Agronomic performance of ten perennial ryegrass varieties on commercial grassland farms

C. Hearn1,2, M. Egan1, D. P. Berry1, A. Geoghegan1, M. O’Leary1, M. B. Lynch2,3 and M. O’Donovan1

1Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland; 2School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland and 3Teagasc Environmental Research Centre, Johnstown Castle, Wexford, Ireland

Abstract

Little information is available on the phenotypic performance of perennial ryegrass varieties when exposed to grazing conditions on commercial grassland farms. Grass varieties are classically evaluated in mechanically defoliated plot systems which, although designed to mimic grazing conditions, do not fully capture the range of stresses or interactions that a sward is subjected to under commercial settings or over any period longer than 4 years. 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. Data used in the current study consisted of dry matter (DM) production and ground score data across a 7-year period from ten perennial ryegrass varieties grown as monocultures in 559 paddocks on 98 commercial farms. The results demonstrated how perennial ryegrass variety is associated with a range of agronomic performance traits on commercial farms; including total and seasonal DM production, grazing DM production and number of grazing events. Varieties with the highest total DM production also had the highest spring and mid-season DM production; autumn DM production was associated with the interaction between variety and year. The highest producing variety in the study, AberGain, produced 1342 kg DM/ha/year more than the mean of all other varieties. Variety differences manifested themselves as swards aged, with some varieties increasing in total DM production while others reduced in total DM production. The current work provides a basis for the consideration of on-farm variety assessment in the composition of future variety evaluation protocols.

Introduction

Improved grass growth and utilization is a key component of maintaining the economic and environmental sustainability of ruminant production systems in temperate environments (Peyraud et al., 2010; Conant et al., 2017; Neal and Roche, 2020). Chapman et al. (2008) outlined how farm profitability is directly related to the quantity of grass grown and utilized through grazing on-farm. Perennial ryegrass (Lolium perenne L., PRG) is considered the most important temperate forage species used in pasture production (Easton et al., 2001; McEvoy et al., 2011). This is due to its high nutritive value and relatively low cost compared to other feed sources for ruminants (Finneran et al., 2010).

European grassland farmers are under increasing pressure to reduce the extent of fertilizer usage (Velthof et al., 2014), including a prescribed reduction of 20% from 2020 usage levels before the year 2030 (EU, 2020). A review of New Zealand (NZ) grass breeding stated that any further increase in fertilizer inputs above those already used by grassland farmers will not increase PRG dry matter (DM) production (Parsons et al., 2011). Alternative strategies for increasing DM production on commercial farms are therefore required. Grass growth and utilization can be improved through a combination of reseeding of poor-performing pastures with higher-performing grass varieties as well as better aligning grass growth and feed requirement over the grazing season (Shallow et al., 2011). The use of improved grass varieties, with increased DM production and nitrogen (N) use efficiency, will be required in the future to increase the efficiency of pasture production systems (O’Donovan et al., 2011; Cameron et al., 2013).

The development of new grass varieties in Ireland has been directed mainly by recommended list (RL) evaluation trials since their establishment in 1973 (Grogan and Gilliland, 2011; Stewart and Hayes, 2011). RL evaluations assess a variety’s value for cultivation and use (VCU) through a system of mechanically defoliated plot trials, a protocol common throughout Europe. The Irish system involves assessing varieties for DM production, nutritive value and short term persistency across two growing seasons following an establishment year.
This system has been used effectively by breeders to select and develop PRG varieties with greater DM production over the last number of decades (Lee et al., 2012; McDonagh et al., 2016). Nonetheless, mechanically defoliated plot trials are limited in terms of the information generated (O’Donovan et al., 2011; Kerr et al., 2012). These limitations include a lack of information on lifetime variety persistence, performance metrics under animal grazing scenarios, including tolerance to grazing pressures such as treating and plant pulling, and a limited number of evaluation sites across differing environments (Wilkins and Humphreys, 2003; Kerr et al., 2012). Such limitations question the suitability of plot evaluation systems alone to deliver on the current needs of grassland farmers (Byrne et al., 2017).

In order to overcome the limitations of plot evaluation trials in reflecting on-farm performance, Lee et al. (2012) recommended improved overall integration, and thus alignment, of plant breeding, variety evaluation, and farm systems analyses. Since 2015, PRG varieties in Ireland are ranked on a system called the pasture profit index (McEvoy et al., 2011a) based on performance values from the evaluation trials. This index ranks varieties on the sum of the economic performance of the key pasture metrics, namely total and seasonal DM production, sward persistency and quality. Such a system provides clear direction to farmers and plant breeders (McEvoy et al., 2011a) in selecting suitable varieties bespoke to their needs (McEvoy et al., 2011b). Similar indexes are being developed in other jurisdictions, including Australia and NZ (Chapman et al., 2017; Leddin et al., 2018).

Despite refinements of the plot-based evaluation system, there is a lack of information on long-term sward performance under grazing. Grazed plots are rarely used in evaluation systems as they are considered prohibitively expensive (Gilliland et al., 2002). Conflicting evidence of how well mechanically defoliated plots and animal grazed plots relate to each other have been reported (Frame and Hunt, 1971) with more recent studies reporting no significant differences in DM production between the two strategies (Cashman et al., 2016). An NZ sheep grazing trial provided some information on the DM production performance of PRG varieties over a 10-year period (Chapman et al., 2015). While providing some useful information on the long-term growth of PRG varieties, the dataset from that study had some shortcomings, including representation of only one trial site. Conducting PRG variety evaluations on-farm has been promoted as the most accurate way to assess the value of varieties to farmers (Wilkins and Humphreys, 2003; Smith et al., 2014). The evolution of technology in the form of PastureBase Ireland has provided researchers with access to commercial grassland data that was previously unavailable (Hanrahan et al., 2017). PastureBase Ireland acts as both a grassland management decision support tool for farmers who use it regularly and as a national database of grassland growth information which can be utilized by researchers, as is the case with the current study.

The objective of the current study was to quantify the phenotypic performance (DM production and grazing events) of ten PRG varieties over a 7-year period (2013–2019) on commercial Irish grassland farms. The results from this study could be instrumental in progressing the development of the PPI and promoting the use of on-farm data as an indicator of variety performance.

