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Utilising commercial farm grass growth data to evaluate long-term dry matter production of perennial ryegrass varieties

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Abstract

Little data are currently available on either the dry matter (DM) production of perennial ryegrass (PRG) swards as they age beyond 5 yr (i.e. permanent pasture) or the performance of PRG varieties on commercial grassland farms. Previous work has generally assumed a connection between DM production and ground score (GS) and this link has been used as a proxy for variety persistence. The evolution of technology in the form of PastureBase Ireland has led to agronomic data of individual paddocks being made available for analysis over multiple years which has allowed the long-term assessment of varieties sown as monocultures on commercial farms. This technology allowed for the inclusion of eight PRG varieties sown in 649 paddocks across 101 farms in Ireland in the current analysis. The results show little association between GS and variety DM production as varieties age to 7 yr. Dry matter production of 1- to 4-yr-old swards appeared to provide a strong indication of variety DM production in years 5–7 post-sowing ($r = 0.72$, $P < 0.05$). The interaction of variety and sward age was not associated with DM production. Generally, varieties which produced the most DM in younger swards also produced the most DM in permanent pasture swards. Over longer-term periods these variety differences can manifest into large differences in DM produced and consumed on farm. The current analysis suggests that the long-term production benefits of utilising improved PRG varieties in pasture reseeding may be underestimated.

Keywords

Ground score • PastureBase Ireland • permanent pasture • persistency

Introduction

Temperate regions of the world have a high grass growth potential and are able to support efficient low-input ruminant animal production systems. Low-input, and thus low-cost, grazing systems were pioneered in New Zealand and Ireland, utilising a competitive advantage to produce pasture over a long growing season due to cool summers and mild winters (Roche *et al*., 2017). In Ireland, ruminant diets consist of between 65% and 90% pasture (Keady *et al*., 2009; O'Donovan *et al*., 2011; O'Brien *et al*., 2018), either as a grazed or ensiled home-grown feedstuff. Within these production systems, perennial ryegrass (*Lolium perenne L.*, PRG) is the most important forage species as it provides large quantities of digestible forage to grazing animals at a relatively low cost compared to other feed sources (Finneran *et al*., 2012).

Increasing the level of PRG in the sward will improve the quality and amount of pasture dry matter (DM) produced throughout the grazing season (Sheldrick *et al*., 1990; Lawson & Kelly, 2007; Creighton *et al*., 2011), and thus increase the level of forage harvested directly by grazing animals (Tubritt *et al*., 2020a); when combined these benefits lead to increased economic sustainability for ruminant production enterprises (Peyraud *et al*., 2010; Tozer *et al*., 2015). The most effective method of increasing PRG sward content is to reseed pastures with improved PRG varieties (Creighton *et al*., 2016). Pasture reseeding is an expensive procedure, estimated at €799/ha (Tubritt *et al*., 2021), and this cost is cited as a reason not to reseed paddocks by farmers (Creighton *et al*., 2011). Previous studies have shown that any costs incurred during the reseeding process will be repaid by the renewed sward within 3 yr post-establishment under Irish conditions (Creighton, 2012) and that these swards will continue to positively contribute to farm performance after this point (Shalloo *et al*., 2011; Creighton, 2012). In order to fully capitalise on the benefits of reseeding, and to encourage

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greater uptake of reseeding technologies, improved PRG varieties are required on an ongoing basis (O'Donovan *et al*., 2011; Shalloo *et al*., 2011).

Improved PRG varieties are those which provide higher levels of DM production, particularly under less favourable climatic conditions such as colder periods of the year, or increased levels of nutrients to grazing animals or greater yield persistency over time thus increasing the benefit of a reseeding event. Generally, it is recommended that pasture be reseeded every 12 yr to optimise sward performance on Irish farms (Tubritt *et al*., 2021), although this is based more on the generation interval of PRG breeding rather than actual recorded instances of either DM production loss or decline of PRG within grazing swards (O'Donovan *et al*., 2017). Little data are available on the actual performance of varieties as they mature to permanent pasture, defined as swards older than 5 yr (Allen *et al*., 2011; Huyghe *et al*., 2014), as variety evaluation protocols are often not managed beyond a period of 3 yr (Conaghan *et al*., 2008). Due to the costs of reseeding pasture, large economic weighting is given to variety persistence in variety ranking indexes, such as the Pasture Profit Index (PPI) in Ireland where persistency accounts for 29% of the total value given to a variety (Tubritt *et al*., 2021). Currently, persistence measurements are centred on the theory that the number of PRG tillers, or the percentage of ground covered by PRG tillers, and the annual changes in tiller numbers can influence the long-term productivity of PRG-based swards (Creighton, 2012; Jayasinghe *et al*., 2021). While this theory may have some value in short-term trials, there is no evidence available to show that the extrapolation of ground score (GS) data can predict the lifetime DM production of a variety. On the contrary, previous on-farm evaluations have shown little or no relationship between GS and on-farm sward DM production (Byrne *et al*., 2017; Hearn *et al*., 2021).

