

Dry-matter production and botanical composition of multispecies and perennial ryegrass swards under varying defoliation management

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Abstract

Multispecies swards, comprised of different plant functional groups have comparable production potential to high N input *L. perenne* swards at reduced N when legumes are included. However, information on the appropriate management of multispecies swards is limited. The effect of differing management practices on the herbage dry-matter (DM) production and botanical composition of different sward types was investigated using a $3 \times 2 \times 2$ factorial design plot experiment. The experiment consisted of three sward types: *L. perenne*-only receiving (LP; $250 \text{ kg N ha}^{-1} \text{ a}^{-1}$); *L. perenne*-*Trifolium repens* (LP-TR); multispecies sward containing *L. perenne*, *Phleum pratense*, *Trifolium repens*, *Trifolium pratense*, *Plantago lanceolata* and *Cichorium intybus* (MSS). LP-TR and MSS received $90 \text{ kg N ha}^{-1} \text{ a}^{-1}$. Harvesting of plot herbage took place every 21 or 28 days to a defoliation height of 4 or 6 cm, over two growing seasons (March to November 2020 and 2021 inclusive). Annual herbage produced by both LP and LP-TR was not significantly affected by defoliation frequency. However, MSS produced $1923 \text{ kg DM ha}^{-1} \text{ a}^{-1}$ more herbage when harvested less frequently. Unsown species contributed significantly less to the herbage DM of MSS compared to LP and LP-TR and remained similar in 2020 and 2021, whereas the contribution of unsown species to herbage DM increased in LP and LP-TR from 2020 to 2021, with noxious species more associated with LP and LP-TR than MSS. Results demonstrate the role of multispecies swards in improving the sustainability of grass-based agricultural systems in an environment of reduced fertilizer inputs.

KEYWORDS

defoliation management, forage herbs, forage yield, legumes, multispecies swards, nitrogen

1 | INTRODUCTION

Grasslands are the main source of feedstuff for ruminants in temperate regions of the world, being the most economical feed source for

such animals (Van den Pol-van Dasselaar et al., 2020). In Ireland and other temperate regions, *Lolium perenne* L. (perennial ryegrass) swards in particular are heavily relied upon in intensive rotational grazing systems, due to their productivity, ease of establishment and resistance

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to grazing pressure (Frame & Laidlaw, 2011; Grogan & Gilliland, 2011; Kemp et al., 2000). However, *L. perenne* swards require high levels of inorganic nitrogen (N) input (Frame, 1991). With 250–300 kg N ha⁻¹ a⁻¹ required to support a stocking rate of 2.5 LU ha⁻¹. Production systems that are reliant on such high N input monocultures are increasingly regarded as unsustainable owing to the economic and environmental costs related to their use (DAFM, 2020; European Commission, 2019). Coupled with this, there is increasing political and social pressure to lessen the environmental impact of livestock production systems.

Multispecies swards that include a mix of species from grass, legume, and herb functional groups have emerged as a promising approach for enhancing pasture productivity while reducing the need for fertilizer N input. Within these functional groups, individual plant species possess unique functional traits. For example, *L. perenne* and *Phleum pratense* L. (timothy) are grasses with fibrous roots that provide structural support to the soil, however *P. pratense* has greater spring growth than *L. perenne* (Charlton & Stewart, 2000). Legumes, such as *Trifolium pratense* L. (red clover) and *Trifolium repens* L. (white clover) both form symbiotic relationships with nitrogen-fixing bacteria, which allows them to fix nitrogen (Nyfeler et al., 2011), have different establishment rates, with *T. pratense* being fast-establishing non-persistent legume and *T. repens* being a slow establishing and temporally persistent (Connolly et al., 2009). Herbs, such as *Cichorium intybus* L. (chicory) and *Plantago lanceolata* L. (plantain), provide different ecosystem services, with *C. intybus* having a deep taproot system that improves soil structure and nutrient cycling, while cows grazing on forage *P. lanceolata*-containing forages have lower urine N concentrations compared to those grazing on *L. perenne*-only or *L. perenne*-*T. repens* swards (Totty et al., 2013) and it has been suggested that forages containing *P. lanceolata* releases biological nitrification inhibiting compounds into the soil, which could lower the risk of NO³ leaching (Bracken et al., 2020; Carlton et al., 2019).

Compared to pastures composed solely of *L. perenne*, functionally diverse, multispecies swards have been found to maintain or increase herbage dry-matter production at significantly lower fertilizer N input (Baker et al., 2023; Distel et al., 2020; Grace et al., 2018; Moloney et al., 2020) and reduce weed ingress (Black et al., 2017). This in turn reduces the potential for associated environmental impacts (Connolly et al., 2009; Cranston et al., 2020; Suter et al., 2015). Such benefits have been accredited to complementary and interspecific interactions such as biological N fixation by rhizobia bacteria on legume root nodules (Nyfeler et al., 2011) in addition to good spatial and temporal resource-utilization due to increased functional diversity both above and below ground (Jing et al., 2017). Research conducted by Grange et al. (2021) showed that functional group interactions promoted greater herbage dry-matter production in a six species multispecies sward compared to a high nitrogen input *L. perenne* sward under both rain fed and drought conditions.

While sward management principles (e.g. grazing timing, intensity and N fertilizer requirements) are established for *L. perenne* and *L. perenne*-*T. repens* swards (O'Donovan et al., 2011; Phelan et al., 2013) far less is understood with regard to managing

multispecies swards to optimize their productivity (Cun, 2018; Lee et al., 2012; Pembleton et al., 2015). Identifying sward management effects on herbage DM production and botanical composition of these swards is important, as both are directly linked to their productivity and environmental performance. Though there is available information regarding the effects of grazing management on individual species (e.g. *T. repens* and *Trifolium pratense* L., *Cichorium intybus* L. and *Plantago lanceolata* L.). (Lee et al., 2012), information on the management of multispecies swards containing a combination of herbs, legumes and grasses is limited.