Materials and methods

This longitudinal study of PRG variety performance was based on data collected from 559 paddocks across 98 commercial Irish grassland farms between the years 2013 and 2019 inclusive. Each farm acted as a replicate and paddocks were treated as the experimental unit nested within each farm. Farms were located across a range of agroclimatic regions on differing soil types; all operating grass-based ruminant production systems in the Republic of Ireland, of which the majority were dairy farms. All participating farmers used PastureBase Ireland (Hanrahan et al., 2017) to assist with grassland management decisions. The farms (number of farms in parenthesis) were located in the following counties: Cavan (1), Cork (29), Donegal (3), Galway (8), Kerry (5), Kildare (3), Kilkenny (6), Laois (2), Limerick (9), Longford (2), Louth (1), Mayo (4), Roscommon (4), Sligo (3), Tipperary (9), Waterford (2), Westmeath (4) and Wexford (3). The majority of the participating farms required a Nitrates Derogation (DAFM, 2020) for each of the evaluation years, permitting application of between 170 and 250 kg organic N/ha/year across all farm paddocks in addition to 250 kg of inorganic N/ha/year.

Data capture and storage – PastureBase Ireland

PastureBase Ireland is comprehensively described in Hanrahan et al. (2017). Briefly, it is a web-based grassland database which has a 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 PastureBase Ireland are calculated and presented on a per hectare basis for individual paddocks.

The PastureBase Ireland system is operated by the farmer entering grassland information through a web front end; the accuracy of the information collected, therefore, is dependent on the accuracy of the information inputted by the farmer. Nonetheless, data recorded in PastureBase Ireland must satisfy predefined verification rules programmed into the system. Such verification checks include restrictions on grass DM production estimates (0–3500 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 and all farmers were part of discussion groups, which met monthly during the main grass growing season. This helped ensure that data were recorded correctly and that grassland management standards were adhered to (Teagasc, 2011).

Farmer inputs

All grassland information was recorded by the farmers in the PastureBase Ireland application through either web-based or smartphone enabled interfaces. The operator 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. Grass cover estimates were entered on a weekly or bi-weekly basis. Estimates were taken by using either a plate meter (O’Donovan et al., 2002b; Jenquip, 2019) or by visual assessment (O’Donovan et al., 2002a) prior to grazing or silage harvesting. Total and seasonal DM production was calculated from farmer-inputted grass cover estimates throughout the year; seasons were defined as spring (1 February to 10 April), mid-season (11 April to 6 August) and autumn (7 August onwards) (McEvoy et al., 2011a). The farmer was also required to enter information including the current status of grassland farms between the years 2013 and 2019 inclusive. Each farm acted as a replicate and paddocks were treated as the experimental unit nested within each farm. Farms were located across a range of agroclimatic regions on differing soil types; all operating grass-based ruminant production systems in the Republic of Ireland, of which the majority were dairy farms. All participating farmers used PastureBase Ireland (Hanrahan et al., 2017) to assist with grassland management decisions. The farms (number of farms in parenthesis) were located in the following counties: Cavan (1), Cork (29), Donegal (3), Galway (8), Kerry (5), Kildare (3), Kilkenny (6), Laois (2), Limerick (9), Longford (2), Louth (1), Mayo (4), Roscommon (4), Sligo (3), Tipperary (9), Waterford (2), Westmeath (4) and Wexford (3). The majority of the participating farms required a Nitrates Derogation (DAFM, 2020) for each of the evaluation years, permitting application of between 170 and 250 kg organic N/ha/year across all farm paddocks in addition to 250 kg of inorganic N/ha/year.
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).

Meteorological data

Meteorological data generated from four inland weather stations operated by Met-Éireann (2021) were recorded; these sites were located in the south-west (Moorepark, 52°16’N, 8°26’W), south-east (Johnstown Castle, 52°16’N, 6°30’W), north-east (Ballyhaise, 54°51’N, 7°31’W) and north-west (Athlone, 53°17’N, 8°47’W) of Ireland. Annual data from these stations was taken from the Irish national meteorological database (Met-Éireann, 2020) where records for rainfall, minimum and maximum air and soil temperatures (10 cm depth) were accessed.

Ground score

Perennial ryegrass sward ground score (GS) was established by visually scoring swards annually over the winter period (December–January). Swards were scored on a scale of 0–9 (where 0 = 0.0–0.10 perennial ryegrass and 9 = 0.91–1.00 perennial ryegrass) (Cashman et al., 2016). This protocol is similar to that undertaken in VCU cultivar evaluation at the plot level (Grogan and Gilliland, 2011).

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. The cultivation methods were limited to plough-till-sow, discing, one-pass and direct drilling, where air seeders were generally used to distribute the seed evenly into the seedbed. Each of these is proven to be an equally effective method of sward establishment in Ireland (Creighton et al., 2016) and farmers were encouraged to choose the practice best suited to their farm at the time of sowing. Fertilizer, including lime, was applied as appropriate (according to soil test results) at sowing and post-emergent herbicide was applied within the first 6 weeks after sowing.

Perennial ryegrass varieties were selected from the Irish RL for grass and white clover varieties in each of the years 2011–2016 (DAFM, 2021). Diploid (D) and tetraploid (T) varieties with heading dates ranging from 29 May to 9 June were selected for use. AberGain (late heading T) was sown in at least one paddock across all 98 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; varieties were sown between April and August from 2011–2016. Variety allocation was dependent on a number of factors such as the farmer’s reseeding programmes, previously sown varieties and, to a lesser extent, seed availability. The varieties sown (along with the associated ploidy and heading date in parenthesis) were: AberChoice (D; 9 June), AberGain (T; 4 June), Astonenergy (T; 2 June), Drumbo (D; 7 June), Dunluc (T; 29 May), Glenveagh (D; 1 June), Kintyre (T; 6 June), Majestic (D; 1 June), Twymax (T; 7 June) and Tyrella (D; 4 June).

Data analyses

Only farms with a minimum of thirty completed farm grass measurements per annum (equating to one 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 a 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). 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 production dependent variables assessed were total, spring, mid-season and autumn DM production, grazing DM production and silage DM production (kg DM/ha); GS and number of grazing and silage events were also considered as dependent variables. In all models, the fixed effects were variety, year, sward age and a two-way interaction between variety and year. Sward age was defined as measurement year minus sowing year with sward ages ≥7 coded as 7-years-old. The model used to assess variety DM production and GS as they aged was similar to that used above for annual performance except the interaction between variety and sward age was included as a fixed effect in the model instead of the interaction between variety and year.