The process of developing an improved PRG variety can take approximately 15 yr from first cross to commercial seed production (Hayes *et al*., 2013). Within breeding programmes, plant selection focusses on varieties that will excel within the evaluation protocols used in target seed markets. Such protocols are typically carried out in mechanically defoliated plot systems over short periods of 2–3 yr and often include a limited number of locations (Conaghan *et al*., 2008). These protocols allow evaluating authorities to assess large numbers of varieties over a relatively short period of time (<3 yr) in a cost-efficient manner while simultaneously allowing seed companies to minimise the time taken to bring new varieties to the market; they provide useful data on a range of agronomic traits including sward quality and DM production in young swards and have allowed substantial gain in many agronomic traits since their introduction (Smith *et al*., 2014; McDonagh *et al*., 2016). However, limitations of these protocols are recognised as they are unable to provide data on either long-term growth or variety performance under animal grazing (Stewart & Hayes, 2011).

While studies have shown that mechanically defoliated plots and animal grazed plots provide similar results for DM production (Cashman *et al*., 2016), there have been calls for the evaluation of PRG varieties on farms as this is the environment in which they are ultimately intended for use (Kerr *et al*., 2012; Lee *et al*., 2012). On-farm evaluation of PRG varieties has been made possible in recent years due to the evolution of technology in the form of PastureBase Ireland (PBI), a software application which acts as both a decision support tool for farmers and a national grassland database for researchers (Hanrahan *et al*., 2017). Previous on-farm analyses have shown that varietal DM production differences become evident over years on-farm, while GSs are of little relevance to pasture performance (Byrne *et al*., 2017; Hearn *et al*., 2021). As such, it seems clear that actual DM produced annually is a more accurate measure of persistence than other available metrics (Parsons *et al*., 2011, O'Donovan *et al*., 2017). The objectives of the current study were to analyse on-farm production and GS differences between varieties as they age, to quantify the changes in these differences over time and to analyse the overall relationship of DM production between newly sown pastures and permanent grasslands of the same variety.

Materials and methods

This longitudinal study of PRG variety performance was based on data collected from 649 paddocks across 101 commercial Irish grassland farms between the years 2013 and 2020 inclusive. Each farm acted as a replicate, and paddocks were treated as the experimental unit nested within farm. Farms were located across a range of agroclimatic regions on differing soil types, all operating grazing-based ruminant production systems in the Republic of Ireland, of which the majority were dairy farms (n = 98) along with a small number of beef and sheep farms (n = 3). The farms (number of farms in parenthesis) were located in the following counties: Cavan (1), Cork (30), Donegal (3), Galway (10), Kerry (5), Kildare (4), Kilkenny (5), Laois (2), Limerick (10), Longford (1), Louth (1), Mayo (4), Roscommon (5), Sligo (3), Tipperary (8), Waterford (2), Westmeath (4) and Wexford (3) (Figure 1). The majority of the participating farms required a Nitrates Derogation (DAFM, 2023a) for each of the evaluation years, permitting application of between 170 and 250 kg organic N/ha per year across all farm paddocks in addition to 250 kg of inorganic N/ha per year.

Data capture and storage – PastureBase Ireland

All participating farmers used PBI (Hanrahan *et al*., 2017) to assist with grassland management decisions. PastureBase

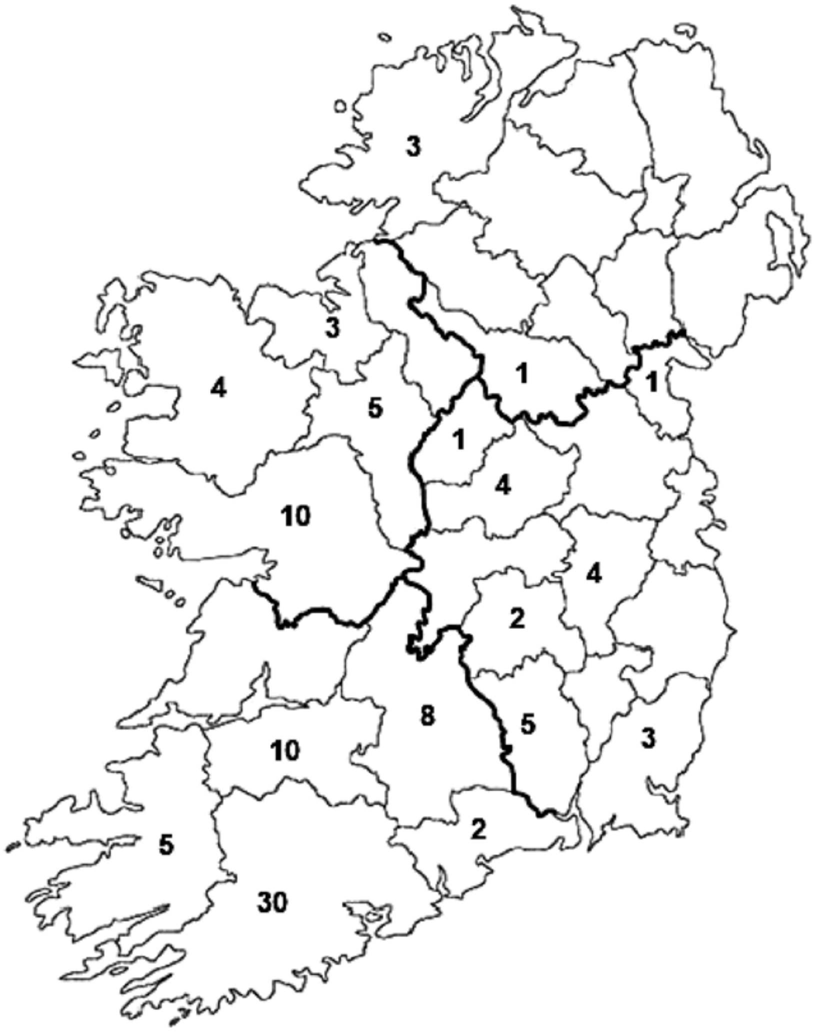

Figure 1. Regional distribution and number of farms per county.