The objective of this study was to determine the effect of defoliation interval and residual height on the annual and seasonal DM production and botanical composition of three sward types: (1) *L. perenne*-monoculture sward; (2) *L. perenne*-*T. repens* sward and (3) multispecies sward comprised of six species. We hypothesized that: (1) legume and forage herb containing multispecies sward would have a higher DM production than either the *L. perenne*-*T. repens* or the *L. perenne* monoculture, especially when managed on a longer rotation length and to a greater post-cutting residual height; (2) The forage-herb component of the multispecies sward would decline over the course of the experiment, but that this decline in forage herbs would not be as severe when swards were managed on a longer rotation length and to a greater post-cutting residual; (3) That the multispecies sward would have a similar weed burden to *L. perenne*-*T. repens* and *L. perenne* monocultures.

2 | MATERIALS AND METHODS

2.1 | Experimental site and ground preparation

A plot-scale study was established in June 2019 at University College Dublin, Lyons Farm (53°18' N, 6°32' W, ca. 80 m above mean sea level). The soil type at the experimental site was moderately well-drained silty clay loam Brown Earth (Cambisol) with a pH of 6.5. The site was under long-term grassland before establishing the present experiment. Soil organic matter content was 12% at the surface (0 to 10 cm). Phosphorous, Potassium, Magnesium, Manganese and Copper levels were 2.13 mg l⁻¹, 139 mg l⁻¹, 268 mg l⁻¹, 821.5 mg kg⁻¹ and 7 mg kg⁻¹ respectively. Prior to sowing, the site was sprayed with glyphosate at a rate of 5 L ha⁻¹ (Roundup; Monsanto Meath, Ireland) in March 2019 and ploughed to a depth of 15 cm in April 2019. The site was then re-sprayed with glyphosate at a rate of 1 L ha⁻¹ in June 2019 to insure a clean seedbed.

2.2 | Meteorological data

Meteorological data (from the Irish meteorological service), including mean air and soil temperature (°C), mean rainfall (mm day⁻¹), total rainfall for the year (mm a⁻¹) and soil moisture deficit (mm) were recorded for the duration of the current study at casement aerodrome (53°30' N, -6°44' W), located approximately 5.8 km east of Lyons farm and of a similar elevation above sea level

2.3 | Experimental design and treatments

The study took place over two growing seasons (March to November 2020 and 2021 inclusive). A $3 \times 2 \times 2$ randomized factorial block design experiment was established to investigate three sward types, two defoliation heights and two rotation lengths with four replications of each. The three sward types were: (1) *L. perenne* monoculture; (2) *L. perenne*-*T. repens* (LP-TR); (3) Multispecies sward containing *L. perenne*, *Phleum pratense* L. (timothy), *T. repens*, *Trifolium pratense* L. (red clover), *P. lanceolata* and *C. intybus* (MSS). The two defoliation residuals were: 4 and 6 cm and the two rotation lengths were: 21 and 28 days.

Regarding the choice of defoliation residuals, it is well established that both LP and LP-TR perform well in terms of DM production, persistence and nutritive value when managed at a 4 cm post-grazing sward height (Frame and Boyd, 1987, Fulkerson and Donaghy, 2001, Lee et al., 2008, Lee et al., 2009, Phelan et al., 2013). However, *T. pratense*, *C. intybus*, *P. lanceolata* and *P. pratense* have higher growth points than *L. perenne* and *T. repens*, and therefore, have a recommended post-grazing residual of ca. 8 cm (Hay and Ryan, 1989, Li et al., 1997, Carlassare and Karsten, 2002, Labreux et al., 2004, Black et al., 2009, Lee et al., 2015). The 6 cm post-grazing residual height in the current study was selected as an intermediary between 4 cm and 8 cm, aimed to balance the requirements of the component species.

In June 2019, following seedbed preparation a total of 48 plots were sown, each of area 10.5 m² (1.5 × 7 m) plots using a Wintersteiger plot sowing machine (Wintersteiger, Austria). The plots were arranged in four blocks, of 12 plots across, within which treatments were randomized. The seed sowing rate for each species included in the different sward types and their varieties are presented in Table 1.

2.4 | Defoliation management and herbage measurements

Plots were harvested from the 19th of March until the 5th of November 2020 and from the 30th of March to the 16th of November

2021. Forage remained dormant over the winter period between both growing seasons. Plots on a 21-day cutting rotation were harvested 12 times in 2020 and 2021 to a residual height of 4 cm or 6 cm above ground level (measured with a platometer; Jenquip, Feilding, New Zealand), depending on their treatment. Similarly, plots on the 28-day cutting rotation were harvested 9 times in 2020 and 2021 to a residual height of 4 cm or 6 cm above ground level, depending on their treatment.

Herbage mass was measured by cutting and weighing the fresh herbage of the entire plot with a Haldrup Forage Harvester (Løgstør, Denmark) to the plot's respective residual height. A 250 g fresh-weight sample of herbage was collected per plot and dried in a draught oven at 45°C for 72 h and subsequently ground through a 1 mm sieve (Christy and Norris Hammer Mill, Chelmsford, England) and stored before being dried at 105°C for 16 h in an incubator to determine the absolute DM content (g kg⁻¹) of each sample. Post-cutting sward heights were determined using a rising platometer (Jenquip, Feilding, New Zealand), by taking 10 measurements in each plot immediately before and after each harvest. Seasonal and annual cumulative DM production was determined by summing the appropriate pre-grazing herbage mass from each harvest each year. The grazing season was divided into early-season (March to May), mid-season (June to August) and late-season (September to November) for analysis.