Results

Meteorological data

Meteorological data for the study period (2013–2019) from the four inland weather stations located across the country indicated some inter-annual and inter-location differences existed in summer rainfall. There was a severe moisture deficit in Ireland in the summer of 2018 with all locations recording between 0.55 and 0.71 of their respective seasonal mean for the 7-year period. Drought conditions prevailed across Ireland for approximately 12–16 weeks in the summer of 2018 causing daily grass growth rates to fall below 30 kg DM/ha/day when the 7-year average was 60 kg DM/ha/day for the same 4 week period (Fig. 1). There was a similar, but shorter, dry period in the summer of 2013 which affected the South-East of Ireland more severely than other regions; Johnstown Castle, which is located in the South-East, recorded 0.67 of its mean summer rainfall for the 7-year period. Little variation in temperature parameters existed for each location across seasons and years. Over the course of the current study, the minimum soil temperature reached was 0.4°C while the maximum air temperature peaked at 30.2°C, both occurring in 2018 at Athenry in the North-West of the country.

Variety phenotypic performance

Variety was associated with total, spring and mid-season DM production, grazing DM production and a number of grazing events; variety was not associated with silage DM production (P = 0.48). Only the associations between variety and autumn DM
production and between variety and GS differed by year. The year was associated with total, spring and mid-season DM production, grazing DM production and a number of grazing events (Table 2).

Total dry matter production
AberGain had the highest DM production (15 434, SE = 205 kg DM/ha), growing 1342 kg DM/ha/year more than the mean DM produced by all other varieties. The second-highest producing variety, Drumbo, produced 996 kg DM/ha/year less than AberGain (Table 3) over the study period. The poorest growing year was 2018 in which a summer drought occurred; 2018 DM production fell to 0.82 of mean DM production of all other years. The best year for DM production was 2017 when the average DM production was 1.1 of the mean DM production of all other years (Table 4).

Seasonal dry matter production
The interaction between variety and year for autumn DM production is most clearly illustrated by Dunluce which was the highest producing variety in autumn 2015 but lowest producing variety in autumn 2017, a range of 1594 kg DM/ha within a 3-year period (data not shown). AberGain, Astonenergy and Majestic had the highest autumn DM production across the trial period (Table 5). AberGain had the highest spring and mid-season DM production, producing 184 and 787 kg DM/ha/year more than the mean of all other varieties, respectively. The most productive year across all varieties for both spring and mid-season growth was 2017 with averages of 1536 (SE = 86) and 8845 (SE = 338) kg DM/ha, respectively. Spring and mid-season DM production reduced to their lowest in 2018, reducing by 827 and 2496 kg DM/ha, respectively, compared to 2017 (data not shown).

Grazing DM production and defoliation events
AberGain had the highest grazing DM production, producing significantly more than all other varieties except AberChoice, Astonenergy and Drumbo (Table 3). Across all varieties, the highest and lowest mean grazing DM production figures of 13 301 and 10 069 kg DM/ha were recorded in 2017 and 2018, respectively (data not shown). The most grazing events were for Astonenergy and AberGain (8.0) which were greater than those achieved by Dunluce (7.2), Glenveagh (7.3) or Tyrella (7.5) (Table 3). The most grazing events (i.e. 8.2) were in 2016, which was 1.3 events more than recorded in 2018, the year with the fewest grazing events (data not shown).

Ground score
The association between GS and variety was influenced by year. This is most clearly illustrated by Glenveagh which recorded the highest GS value of the varieties measured in 2013 and the lowest GS value in 2018 (Fig. 2). Similarly, Majestic showed changes in GS values over the years while the GS of Drumbo was stable across 7 years of the study with a range of 0.4 GS units. Glenveagh had the highest mean GS over the trial period while Astonenergy had the lowest.

Variety sward age
Variety was also associated with total DM production (P < 0.001) when the model included the interaction between variety and sward age. Swards of Dunluce increased DM production by

| Year | AberChoice | AberGain (T) | Astonenergy (T) | Drumbo | Dunluce (T) | Glenveagh | Kintyre (T) | Majestic | Twymax (T) | Tyrella | Total |
|------|------------|-------------|----------------|-------|-------------|-----------|-------------|----------|------------|---------|-------|
| 2013 | 10         | 23          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2014 | 16         | 18          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2015 | 19         | 21          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2016 | 24         | 48          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2017 | 24         | 21          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2018 | 24         | 78          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |
| 2019 | 24         | 28          | 7              | 15    | 0           | 4         | 4           | 1        | 13         | 36      | 117   |

| Total | 156       | 285         | 116            | 146   | 89          | 182       | 182         | 89       | 182        | 371     | 1912 |

* denotes tetraploid varieties, all other varieties are diploid.
Fig. 1. National herbage growth (kg DM/ha/day) for 2013–2019 inclusive (M. O’Leary 2020, personal communication).

Table 2. Significance levels (P values) of the main phenotypic effects and their interactions across production and management data

|                  | Dry matter production traits | Management traits       |
|------------------|-----------------------------|-------------------------|
|                  | Total | Spring | Mid-season | Autumn | Grazing | Silage | Grazing events | Silage events | Ground score |
| Variety          | <0.001 | <0.01  | <0.001    | <0.001 | NS      |        | <0.01         | NS           | <0.001    |
| Year             | <0.001 | <0.001 | <0.001    | <0.01  | NS      |        | <0.001        | NS           | NS         |
| Age              | <0.01  | NS     | NS        | NS     | NS      | NS     | NS            | NS           | <0.05     |
| Variety × Year   | NS    | NS     | NS        | <0.001 | NS      | NS     | NS            | NS           | <0.05     |

NS, not significant.

Table 3. Total (grazing plus silage), grazing and silage DM production (kg DM/ha) (LS means with standard errors in parentheses) and number of defoliation events achieved1,2

| Variety          | Total (±) | Grazing (±) | Grazing Events (±) | Silage (±) | Silage Events (±) |
|------------------|-----------|-------------|-------------------|------------|-------------------|
| AberChoice       | 14 390 (229)bc | 12 820 (309)ab | 7.7 (0.19)abcd | 1687 (263)ab | 0.60 (0.069)bc      |
| AberGain (T)3   | 15 434 (205)a | 13 281 (268)a | 8.0 (0.17)a    | 2243 (224)a | 0.77 (0.060)a      |
| Astonenergy (T)  | 14 224 (205)bc | 12 899 (271)ab | 8.0 (0.17)ab   | 1569 (224)b | 0.56 (0.059)bc      |
| Drumbo           | 14 438 (227)b | 12 863 (306)ab | 7.9 (0.19)abc  | 1745 (261)ab | 0.45 (0.068)c      |
| Dunluce (T)      | 13 947 (246)bced | 11 741 (334)cd  | 7.2 (0.21)d    | 2382 (285)a | 0.66 (0.075)ab      |
| Glenveagh        | 13 568 (273)d | 11 541 (371)d | 7.3 (0.23)d   | 2263 (324)ab | 0.65 (0.086)abc     |
| Kintyre (T)      | 13 936 (212)ced | 12 408 (281)bc  | 7.9 (0.17)abc  | 1594 (235)b | 0.55 (0.062)bc      |
| Majestic         | 14 245 (286)bced | 12 365 (389)biod | 7.8 (0.24)abcd | 2009 (332)ab | 0.63 (0.087)abc     |
| Twymax (T)       | 14 326 (216)bc | 12 360 (289)bc  | 7.6 (0.18)bd   | 2100 (244)ab | 0.63 (0.064)ab      |
| Tyrella          | 13 752 (163)d | 11 946 (206)ced | 7.5 (0.13)cd   | 1785 (166)abcd | 0.64 (0.044)b       |