Ireland is described in Hanrahan *et al*. (2017). Briefly, it is a web-based grassland database having the dual function of providing real-time decision support for farmers while acting as a national grassland database, capturing information for benchmarking and research purposes. The system operates with the individual farm paddock as the basic unit of measurement; all measurements on PBI are calculated and presented on a per hectare basis for individual paddocks.

Data for the current analysis were collected using PBI with similar methodology to that used in Byrne *et al*. (2017) and Hearn *et al*. (2021). PastureBase Ireland is operated by the farmer entering grassland information through a web front end; data recorded in PBI must satisfy predefined verification rules programmed into the system. Such verification checks include restrictions on grass DM production estimates (0–3,500 kg DM/ha), silage DM production estimates (0–10,000 kg DM/ha) and residual sward heights (2.5–9.0 cm). All participating farmers were provided with grassland management training for the duration of the study which helped to ensure that data were recorded correctly and that grassland management standards were adhered to (Teagasc, 2011).

The farmer builds a profile for each paddock, entering background information such as size, altitude, aspect, drainage status, reseed date and method, sown varieties and soil fertility records (Byrne *et al*., 2017). Grass cover estimates were entered on a weekly or bi-weekly basis; total and grazed DM production was calculated from farmer-inputted grass cover estimates and the current status of each paddock (silage, grass, reseed, under grazing, other) along with defoliation event date and type (grazed or silage cut) as appropriate (Hanrahan *et al*., 2017).

Variety establishment

Grass varieties were sown following guidelines to ensure successful sward establishment (Teagasc, 2014). These guidelines include treating paddocks with glyphosate, cultivating ground to form a fine, firm seedbed and sowing varieties at a standard rate of 34.5 kg/ha. Farmers were encouraged to choose the cultivation practice best suited to their farm at the time of sowing (Hearn *et al*., 2021). Fertiliser, including lime, was applied as appropriate (according to soil test results) at sowing and post-emergent herbicide was applied within the first 6 wk after sowing.

Perennial ryegrass varieties were selected from the Irish Recommended List (RL) for Grass and White Clover Varieties in each of the years 2011–2019 (DAFM, 2023b). Diploid (D) and tetraploid (T) varieties with heading dates ranging from 1 to 9 June were selected for use. The varieties sown (along with the associated ploidy and heading date in parenthesis) were the following: AberChoice (D; 9 June), AberGain (T; 4 June), Astonenergy (T; 2 June), Drumbo (D; 7 June), Kintyre (T; 6 June), Majestic (D; 1 June), Twymax (T; 7 June) and Tyrella (D; 4 June) (Table 1). AberGain (late heading T) was sown in at least one paddock across all 101 farms over the course of the measurement period and each farm was allocated a subset of the other varieties, both tetraploid and diploid, from the evaluation set of varieties. All paddocks were sown between April and August from 2011 to 2019. Variety allocation was dependent on a number of factors such as the farmer's reseeding programmes and previously sown varieties.

Ground score

Perennial ryegrass sward GS was established annually by trained assessors who visually scored swards over the winter period (December–January). Swards were scored on a scale of 0–9 (where 0 = 0.0–0.10 PRG and 9 = 0.91–1.00 PRG) (Cashman *et al*., 2016). This protocol is similar to that undertaken in value for cultivation and use cultivar evaluation at the plot level (Grogan & Gilliland, 2011).

Statistical analysis

Only farms with a minimum of 30 completed farm grass measurements per annum (equating to 1 grass growing year, between January and December) were retained for that year. Newly reseeded swards were excluded from the analysis; swards were required to have been through one winter (fully established) before they were included in the analysis. The sample size of all varieties is outlined in Table 1.

The association between variety and each agronomic parameter was estimated using linear mixed models in SAS using PROC MIXED (SAS Inst., Cary, NC, USA). Paddock, nested within farm, was included as a repeated measure in all analyses with a first-order autoregressive covariance structure assumed among repeated records (chosen based on the Akaike information criterion). A two-way interaction between farm and year was included as a random effect in all models to account for any possible changes in farm management practices or conditions (e.g. weather) over the trial period. The dependent variables assessed were annual grazing DM production (kg DM/ha), total DM production (kg DM/ha), number of grazing events and GS. In all models the fixed effects were variety, year, sward age and a two-way interaction between variety and sward age. Sward age was defined as measurement year minus sowing year with sward ages ≥7 coded as 7 yr old. The correlation between yields as varieties aged was tested using regression analysis of variety mean DM production in SAS.

Results

Sward total dry matter production

Total DM production was associated with sward age ($P < 0.01$; Figure 2) but there was no interaction between variety and sward age indicating that there is little change in the difference of DM production between varieties as they age (Table 2). One-year-old swards produced 998 kg DM/ha more

Table 1: On-farm sample size (number of paddocks) per variety and year

Year	AberChoice	AberGain (T)[1]	Astonenergy (T)	Drumbo	Kintyre (T)	Majestic	Twymax (T)	Tyrella	Total
1	35	88	28	25	29	24	25	43	297
2	31	88	31	26	30	20	29	52	307
3	27	80	31	26	27	18	29	51	289
4	29	54	26	25	29	17	35	55	270
5	24	30	25	26	27	14	36	62	244
6	20	16	18	23	23	11	31	53	195
7	12	12	40	17	24	8	19	73	205
Total	178	368	199	168	189	112	204	389	1807

[1](T) denotes tetraploid varieties, all other varieties are diploid.