2.5 | Nutrient management

Nitrogen fertilizer management was informed by standard recommendations for *L. perenne* monocultures, guidance for legume-containing swards (Wall & Plunkett, 2020), together with N fertilizer responses from a previous study examining similar sward types (Grace et al., 2018). Therefore, LP received 250 kg N ha⁻¹ a⁻¹, while LP-TR and MSS each received 90 kg N ha⁻¹ a⁻¹. Applications were made to plots using a FIONA probe plot fertilizer spreader (Fiona Maskinfabrik A/S, DK 5400 Bogense, Denmark) following defoliation.

TABLE 1 Percentages of the three functional groups (–¹) and of each species component of the sward types and corresponding seeding rate (kg ha⁻¹) for each species.

Functional group Species ^a	Grass			Legume			Herb		
	<i>Lol. per</i>	<i>Phl. pra</i>	Total	<i>Tri. rep</i>	<i>Tri. pra</i>	Total	<i>Cic. int</i>	<i>Pla. lan</i>	Total
<i>Lolium perenne</i> sward									
Percentage	100	0	100	0	0	0	0	0	0
Seeding rate	37	0	37	0	0	0	0	0	0
<i>Lolium perenne</i> - <i>Trifolium repens</i> sward									
Percentage	90	0	90	10	0	10	0	0	0
Seeding rate	33	0	33	5	0	5	0	0	0
Multispecies sward									
Percentage	35	8	43	14	27	41	8	8	16
Seeding rate	13	3	16	5	10	15	3	3	6

^a*Lol.per*: *L. perenne* (AberGain and AberChoice); *Phl.pra*: *P. pratense* (Presto and Winnetou); *Tri.rep*: *T. repens* (Buddy and AberHerald); *Tri.pra*: *T. pratense* (AberChianti and AberClaret); *Cic.int*: *C. intybus* (Puna II and Choice); *Pla.lan*: *P. lanceolata* (Tonic and AgriTonic).

Nitrogen was applied to all plots in the form of protected urea + sulphur (S; Grassland Agro 38% N + 5.6% S) at a rate of 50 kg N ha⁻¹ and 9.2 kg S ha⁻¹ respectively, following harvest 1 in each year. Plots sown with LP and harvested every 21 days received N at a rate of 25 kg N ha⁻¹ in the form of protected urea (Grassland Agro 46% N) following harvests 2, 3, 4, 5, 6, 7, 8 and 9. Plots sown with LP and harvested every 28 days received N at a rate of 33 kg N ha⁻¹ in the form of protected urea, following harvests 2, 3, 4, 5, 6 and 7. Plots sown with LP-TR or MSS and harvested every 21 days received N at a rate of 10 kg N ha⁻¹ in the form of protected urea following harvests 2, 3, 5 and 9. Plots sown with LP-TR or MSS and harvested every 28 days received N at a rate of 10 kg N ha⁻¹ in the form of protected urea (Grassland Agro 46% N) following harvests 2, 3, 4 and 7. Annual surface (0 to 10 cm) soil sampling was carried out at the block scale to assess plant-available Phosphorus (P) and Potassium (K) using Morgan's soil extraction (Morgan, 1941); the standard test for Irish soils. Phosphorus and K application at the plot scale was based on the soil test results (Soil P or K Index). All plots received 30 kg P ha⁻¹ a⁻¹ in the form of superphosphate (Westland 16% P) and 200 kg K ha⁻¹ a⁻¹ in the form of muriate of potassium (Grassland Agro 50% K).

2.6 | Botanical composition and bare ground

A 300 g fresh weight sample of herbage (cut to 4 or 6 cm depending on treatment) was collected from each plot at harvest time 3 times per year (early-season [harvest 2], mid-season [harvest 5] and late-season [harvest 8]). Plant samples were manually separated by component species to determine their contribution to herbage DM produced. Unsown species were identified to species level, however given their small quantities, they were later bulked together and referred to as unsown species. Unidentifiable, decomposed plant material in the subsample was referred to as dead material. Botanical composition was determined by the dry-weight rank method (Jones & Hargreaves, 1979; Mannelje & Haydock, 1963), following drying in a draught oven at 45°C for 72 h.

Further non-destructive sampling pertaining to the unsown component of the swards involved recording the botanical composition of two 0.25 m² quadrats, placed 2 m from either end of each plot, three times per year, 1 week following harvest 2 (early-season), harvest 5 (mid-season) and harvest 8 (late-season) when sward height was ca. 8–12 cm above ground level. The percentage cover (abundance) of individual species rooted within each quadrat, and bare ground, was estimated visually.

2.7 | Statistical analysis

2.7.1 | Regression analysis

Data were analysed as a complete randomized block design using the mixed model procedure (PROC MIXED) in SAS (SAS, version 9.4, Inst.

Inc., Cary, NC). The individual plot served as the experimental unit for all parameters analysed. The data regarding herbage DM production and pre-cutting herbage mass was analysed using a statistical model, which contained the fixed effects of sward type, rotation length, defoliation height, season, year and their interactions. The data pertaining to species composition were analysed by sward type where botanical component, rotation length, defoliation height, season, year and their interactions were fixed effects. All data presented in tables are expressed as least squares means ± SEM. The probability value which denotes statistical significance is $p < .05$.

2.7.2 | Ordination analysis

The spatial relationship between unsown species, sward type and cutting management was visualized using non-metric multidimensional scaling (NMDS) which involved data being double square root transformed to reduce issues of scale and heterogeneity. Stress on the two-dimensional NMDS analysis of ecological niche dimensions was 0.06, indicating ecological distances were well represented, while transformed and observed distance pairs were highly correlated ($r^2 = .99$) signifying a good model fit.