1abcdMeans within a column with different superscripts differ significantly (P < 0.05).
2All DM production totals are subject to rounding in the PastureBase Ireland system, hence silage and grazing totals may not always sum up exactly to total DM production figures.
3(T) denotes tetraploid varieties, all other varieties are diploid.
One-year-old swards had the highest average GS of 4.1 (SE = 0.05) with total DM production, swards were most productive. A decrease in GS in the same period of maturity.

Table 4. Total DM production (kg DM/ha) (LS means with standard errors in parentheses) per variety, and mean of all varieties, across the 2013–2019 production years

| Variety       | 2013 (±)  | 2014 (±)  | 2015 (±)  | 2016 (±)  | 2017 (±)  | 2018 (±)  | 2019 (±)  |
|---------------|----------|----------|----------|----------|----------|----------|----------|
| AberChoice    | 14 710 (449) | 14 180 (581) | 14 951 (530) | 14 619 (476) | 15 562 (427) | 12 297 (451) | 14 413 (467) |
| AberGain (T)² | –        | 15 574 (579) | 16 432 (526) | 15 634 (393) | 16 682 (363) | 12 800 (383) | 15 482 (335) |
| Astonenergy (T) | 13 248 (613) | 15 136 (524) | 14 933 (487) | 15 407 (458) | 15 286 (409) | 11 661 (442) | 13 899 (456) |
| Drumbo        | 14 374 (765) | 14 858 (545) | 14 605 (493) | 15 360 (488) | 15 663 (442) | 12 051 (471) | 14 153 (496) |
| Dunluce (T)   | 13 423 (863) | 12 805 (684) | 13 691 (528) | 14 807 (459) | 16 469 (440) | 11 924 (445) | 14 512 (479) |
| Glenveagh     | 12 230 (1037) | 13 633 (680) | 13 982 (560) | 13 708 (491) | 15 344 (458) | 11 533 (487) | 14 549 (630) |
| Kintyre (T)   | 13 719 (677) | 14 554 (493) | 15 022 (463) | 14 148 (473) | 14 842 (424) | 11 360 (453) | 13 906 (493) |
| Majestic      | –        | 14 243 (791) | 14 856 (661) | 14 707 (587) | 15 837 (519) | 11 619 (574) | 14 210 (552) |
| Twymax (T)    | 13 999 (691) | 14 423 (605) | 14 296 (456) | 15 371 (437) | 15 651 (431) | 12 316 (440) | 14 225 (474) |
| Tyrella       | 13 577 (528) | 14 111 (397) | 14 064 (370) | 14 489 (353) | 15 159 (368) | 11 367 (389) | 13 495 (402) |
| Mean³        | 13 919 (483) | 14 586 (361) | 14 658 (326) | 14 801 (295) | 15 608 (292) | 11 854 (313) | 14 259 (287) |

¹(T) denotes tetraploid varieties, all other varieties are diploid.
²Data missing for Majestic and AberGain as those varieties did not meet the threshold of paddocks sown in 2013.
³Means within a row with different superscripts differ significantly (P < 0.05).

Variety age and ground score

Variety (P < 0.05) and age (P < 0.01) were associated with GS. One-year-old swards had the highest average GS of 4.1 (SE = 0.19) while 3-year-old swards had, on average, the lowest GS of 3.6 (SE = 0.21) across all varieties. AberChoice and Drumbo increased GS between ages one and seven while all other varieties decreased in GS in the same period of maturity.

Discussion

The focus of grassland farms is to achieve high performance from the whole farm system by optimizing the interaction between pasture, supplementary feeding and grazing animals (Chapman et al., 2006; Shalloo and Hanrahan, 2018). Changes will be required in grazing systems to embrace more environmentally sustainable approaches and benchmarks (Herrero et al., 2013; Lüscher et al., 2014), necessitated by a range of environmental directives including the EU Nitrates Directive and the EU Farm to Fork strategy (Smith et al., 2000; Velthof et al., 2014; EU, 2020). Grazing systems must adopt technologies, including pasture measurement, fertilization and reseeding, within the farm system to achieve a balance between maximizing grass growth and utilization, and continuing to achieve high animal performance. The amount of pasture grown and utilized on-farm is known to be a major limiting factor to increased animal production (O’Donovan et al., 2011; Smith et al., 2014).

The current study focussed on identifying new avenues for evaluating the performance of PRG varieties, including establishing long-term (i.e. 7 years) DM production, on commercial grassland farms. Given resource constraints (Gilliland et al., 2002), such a long term study is not generally part of established research protocols. Providing grassland farmers with timely feedback regarding the performance of grass varieties on-farm is crucial to improving grassland decision making (Chapman et al., 2019). On-farm variety evaluations also have the potential to stimulate interest in pasture reseeding with superior PRG varieties on farms, via the influence of peer to peer learning (O’Dwyer and Macken-Walsh, 2018), where farmers adopt practices that are...
known to work on other commercial farms (Mulkerrins et al., 2018). The introduction of PastureBase Ireland (Hanrahan et al., 2017) and the use of routine grass measurement on farm delivers innovative tools (Garvey et al., 2018) empowering producers and the wider agricultural industry to embrace results emanating from grassland research. The current work represents a demonstration of what can be achieved when data from PastureBase Ireland are utilized to evaluate grass variety performance.

**Grass production**

Ultimately, the superior phenotypic varieties are those excelling in DM production in a growing season, particularly during colder

---

Fig. 2. Annual ground score of each variety (error bars represent the standard error) and the mean of varieties over 7 years. 1(T) denotes tetraploid varieties, all other varieties are diploid. 2Data missing for AberGain and Majestic as those varieties did not meet the threshold of paddocks sown in 2013.