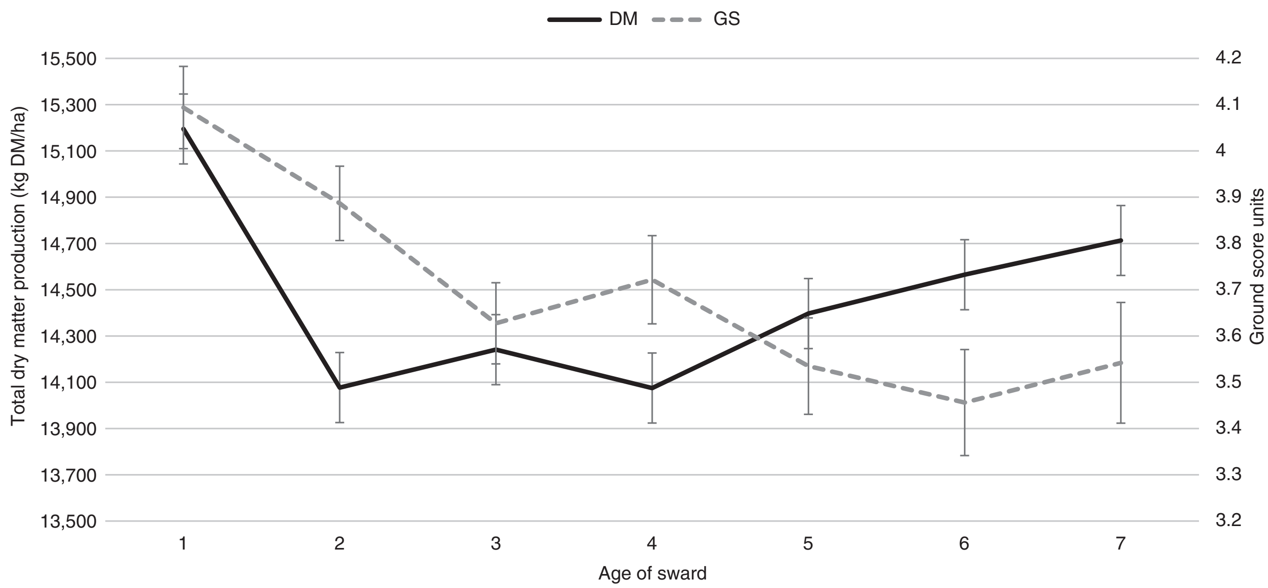

Figure 2. Mean total dry matter production (kg DM/ha) and ground score (GS) of eight perennial ryegrass varieties (error bars represent standard error) from ages 1 to 7.

Table 2: Total dry matter production (kg DM/ha) (least square means with standard errors in parentheses) per variety, and mean of all varieties, across the ages 1–7 yr post-sowing

Total annual herbage production (kg DM/ha)							
Variety	**1 (±)**	**2 (±)**	**3 (±)**	**4 (±)**	**5 (±)**	**6 (±)**	**7 (±)**
AberChoice	15,133 (534)	12,763 (520)	14,772 (582)	14,348 (550)	14,845 (666)	14,486 (684)	14,999 (714)
AberGain (T)[1]	16,004 (362)	14,835 (399)	14,907 (402)	15,812 (520)	15,310 (590)	15,882 (701)	15,451 (802)
Astonenergy (T)	15,046 (579)	14,592 (508)	14,840 (533)	14,062 (628)	14,334 (654)	14,050 (691)	14,141 (582)
Drumbo	15,901 (581)	15,119 (615)	13,917 (589)	14,881 (570)	15,039 (588)	14,251 (593)	14,610 (703)
Kintyre (T)	14,626 (549)	13,721 (556)	14,778 (529)	12,795 (512)	13,984 (565)	14,785 (596)	14,335 (612)
Majestic	14,158 (670)	13,931 (715)	13,111 (710)	13,727 (697)	13,565 (727)	14,286 (774)	15,199 (807)
Twymax (T)	15,385 (750)	14,171 (655)	13,293 (588)	13,605 (586)	14,300 (601)	14,438 (599)	14,658 (586)
Tyrella	15,307 (673)	13,483 (508)	14,311 (463)	13,373 (418)	13,801 (392)	14,343 (413)	14,310 (377)
Mean	15,195 (281)	14,077 (264)	14,241 (252)	14,075 (259)	14,397 (279)	14,565 (306)	14,713 (345)

[1](T) denotes tetraploid varieties, all other varieties are diploid.

than the average of 2- to 5-yr-old swards; however, there was no difference between 1- and 6- or 7-yr-old sward production (Figure 2). Variety was associated with total DM production ($P < 0.01$); AberGain had the highest level of DM production (15,457 s.e. = 298 kg DM/ha), growing 1,461 kg DM/ha per year more than the lowest producing variety (Tables 2 and 3).