3 | RESULTS

3.1 | Meteorological data

The mean monthly air temperatures, rainfall, soil surface temperatures (100 mm depth) and soil moisture deficits for 2020 and 2021 and the 10-year average values (2010–2020) from the weather station at casement aerodrome (Met Éireann, 2021) are presented in Table 2. Overall, the average air temperature was 0.2°C and 0.5°C warmer in 2020 and 2021, respectively, than the 10-year average. Average monthly rainfall was 5.1% higher in 2020 and 10.6% lower in 2021 than the 10-year average. Average soil moisture deficits were 7.0% and 43.8% higher in 2020 and 2021, respectively, than the 10-year average, although the highest soil moisture deficits of the experimental timeframe 63.5 mm and 55.4 mm occurred in May and June 2020, respectively. The average soil surface temperature was 0.6°C and 0.2°C lower in 2020 and 2021, respectively, compared to the 10-year average.

3.2 | Herbage measurements

3.2.1 | Dry-matter production

A highly significant interaction ($p < .0001$) was found between sward type and rotation length with regard to annual herbage DM production. When managed on a 21-day rotation, LP and MSS produced similar yields of 15,430 and 15,823 kg ha⁻¹ a⁻¹ respectively, while the yield from LP-TR was significantly lower at 13,765 kg ha⁻¹ a⁻¹.

TABLE 2 Average daily temperature (°C), soil temperature (°C 100 mm depth), rainfall (mm) and soil moisture deficit (mm) at the Casement Aerodrome weather station for 2020 and 2021 compared to the 10-year average (2010–2020).

Month	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec	Average
Temperature (°C)													
2020	6.1	5.6	6.1	9.4	12.1	13.5	14.6	15.1	13.0	9.4	8.2	4.6	9.8
2021	3.8	6.1	7.4	6.5	9.5	14.2	17.0	15.2	15.0	11.8	7.6	6.6	10.1
10-year average	4.7	5.1	6.2	8.2	10.9	13.7	15.5	14.7	13.1	10.7	6.8	5.4	9.6
Soil temperature (°C)													
2020	5.0	4.5	5.2	9.4	13.4	14.9	15.7	15.9	13.1	9.4	7.5	4.5	9.9
2021	3.4	4.7	6.6	8.1	11.1	15.9	18.3	15.9	15.2	11.3	7.5	5.6	10.3
10-year average	4.5	4.8	6.4	9.5	13.1	16.3	17.9	16.3	14.0	10.6	7.0	5.2	10.5
Rainfall (mm)													
2020	49.3	155.4	32.5	19.3	10.7	87.0	114.4	85.1	48.1	81.7	58.6	77.9	68.3
2021	95.8	69.7	29.6	17.9	112.7	17.8	94.0	47.3	42.1	77.2	16.4	76.4	58.1
10-year average	61.9	51.0	53.8	51.4	58.1	69.5	54.2	72.8	63.4	74.8	89.5	79.3	65.0
Soil moisture deficit (mm)													
2020	−5.5	−5.4	−1.0	32.0	63.5	55.4	3.2	4.0	4.2	−7.1	−9.0	−9.3	10.4
2021	−9.2	−7.0	−1.9	24.0	11.7	36.6	34.4	27.6	42.1	21.9	−4.1	−8.1	14.0
10-year average	−7.5	−7.3	−2.4	6.6	20.8	27.3	42.2	29.2	19.7	3.7	−7.3	−8.2	9.7

TABLE 3 The effect of sward type and rotation length on mean annual and seasonal yield, pre-cutting herbage mass (kg DM ha^{−1}, pre-cutting herbage height and post-cutting herbage height [cm]); least square means ± SEM of 2020 to 2021.

	21-day rotation length				28-day rotation length				Sward	Rotation length	Sward × rotation Length
Sward ^a	LP	LP-TR	MSS	SEM	LP	LP-TR	MSS	SEM			
Herbage yield (kg DM ha ^{−1})											
Annual	15430 ^x	13765 ^y	15823 ^x	619	15339 ^x	14567 ^x	17746 ^y	585	****	*	****
Early ^b	5719	5633	5478	390	5489	5640	5826	296	ns	ns	ns
Mid ^b	7894 ^{xy}	6619 ^y	8577 ^x	427	5768 ^x	5500 ^x	7598 ^y	307	****	****	****
Late ^b	1817	1513	1769	116	4082 ^x	3427 ^y	4323 ^x	146	ns	****	****
Pre-cutting herbage mass (kg DM ha ^{−1})											
Annual	1543 ^x	1376 ^x	1582 ^y	62	1917 ^x	1821 ^x	2218 ^y	73	***	****	****
Early ^b	1617	1586	1536	83	1830	1880	1942	99	ns	****	****
Mid ^b	1773 ^x	1447 ^y	1889 ^x	79	2279 ^x	2239 ^x	3118 ^y	92	****	****	****
Late ^b	909	757	884	58	1672 ^x	1408 ^y	1764 ^x	66	ns	****	****

Note: ^{x-z}: Within rows, means with differing superscripts differ significantly ($p < .05$). Sig. (significance levels) p : ns $> .05$.

^aLP: *L. perenne* only, LP-TR: *L. perenne* and *T. repens*, MSS: 6 species (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *P. lanceolata* and *C. intybus*).

^bEarly: March – May; Mid: June – August; Late: September – November. The fixed effect of post-cutting residual is not included as it did not influence herbage parameters included in this table.

* $p < .05$; ** $p < .01$; *** $p < .001$; **** $p < .0001$.

However, when managed on a 28-day rotation, the yield from MSS was significantly higher at 17,746 kg ha^{−1} a^{−1} than the other swards (Table 3).

In the early-season, there was no relationship between sward type and defoliation frequency in terms of the quantity of herbage DM produced ($p > .05$; Table 3). However, a highly significant interaction ($p < .0001$) was found between sward type and rotation length in

terms of mid-season herbage DM production. When managed on a 21-day rotation, LP and MSS produced similar yields, while the yield from LP-TR, was significantly lower than MSS. When managed on a 28-day rotation, the herbage DM produced by MSS during mid-season was significantly higher than either of the other sward types (Table 3). Although the effect of sward type on herbage DM produced in the late-season was not significant ($p > .05$), there was a significant

TABLE 4 The percentage contribution of sown species to herbage DM production group per sward type to experimental year, season and rotation length (SEM $\pm$ standard error of the mean).