Fig. 3. Total DM production (kg DM/ha) of each variety (error bars represent the standard error) and mean DM production of all varieties, per sward age. 1(T) denotes tetraploid varieties, all other varieties are diploid. 2Data missing for AberGain, Glenveagh and Majestic as those varieties were not represented by any swards older than 6 years in the current analysis.
periods of the year (i.e. spring and autumn) when growth is naturally limited for PRG (Bereton and McGilloway, 1999). AberGain had consistently higher total and seasonal DM production compared to all other varieties. In a previous 3-year on-farm variety evaluation study, Byrne et al. (2017) reported annual changes in differences of DM production between PRG varieties. The current, longer-term analysis indicates that inter-variety differences in total DM production are consistent between years. Given the consistency of the DM production advantage of varieties across years, large differences between the highest and lowest producing varieties become clear. In the current study, the difference between AberGain and Glenveagh was large, equating to almost 10 t DM/ha over a 6-year period. It has been shown in previous research that each tonne of grass DM utilized/ha on a commercial dairy farm in Ireland is worth €173 net profit/ha (Hanrahan et al., 2018), a figure that can contribute substantially to farm income.

Variety total DM production in the RL simulated grazing trials (DAFM, 2021) was positively correlated ($r = 0.56$) with total DM production in the current study; such a figure indicates that there is a similarity in the ranking of varieties between the datasets. It is also clear that data generated from commercial farms can provide an alternative perspective on variety performance with some re-ranking of varieties occurring, particularly amongst mid-ranking varieties. Some differences between these datasets can be expected given that the origin of the data sources differs. On-farm variety evaluation provides data on variety performance and persistence under grazing and long-term DM production that are not available under current evaluation protocols. Current plot-based evaluation protocols screen a large number of varieties and have proven an effective tool for the identification of elite PRG varieties in recent decades (Grogan and Gilliland, 2011; McDonagh et al., 2016). Utilizing data from on-farm variety evaluation in future PPI calculations, to complement the plot-based evaluation data currently used for such calculations, could make a positive contribution towards increasing the accuracy of the index which can enhance farm planning and decision making.

Improved seasonal DM production is cited as one of the major reasons why grassland farmers undertake the expensive process of pasture reseeding (Creighton et al., 2011) and has become a leading objective for PRG breeders in recent years (Lee et al., 2012; O’Donovan et al., 2017). From the current research, it is clear that significant exploitable inter-varietal differences exist to enable breeders to make gains in both seasonal and total herbage production. The varieties that had the higher total DM production tended to be more productive throughout the entire growing season. All of the varieties evaluated in the present study had heading dates within ten days of each other, meaning that the influence of heading date on seasonal production between PRG varieties was minimal (Laidlaw, 2005). Similar to previous studies on grass ploidy (O’Donovan and Delaby, 2005; McClearn et al., 2020), no clear DM production advantage for either diploid or tetraploid varieties was detected in the present study. Results from the present study also agree with Byrne et al. (2017) who reported changes in differences between varieties for autumn DM production across years. When tested on-farm, paddocks (varieties) can be managed individually whereas herbage from all varieties is removed at the same time in mechanically defoliated plots (Grogan and Gilliland, 2011). This tailored management may have contributed to the fluctuating DM production of individual varieties, relative to each other, in autumn as farmers reacted to the prevailing weather. On-farm measurement may be a closer representation of how varieties perform on commercial farms than the plot evaluation system in isolation.

The current study accounts for the impact of factors such as soil type and geographical location within Ireland via the random effect of a farm within the model used for analysis; previous work has shown that the impact of farm management on herbage DM production is greater than that of farm location in Ireland (O’Donovan and Delaby, 2016). Future work which includes greater sample sizes for varieties and farm locations may provide more information around the possible interactions of variety and location within Ireland.

Grazing

Under climatically and topographically favourable conditions, the area of European grasslands has been relatively stable during the last four decades (1970–2007; Huyghe et al., 2014). More recently, some European countries have identified grassland as an important source of delivery of ecosystem services such as biodiversity, protection of soils against erosion, sequestering carbon and preserving the value of rural landscapes for wider society (Bermúdez et al., 2011; Isselstein and Kayser, 2014). Within Europe, Ireland has a unique focus on grazing (O’Donovan et al., 2021), which is not the case in other European countries, where grazing is under threat (Schils et al., 2018; van den Pol-van Dasselar et al., 2020). The management of grasslands in a rotational grazing management system can contribute to ruminant feed resources, conservation of biodiversity and carbon sequestration (Conant et al., 2017; Enri et al., 2017; Klump and Fornara, 2018).

The level of DM which is grazed directly by animals, as opposed to being conserved for silage, is a measure of a variety’s success on-farm, as grazing is the most efficient method of feeding ruminants and converting grass into milk or meat (Horan and Roche, 2020). Byrne et al. (2017) found on-farm grazing DM production to be a reliable indicator of the DM production advantage of individual grass varieties due to a strong correlation between total and grazing DM production of varieties. In recent analyses of PRG grazing traits, it was documented that tetraploid varieties were more suitable to grazing than diploids as they tend to have advantageous nutritive and morphological characteristics, including higher values for dry matter digestibility and increased levels of leaf in the sward, which lead to greater herbage utilisation (Byrne et al., 2018; Tubritt et al., 2020a). Variety grazing event differences do not appear to be explained by ploidy differences in the current work. Further on-farm measurements, particularly around post-grazing sward height and sward nutrient content, would provide information which could add to the current knowledge of grazing efficiency.

In agreement with Byrne et al. (2017), a recent report of grazing management on grassland farms in Ireland found a clear relationship ($R^2 = 0.73$) between grazed grass DM produced and the number of grazing events achieved (Maher et al., 2021). In Ireland, the main selection criteria for grass varieties for commercial pasture reseeding are taken from the PPI, in which there is a major focus on grazing characteristics (McEvoy et al., 2011; Tubritt et al., 2020a). The relative emphasis on grazing in the current PPI is 0.54 of the total index, consisting of 0.30 for seasonal DM production, 0.20 for grass nutritional quality and 0.04 for grazing utilization (Tubritt, 2020). The PPI was introduced into Ireland in 2015 and it has influenced grass varieties recommended to date; in future it will be important to quantify improvements in grazing efficiency of varieties on-farm.
Variety persistence

Chapman et al. (2015) found that PRG varieties that produced the most DM in the first 3 years post-sowing also produced the most DM 7–8 years post-sowing. There was a similar trend in the current study where the average sward produced a similar level of DM in years one, five, six and seven. Of varieties with 7-year-old swards in the current analysis, the largest reduction in DM production by any variety represented a loss of just 0.05 (Astonenergy) of its year-one DM production in year seven. The change in DM production across the years varied by variety. It is often assumed that swards reach peak DM production within the first year post sowing (Shalloo et al., 2011), which is partly due to soil N mineralization during soil tilling (Hopkins et al., 1990). While this is true for the mean DM production of all varieties in the current study, DM production of some varieties increased with age, often beyond the DM production of newly established swards.