Grazing dry matter production and events

Grazing DM production was not associated with either sward age or the interaction between varieties and sward age. Pairwise comparisons between sward ages show a difference of 525 kg DM/ha ($P < 0.05$) between 1 and 2-yr-old swards where 1-yr-old swards were highest; no other differences were apparent. Variety was associated with grazing DM production ($P < 0.001$); AberGain had the highest level of DM production (13,416 s.e. = 259 kg DM/ha), while Tyrella had the lowest (11,811 s.e. = 196 kg DM/ha) (Table 3).

The number of grazing events was not associated with age or variety. Pairwise comparisons between varieties show a difference of 0.9 grazing events ($P < 0.05$) between AberGain and Twymax, the varieties with the highest and lowest grazing events, respectively (Table 3).

Table 3: Mean total (grazing plus silage) and grazing dry matter production (kg DM/ha) (least square means with standard error in parentheses) and grazing events achieved[1]

	Varietal total and grazing dry matter production (kg DM/ha), number of grazing events achieved and ground score			
Variety	**Total (±)**	**Grazing (±)**	**Grazing events (±)**	**Ground score (±)**
AberChoice	14,478 (314)[b,c]	12,880 (279)[a,b]	7.7 (0.23)[a,b,c]	3.9 (0.10)[a,b]
AberGain (T)[2]	15,457 (298)[a]	13,416 (259)[a]	8.2 (0.21)[a]	4 (0.10)[a]
Astonenergy (T)	14,438 (310)[b,c]	12,806 (267)[a,b,c]	7.7 (0.22)[a,b,c]	3.5 (0.10)[c]
Drumbo	14,817 (319)[a,b]	12,729 (281)[b,c,d]	7.7 (0.23)[a,b,c]	3.8 (0.11)[a,b]
Kintyre (T)	14,146 (294)[b,c]	12,285 (264)[b,c,d,e]	7.9 (0.22)[a,b]	3.5 (0.10)[c]
Majestic	13,997 (362)[b,c]	12,061 (357)[c,d,e]	7.8 (0.30)[a,b,c]	3.6 (0.14)[b,c]
Twymax (T)	14,264 (315)[b,c]	12,130 (259)[d,e]	7.3 (0.21)[c]	3.7 (0.10)[b,c]
Tyrella	14,133 (247)[c]	11,811 (196)[e]	7.4 (0.16)[b,c]	3.6 (0.07)[c]

[1]Means within a column with different superscripts (a, b, c, d, e) differ significantly ($P < 0.05$).
[2](T) denotes tetraploid varieties, all other varieties are diploid.

Ground score

Ground score was associated with sward age and variety ($P < 0.001$); 1-yr-old swards had the highest GS, 0.52 units higher than the mean of 3- to 7-yr-old swards (Figure 2). AberGain, AberChoice and Drumbo had the highest GSs, with a mean GS of 0.39 units higher than the mean of Astonenergy, Kintyre and Tyrella (Table 3), which had the lowest GSs. There was no association between GS and ploidy or between GS and the interaction of variety and sward age.

Age of sward correlations

The relationships between swards of different ages and age groups are presented for both total and grazed DM production in Tables 4 and 5, respectively. The correlation coefficient (r) for total DM production of 2- to 4-yr-old swards and 5- to 7-yr-old swards was 0.71, indicating a strong positive relationship ($P < 0.05$) between the performance of younger swards and that of permanent pastures of the same variety. The r value was similar (0.72, $P < 0.05$) when 1- to 4-yr-old swards were compared to 5- to 7-yr-old swards (Table 4); the r values were lower when 6- to 7-yr-old swards were compared to all others. Grazed sward DM production comparisons provided strong positive relationships between 1- to 4-yr-old swards and 6- to 7-yr-old swards (Table 5). Spearman's rank correlation for grazed DM production of 1- to 4-yr-old swards and 5- to 7-yr-old swards was also strong ($r = 0.95$, $P < 0.001$) indicating little re-ranking of variety performance for grazing DM production as the swards age (data not shown). A similar analysis of total DM production showed only moderate positive relationships between variety rankings in 1- to 4-yr-old swards and 5- to 7-yr-old swards ($r = 0.5$; data not shown). Relationships between individual years are generally poor although the performance of varieties in their fourth year of production appears to have the strongest relationship to sward performance in permanent pasture for both total and grazed DM production (Tables 4 and 5). There was a low positive correlation between GS and total ($r = 0.31$) or grazed ($r = 0.19$) DM production as swards aged to 7 yr (data not shown). Ground score accounted for 10%

Table 4: Correlation matrix for the relationships between total dry matter production for individual sward ages (years post-sowing) and mean total dry matter production across various sward age combinations

Sward ages and age combinations	1	2	3	4	1 & 2	1 & 2 & 3	2 & 3	1 & 2 & 3 & 4	2 & 3 & 4
5	0.82*	0.41	0.44	0.86**	0.68	0.78*	0.63	0.88**	0.83*
6	0.42	0.19	0.40	0.54	0.34	0.48	0.44	0.55	0.55
7	0.12	0.03	−0.17	0.62	0.08	−0.01	−0.10	0.26	0.28
5 & 6	0.72*	0.35	0.48	0.81*	0.59	0.73*	0.61	0.82*	0.80*
6 & 7	0.32	0.13	0.16	0.64	0.25	0.29	0.22	0.46	0.48
5 & 6 & 7	0.60	0.28	0.31	0.83*	0.48	0.55	0.44	0.72*	0.71*

Significant regression values are indicated beside each coefficient (r values) where * and ** denote $P < 0.05$ and $P < 0.01$, respectively.

