Schwartz & Ellis, 1981). This selective feeding behaviour and different feeding preferences between ruminant species could further impact on plant persistence.

This makes the rejuvenation of MSS with the herb component necessary 3–4 years following sowing. However, full reseeding involving soil cultivation at such short intervals is not desirable from an economic or environmental perspective. There is limited availability of research focusing on the reintroduction of herb species into existing swards under various sowing methods (Glassey et al., 2013; Raedts & Langworthy, 2019). Therefore, further research to determine appropriate rejuvenation techniques for grazed MSS is necessary.

The legume component of both 6S and 12S was dominated by *T. pratense* with a relatively minor contribution of *T. repens* to herbage DM recorded across all seasons in both years. This was likely influenced by the high pre-grazing herbage mass, which likely favoured the erect growth habit of *T. pratense*, while compromising the potential of the lower growing, stoloniferous species *T. repens* through limiting light interception and therefore growth (Black et al., 2009; Tamele et al., 2018). The contribution of *T. pratense* to herbage DM is believed to reduce over time and particularly 3+ years beyond sowing (Black et al., 2009). While its contribution to herbage DM remained unchanged over the current experimental period, longer term observation of the swards would be necessary to fully evaluate its overall persistence under co-grazing conditions.

A number of the additional species included in the 12S seed mixture i.e., *A. millefolium*, *L. corniculatus*, *S. minor*, *O. viciifolia* and

P. crispum were not observed within the swards during the 2020 and 2021 grazing seasons. Similar findings have been reported by Elgersma et al. (2014), Halling et al. (2004), Loza et al. (2021), Pirhofer-Walzl et al. (2011) and Søgaard et al. (2008). These findings may, in part, be due to reduced light penetration through the swards and confounded by relatively low seeding rates at sward establishment. Overall, the seeding rates used in the present study were based on the recommended monoculture seeding rates for each species (Cotswold seeds, UK) as is frequently demonstrated in studies on mixed pastures (Ergon et al., 2017; Grace, Lynch, et al., 2018b; Grange et al., 2021; Holohan et al., 2022). Furthermore, given that the establishment and persistence of legumes and herbs have been observed to be lower than targeted in MSS studies (Baker, Lynch, Godwin, Boland, Kelly, et al., 2023; Grace, Boland, et al., 2018a), higher seeding rates could potentially help to offset this reduction. However, seeding rate can, but not always, influence short-term pasture yield (Lee et al., 2015) and this could be a contributing factor to the DM increases in the present study. This highlights the need for further research to appropriately inform the composition of MSS seed mixtures and their subsequent management.

Given that there are no herbicides currently licenced within the European Union that are safe to apply to MSS, control of unsown / undesirable species can often be a concern for farmers (Walsh, 2022). However, a number of studies have reported a lower contribution of unsown species to herbage DM in MSS or binary mixtures compared to monocultures (Baker et al., 2023a; Beaumont et al., 2020; Connolly et al., 2018). In the current study, there was no evidence of unsown species encroachment in the 12S. This may have been due to the presence of species such as *D. glomerata* which has been shown to have weed suppression characteristics (Connolly et al., 2018; Sanderson et al., 2013). However, there was a significant increase (from 1 to 5%) in the proportion of DM from unsown species (mainly *Ranunculus* spp. and *R. obtusifolius*) in 6S between 2020 and 2021. While these species are commonly regarded as undesirable, largely due to low palatability and reduced pasture utilization, certain herbage quality and mineral parameters within these species are comparable or higher to that of *L. perenne* (Harrington et al., 2006). Nonetheless, their increase is notable and could be linked to the specific site conditions or the chosen grazing management approach whereby herbage was allowed to reach a heavier pre-grazing herbage mass, and therefore maturity, compared to previous grazing studies (Baker, Lynch, Godwin, Boland, Kelly, et al., 2023; Grace, Boland, et al., 2018a), thus preventing control by grazing in the case of *R. obtusifolius* (Dierauer, 2018).

