External Assessment of Teagasc's Clover and Multi Species Sward Research Programme

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Executive Summary

Perennial ryegrass (PRG) swards with moderate levels of fertilizer nitrogen (Fert N) application have underpinned pasture-based milk, beef and lamb production systems in Ireland for over 50 years. However, the efficiency of N use in grazing systems is low, with N losses as nitrate in drainage water and ammonia and nitrous oxide to air. Concerns regarding these environmental impacts, coupled with significant increases in Fert N costs have resulted in a 31% reduction in N fertilizer use between 2018 and 2023. This reduction in Fert N use is likely to have reduced grass production at national level by between 2.0 and 2.5 million tonnes of DM, or around 7 - 9 % of national grass production. In order to fill this gap cost effectively, and avoid the need for higher cost feed supplements, there is an urgent need to consider alternative sward types that can maintain herbage yield at lower Fert N levels. The two main alternatives being considered for grazing systems are PRG/white clover swards (PRG/WC) and multi-species swards (MSS), the latter containing a mixture of grass species, legumes and herbs. Perennial ryegrass/red clover swards are also being considered for silage production.

The purpose of this review was to assess a portfolio of research and associated knowledge transfer documentation summarising results of animal-based studies on PRG/WC, PRG/Red clover and MSS undertaken by Teagasc over the last fifteen years. In addition, UCD provided a summary of research on MSS, together with a list of publications, and this was included in the review. This report presents a summary of the research reviewed, together with recommendations for future research.

Perennial ryegrass/white clover swards

Well-managed PRG/WC swards (20 - 25 % WC on average over the whole season) receiving 100 -150 kg Fert N/ha (primarily applied in spring) can produce similar herbage yields to PRG only swards receiving 200 - 250 kg Fert N/ha. Clear recommendations for establishment of PRG/WC swards have been developed and published in the Teagasc document 'Management and Establishment of Grass/White Clover Swards.' However, there is a wide variation in performance of PRG/WC swards across Teagasc studies and consequently a precautionary approach is needed in relation to adopting a very low or Zero Fert N approach with PRG/WC swards. The variation appears to be related to differences in the level of Biological N Fixation (BNF) with white clover and to changes in study design. More detailed research is needed to fully quantify and understand factors influencing BNF under a range of sward conditions and soil types. Low rates of BNF in early Spring are a particular concern and this is the primary justification for applying Fert N to PRG/WC swards in February and March. This is particularly important in spring calving dairy systems, as feed shortages in spring can have profound economic and animal welfare implications. Further research is urgently needed to develop Fert N recommendations for PRG/WC swards based on the plant available N required to support herbage yield at specific time points in the season. The new Teagasc PRG/WC herbage growth model currently being developed should provide a more accurate basis for Fert N recommendations for PRG/WC swards and this could provide a basis for using lower or Zero Fert N levels in the future with some PRG/WC swards, without risking a deficit in early season growth.

Improvements in sward quality have been observed in PRG/WC swards, resulting in higher DM intakes with sheep, beef and dairy cattle, increases in ADG in lambs and beef cattle and increases in milk solids yield (20 – 40 kg MS/cow) in dairy cattle. Consequently, Teagasc research has consistently shown increases in profitability per head and per ha, across sheep, beef and dairy enterprises when white clover is used as an alternative to part of the Fert N used on grass only swards. Whilst research on the environmental impacts of PRG/WC swards is ongoing, the effect of sward type on methane emissions is inconclusive, whereas emissions of nitrous oxide are reduced compared to PRG swards receiving higher levels of Fert N, with GHG emissions being reduced by up to 11%. Nitrate leaching losses are similar for both sward types. Further research is needed to accurately assess the impact of PRG/WC

swards on GHG and ammonia emissions and nitrate leaching across a range of soil types and grazing conditions, linked to work on developing improved Fert N recommendations.

Lack of persistency can be an issue with PRG/WC swards, but when swards are established and managed well, high clover contents have been maintained for over 10 years. Incidences of bloat have been relatively low in Teagasc studies when clover content is maintained at 20 to 25%, but bloat is a significant risk issue particularly with high clover, low DM herbage and careful management of clover content and monitoring of stock is essential.

There is evidence of differences between white clover cultivars in N fixing ability and tolerance to competition within a mixed PRG/WC sward. Research to evaluate the effect of WC cultivars and their interactions with grass varieties and Fert N application should be a priority area with the aim of developing a Clover Profit Index, similar to the Teagasc Pasture Profit Index.

Teagasc research has shown the potential of PRG/WC swards to increase animal performance and profitability of beef and lamb production, but there has been very limited adoption of PRG/WC on beef and sheep farms, despite the much lower levels of Fert N being used. Given the relatively limited use of rotational grazing on beef and sheep farms, further research is needed to examine the role of PRG/WC under alternative grazing systems.

Multispecies swards

From the limited number of long-term scientific studies undertaken to date, across both Teagasc and UCD, there is insufficient evidence to support the use of MSS in farm practice, with MSS producing similar herbage yields and animal performance to PRG/WC swards in the majority of studies. Whilst improvements in herbage yield with MSS were obtained relative to PRG/WC swards in studies at UCD, in one of the studies white clover contents in both the PRG/WC sward and the MSS were very low (9 -10 % and 12 – 15.5 % respectively), studies were short term (2-3 grazing seasons) and in one study different grazing management protocols were used with the different swards. Across both Teagasc and UCD studies, improvements in animal performance have been obtained with MSS relative to PRG + Fert N swards in both sheep and cattle grazing studies, although in the majority of Teagasc studies, animal performance was similar to that obtained with PRG/legume swards. Lack of persistency of MSS has also emerged as a major issue, with chicory and plantain, and to a lesser extent red clover, largely disappearing within 2 - 3 years of sward establishment. Further research is required to evaluate grazing management strategies more suited to MSS, whilst maintaining legume content in the sward. The role of MSS under drought conditions also requires further investigation under Irish conditions, as there is some evidence of greater drought resilience with MSS.