The change in GS per variety over years is interesting as, for example, after the drought period, varieties compensated and improved ground cover. Tetraploid varieties are known to form swards of lower density but have larger individual tillers which can compensate in terms of overall DM production (Smith et al., 2001; Byrne et al., 2018). Previous research has stated that PRG can increase tiller mass when competition for space and light is reduced (Davies and Thomas, 1983). Tozer et al. (2014) stated that tetraploids with lower tiller density may have limited ability to recover from periods of moisture stress. While the current study experienced only one major drought period (2018), the majority of swards did recover from this period to record acceptable DM production in subsequent seasons with no apparent differences between tetraploid and diploid varieties. The relative difference in GS among varieties as the swards age appears to be small. Generally, as swards age, GS decreases, with just two varieties increasing in GS up to 7 years of age. There has been some debate about which traits to use in order to measure variety persistence over time in plot evaluation systems, with annual GS, GS change and tiller density all providing a level of indication of sward PRG content (Wilkins and Humphreys, 2003; Lee et al., 2017). Ground score change, as currently used in the PPI persistency sub-index assessment, is probably the most appropriate metric to document sward PRG content change over time (O’Donovan et al., 2017). In agreement with the current study, the PPI generally indicates little variation in persistence between varieties with the majority expected to maintain consistent DM production for longer than 12 years post-sowing. Sward DM production over time, on-farm, is the best metric by which variety DM production persistence can be accurately measured; other metrics of DM production persistency make long term assumptions based on short term data sets with little validation available (McEvoy et al., 2011a). The approach used in the current study can deliver in the longer term for the Irish grassland industry.

Conclusion

While total DM production was associated with variety, year and sward age, the lack of interaction between variety and year or between variety and age indicates that varieties that perform well on-farm, relative to other varieties, continue to do so despite the effects of age or annual agronomic changes. These effects require ongoing monitoring and DM production of varieties as they mature beyond 10 years will be of major interest. The current study has shown that there is a mechanism available to evaluate the performance of grass varieties on commercial farms, including over and above a period of 4 years which is often the protocol in plot evaluation systems. The current study provides novel insight to the long term performance of grass varieties on grazing-focussed grassland farms in Ireland and challenges the norms of both classical and component type research to further the grassland industry with new knowledge. Increased integration of the on-farm phenotypic performance of grass varieties within the Irish PRG evaluation index will be important for the continued development of the PPI.

Financial support. The authors would like to thank the Teagasc Walsh Scholarship scheme, VistaMilk (16/RC/3835) and UCD for providing the financial support which facilitated the current study.

Conflict of interest. The authors declare there are no conflicts of interest.

Ethical standards. Not applicable.

References

Bernués A, Ruiz R, Olaizola A, Villalba D and Casasús I (2011) Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies and trade-offs. Livestock Science 139, 44–57.

Bresleren A and McGilloway D (1999) Winter growth of varieties of perennial ryegrass (Lolium perenne L.). Irish Journal of Agricultural and Food Research 38, 1–12.

Byrne N, Gilliland TJ, Mchugh N, Delaby L, Geoghegan A and O’Donovan M (2017) Establishing phenotypic performance of grass varieties on Irish grassland farms. Journal of Agricultural Science 155, 1633–1645.

Byrne N, Gilliland TJ, Delaby L, Cummins D and O’Donovan M (2018) Understanding factors associated with the grazing efficiency of perennial ryegrass varieties. European Journal of Agronomy 101, 101–108.

Cameron K, Di HJ and Moir J (2013) Nitrogen losses from the soil/plant system: a review. Annals of Applied Biology 162, 145–173.

Cashman P, McEvoy M, Gilliland T and O’Donovan M (2016) A comparison between cutting and animal grazing for dry-matter yield, quality and tiller density of perennial ryegrass cultivars. Grass and Forage Science 71, 112–122.

Chapman D, Jacobs J, Ward G, O’Brien G, Kenny S, Beca D and Mckenzie F (2006) Forage supply systems for dryland dairy farms in southern Australia. Proceedings of the New Zealand Grassland Association, pp. 255–260.

Chapman D, Kenny S, Beca D and Johnson I (2008) Pasture and forage crop systems for non-irrigated dairy farms in southern Australia. 1. Physical production and economic performance. Agricultural Systems 97, 108–125.

Chapman DF, Muir PD and Faville M (2015) Persistence of dry matter yield among New Zealand perennial ryegrass (Lolium perenne L.) cultivars: insights from a long-term data set. Journal of New Zealand Grasslands 77, 177–184.

Chapman D, Bryant J, Olayemi M, Edwards G, Thorrold B, Mcmillan W, Kerr G, Judson G, Cookson T and Moorhead A (2017) A comparison of grassland dairy farming in Ireland, investigating grassland production and economic performance. Irish Journal of Agricultural and Food Research 97, 108–125.

Chapman DF, Cosgrove GP, Kuhn-Sherlock B, Stevens DR, Lee JM and Rossi L (2019) Scaling issues in the interpretation of dry matter yield differences among perennial ryegrass (Lolium perenne L.) cultivars. Journal of New Zealand Grasslands 81, 209–216.

Conant RT, Cerri CE, Osborne BB and Paustian K (2017) Grassland management impacts on soil carbon stocks: a new synthesis. Ecological Applications 27, 662–668.

Creighton P, Kennedy E, Shalloo L, Boland T and O’Donovan M (2011) A survey analysis of grassland dairy farming in Ireland, investigating grassland...
management, technology adoption and sward renewal. *Grass and Forage Science* 66, 251–264.

Creighton P, Kennedy E, Hennessy D and O’Donovan M (2016) Impacts of sward renewal method with perennial ryegrass (*Lolium perenne*) on dry matter yield, tiller density and nitrate leaching. *American Journal of Plant Sciences* 7, 684–694.

DAFM (2020) 2020 Nitrates Derogation Terms and Conditions [Online]. Available at: https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/nitrates/2020/NitratesDerogation2020TermsConditions260320.pdf (Accessed 23 November 2020).

DAFM (2021). *Irish Recommended List 2021 Grass & White Clover Varieties* [Online]. Ireland: www.gov.ie. Available at: file:///C/Users/Ciaran.Hearn/Downloads/127098_4d6c4876-fd09-4c6e-a077-7545863111c5%20(6).pdf (Accessed 13 July 2021).