4.3 | Herbage nutritive value

Plant species composition, maturity, season, and management greatly influence the nutritive value of herbage (Curran et al., 2010; Delaby et al., 2010; Jing et al., 2017) and consequently impact animal performance when herbage is fed to livestock (Buxton, 2015). From an animal performance perspective, it is imperative to identify any potential

trade-off between herbage quantity and quality (Baumont et al., 2020).

While CP levels in PRG in the present study were similar to those reported in Baker et al. (2023b), the CP levels in MSS were lower in the present study. Lower herbage growth rates often lead to challenges in controlling pre-grazing herbage mass (McEvoy et al., 2010). Herbage growth rates were affected by the lack of rainfall in spring 2020 resulting in paddocks, which had initially been assigned for silage, being grazed at a pre-grazing herbage mass that was above the grazing management target. This action was taken to avoid a potential herbage deficit which could have resulted in the supplementation of animals with concentrates or silage. This high pre-grazing herbage mass and consequent maturity of PRG swards in 2020 likely impacted their CP levels, as maturity of PRG is inversely related to CP content (Beecher et al., 2018). Additionally, although the legume component in both MSS was predominantly *T. pratense*, the higher pre-grazing herbage mass target likely led to increased overall herbage maturity resulting in lower CP levels than typically expected in legume containing swards. However, it is important to note that the principal driver of N loss from ruminants into the wider environment is N intake. Consequently, reducing CP levels in pastures, while still meeting the CP requirements of grazing livestock, can decrease N losses (Hoekstra et al., 2007), thereby benefiting the wider environment.

High grass content of a sward is usually positively correlated with sward NDF levels (Hearn et al., 2023; Sanderson, 2010) with legume containing swards generally having lower NDF levels in comparison (Fulkerson et al., 2007). This was evident in the current study with higher NDF levels recorded in PP and PRG compared to both MSS. The range of native species (Toupet et al., 2020), combined with sward age (Bell et al., 2018), most likely resulted in increased NDF levels in PP over and above those recorded from the PRG system. NDF levels in MSS were similar to Baker et al. (2023b) despite the target pre-grazing herbage mass in that study being much lower i.e., 1500 kg DM ha⁻¹ for a 6S sward. Therefore, it can be concluded that when MSS are grazed at a higher pre-grazing herbage mass, as was the case in this study i.e., 2500 kg DM ha⁻¹, NDF content is unaffected. This may provide greater opportunity for flexibility in terms of grazing management associated with MSS. The NDF and ADF concentrations were lowest across all swards in the early season which is consistent with Baker et al. (2023b) and reflects the fact that this is when plants are generally less mature and consequently have lower proportions of stem relative to leaf material. As a plant matures, the proportion of stem increases, and the cell walls thicken, leading to higher NDF concentrations. This high NDF content can limit intake of herbage by ruminants (Elgersma & Sørensen, 2018).

Lignin concentrations are generally higher in herb species compared to legumes and grasses (Barry, 1998; Elgersma et al., 2014; Niderkorn et al., 2019). The presence of herb species such as *P. lanceolata* and *C. intybus* in both MSS systems reflect the higher ADL concentrations compared to PRG and PP. While the differences between 6S and 12S were not statistically significant, the inclusion of *D. glomerata* in 12S, which has a known higher concentration of ADL than *L. perenne* and *P. pratense* (King et al., 2012), could potentially account for the higher ADL concentration associated with this system.

Ash refers to the complete mineral content found in forage (Hoffman, 2005). In this study, lowest concentration of ash was associated with PRG compared to both MSS. Several studies have shown that legumes and herbs have higher concentrations of micronutrients than grasses (Belesky et al., 2001; Pirhofer-Walzl et al., 2011). Ash levels in PRG in the current study were comparable with Baker et al. (2023b) and Grace, Boland, et al. (2018a) but were higher for both MSS. Despite changes in the botanical composition of both MSS across the experimental period, there was no difference in ash content associated with either MSS between 2020 and 2021. This was likely due to the high contribution of *T. pratense* to herbage DM production in these systems. *T. pratense* has been reported to have a high ash content when grown in monoculture i.e., 91–106 g kg DM (Moloney et al., 2020b). This could potentially have negated any reduction in ash content caused through the decrease in the herb component of these swards over the same time period.