Table 5: Correlation matrix for the relationships between grazing dry matter production for individual sward ages (years post-sowing) and mean grazing dry matter production across various sward age combinations

Sward ages and age combinations	1	2	3	4	1 & 2	1 & 2 & 3	2 & 3	1 & 2 & 3 & 4	2 & 3 & 4
5	0.53	0.65	0.19	0.72*	0.65	0.49	0.45	0.61	0.61
6	0.66	0.58	0.63	0.77*	0.66	0.74*	0.72*	0.80*	0.82*
7	0.48	0.49	0.58	0.60	0.53	0.64	0.65	0.67	0.69
5 & 6	0.69	0.66	0.56	0.84**	0.73*	0.74*	0.71*	0.83*	0.84**
6 & 7	0.60	0.56	0.63	0.72*	0.62	0.72*	0.72*	0.77*	0.79*
5 & 6 & 7	0.63	0.62	0.61	0.78*	0.68	0.74*	0.73*	0.80*	0.82*

Significant regression values are indicated beside each coefficient (r values) where * and ** denote $P < 0.05$ and $P < 0.01$, respectively.

of the variation in total DM production of swards as they age ($R^2 = 0.10$).

Discussion

Grassland farmers are now being asked to balance production and environmental goals, while simultaneously remaining profitable within a system where product pricing is beyond their control (Lüscher *et al*., 2014; Roche *et al*., 2017; EU, 2020). The current analysis highlights the long-term benefits of reseeding pastures using improved PRG varieties, which can have knock on economic and environmental impacts, while raising some questions around the optimum reseeding frequency for paddocks.

Persistence of dry matter production

Perennial ryegrass DM production persistence is a key component of both the economic and environmental sustainability credentials of grassland systems (Ludemann *et al*., 2015; Conant *et al*., 2017). The requirement to replace a poorly performing variety has been modelled within the PPI with a variety deemed invalid when DM production has fallen to below 50% of its year 1 production (O'Donovan *et al*., 2017). The economic return on reseeding such paddocks with improved PRG varieties is substantial (Shalloo *et al*., 2011); each tonne of pasture DM utilised on Irish dairy farms increases net profit by €173/ha (Hanrahan *et al*., 2018), while reseeding costs are estimated at €799/ha (Tubritt *et al*., 2021). Very little data are available regarding the actual performance of PRG varieties over a period of longer than 4 yr, with none being available regarding persistence on farm. Assuming that PRG varieties lose productivity as they age may seem intuitively correct, yet this did not occur in the current analysis. Results from the current study indicate that DM production is similar in years 6–7 as it is in years 1–3 for all varieties evaluated. The paddocks evaluated in the current trial are part of well-managed grassland farms conducting greater than 30 farm cover assessments every year (Maher *et al*., 2021). These paddocks were also closely monitored by Teagasc and PBI researchers to ensure that high quality data were collected; reseeding of variety monocultures post-initial sowing rarely took place during the period of the current study and did not impact the results. The farms involved in the current trial are managed for optimal sward production and variety effects should be clearly realised in this scenario, similar to Byrne *et al*. (2017). The highest correlations with permanent pasture DM production (total and grazing) are achieved when DM production in the fourth year post-sowing is included in the analysis. As animal grazed and mechanically defoliated plots have previously been shown to rank varieties similarly for DM production (Cashman, 2016), the current analysis indicates that persistence of PRG DM production could be better evaluated over a period of 4 yr using mechanically defoliated plots.

A plot-based study carried out by Chapman *et al.* (2015) broadly agreed with the current findings as they showed that DM production of PRG varieties was not significantly different between years 1–3 and years 7–8. The current analysis provides greater evidence of these relationships as it utilises data generated on commercial farms including multiple locations and sowing years for each variety. Although lacking some of the control of plot-based trials, on-farm evaluation is an effective tool for evaluating varieties under the management and climatic conditions in which they are expected to perform; paddocks in the current analysis were measured over a period which included a variety of weather events in Ireland, such as periods of high rainfall and low temperatures along with a particular period of severe soil moisture deficit conditions in 2018. Varieties evaluated over a longer-term period in a New Zealand plot study did suffer some decline in DM production in year 10 which was attributed to several factors including site location, trial protocols and range of PRG varieties used (Chapman *et al*., 2015). Whether a similar decline is observed within the current trial remains to be seen. Chapman *et al.* (2015) attributed some of the decline in year 10 to ploidy where it was theorised that tetraploid varieties did not sustain their ranking of DM production as their ability to recover from periods of soil moisture deficit is limited due to their lower tiller density. Both diploid and tetraploid varieties are equally represented in the current analysis but little differences were observed between ploidy groups for either DM production or GS (Table 2). While Byrne *et al*. (2017) observed that tetraploid varieties had a lower GS change in a shorter-term (3-yr-old swards) on-farm trial, the opposite trend was observed between ploidies for this metric in PPI evaluations (DAFM, 2023b). The current analysis provides more robust analysis of persistence as it is conducted on varieties up to 7 yr post-sowing.