Initial results suggest MSS may have a role in reducing GHG and ammonia emissions, and nitrate losses to water compared to PRG/WC swards, but longer-term studies are needed to fully quantify these effects and to assess whether the potential environmental benefits justify the additional risk and management complexity associated with MSS. Research needs to identify the underlying response mechanisms and whether similar benefits can be obtained with a reduced number of species e.g. a simple PRG/WC/Plantain mix. Sward proportions required to improve environmental outcomes need to be achievable and demonstrated at farm level across multiple years.

Bloat incidence with MSS has been relatively low, but bloat is a significant risk issue with MSS and vigilance is essential. Whilst MSS have been shown to have anthelmintic properties (due to the presence of chicory and plantain), differences in levels of worm infection or faecal egg counts in both Teagasc and UCD studies have been relatively small. There is evidence that the plant diversity within

MSS increases nematode-based soil health indices, with MSS (6 species) having higher nematode diversity and proportion of sensitive taxa than a pure grass sward.

Perennial ryegrass/red clover swards for silage

Results of Teagasc research indicate that PRG/RC swards have considerable potential for silage production, producing high DM yields with low Fert N levels, although large varietal differences have been observed in both yield potential and persistency. There is some evidence of increases in liveweight gain with growing cattle offered PRG/RC silage, but when fed to grazing dairy cows at night, no performance benefit was observed. Further research on PRG/RC for silage production should focus on opportunities to maximise the use of manure N as the primary source of N and to evaluate varietal differences in yield potential and persistency.

Recommendations for Programme Management

Given the scale and cross-centre, cross-programme nature of PRG/WC and MSS research within Teagasc, it is recommended that consideration should be given to establishing a PRG/WC and MSS Research Co-ordination Group to co-ordinate all aspects of research, and to develop appropriate platforms for future research in this area (e.g. Future Sward Platform). Key objectives of the Platform should be to identify the most important questions in relation to sward types for use in the future, and to establish robust mechanisms to maximise the scientific merit of ongoing research projects.

Key Recommendations

1. Given the scale and cross-centre, cross-programme nature of PRG/WC and MSS research within Teagasc, it is recommended that consideration should be given to establishing a PRG/WC and MSS Research Co-ordination Group to co-ordinate all aspects of research, and to develop appropriate platforms for future research in this area (e.g. Future Sward Platform).

2. The wide variation in performance of PRG/WC swards is a major concern and highlights the need for more detailed research on factors influencing Biological N Fixation (BNF). Research should aim to quantify and understand the factors that influence BNF from white clover under a range of sward conditions and soil types.

3. The primary justification for applying Fert N to PRG/WC swards relates to concerns re poor early spring growth with these swards. Further research is needed to develop Fert N recommendations based on the plant available N required to support herbage yield at specific time points in the season. The new Teagasc PRG/WC herbage growth model being developed at present could provide a good basis for developing Fert N recommendations for PRG/WC swards. The model needs to consider variables such as clover content, soil temperature, soil type, geographic location, legacy N from the previous autumn, manure N (slurry N and recycled N from grazing animals) herbage yield and soil N mineralization.

4. There is evidence of differences between clover varieties in N fixing ability and tolerance to competition within a mixed PRG/WC sward. Research is ongoing within Teagasc to develop a Clover Profit Index and this work should examine possible varietal differences in spring growth characteristics potentially related to onset of N fixation. Research into the effects of WC cultivars and their interactions with grass variety and Fert N application should also be a priority area for research going forward.

5. Further research is needed to quantify the impact of PRG/WC versus PRG + Fert N swards, on GHG and ammonia emissions and nitrate leaching across a range of soil types, using the improved recommendations for Fert N on PRG/WC swards being developed under 3 above.

6. Reliable establishment of PRG/WC swards remains a challenge on some farms and further research is needed to develop best management practices for grazing management in the first year of establishment, across a range of soil types. Further research is also required on best practice for maintaining a high proportion of white clover in the sward using strategic over sowing;

7. Whilst there has been limited adoption of PRG/WC on dairy farms, uptake on beef and sheep farms has been much slower, despite the much lower levels of Fert N being used. Given the relatively limited use of rotational grazing on beef and sheep farms, further research is needed to examine the role of PRG/WC under alternative grazing systems, including the potential of zero Fert N systems.

8. From the limited number of long-term scientific studies undertaken to date, across both Teagasc and UCD, there is insufficient evidence to support the use of MSS in farm practice, particularly in relation to agronomic or animal performance benefits when compared with PRG/WC swards. However, there is some evidence of potential environmental impacts – particularly in relation to reduced N losses. On this basis, further research on MSS is justified with specific emphasis on accurately quantifying environmental impacts and determining whether similar benefits can be obtained with a reduced number of species, for example a

simple PRG/WC/Plantain mix. Sward proportions required to improve environmental outcomes need to be achievable and demonstrated at farm level across multiple years.

9. Research is required to improve the establishment and persistency of MSS. This work should incorporate herb cultivar evaluation and compatibility with grasses and legumes as most of the research studies to date have used a single Plantain cultivar. The work should also investigate cultivar interactions with Fert N application and grazing management.