Previous research has indicated that higher pre-grazing herbage mass (above 2000 kg DM ha⁻¹) influences forage digestibility (Curran et al., 2010; McEvoy et al., 2010), while some studies have shown consistent OMD up to 2000 kg DM ha⁻¹ (Doyle et al., 2022; Wims et al., 2014). Notably, despite different pre-grazing herbage mass targets for MSS and PRG, no difference in OMD between sward types was observed. This is important as OMD plays a crucial role in ruminant animal performance (O'Donovan et al., 2022). This finding aligns with theories by Sanderson (2010), Baumont et al. (2020) and Jing et al. (2017), suggesting that diverse swards counterbalance the effects of plant maturity, resulting in more consistent nutritive values. This again indicates a greater potential flexibility associated with grazing management of MSS compared with *L. perenne* based swards. In this study, PRG had higher OMD than PP which can be explained by additional species present in PP such as *D. glomerata*, *P. pratense*, *H. lanatus*, *Poa* spp. etc. These species have individually been shown to decrease digestibility relative to *L. perenne* (Frame, 1991; Jančík et al., 2011).

The higher WSC concentrations associated with the PRG system compared to PP, 6S and 12S, can be explained, in part at least, by the dominance of *L. perenne* in this system (King et al., 2012). It is well documented that MSS has lower WSC compared to PRG (Ergon et al., 2017; Moloney et al., 2020b). Elevated WSC concentrations associated with PRG in early season are likely attributable to the low CP levels mentioned previously. These low CP levels are known to be associated with high WSC content in grasses (Peyraud & Astigarraga, 1998). In addition, the period of reduced rainfall in early 2020, where moisture was limited, could have further increased WSC content in PRG as shown in studies by Fariaszewska et al. (2020) and Volaire et al. (1998). Similar trends were observed with DM whereby PRG and PP had higher DM content than either 6S or 12S. The low WSC and DM concentrations associated with both MSS systems were likely influenced by the contribution of *T. pratense*, *C. intybus* and *P. lanceolata* to herbage DM. This can result in challenges for farmers with regard to the ensilability of forage and may require adjustments to conventional silage making techniques, such as the need for a more prolonged period of wilting relative to that required for grass dominated systems (Clavin et al., 2016; Moloney et al., 2020a).

Despite differences in terms of grazing management and botanical composition, MSS compared very favourably to PRG and PP in terms of nutritive value of the swards. Indeed, all four sward types produced herbage of adequate quality to meet the needs of grazing animals as outlined in terms of animal performance (Beaucarne et al., [under review](#)). The botanical composition of both MSS did not seem to significantly influence the herbage nutritive values greatly. This means that these swards may lend themselves to greater flexibility regarding grazing management while still maintaining forage of high nutritive status.

5 | CONCLUSION

This large grazing study demonstrated the ability of multispecies swards to produce greater herbage DM from reduced N inputs compared to PRG monocultures and PP swards, when co-grazed by cattle and sheep over a two-year period. Additionally, the study demonstrates the herbage DM production capacity of pre-existing permanent pastures, which can produce comparable levels of herbage DM to PRG. The nutritive value of MSS compared favourably with PRG regardless of the higher pre-grazing herbage mass targets, indicating potential for greater flexibility in terms of grazing management. However, there were significant reductions in the forage herb component between years, thus highlighting the need for long-term observation (beyond 2 years) of these sward types to further investigate sward botanical changes and the maintenance of forage herbs.

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The authors declare no conflict of interest.

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