The sustained DM production of the eight varieties assessed in the current analysis is to be anticipated; PRG is a perennial species and should, all other factors being equal, produce similar levels of DM each year indefinitely. Management factors such as soil fertility, weed control and grazing rotations along with annual climate variability have been shown to have a greater impact on sward DM production than PRG variety selection (Clark *et al*., 2007; Conaghan & Casler, 2011). Reseeding paddocks when they reach a threshold of 50% of year 1 production will have clear economic benefits but the idea that a paddock would reach such a threshold based solely on the sown variety appears unlikely, certainly within a 7-yr period. Other factors related to PRG variety including sward grazing efficiency and sward quality may influence a farmers' decision to reseed paddocks. It is clear that grazing sward quality has a direct impact on animal performance (NRC, 2021) and improving sward quality is a determining factor when farmers are reseeding pastures (Creighton *et al*., 2011). More recently, as farmers focus on maximising pasture DM utilisation, clear differences in pasture utilisation between PRG varieties have become apparent (Tubritt *et al*., 2020a). These factors of sward quality and grazing efficiency are linked (Tubritt *et al*., 2020b) and future on-farm analysis should aim to account for such factors as they would enhance understanding of all round variety performance and persistence.

Variety evaluation protocols often show a drop in production after year 1 and this is reflected in the current analysis where varieties had a mean reduction of 1,118 kg DM/ha in year 2 compared to year 1. This downward trend does not continue as varieties mature into permanent pasture swards and appears, in agreement with Parsons *et al*. (2011), to be more of a periodic adjustment or 'settling in' phase before the true genetic potential of the variety can be seen. Previous work has shown that soil disturbance (such as paddock reseeding) events increase the level of pasture DM production regardless of species (Tilman, 1990); this is attributed to soil N mineralisation (Hopkins *et al*., 1990) and species competitive dynamics within habitats (Hodgson & Illius, 1998). It is possible that as swards mature resources are allocated to leaf, stem or root development periodically as plants settle into their environment (Parsons *et al*., 2011); this may be reflected in the current analysis which appears to show that DM production increases numerically as varieties age from 2- to 7-yr-old swards (Figure 1), although this increase is not statistically significant. Preliminary indications from a limited number of older paddocks (7–10 yr old) in the current dataset show that this upward trend in DM production is not likely to continue (data not shown) post-year 7; a stabilisation of DM production in permanent pastures (>5 yr old) appears more likely. These results from a unique dataset of PRG varieties grown on well-managed commercial grassland farms, where soil fertility was managed to promote PRG production under optimal climatic conditions for this species (Hopkins, 2000), agree with Frame and Laidlaw (2013) who stated that late heading PRG varieties are persistent and remain productive over time when grown in fertile soil conditions. It may be beneficial for variety evaluation protocols to prolong measurement periods to capture variety performance in years 4 and 5 post-sowing; such protocols would be more reflective of variety performance in permanent pastures where they are ultimately intended for use.

Impact for grazing systems

The strong relationships observed in the current analysis between sward ages for grazed DM production (Table 5) indicate that varieties are generally able to withstand and recover from both climatic and animal stressors experienced on farms. Grazed DM production is an important metric as it quantifies the level of forage harvested directly by animals and, as this is the most efficient method of fresh forage harvesting, it can be directly linked to farm profitability (Shalloo & Hanrahan, 2018). Recent studies have outlined the value of PRG suitability to grazing and the differences between PRG variety utilisation within grazing systems (Byrne *et al*., 2018; Tubritt *et al*., 2020a). The differences in grazing DM production between varieties can be clearly seen in the current study but are difficult to quantify at the plot level due to the lack of influence of farm management practices (including selective silage conservation or paddock poaching during poor weather conditions on farm). The lack of interaction between variety and sward age on grazed DM production indicates that varieties contributing most to grazing systems in years 1–4 are continuing to do so in years 6–7. Quantification of each variety's contribution to the actual amount of DM grazed directly by animals is important and grazing metrics will become an increasingly important factor within variety evaluation systems moving forward (Tubritt *et al*., 2021).

The large disparity between varieties in terms of overall DM production is a notable issue as the highest producing variety continues to produce enough DM to provide an additional grazing rotation per year compared to the lowest producing variety up to 7 yr post-sowing. Quantification of these differences in evaluation protocols may be aided by increasing evaluation years in plot-based evaluation trials. The correlation coefficient with permanent pastures tends to increase as more evaluation years are included in the comparison (Table 5). Strong positive correlations between the performance of younger swards and permanent pastures indicate that production advantages are maintained in grazing systems over a long period of time despite the stresses experienced on commercial farms. Due to high variability in trial sites and sowing years, multiple plot trials are generally required to identify superior varieties (Easton *et al*., 2001); the current methodology allows for the evaluation of varieties across locations and sowing years at a relatively low cost compared to plot trials. Moving forward, on-farm PRG variety assessment could be conducted on a smaller scale than the current analysis where fewer farms are selected for evaluations, possibly using historical PBI records, but provide consistent data over a long time period across multiple agroclimatic regions and soil types; such changes would allow more comprehensive measurement of all PRG traits on farm with fewer replications required. The continuation of the on-farm assessment of PRG varieties would be of value (Wilkins & Humphreys, 2003) as it can provide an accurate indication of any future DM production persistence issues which may arise, at a relatively low cost. It is important now to establish the indirect effect of DM production of the variety over the longer term and extrapolate this as its persistence estimate.