10. Further research is required to evaluate grazing management strategies more suited to MSS, whilst maintaining legume content in the sward (potentially with red clover rather than white clover), and the persistency of these swards needs to be examined. The role of MSS under drought conditions also requires further investigation.

11. Further research on PRG/RC swards for silage production should focus on opportunities to maximise the use of manure N as the primary source of N and to evaluate varietal differences in yield potential and persistency in longer term studies (5 – 10 years).

Section 1: General Introduction

This review was commissioned by Teagasc in December, 2024 and undertaken from 20 January to 23 March, 2025. The terms of reference of the review are included below:

Terms of Reference

The objectives of the assessment were to:

- Assess a portfolio of research and associated knowledge transfer documentation summarising all animal-based studies relating to perennial ryegrass/clover and multispecies (MS) swards undertaken by Teagasc over the last fifteen years in advance of a site visit. In addition, UCD provided a summary of research on MSS, together with a list of publications and this was included in the review;
- Examine both the management and delivery of the programme and associated research quality. The management assessment examined strategy, organisation and management of the programme, while delivery focused on the assessment criteria of quality and productivity, relevance to stakeholders and viability;
- Prepare a short evaluation report on the research programmes and make appropriate recommendations for the future of the programme; and
- Provide recommendations that focus on benchmarking of performance, peer assessment and future strategic priorities.

A portfolio of all research on perennial ryegrass/clover and multispecies swards (both animal and plot-based studies) undertaken by Teagasc over the last fifteen years was prepared by Teagasc and formed the major part of this assessment. This document contained a summary of the research being undertaken at each of the ten Teagasc Research Sites, including copies of the research papers and related knowledge transfer material, the associated organisational structures, research projects and research programmes and the international and national impacts. UCD also provided a summary of research on MSS, together with a list of publications and this was included in the review. Additional relevant documents, including the Teagasc Statement of Strategy were provided. A total of 140 scientific publications were reviewed as part of this assessment, demonstrating the depth of the research programme across Teagasc and UCD.

In the review, I have referred to the Summary Reports from each of the ten Teagasc Research Sites and the UCD Summary Report and, where appropriate, I have also included references to individual scientific publications to highlight key research findings. The full list of publications is included as Appendix 3.

The documentation was received on 20 January, 2025 and reviewed in advance of a two-day site visit on 26 and 27 February, 2025. The visit involved meetings, presentations and discussion with the Director; the Director of Research; the AGRIP HoP, the CELUP HoP; Heads of Departments; key researchers and Dr Helen Sheridan (UCD).

Background

Perennial ryegrass (PRG) swards with moderate levels of fertilizer nitrogen (N) application have underpinned efficient milk, beef and sheep production systems in Ireland for over 50 years. Under good management, PRG swards can persist for many years and the response to fertilizer N level is relatively linear up to 250 kg N/ha/year, with yield increases of between 20 - 30 kg grass DM/ha per kg of additional N, depending on soil nitrogen and moisture status. Consequently, with levels of fertilizer N up to 250 kg/ha, grass dry matter yields of between 12 - 14 t/ha can be achieved under well managed rotational grazing. However, in recent years concerns regarding the environmental impact of N fertilizer application on air and water quality, coupled with increases in N fertilizer cost, have resulted in a 31% reduction in N fertilizer use (408,495 t in 2018 to 280,569 t in 2023). Assuming a DM yield

response of 15 - 20 kg grass DM/kg Fert N, the reduction in Fert N use is likely to have resulted in a reduction in grass DM production at national level of between 2.0 and 2.5 m tonnes. In order to fill this gap cost effectively, and avoid the need for higher cost compound feeds, there is an urgent need to consider alternative sward types that can maintain herbage yield at lower Fert N levels. The two main alternatives being considered for grazing systems are PRG/white clover swards (PRG/WC) and multi-species swards (MSS), the latter containing a mixture of grass species, legumes and herbs. Perennial ryegrass/red clover swards are also being considered for silage production.

Much research has been undertaken on PRG/WC swards over the years, and these swards have historically formed the mainstay of New Zealand dairy systems (Gray, 2024). Under Irish conditions, research studies in the 1970's and 1980's have shown that PRG/WC swards containing up to 30% white clover can produce similar DM yields to pure PRG swards receiving 150 kg Fert N/ha, due to biological fixation of N (BFN) by rhizobia bacteria located in white clover root nodules. The superior animal performance of PRG/WC swards relative to pure PRG swards has also been noted. However, adoption of PRG/WC systems at farm level has been relatively low historically in Ireland due to concerns regarding poor spring growth, low overall productivity, risk of bloat, increased year-to-year variability in production and the relatively low cost of Fert N.

More recent interest in alternatives to PRG swards have centered around MSS. Several recent short-term studies have shown the potential of MSS to increase overall sward productivity, with some evidence of animal performance and/or animal health benefits. Multispecies swards range from relatively simple mixes eg. PRG, WC, chicory and plantain to much more complex mixtures containing grasses, herbs and legumes such as PRG, Timothy and Cocksfoot, plantain, chicory, sainfoin and red and white clover. The overall aim of MSS is to utilize the N fixing ability of legumes, whilst potentially benefitting from the complementary growth characteristics of the different species, and reducing environmental impacts on air and water quality.

In undertaking this review, the key questions considered were:

1. Herbage Production and Quality
    i) What level of DM production can be achieved with PRG/WC and MSS relative to that of pure PRG at various levels of N fertilizer?
    ii) What implications are there for seasonality of growth, particularly spring and mid-season growth and are there opportunities to alter these seasonal growth characteristics through management or fertilizer N application?