Davies A and Thomas H (1983) Rates of leaf and tiller production in young spaced perennial ryegrass plants in relation to soil temperature and solar radiation. *Annals of Botany* 51, 591–597.

Easton H, Baird D, Cameron N, Kerr G, Norris M and Stewart A (2001) Perennial ryegrass cultivars: herbage yield in multi-site plot trials. *Proceedings of The Conference-New Zealand Grassland Association*, pp. 183–188.

Enri SR, Probo M, Farruggia A, Lanore L, Blanchetace A and Dumont B (2017) A biodiversity-friendly rotational grazing system enhancing flowering-visitor assemblages while maintaining animal and grassland productivity. *Agriculture, Ecosystems & Environment* 241, 1–10.

EU (2020) *Farm to Fork Strategy For A Fair, Healthy and Environmentally Friendly Food System*. Brussels, Belgium: European Union.

Finneran E, Crosson P, O’Kiely P, Shalloo L, Forristol D and Wallace M (2010) Simulation modelling of the cost of producing and utilising feeds for ruminants on Irish farms. *Journal of Farm Management* 14, 95–116.

Frame J and Hunt I (1971) The effects of cutting and grazing systems on herbage production from grass swards. *Grass and Forage Science* 26, 163–172.

Garvey N, Ramsbottom G and Lynch M (2018) Adoption of grass measurement and management technologies in dairy discussion groups. *Sustainable meat and milk production from grasslands, Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17-21 June, 2018*. Teagasc, Animal & Grassland Research and Innovation Centre, pp. 980–982.

Gilliland TJ, Barrett PD, Mann RL, Agnew RE and Fearon AM (2002) Canopy morphology and nutritional quality traits as potential grazing value indicators for *Lolium perenne* varieties. *Journal of Agricultural Science* 139, 257–273.

Grogan D and Gilliland TJ (2011) A review of perennial ryegrass variety evaluation in Ireland. *Irish Journal of Agricultural and Food Research* 50, 65–81.

Hanrahan L, Geoghegan A, O’Donovan M, Griffith V, Ruelle E, Wallace M and Shalloo L (2017) PastureBase Ireland: a grassland decision support system and national database. *Computers and Electronics in Agriculture* 136, 193–201.

Hanrahan L, Mchugh N, Hennessy T, Moran B, Kearney R, Wallace M and Shalloo L (2018) Factors associated with profitability in pasture-based systems of milk production. *Journal of Dairy Science* 101, 5474–5485.

Herrero M, Havlik P, Vain H, Notenbaert A, Rufino MG, Thornton PT, Blimmer M, Weiss F, Grace D and Obersteiner M (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences* 110, 20888–20893.

Hopkins A, Gilby J, Dibb C, Bowling P and Murray P (1990) Response of permanent and reseeded grassland to fertilizer nitrogen. 1. Herbage production and herbage quality. *Grass and Forage Science* 45, 43–55.

Horan B and Roche J (2020) Defining resilience in pasture-based dairy-farm systems in temperate regions. *Annual Production Science* 60, 55–66.

Huyghe C, Vliegher AD and Golinski P (2014) European grasslands overview: temperate region. EGF at 50: The future of European grasslands. *Proceedings of the 25th General Meeting of the European Grassland Federation, Aberystwyth, Wales, 2014*. IBERS, Aberystwyth University, pp. 29–40.

Isselstein J and Kayser M (2014) Functions of grassland and their potential in delivering ecosystem services. *Grassland Science in Europe* 19, 199–214.

JENQUIP (2019) Manual Platemeter [Online]. Fielding, New Zealand. Available at: https://www.jenquip.nz/manual-platemeter/ (Accessed 18 February 2020).

Kerr GA, Chapman DF, Thom ER, Matthew C, Linden AVD, Barid DB, Johnston E and Corkran JR (2012) Evaluating perennial ryegrass cultivars: improving testing. *New Zealand Grassland Association, New Zealand*, pp. 127–136.

Klump K and Fornara D. (2018) The carbon sequestration of grassland soils-climate change and mitigation strategies. *Sustainable meat and milk production from grasslands, Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17-21 June, 2018*. Teagasc, Animal & Grassland Research and Innovation Centre, pp. 509–519.

Laidlaw A (2005) The relationship between tiller appearance in spring and contribution to dry-matter yield in perennial ryegrass (*Lolium perenne*) cultivars differing in heading date. *Grass and Forage Science* 60, 200–209.

Leddin C, Jacobs J, Smith K, Malcolm B and Ho C (2018) Development of a system to rank perennial ryegrass cultivars according to their economic value to dairy farm businesses in south-eastern Australia. *Animal Production Science* 58, 1552–1558.

Lee JM, Matthew C, Thom ER and Chapman DF (2012) Perennial ryegrass breeding in New Zealand: a dairy industry perspective. *Crop and Pasture Science* 63, 107–127.

Lee J, Thom E, Wynn K, Waugh D, Rossi L and Chapman D (2017) High perennial ryegrass seeding rates reduce plant size and survival during the first year after sowing: does this have implications for pasture sward persistence? *Grass and Forage Science* 72, 382–400.

Lüscher A, Mueller-Harvey I, Sousssa JF, Rees RM and Peyraud JL (2014) Potential of legume-based grassland–livestock systems in Europe: a review. *Grass and Forage Science* 69, 206–228.

Maher J, O’Donovan M, O’Leary M, Dillon P, Dunphy J and Douglas J (2021) *Grass10 Report 2017–2020*. Cork, Ireland: Teagasc.

Mcclern B, Gilliland T, Guy C, Dineen M, Coughlan F and Mccarthy B (2020) The effect of perennial ryegrass ploidy and white clover inclusion on milk production of dairy cows. *Animal Production Science* 60, 143–147.

Mcdonagh J, O’Donovan M, McEvoy M and Gilliland T (2016) Genetic gain in perennial ryegrass (*Lolium perenne*) varieties 1973 to 2013. *Euphytica* 212, 187–199.

McEvoy M, O’Donovan M and Shalloo L (2011a) Development and application of an economic ranking index for perennial ryegrass cultivars. *Journal of Dairy Science* 94, 1627–1639.

McEvoy M, O’Donovan M and Shalloo L (2011b) Capturing the economic benefit of *Lolium perenne* cultivar performance. *Irish Journal of Agricultural and Food Research* 50, 83–98.

MET-ÉIREANN (2020) *Climate – Historical Data* [Online]. Available at: https://www.met.ie/climate/available-data/historical-data (Accessed 23/11/2020).