While RL evaluation protocols have been optimised for the information that they currently provide (Conaghan *et al*., 2008), the high weighting for persistence within the PPI (29%) leads to questions around their suitability for complete variety assessment. This question is relevant in light of the current analysis where the metric used as a proxy for DM production persistence in the PPI, GS (McEvoy *et al*., 2011; Tubritt *et al*., 2021), has been shown to have little relationship with either total or grazed DM production. While GS can be useful in the early stages of variety screening protocols of RL evaluations, which are carried out on varieties up to 3 yr post-sowing (DAFM, 2023b), it appears to have almost no bearing on long-term DM production of varieties which survive that original screening. It can be suggested here that DM production change over time is a better indicator of persistence of a sward; it may be possible to combine values of GS changes and DM production changes in RL trials to give a more accurate estimation of longer-term persistence. The overall objective of a grassland reseeding programme on Irish grazing farms is to establish long-term swards producing high quantities of herbage for a minimum period of 10 yr (Creighton *et al*., 2011). Incorporation of on-farm variety DM production to the PPI may provide another solution to increasing the reliability of variety persistence evaluation.

It is notable that researchers responsible for the development of the Australian Forage Value Index (FVI) excluded any measure of persistence as they did not believe there was a reliable metric available to measure long-term persistence within the plot trial system being used to calculate FVI values (Leddin *et al*., 2018). Persistence of PRG is of greater concern in Australia due to the more variable climate and increased pest pressures; the lack of inclusion of the trait within the Australian FVI highlights the issues around attaching an economic value to it. Utilising the current methodology, analysis which includes more varieties would be beneficial as would an extended time period of analysis for the current varieties. Developments in imaging technology may provide another solution to the problem of accurately measuring pasture persistence in the future (Jayasinghe *et al*., 2021); such methods would remove subjective differences between human assessors of GS. Trials which could examine in detail the interactions between farm management practices and variety selection over time may be most informative on the question of PRG variety persistence differences (Edmond, 1964; Wilkins & Humphreys, 2003).

Impact for paddock reseeding and soil carbon

Maintaining a high percentage of PRG tillers within swards is crucial to sward DM production in Ireland and pasture reseeding is the most effective method of increasing sward PRG content (Creighton *et al*., 2011). It has also been shown that soil disturbance events, including paddock reseeding, lead to losses of carbon (16–32 Mg carbon/ha) from the soil (Willems *et al*., 2011; Gilliland, 2022). While a reseeding strategy of 8–10% of the grazing area per year would optimise DM production and capitalise on the latest gains in PRG breeding (Teagasc, 2014), farmers may need to balance such gains with carbon and soil nutrient losses (Kayser *et al*., 2018). It is well established that soil disturbance events can lead to losses of N and P from Irish grasslands, via leaching and over-ground flow, respectively, when herbage growth is suppressed (Schulte *et al*., 2006). Similarly, Reinsch *et al*. (2018) showed that, on a sandy loam soil, regular ploughing (every 5 or 10 yr) of grasslands would lead to cumulative losses of soil carbon over an extended time period (100 yr). Another analysis, from a combination of clay loam and poorly drained gley soils, has suggested that, while carbon is lost during reseeding events, soil carbon stocks of permanent and newly reseeded swards are very similar, and soil physical properties, often determined by management factors other than reseeding strategy, are strongly associated with soil carbon stocks (Carolan & Fornara, 2016). Willems *et al*. (2011) showed that the lack of herbage growth during the reseeding period was likely associated with net carbon dioxide losses as no photosynthetic activity occurred; minimising this period where soil is fallow can reduce the impact of reseeding on net soil carbon loss.

A balance between the carbon being sequestered by productive grassland and that being lost during reseeding events to promote productivity must be struck (Kayser *et al*., 2018) as poorly managed or neglected grassland systems can pose further issues for the environment including nitrous oxide emissions (Eckard *et al*., 2010). Less than 2% of grassland in Ireland is reseeded annually, equating to a one-in-fifty-year event, although this is greater on specialist dairy farms at approximately 7% (Creighton *et al*., 2011). A large majority of grassland paddocks in Ireland are permanent pastures likely consisting of less productive grassland species; such pastures could produce more DM after a comprehensive reseeding programme which includes improved varieties of PRG. Increasing pasture DM production of swards would allow farmers to reduce reliance on imported feed, thus increasing production efficiency and farm profitability (Horan & Roche, 2019). Such production benefits also need to be weighed against ecosystem services, such as habitat provision for a diverse range of species, which are available in permanent grasslands but lost in reseeded pastures (Huyghe *et al*., 2014). The current research suggests that farmers who undertake pasture reseeding with improved PRG varieties may see the production benefits for a longer period post-sowing than previously thought. Similarly, reseeding of pastures too frequently may not be beneficial, and may lead to increased soil carbon losses (Gilliland, 2022), if all other factors affecting grass growth are not optimised.

Conclusion

The results of the current study demonstrate that PRG variety DM production is stable on commercial grassland farms in Ireland up to 7 yr post-sowing. This persistence is characterised by similar DM production in year 1 and years 6–7. Given the strength of these relationships, the long-term benefits of reseeding less productive swards with improved PRG varieties may be underestimated. Ongoing measurement of these paddocks will reveal the full extent of PRG variety DM production stability and the benefits of reseeding pastures using improved PRG varieties; these measurements may form the basis for a future review of optimal long-term sward renewal practices on Irish grassland farms. The weak association between DM production and GS in the current analysis raises an issue with the use of GS in long-term PRG evaluation trials. The lack of association between DM production, either grazed or total, and the interaction of variety and age indicates little change in DM production between varieties as they age on farms, thus variety selection will significantly impact total sward DM production in the long term.

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Conflicts of Interest

The authors declare there are no conflicts of interest.

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