2. Animal production and health
    i. Potential impacts on animal performance – milk yield and quality, liveweight gain in beef and sheep.
    ii. Implications for herd health – bloat and anthelmintic properties.

3. Environmental impact
    i. Overall environmental aspects of different systems – impacts on air and water quality and potential implications for biodiversity.

4. Overall system impacts
    i. Farm output and profitability
    ii. Resilience to weather and disease impacts

Section 2: Assessment of the Research Programmes

Programme Strategy

The overall objective of the Teagasc Grass/Clover and MSS research programme is to examine the potential of Grass/Clover and MSS pasture-based systems for beef, lamb and dairy production with specific reference to:

i. Reducing chemical fertilizer N (Fert N) use and thereby reducing GHG emissions (given that Fert N is energy intensive to produce and is associated with high nitrous oxide losses when applied to grass swards);
ii. Maintaining herbage yield and quality;
iii. Examining factors influencing persistency in PRG/WC and MSS;
iv. Maintaining or enhancing animal performance and health;
v. Reducing environmental impacts on air and water quality; and
vi. Maintaining or increasing overall farm profitability.

Other considerations include developing key recommendations for sward establishment and an understanding of factors influencing year to year variation in species composition and productivity in order to improve resilience to climate change effects. Knowledge exchange from the programme is also an important consideration – both for farmers and for farm policy development, based on a sound scientific evidence base

The overarching objective of the research programme on MSS at UCD is to determine the agronomic, animal, environmental and economic performance of MSS versus PRG and PRG/WC swards. While research on MSS has been ongoing at UCD Lyons Farm since 2013, the Long Term Grazing Platform, a participant site in the Global Farm Platform (https://globalfarmplatform.org) was established in 2019 to facilitate long-term evaluation of the different sward types under cattle grazing. More specifically, the UCD programme of research seeks to determine the potential of the different sward types and their associated management in terms of: herbage DM production and quality; sward composition and resilience over time; impacts on animal performance and health; GHG emissions; economics; water quality; biodiversity; and soil health.

Section 3: Key Findings from Teagasc and UCD Research Programmes

Teagasc has undertaken an extensive research programme on the potential of PRG/WC swards for dairy, beef and sheep production since 2010, with earlier work commencing at Solohead Farm in 2000. More recent research has examined the potential of MSS for grazing systems and PRG/red clover for silage systems. The UCD research programme on MSS was initiated in 2013 with the original objective of identifying sward types that produce comparable levels of herbage and animal performance to PRG swards, but with lower inputs of N fertiliser. The programme has evolved since then and now encompasses evaluation of the agronomic, animal, environmental and economic performance of MSS versus PRG and PRG/WC swards.

Key findings of the programmes can be summarized as follows:

Perennial Ryegrass/White Clover Swards

- Sward establishment and productivity.
  Clear recommendations for establishment of PRG/WC swards have been developed and published in the Teagasc document 'Management and Establishment of Grass White Clover Swards' Series 42, March, 2024 and these protocols have been widely used by farmers across the Clover 150 programme.

Teagasc research has demonstrated that well-managed PRG/WC swards (20 - 25 % WC on average over the whole season) can enable significant reductions in Fert N use (100 - 150 kg N/ha), whilst maintaining herbage yield and quality. Consequently, a well-managed PRG/WC sward receiving 100 to 150 kg Fert N (primarily applied in spring) can produce a similar yield to a PRG sward receiving 200 - 250 kg Fert N.

- Persistency of swards.
  Sward persistency remains a key issue with PRG/WC swards, but under good establishment conditions and with good grazing management, high clover contents have been maintained for over 10 years in some studies. Tight grazing in spring (to a residual sward height of 3.5 - 4 cm), avoiding poaching damage, longer grazing rotations in August and tight grazing in the final rotation (residual height of 4 cm) are crucial for clover survival. Nonetheless, on farm experience from the Clover 150 project indicates that periodic over sowing of part of the grazing area (typically 10% per year) is required to maintain average white clover contents of 20 – 25% over the grazing season (30 - 40 % WC in mid-season).

- Animal performance and health.
  In Teagasc grazing studies where clover content was maintained at 20 - 25%, improvements in sward quality have been observed in PRG/WC swards, particularly from mid-season onwards, with increases in crude protein content and reductions in neutral detergent fibre content. Higher DM intakes have been observed in sheep, beef and dairy cattle studies, increased ADG in lambs and beef cattle and increases in milk solids yield (20 – 40 kg increase in milk solids yield per cow) in dairy cattle.
  Incidences of bloat across the Teagasc research programme have been relatively low, where clover content was maintained at 20 - 25%. However, careful management and monitoring of stock is essential, as bloat is a significant risk issue and vigilance is essential, particularly where clover content is high and/or herbage DM content is low.

- Environmental impacts.
  In contrast to agronomic and animal performance aspects, the research programme on environmental impacts of reducing Fert N with biologically fixed N is more recent, and ongoing at present, and therefore many findings are at a preliminary stage. The effect of sward type on methane emissions is inconclusive and further research is needed. Research results show that N2O emissions due to BNF and clover residue decomposition in PRG/WC swards is negligible and consequently nitrous oxide emissions with PRG/WC swards with low levels of Fert N are lower than those from PRG only swards receiving higher Fert N levels. Further research is required to examine N2O emissions when protected urea is the principal source of Fert N, with both PRG/WC and PRG swards, given the lower N2O emissions from protected urea.