	2020	2021	SEM	Early	Mid	Late	SEM	21-day	28-day	SEM	Year ^a	Season ^b	Rotation length ^c
<i>Lolium perenne</i> sward (%)													
<i>Lolium perenne</i>	94	89	1	97 ^x	88 ^y	88 ^y	1	92	90	1	***	****	ns
<i>Lolium perenne</i> - <i>Trifolium repens</i> sward (%)													
<i>Lolium perenne</i>	75	62	2	92 ^x	57 ^y	57 ^y	2	72	66	2	****	****	ns
<i>Trifolium repens</i>	18	28	2	5 ^x	32 ^y	33 ^y	2	22	25	2	****	****	ns
Multispecies sward (%)													
<i>Lolium perenne</i>	13	24	2	26 ^x	15 ^y	15 ^y	2	22	15	2	****	****	*
<i>Phleum pratense</i>	5	6	1	7 ^x	5 ^y	4 ^y	1	5	5	1	*	****	ns
<i>Trifolium repens</i>	5	7	0	3 ^x	7 ^y	9 ^z	1	7	6	0	**	****	ns
<i>Trifolium pratense</i>	34	37	3	17 ^x	41 ^y	48 ^z	3	28	42	2	ns	****	****
<i>Plantago lanceolata</i>	26	18	2	30 ^x	23 ^y	12 ^z	2	24	19	2	**	****	ns
<i>Cichorium intybus</i>	14	3	1	14 ^x	5 ^y	6 ^y	2	72	66	2	****	****	ns

Note: ^{x-z}: Within rows, means with differing superscripts differ significantly ($p < .05$). Sig. (significance levels) p : ns $> .05$.

^aYear: 2020, 2021.

^bSeason: Early (March to May), Mid (June to August), Late (September to November).

^cRotation length: 21-day rotation length, 28-day rotation length.

* $p < .05$; ** $p < .01$; *** $p < .001$; **** $p < .0001$.

interaction ($p < .0001$) between sward type and rotation length in terms of late-season herbage DM production. When managed on a 28-day rotation both the herbage DM produced by LP and MSS was significantly more than that produced by LP-TR (Table 3).

3.2.2 | Pre-cutting herbage mass

A highly significant interaction ($p < .0001$) was found between sward type and rotation length in terms of annual pre-cutting herbage mass. When managed on a 21-day rotation, LP and LP-TR had similar pre-cutting herbage mass, while the pre-cutting herbage mass of MSS was significantly higher. The same relationship was observed when the swards were managed on a 28-day rotation, but the pre-cutting herbage mass of all swards was increased ($p < .0001$; Table 3). Although sward type alone did not have a significant impact on pre-cutting herbage mass, there was an interaction ($p < .0001$) between sward type and rotation length in terms of early-season pre-cutting herbage mass, whereby numerically the pre-cutting herbage mass of MSS increased to a greater degree when managed on a longer rotation length than both other swards (Table 3). A significant interaction ($p < .0001$) was found between sward type and rotation length in terms of mid-season pre-cutting herbage mass. When managed on a 21-day rotation, LP and MSS had similar pre-cutting herbage mass, while the pre-cutting herbage mass of LP-TR was significantly lower than either of the other sward types (Table 3). However, when managed on a 28-day rotation, the pre-cutting herbage mass of MSS was significantly higher than either of the other sward types (Table 3). Similarly, a significant interaction ($p < .0001$) was also found between

sward type and rotation length in terms of late-season pre-cutting herbage mass. When managed on a 21-day rotation, LP and MSS had similar pre-cutting herbage mass (Table 3). When managed on a 28-day rotation, LP and MSS had similar pre-cutting herbage mass, while the pre-cutting herbage mass of LP-TR, was significantly lower than either of the other sward types (Table 3).

3.3 | Botanical composition

3.3.1 | Sown species composition

The percentage of each sown species per year, season and rotation length, by sward type are presented in Table 4. There were no interactions between rotation length and post-cutting residual height on individual sward types in terms of sown species composition ($p > .05$). As post-cutting residual height had no effect ($p > .05$) on the sown species composition of the swards, it is not included in Table 4. The percentage contribution of *L. perenne* to the DM of LP swards decreased from 94% in 2020 to 89% in 2021 ($p < .001$; Table 4). Similarly, the percentage contribution of *L. perenne* to the DM of LP-TR swards decreased by 13% from 2020 to 2021 ($p < .0001$; Table 4), while the percentage contribution of *T. repens* increased by 10% ($p < .0001$; Table 5). For MSS, the percentage contribution of *L. perenne*, *P. pratense* and *T. repens* to sward DM increased from 2020 to 2021 (by 11; 1; 2%; $p < .0001$; $< .05$; $< .01$; respectively; Table 4). The sown herb component contribution to sward DM decreased significantly between 2020 and 2021; by 8% in the case of *P. lanceolata* ($p < .01$) and 11% in the case of *C. intybus* ($p < .0001$). However, the

Sward ^a			LP	LP-TR	MSS	SEM	Sig.
Unsown species	Year	2020	5 ^x	5 ^x	2 ^y	0.8	*
		2021	8 ^x	6 ^x	2 ^y	0.8	*
	Season	Early	2 ^x	3 ^x	2 ^x	0.9	***
		Mid	9 ^x	7 ^x	2 ^y	0.9	***
		Late	8 ^x	7 ^x	2 ^y	0.9	***
Dead plant material	Year	2020	1 ^x	2 ^x	2 ^x	0.2	*
		2021	3 ^x	3 ^x	3 ^x	0.2	*
	Season	Early	1 ^x	1 ^x	1 ^x	0.3	*
		Mid	3 ^x	3 ^x	3 ^x	0.3	*
		Late	2 ^x	3 ^x	3 ^x	0.3	*

Note: ^{x-z}: Within rows, means with differing superscripts differ significantly ($p < .05$). Sig. (significance levels) p : ns $> .05$.