MET-ÉIREANN (2021) *Historical Data – Display and Download Historical Data from current stations* [Online]. Available at: [https://www.met.ie/cli-mate/available-data/historical-data](https://www.met.ie/climate/available-data/historical-data) (Accessed 12/03/2021).

Mulkerrins M, Gottstein M and Lynch M (2018) The influence of an Irish sheep monitor farm programme in terms of practice change. *Sustainable Meat and Milk Production from Grasslands, Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17-21 June, 2018*. Teagasc, Animal & Grassland Research and Innovation Centre, pp. 1005–1007.

Neal M and Roche JR (2020) Profitable and resilient pasture-based dairy farm businesses in New Zealand. *Animal Production Science* 60, 169–174.

O’Donovan M and Delaby L (2005) A comparison of perennial ryegrass cultivars differing in heading date and grass ploidy with spring calving dairy cows grazed at two different stocking rates. *Annual Research* 54, 337–350.

O’Donovan M and Delaby L (2016) Grazed grass in the dairy cow diet–how this can be achieved better! 26. *General meeting of the European Grassland Federation (EGF)*. Wageningen Academic Publishers.

O’Donovan M, Connolly J, Dillon P, Rath M and Stakelum G (2002a) Visual assessment of herbage mass. *Irish Journal of Agricultural and Food Research* 41, 201–211.
O’Donovan M, Dillon P, Rath M and Stakelum G (2002b) A comparison of four methods of herbage mass estimation. *Irish Journal of Agricultural and Food Research* 41, 17–27.

O’Donovan M, Lewis E and O’Kiely P (2011) Requirements of future grass-based ruminant production systems in Ireland. *Irish Journal of Agricultural and Food Research* 50, 1–21.

O’Donovan M, Mchugh N, Mcevoy M, Grogan D and Shalloo L (2017) Combining seasonal yield, silage dry matter yield, quality and persistency in an economic index to assist perennial ryegrass variety selection. *The Journal of Agricultural Science* 155, 556–568.

O’Donovan M, Hennessy D and Creighton P (2021) Ruminant grassland production systems in Ireland. *Irish Journal of Agricultural and Food Research* 59, doi: 10.15212/ijafr-2020-0118.

O’Dwyer T and Macken-Walsh A (2018) ‘Out in the field’: supporting grassland management through discussion groups. *Sustainable meat and milk production from grasslands, Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17–21 June, 2018*. Teagasc, Animal & Grassland Research and Innovation Centre, pp. 1009–1011.

Parsons A, Edwards G, Newton P, Chapman D, Caradus J, Rasmussen S and Rowarth J (2011) Past lessons and future prospects: plant breeding for yield and persistence in cool-temperate pastures. *Grass and Forage Science* 66, 153–172.

Peyraud J-J, van den Poel A, Dillon P and Delaby L (2010) Producing milk from grazing to reconcile economic and environmental performances. 23th General Meeting of the European Grassland Federation, Kiel, Germany, 29 August–02 September, 2010, pp. 163–164.

Schils R, Philipsen A, Holshof G, Zom R, Hoving I, van Reenen C, van der Werf J, Galama P, Sebek L and Klooijjwijk C (2018) Amazing grazing: science in support of future grass based dairy systems. *Sustainable meat and milk production from grasslands, Proceedings of the 27th General Meeting of the European Grassland Federation, Cork, Ireland, 17–21 June, 2018*. Teagasc, Animal & Grassland Research and Innovation Centre, pp. 336–338.

Shalloo L and Hanrahan L (2018) Setting targets for the Irish dairy industry. *Animal Production Science* 60, 159–163.

Shalloo L, Creighton P and O’Donovan M (2011) The economics of reseeding on a dairy farm. *Irish Journal of Agricultural and Food Research* 50, 113–122.

Smith P, Powlson DS, Smith JU, Falloon P and Coleman K (2000) Meeting Europe’s climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. *Global Change Biology* 6, 525–539.

Smith KF, Simpson R, Culvenor R, Humphreys MO, Prud’homme M-P and Oram R (2001) The effects of ploidy and a phenotype conferring a high water-soluble carbohydrate concentration on carbohydrate accumulation, nutritive value and morphology of perennial ryegrass (*Lolium perenne* L.). *The Journal of Agricultural Science* 136, 65–74.

Smith K, Ludemann C, Lewis C, Malcolm B, Banks R, Jacobs J, Hennessy P and Spangenberg G (2014) Estimating the value of genetic gain in perennial pastures with emphasis on temperate species. *Crop and Pasture Science* 65, 1230–1237.

Stewart A and Hayes R (2011) Ryegrass breeding-balancing trait priorities. *Irish Journal of Agricultural and Food Research* 50, 31–46.

TEAGASC (2011) Grazing Guide. Ireland: Cork, Ireland: Teagasc.

TEAGASC (2014) Moorepark Dairy Levy Research Update: Pocket Manual for Reseeding. Cork, Ireland: Teagasc.

Tozer K, Chapman D, Bell N, Crush J, King W, Rennie G, Wilson D, Mapp N, Rossi L and Aalders L (2014) Botanical survey of perennial ryegrass-based dairy pastures in three regions of New Zealand: implications for ryegrass persistence. *New Zealand Journal of Agricultural Research* 57, 14–29.

Tubritt T (2020) Differential Dry Matter Production, Nutritive Value and Grazing Utilisation of Perennial Ryegrass Varieties and Mixtures Evaluated Within Intensive Grazing Regimes (Doctorate of Philosophy). The Queen’s University of Belfast, United Kingdom.

Tubritt T, Delaby L, Gilliland TJ and O’Donovan M (2020a) The relationship between the grazing efficiency and the production, morphology and nutritional traits of perennial ryegrass varieties. *The Journal of Agricultural Science* 158, 583–593.

Tubritt T, Delaby L, Gilliland T and O’Donovan M (2020b) An investigation into the grazing efficiency of perennial ryegrass varieties. *Grass and Forage Science* 75, 253–265.

van den Pol van Dasselaar A, Hennessy D and Iselestein J (2020) Grazing of dairy cows in Europe – An in-depth analysis based on the perception of grassland experts. *Sustainability* 12, 1098.

Velthof GL, Lesschen J, Webb J, Pietrzak S, Miatkowski Z, Pinto M, Kros J and Oenema O (2014) The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000–2008. *Science of the Total Environment* 468, 1225–1233.

Wilkins PW and Humphreys MO (2003) Progress in breeding perennial forage grasses for temperate agriculture. *Journal of Agricultural Science* 140, 129–150.