  It is often assumed that PRG/WC swards will result in improved nitrogen utilisation efficiency (NUE) relative to PRG + Fert N swards. However, in very high clover content swards (30 % and above) high levels of biological N fixation can result in similar N losses (primarily as nitrate-N) to those observed with PRG + Fert N swards, and estimates of NUE at 'farmgate' level are relatively meaningless.

  There is some evidence of lower ammonia N emissions with PRG/WC swards, but further research is required. Nitrate leaching losses with PRG/WC swards are similar to PRG + Fert N swards receiving the same level of Fert N as that biologically fixed by clover. When assessed in terms of overall C footprint, PRG/WC swards receiving 100 – 150 kg Fert N/ha have

produced lower GHG emissions, by up to 11%, compared to PRG only swards receiving 200 – 250 kg Fert N/ha, when CAN and urea are the main sources of N.

- Farm profitability
  Teagasc research has consistently shown increases in profitability per head and per ha, across sheep, beef and dairy enterprises when white clover is used as an alternative to replace part of the Fert N used on grass only swards. However, there is a risk that if Fert N levels are reduced too severely with swards with low clover contents (less than 15% on average across the year), herbage DM production could be compromised leading to an increased requirement for purchased feed supplements.

Multispecies Swards

- Sward establishment and productivity.
  A range of MSS have been evaluated across the Teagasc research programme, ranging from 3 to 8 species including PRG, Timothy, Meadow Fescue, Red Clover, White Clover, Hybrid Clover, Chicory and Plantain. Results of a 5-year Moorepark grazed plots trial, established in 2020 and with all plots grazed to a residual sward height of 4 cm and receiving a range of Fert N levels from 0 to 200 kg N/ha, indicate that the addition of herb species, chicory or plantain did not increase either seasonal or annual DM production, across the range of Fert N levels. In contrast, inclusion of white clover increased DM production in all sward types and across all Fert N levels. DM Yield over five years was similar for a PRG/WC sward and either a 3, 4 or 5 species mix, when all contained white clover.

  The MSS established at UCD have involved 6, 9 and 12 species mixes, including cocksfoot, bird's foot trefoil, yarrow, sainfoin, salad burnet and sheep's parsley in addition to Timothy, Red Clover, White Clover, Chicory and Plantain species. In two grazing studies at UCD, MSS + 90 kg Fert N/ha produced higher DM yields than either PRG only swards (receiving either 163 or 205 kg Fert N/ha) or PRG/WC swards receiving 90 kg Fert N/ha. However, in one of the studies, white clover contents in both the PRG/WC sward and the MSS were very low (9 – 10% and 12 -15.5% respectively) over the two-year trial and in the second study, the MSS was grazed to 6 cm, whereas the PRG/WC sward was grazed to 4 cm.

  An additional challenge in establishing MSS is weed control, given that there are currently no herb-safe herbicides available for use on MSS. Results of small plot studies at Johnstown Castle and a paddock grazing study at UCD suggest that MSS have some potential to mitigate the effects of moderate drought on herbage yield and are more resilient once soil moisture is restored after drought, but further research is needed to validate these effects over a range of soil types and drought severities.

- Persistency of swards.
  Persistency of MSS has now been identified as a major challenge with MSS, with both plantain and chicory, and to a lesser extent red clover, largely disappearing after 2-3 years under grazing. In the UCD studies, the proportional contribution of herbs decreased significantly in the 2 years following establishment. Given their more erect growth habit, red clover and chicory are particularly susceptible to tight grazing in spring.

- Animal performance and health.
  Across the Teagasc studies, small improvements in animal performance have been obtained with MSS relative to PRG + Fert N swards in both sheep and cattle grazing studies. However, in the majority of studies, liveweight gain was similar with MSS and PRG/legume swards and

in dairy cow studies similar animal performance was obtained with the two sward types. In UCD studies, ewe and lamb performance was significantly higher with 6 and 9 species MSS compared to PRG/WC (all swards receiving 90 kg Fert N/ha) and better than performance on PRG only swards receiving 163 kg Fert N/ha. However, the WC content of the PRG/WC sward was low (9.5%) compared to legume contents of 15.5 and 12 % for the 6 and 9 species MSS respectively. In the UCD dairy beef systems trial, ADG on a PRG/WC +92 kg Fert N/ha sward was similar to that on a 6 species MSS at a similar Fert N level, and higher than on a PRG + 205 kg Fert N/ha sward.

Incidences of bloat with MSS have been relatively low, as a result of careful management and monitoring of stock, but bloat is a significant risk issue with MSS and vigilance is essential. Whilst MSS have been shown to have anthelmintic properties (due to the presence of chicory and plantain), effects on levels of worm infection or faecal egg counts in the Teagasc studies have been relatively small. In contrast, results of a UCD study showed a highly significant impact of MSS on the number of anthelmintic treatments administered to lambs compared to PRG or PRG/WC swards.

- Environmental impacts.
  As with PRG/WC swards, work on the environmental impact of MSS is relatively recent and ongoing, and therefore findings are at a preliminary stage. Indoor feeding studies with sheep have shown reduced methane emissions (27% reduction/kg DM intake) with PRG/WC diets compared to PRG only, with emissions with PRG/chicory and PRG/plantain being intermediate (14 and 17% reduction respectively compared to PRG only). Methane emissions from cattle grazing MSS are generally lower than those grazing PRG + Fert N swards, with some evidence of lower emissions relative to PRG/WC swards. Inclusion of plantain has been shown to increase urine volume and reduce urinary N concentration in both sheep and dairy cattle, and some initial research with a six species MSS (including plantain) suggests this could lower nitrous oxide emissions by up to 24% compared to a PRG + Fert N sward. UCD results suggest that cumulative N2O emissions from MSS + 45 kg Fert N/ha were 16% lower than from PRG + 250 kg Fert N/ha swards.