^aLP: *L. perenne* only, LP-TR: *L. perenne* and *T. repens*, MSS: 6 species (*L. perenne*, *P. pratense*, *T. repens*, *T. pratense*, *P. lanceolata* and *C. intybus*).

* $p < .05$; ** $p < .01$; *** $p < .001$; **** $p < .0001$.

TABLE 5 The interaction between sward type and experimental year and sward type and season on the contribution of unsown species to herbage dry-matter (%; SEM $\pm$ standard error of the mean).

percentage contribution of *T. pratense* did not significantly differ from year to year ($p > .05$; Table 4).

The effects of season (early, mid or late) on the contribution of sown species to sward DM are presented in Table 4. The contribution of *L. perenne* to LP sward DM was higher in the early part of the grazing season than mid- or late-season. In terms of LP-TR swards, the percentage contribution of *L. perenne* to herbage DM was higher in the early-season than the mid- or late-season, although the percentage contribution of *T. repens* to sward DM was lower in the early compared with mid- or late-season ($p < .0001$; $< .0001$; respectively; Table 4). The sown grass component of MSS contributed more to herbage DM produced in the early-season than the mid- or late-season, with the same being true for *C. intybus*, while the opposite was the case for the dead component ($p < .0001$; $< .0001$; $< .0001$; respectively; Table 4). Legume and *P. lanceolata* contributions to the herbage DM of MSS were highest in the late-season and lowest in the early-season ($p < .0001$; $< .0001$; respectively; Table 4).

Rotation length influenced sown botanical composition, with a higher percentage of *L. perenne* contributing to the herbage DM produced by MSS managed on a 21-day compared with a 28-day rotation length (22 vs. 15%, $p < .05$). In contrast, there was a higher contribution of *T. pratense* to herbage DM when swards were harvested every 28 compared to 21-days (42 vs. 28%; $p < .0001$; Table 4). Post-cutting residual height did not affect the contribution of sown species to sward DM across all sward types ($p > .05$).

3.3.2 | Unsown species composition

Neither rotation length nor post-cutting residual height interacted with sward type in terms of their unsown species composition ($p > .05$). As there were interactions between year and sward type, and season and sward type, these results are presented separately in Table 5. In both 2020 and 2021, the percentage contribution of

unsown species to herbage DM was significantly lower in MSS than in LP and LP-TR ($p < .05$; Table 5). The contribution of unsown species to herbage DM increased in LP and LP-TR from 2020 to 2021, while remaining similar across years in MSS ($p < .05$; Table 5). The contribution of unsown species to herbage DM was greater in the mid- and late-season than the early-season in both LP and LP-TR ($p < .001$). However, the contribution of unsown species to the herbage DM of MSS did not vary across seasons ($p > .05$; Table 5). In the early-season, the contribution of unsown species to herbage DM did not vary among sward types ($p > .05$), however, in both the mid- and late-season their contribution to herbage DM was greater in both LP and LP-TR compared to MSS ($p < .001$; Table 5).

In 2020, the percentage contribution of dead plant material to herbage DM was significantly lower in LP than both other sward types ($p < .05$), however, in 2021 the percentage contribution of dead plant material to herbage DM did not vary across sward types ($p > .05$; Table 5). The contribution of dead plant material to herbage DM was similar across sward types and seasons ($p > .05$; Table 5).

In total, 16 unsown species were recorded across the three sward types over the two-year study. Figure 1 shows the two-dimensional space of the NMDS analysis, where *Poa annua* L. reside in the most peripheral location of the communities' ecological space, signifying that its distribution was not closely related to any of the treatment types. The LP sward managed on various cutting regimes (1–4) and LP-TR sward on various cutting regimes (5–8) were more associated to each other than the MSS sward on its various cutting regimes (9–12). Unsown species were more associated with LP and LP-TR treatments than MSS treatments most notably *Cirsium arvense* L. and *Rumex obtusifolius* L.

3.4 | Bare ground

The percentage of bare ground did not differ between 2020 and 2021 (27 vs. 26%; SEM 1.5; $p > .05$). The LP had more bare ground than