  Similarly, there is some evidence of lower ammonia N emissions with MSS, with ammonia emissions being 11.4% lower with a 6 species MSS compared to a pure grass sward.

  Initial results indicate that MSS containing high levels of chicory or plantain may have a role in reducing nitrate leaching losses compared to PRG/WC or PRG + Fert N swards, but further research is required to confirm this effect at farm system level. In UCD studies, nitrate leaching from MSS + 45 kg Fert N/ha swards was similar to that from PRG + 250 kg Fert N/ha swards.

- Biodiversity and ecosystem function.
  Plant diversity has been shown to enhance nematode-based soil quality indices, with MSS (6 species) having higher nematode diversity and proportion of sensitive taxa than a pure grass sward.

- Farm profitability.
  Whilst economic analysis is not yet available for the majority of studies, preliminary analysis of a dairy bred beef study indicates an increase in net margin per head with MSS + 75 kg Fert N/ha compared to PRG + 150 kg Fert N/ha, but lower than a PRG/RC/WC sward +75 kg Fert N/ha (€308, €258 and €334 respectively). Given the persistency challenges with MSS, economic analysis needs to be carried out over a longer time period and take account of the increased costs of reseeding and over sowing.

- Future role of MSS
  From the limited number of long-term scientific studies undertaken to date, across both Teagasc and UCD, there is insufficient evidence to support the use of MSS in farm practice, with MSS producing similar herbage yields and animal performance to PRG/WC swards in the majority of studies. One of the key issues that has emerged from recent research with MSS is the lack of persistency, particularly with chicory and plantain and to a lesser extent red clover, with most of these species disappearing within 2 - 3 years of sward establishment. These species appear to respond poorly to tight grazing in spring and autumn, which is required in order to maintain high white clover content within the sward. There is some evidence of possible environmental benefits with MSS (lower nitrous oxide and nitrate losses), but longer-term studies are needed to fully quantify these effects and to assess whether they justify the additional management complexity associated with MSS.

Perennial Ryegrass/Red Clover Swards for Silage Production

- Sward establishment and productivity
  PRG/RC swards at Grange and Moorepark have been established using a full reseed, with current trials ongoing to evaluate a range of establishment methods and seed rates. Productivity of PRG/RC swards has been excellent with average yields of 14.4 t DM/ha obtained over 2 seasons with PRG/RC swards receiving 75 kg Fert N/ha. Large varietal differences in DM yield were observed. In summary, PRG/red clover swards could have an important role on farms operating a separate silage block, enabling high DM yields with minimal use of Fert N.

- Persistency of swards
  There have been large varietal differences in persistency, with some varieties only persisting for less than three years.

- Animal Performance and health
  Higher DM intakes and growth rates were observed in dairy beef weanling steers offered PRG/RC silage compared to PRG silage over the first winter period, but the improved performance was not maintained in the second grazing season. Higher growth rates were also observed with suckler calf weanlings offered PRG/RC silage compared to those offered PRG silage. In dairy cow studies, no differences in milk yield or milk solids yield were observed when PRG/RC or PRG silage was offered overnight in addition to daytime grazing, although cows on the PRG/RC silage had lower milk fat content.

- Environmental impacts
  No results available

- Farm profitability
  Modelled silage costs were similar for a three cut PRG/RC silage and a two cut PRG silage.

Section 4: Evidence Gaps/Future Research Needs

Perennial Ryegrass/White Clover Swards

- Establishment and maintenance of PRG/WC swards
  Reliable establishment of PRG/WC swards remains a challenge on some farms and further research is needed to develop best management practices for grazing management in the first year of establishment, across a range of soil types. Further research is also required on best practice for maintaining a high proportion of white clover in the sward using strategic over sowing.

- Biological N fixation.
  The wide variation in performance of PRG/WC swards is a concern and highlights the need for more detailed research on factors influencing Biological N Fixation (BNF), as the differences do not appear to be solely due to WC content within the PRG/WC swards. BNF values reported in the Teagasc studies range from 31 - 50 kg N/ha/t clover in the sward. Over a three-year period (2021 – 2023) BNF rates of 100 kg N/ha were measured, although BNF was lower in 2024 (63 kg N/ha). Results of modelling studies suggest potential rates of BNF ranging from 128 - 255 kg N/ha. Given that N is a key driver of herbage production, more detailed research is needed to fully quantify and understand the factors that influence BNF from white clover under a range of sward conditions and soil types.

- Fert N response.
  The primary justification for applying Fert N to PRG/WC swards relates to concerns re poor early spring growth with these swards. This is particularly important in spring calving dairy systems as yield shortages at this time can have profound economic and animal welfare implications. Results from the LegacyNet project at Johnstown Castle indicate that fixed N accumulates in clover stubble, roots and soil over the growing season and the large net loss of root mass over winter releases N which can be recovered by PRG for spring growth. However, the release of this N is temperature dependent and occurs after the onset of spring grass growth. Further research is needed to develop Fert N recommendations based on the plant available N required to support herbage yield at specific time points in the season. The new Teagasc PRG/WC herbage growth model being developed at present could provide a good basis for developing Fert N recommendations for PRG/WC swards. The model needs to consider variables such as clover content, soil temperature, soil type, geographic location, legacy N from the previous autumn, manure N (slurry N and recycled N from grazing animals) herbage yield and soil N mineralization. Incorporating a PRG/WC herbage growth model into PastureBase Ireland could enable use of lower N Fert levels with some Grass/WC swards, without risking a deficit in early season growth.