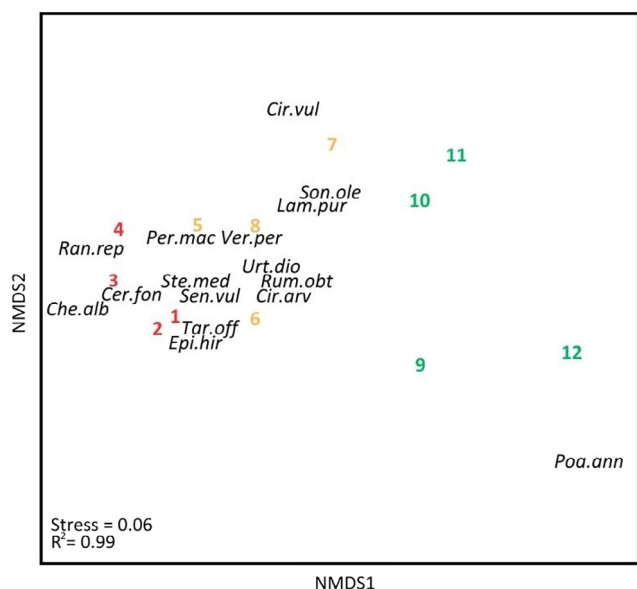


FIGURE 1 Unsown species that occurred in the experimental plots are plotted in two-dimensional space by NMSD. The axes are arbitrary as is the orientation of the plot. Unsown species that are more associated with one another or to a particular treatment are ordinated closer together. Treatments are plotted as follows: 1 – LP on a 21-day rotation cut to 4 cm, 2 – LP on a 21-day rotation cut to 6 cm, 3 – LP on a 28-day rotation cut to 4 cm, 4 – LP on a 28-day rotation cut to 6 cm, 5 – LP-TR on a 21-day rotation cut to 4 cm, 6 – LP-TR on a 21-day rotation cut to 6 cm, 7 – LP-TR on a 28-day rotation cut to 4 cm, 8 – LP-TR on a 28-day rotation cut to 6 cm, 9 – MSS on a 21-day rotation cut to 4 cm, 10 – MSS on a 21-day rotation cut to 6 cm, 11 – MSS on a 28-day rotation cut to 4 cm, 12 – MSS on a 28-day rotation cut to 6 cm. *Per.mac* – *Persicaria maculosa* (redshank), *Cir.arv* – *Cirsium arvense* (creeping thistle), *Cir.vul* – *Cirsium vulgare* (spear thistle), *Lam.pur* – *Lamium purpureum* (dead nettle), *Sen.vul* – *Senecio vulgaris* (groundsel), *Urt.dio* – *Urtica dioica* (nettle), *Poa.ann* – *Poa annua* (annual meadow grass), *Rum.obt* – *Rumex obtusifolius* (dock), *Cer.fon* – *Cerastium fontanum* (mouse ear), *Ste.med* – *Stellaria media* (chickweed), *Tar.off* – *Taraxacum officinale* (dandelion), *Che.alb* – *Chenopodium album* (fat hen), *Son.ole* – *Sonchus oleraceus* (sowthistle), *Epi.hir* – *Epilobium hirsutum* (willowherb), *Ran.rep* – *Ranunculus repens* (creeping buttercup) and *Ver.per* – *Veronica persica* (speedwell).

MSS, which had more bare ground than LP-TR (33 vs. 26 vs. 21%; respectively; SEM 1.6; $p < .001$ and $< .01$). Post-cutting residual height did not affect the percentage of bare ground in the swards ($p > .05$), whereas rotation length did, with all sward types cut on a 21-day rotation having more bare ground than those cut on a 28-day rotation length (22 vs. 31%; SEM 1.4; $p < .0001$).

4 | DISCUSSION

This study provides valuable insight into the effects of cutting frequency and cutting height on herbage DM production and the botanical composition of MSS compared to LP and LP-TR swards. Higher

DM production was achieved from MSS at lower chemical N inputs compared to LP and at the same level of chemical N input as LP-TR, most notably when managed on a 28-day rotation as opposed to a 21-day rotation. This response agrees with similar plot scale studies (Finn et al., 2013; Grace et al., 2019) reflecting multispecies swards' capacity to produce more herbage DM than less functionally diverse swards. Given the environmental and economic benefits associated with lower use of fertilizer N, the greater herbage DM production from MSS receiving 90 kg N ha⁻¹ compared to LP receiving 250 kg N ha⁻¹ indicates the potential of multispecies swards as a more sustainable alternative to *L. perenne*-based production systems. It is worth noting that the low persistence of the herbs, particularly *C. intybus*, may require reseeding after a few years to maintain its contribution to the sward.

In the present study, MSS managed on a 21-day rotation length exhibited a 13% increase in annual herbage DM production (15,823 kg DM ha⁻¹ a⁻¹) compared to LP-TR (13,765 kg DM ha⁻¹ a⁻¹), while MSS managed on a 28-day rotation length exhibited an 18% increase in annual herbage DM production (17,746 kg DM ha⁻¹ a⁻¹) compared to LP-TR (14,567 kg DM ha⁻¹ a⁻¹) at the same level of N input. This increase in productivity likely reflects an increase in plant functional diversity, rather than species diversity, as concluded by Pembleton et al. (2015). The reason for the observed increase in productivity in the present study could be attributed to the greater variety of functional traits in MSS, which allowed for more efficient resource use. This may have enabled the sward to utilize the available resources more effectively, leading to an increase in productivity, as opposed to an increase in nutrient availability alone (Jing et al., 2017). The finding is consistent with previous studies that have shown that adding *P. lanceolata* and/or *C. intybus* to *L. perenne*-*T. repens* swards can increase production benefits (Cong et al., 2018; Grace et al., 2018; Moloney et al., 2020).

The increase in rotation length from 21 to 28 days resulted in an increase in the herbage DM produced by both the MSS and LP-TR (+1923 kg DM ha⁻¹ a⁻¹; +802 kg DM ha⁻¹ a⁻¹; respectively), which suggests that there was more time for the plants to recover between cutting events. This recovery time allowed the plants to accumulate more biomass, resulting in a higher herbage mass. This finding is consistent with previous studies by Brougham (1956), Navarrete et al. (2013), and Lee et al. (2015), who showed that increasing rotation length led to an increase in herbage mass production. In contrast, the slight decrease in herbage DM produced by LP (– 91 kg DM ha⁻¹ a⁻¹), when rotation length was increased could be due to the specific characteristics of this sward type such as competition among individual plants within the monoculture for the same resources. Additionally, the longer rotation length may have led to a greater accumulation of legumes and herbs in MSS and LP-TR swards, which contributed to an overall increase in biomass that was not seen in LP.

The present study found that increasing the post-cutting residual height of the swards did not have a significant impact on the amount of herbage DM produced, which is surprising given that Cranston et al. (2015) reported that herb and legume mixtures produced greater annual herbage DM when grazed to a post-cutting residual height of

4 cm compared to 8 cm. However, it should be noted that the difference in post-cutting residual height between the two studies was 2 cm, which may have contributed to the differing results. A greater quantity of herbage DM was produced by all sward types in 2020 than in 2021, which is due to a decline in the herbage produced per harvest in the early-season of 2021, likely a result of cooler soil and air temperatures in April and May of 2021 compared to 2020, or indeed the prolonged period of soil moisture deficits towards the latter half of the mid-season into the late-season of 2021. These environmental factors could have affected the growth and development of the plants, leading to a reduction in herbage mass produced.