- Grass/clover compatibility.
  There is evidence of differences between clover varieties in N fixing ability and tolerance to competition within a mixed PRG/WC sward. Research is ongoing within Teagasc to develop a Clover Profit Index and this work should examine possible varietal differences in spring growth characteristics potentially related to onset of N fixation. Research into the effects of WC cultivars and their interactions with grass variety and Fert N application should also be a priority area for research going forward.

- PRG/WC on beef and sheep farms.
  Whilst there has been limited adoption of PRG/WC on dairy farms, uptake on beef and sheep farms has been much slower, despite the much lower levels of Fert N being used. Research at Athenry, Grange and Johnstown Castle has shown the potential of PRG/WC swards to increase

animal performance and profitability under well managed rotational grazing, although lack of persistence of WC has been an issue in sheep grazing studies. Given the relatively limited use of rotational grazing on beef and sheep farms, further research is needed to examine the role of PRG/WC under alternative grazing systems.

- Environmental impact of PRG/WC swards
  Further research is needed to quantify the impact of PRG/WC versus PRG + Fert N swards, on GHG and ammonia emissions and nitrate leaching across a range of soil types, using the improved recommendations for N Fert on PRG/WC swards highlighted under c) above. Teagasc have developed ceramic cup and lysimetric platforms across a number of research centres, which should enable assessment of nitrate leaching across a range of soil types and grazing conditions.

- PRG/WC swards with low or Zero Fert N.
  Development of improved Fert N recommendations for PRG/WC swards could provide a basis for using lower or Zero Fert N levels in the future on individual PRG/WC paddocks (for example in cases of high >30 % WC content), without risking a deficit in early season growth. However, consideration needs to be given to the impact on overall pasture production at farm level, given that these paddocks may be inherently higher-yielding.

Multispecies Swards

As highlighted earlier, from the limited number of long-term scientific studies undertaken to date, across both Teagasc and UCD, there is insufficient evidence to support the use of MSS in farm practice, particularly in relation to agronomic or animal performance benefits when compared with PRG/WC swards. However, there is some evidence of potential environmental impacts with reduced N losses to air and water. On this basis, further research on MSS is justified with specific emphasis on accurately quantifying potential environmental impacts and determining whether similar benefits can be obtained with a reduced number of species.

- Establishment and persistency
  Research is required to improve the establishment and persistency of MSS. This work should incorporate herb cultivar evaluation and compatibility with grasses and legumes as most of the research studies to date have used a single Plantain cultivar. The work should also investigate cultivar interactions with Fert N application and grazing management.

- Herbage yield.
  Whilst some published reports from other centres have noted a yield benefit to MSS relative to PRG + Fert N and PRG/WC swards, the majority of Teagasc studies have shown similar yields for MSS and PRG/WC swards under standardized grazing conditions. In these studies, grazing management is designed to maintain a high WC content, with a target residual sward height through most of the season of 4 cm, and consequently species with an erect growth habit, like red clover and chicory, will not have the opportunity to express their yield potential. Research in UCD has shown that under higher post grazing residuals (6 cm sward height) MSS can be more productive. However, these MSS studies have been relatively short term and further work is needed on lifetime performance (over a 6 - 10 year period). Further research is required to evaluate grazing management strategies more suited to MSS, whilst maintaining legume content in the sward (potentially with red clover rather than white clover), and the persistency of these swards needs to be examined. The role of MSS under drought conditions also requires further investigation.

- Environmental impacts.
  Initial results suggest that MSS may have a role in reducing GHG emissions and nitrate losses to water. Further research is required to confirm these findings over a number of grazing seasons, as all of the work to date has been short term (2 -3 grazing seasons). Research is also needed to identify the underlying response mechanisms and whether similar benefits can be obtained with a reduced number of species e.g. PRG/WC/Plantain mix. Sward proportions required to improve environmental outcomes need to be achievable and demonstrated at farm level across multiple years.

Perennial Rye Grass/Red Clover Swards for Silage Production

- Further research on PRG/RC swards for silage production should focus on opportunities to maximise the use of manure N as the primary source of N and to evaluate varietal differences in yield potential and persistency.
- Much of the research on PRG/RC has been relatively short term – there is a need for longer term studies (5 – 10 years) to fully evaluate the potential pf PRG/RC for silage production.

Section 5: Recommendations for Programme Management

Given the scale and cross-centre, cross-programme nature of PRG/WC and MSS research within Teagasc, it is recommended that consideration should be given to establishing a PRG/WC and MSS Research Co-ordination Group to co-ordinate all aspects of research, and to develop appropriate platforms for future research in this area (e.g. A Future Sward Platform).

Section 6: Detailed Review of Research Programmes

Perennial Ryegrass/White Clover Research

- Research evidence on sward establishment.
  Clear recommendations for establishment of PRG/Clover swards have been developed based on Teagasc research. Recommendations have been published in 'Management and Establishment of Grass White Clover Swards' Series 42 by Egan et al March, 2024 and these protocols have been widely used by farmers across the Clover 150 programme. However, more research is needed on the establishment of PRG/WC swards, as success rate at farm level is quite variable, with both reseeding and over sowing methods. Clarification is also required on management of swards in the establishment year and on strategies to maintain a high proportion of clover in the sward through periodic over sowing.