For swards managed on a 21-day rotation length, the average annual response to fertilizer was 62 kg DM ha⁻¹ per kg of chemical N applied to LP versus 153 and 176 kg DM ha⁻¹ in LP-TR and MSS respectively, while the average annual response to fertilizer of swards managed on a 28-day rotation length was 61 kg DM ha⁻¹ per kg of chemical N applied to LP versus 162 and 197 kg DM ha⁻¹ in LP-TR and MSS respectively. This equates to a 69% saving in the quantity of N fertilizer applied to the best-performing LP sward (21-day rotation) compared to the best-performing MSS sward (28-day rotation) and consequently, associated costs incurred by farmers. It should be noted that the response to fertilizer is influenced by a range of factors such as N use by the species, legume N fixation, N provided by the soil, and other environmental factors. Therefore, a deeper analysis of these factors is required to fully understand the reasons behind the varying responses to fertilizer observed in this study.

The additional 2316 kg DM ha⁻¹ a⁻¹ and 3179 kg DM ha⁻¹ a⁻¹ of herbage produced by the best-performing MSS sward compared to the best-performing LP and LP-TR sward (28-day rotation) respectively, is an asset that could serve to provide additional fodder during the housing period or to feed back to cattle at times when herbage demand is greater than that available for grazing. This may become an increasingly important resource given current climate predictions and the likelihood of more distorted weather patterns in the future (Falzoi et al., 2019; Nolan et al., 2017). In addition, according to the price of a tonne of grass DM provided by Hanrahan et al. (2018; €173), the additional herbage produced by MSS is worth approximately an additional € 550 ha⁻¹ in net profit compared to LP-TR and an additional € 400 ha⁻¹ in forage produced plus ca. €140 ha⁻¹ in terms of additional N input to LP (using urea fertilizer prices from 2022) if utilized, figures that can contribute substantially to farm income.

Management practices, such as grazing or cutting rotation length and post-cutting residual, would be expected to influence the botanical composition of swards by favouring certain plant species over others. Compared to monoculture swards, multispecies swards may respond differently to management practices due to varying light, nutrient, and water requirements of component species, leading to changes in sward composition. Although rotation length and post-cutting residual height did not affect the percentage contribution of the herb component to sward dry matter in 2020–2021 as initially hypothesized, there was a decline in the sown herb component overall during that period, with the *C. intybus* component being most notably affected. On the other hand, there was an increase in

L. perenne, *P. pratense*, and *T. repens* percentage contribution to herbage DM from 2020 to 2021, while *T. pratense*'s percentage contribution remained unchanged, as reported in Baker et al. (2023) under grazing conditions. These changes in composition are similar to those found in previous studies by Grace et al. (2018) and Moloney et al. (2020), where there was a significant decrease in the herb component and an increase in the grass component, while the legume content remained consistent over a two-year period. However, it's important to note that *C. intybus*, in particular, is a relatively short-lived herb, and changes to management practices may have little impact on its persistence within swards (Dodd et al., 2019). This suggests that rejuvenating multispecies swards with the herb component is likely necessary 3+ years post initial sowing despite management practices applied. However, recent work on rejuvenation methods, such as the timing of overseeding or stitching-in herb species within an established multispecies sward, has shown promise in terms of restoring the herb component of the pasture (Raedts & Langworthy, 2020).

In terms of the best-practice management guidelines for multispecies swards, results from this study imply that the *T. pratense* component of the sward favours more lax grazing (i.e. longer rotation lengths or silage systems) than the other component species of MSS and the increase in herbage DM production observed in MSS managed on a 28-day rotation is possibly a response to *T. pratense*'s increased contribution to herbage DM when managed according to its requirements.

Previous studies have identified positive links between relaxing post-grazing residual height and herbage DM production (Clark et al., 1990) and the persistence of *C. intybus* and *P. lanceolata* due to their high regrowth point (Cranston et al., 2015). However, this was not the case in the present study, where post-cutting residual height did not affect herbage DM production nor the percentage contribution of individual species to herbage DM. This may have been a consequence of the 2 cm difference in post-cutting residual height, while studies by Clark et al. (1990) and Cranston et al. (2015) compared residuals that varied more drastically. However, studies by Labreuve et al. (2004), Lee et al. (2015) and Mangwe et al. (2020), found that rotation length had a stronger influence on herbage DM production than residual height as was the case in the present study.

The present study provides evidence for the complementary effects of resource utilization in multispecies swards, corroborating previous investigations by Sanderson et al. (2005), Black et al. (2017), and Grace et al. (2018). Specifically, MSS exhibited superior yield performance compared to the less diverse LP and LP-TR swards. Notably, the percentage contribution of the constituent species within MSS displayed significant temporal variation, indicative of complementary interactions that optimized productivity. Furthermore, there was a significant reduction in the percentage contribution of unsown species to herbage DM with LP and LP-TR more closely associated with weed species *Cirsium arvense* and *Rumex obtusifolius* compared to MSS. This finding is particularly promising given the limited availability of post-emergence herbicides suitable for multispecies swards.

5 | CONCLUSION

Multispecies swards are an important biological tool to address some of the sustainability challenges associated with livestock farming. Therefore, enhancing our understanding of appropriate management practices, such as optimum rotation length and residual height, is necessary to optimize their performance and to ensure the herb component persists as long as possible.

Based on the results presented, it can be concluded that the interaction between sward type and rotation length significantly affects herbage production and pre-cutting herbage mass, while sward type alone does not have a significant effect. The study also found that mid-season herbage production is significantly affected by the interaction between sward type and rotation length. Additionally, there were no significant interactions between rotation length and post-cutting residual height on individual sward types in terms of sown species composition. However, the percentage contribution of certain species to sward DM varied between sward types and over time. These findings support the hypotheses that sward type and rotation length affect herbage production and pre-cutting herbage mass, and that sown species composition may vary over time.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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