- Maintaining herbage yield and quality at lower Fert N levels.
  Teagasc Research has successfully demonstrated how inclusion of white clover in grassland swards can enable significant reductions in Fert N use, whilst maintaining herbage yield and quality. The research results have been widely disseminated to farmers and industry. However, a very large range in Fert N saving effects have been obtained with white clover inclusion across Teagasc studies, whilst achieving a similar herbage DM yield to PRG swards. Farm systems studies have evaluated the Fert N savings, depending on livestock enterprise, which have ranged from 55 kg Fert N/ha (Athenry with sheep), 67- 73 kg Fert N/ha (Grange with beef cattle), 75 kg Fert N/ha (Johnstown Castle with dairy beef), 100 kg Fert N/ha (Moorepark with dairy), 110 – 140 Fert kg N/ha (Ballyhaise with dairy), 125 kg Fert N/ha (Curtins Farm with dairy), 75 -150 kg Fert N/ha (Clonakilty with dairy). Other studies have estimated higher levels

of Fert N savings - 240 Fert kg N/ha (Dairygold with dairy). Estimates of potential rates of BNF ranging from 128 to 255 kg Fert N/ha have also been reported (Solohead with dairy).

The longer-term study at Moorepark, involving a 5-year grazing plot trial, indicated yields of 11.2 t DM/ha for a PRG/WC sward + 100 kg Fert N/ha compared to 11.01 t DM/ha for a PRG sward receiving 200kg Fert N/ha.

Given reduced biological fixation of N in spring, and the crucial importance of adequate grass supply in spring calving systems, current recommendations for swards containing > 20 % WC in April are to apply Fert N in spring (75 kg N/ha during February, March and April), with levels reducing to 15 kg N in May, zero in June, July and August, and a final application of 15 kg N/ha in early September. There is scope to lower this level of spring Fert N application by substitution with organic N in slurry or dirty water.

The wide variation in performance of PRG/WC swards is a concern and highlights the need for more detailed research on factors influencing Biological N Fixation (BNF), as the differences do not appear to be solely due to WC content within the PRG/WC swards. Phelan et al., (2010) developed a model to predict BNF from annual clover herbage yield and observed values of 31-34 kg N fixed/ha/t clover herbage DM. Other assessments of BNF have indicated values of 33.6 (Dairygold report) and 50 kg N/ha/t clover DM (Solohead report). Burchill et al., (2014) reported overall BNF levels of 14 – 128 kg N/ha, Moorepark have estimated 100 kg N/ha in studies over the period 2021 to 2023, with 62 kg N/ha in 2024, and Cashman et al., (2024) estimated BNF of 255 kg N/ha. Cummins et al., (2021), in a review of studies in northern temperate pastures, observed a range in BNF from 100 to 380 kg N/ha. Given that N is a key driver of herbage production, more detailed research is needed to fully quantify and understand the factors that influence BNF from white clover under a wide range of sward conditions and soil types. An example of the approach which could be used is that of Burchill et al., (2014) which used a modelling approach to predict BNF based on Fert N level, herbage yield and soil mineral N.

Interpretation of the data is made more difficult by some inconsistencies in experimental design. For example, in dairy studies, PRG/WC treatments have generally included levels of Fert N between 75 to 150 kg N/ha, with some early studies at Dairygold and Moorepark using 250 kg Fert N/ha. In the studies at Solohead, zero Fert N treatments have been included, with other animal genetic and sward management factors being changed at the same time. Studies in Ballyhaise have used 90 and 120 kg Fert N/ha and Clonakilty used 225, 150 and 75 kg Fert N/ha (included in 2022/23), with between 100 and 250 kg Fert N/ha used in Moorepark and 150 kg Fert N/ha at Johnstown Castle. The range in levels of Fert N used with PRG/WC swards makes it more difficult to compare responses to WC inclusion between experiments.

Similarly in beef and sheep studies, whilst lower Fert N levels are used, there is considerable variation between studies and research centres (Athenry 145 and 90 kg Fert N/ha for PRG and PRG/WC swards respectively, Grange 134, 156 and 67, 83 for PRG and PRG/WC swards in 2023 and 2024 respectively). Given the relatively low levels of Fert N being used in the beef and sheep sectors, there is scope to examine the potential of PRG/WC swards at very low or Zero N Fert levels, thereby providing further information on whether a Zero Fert N approach is applicable to the dairy sector, particularly on farms operating at lower stocking rates.

The primary justification for applying Fert N to PRG/WC swards relates to concerns re poor early spring growth with these swards. This is particularly important in spring calving dairy systems as yield shortages at this time can have profound economic and animal welfare

implications. Teagasc have developed a precision nitrogen management strategy to estimate N fertilizer levels for swards with differing clover contents, and this approach is recommended in 'Management and Establishment of White Clover Swards' March, 2024 (Series 42). The recommendations provided in Tables 1 and 2 of the booklet take a precautionary approach to reliance on BNF in spring, with all swards receiving a total of 75 kg Fert N/ha in February, March and April, with recommended levels of Fert N thereafter based on the clover content of the sward in April.

Results from the LegacyNet project at Johnstown Castle indicate that fixed N accumulates in clover stubble, roots and soil over the growing season and the large net loss of root mass over winter releases N which can be recovered by PRG for spring growth. However, the release of this N is temperature dependent and occurs after the onset of spring grass growth. Evidence from the Solohead studies suggests that poor spring growth may be less of an issue for well-established PRG/WC swards in which clover contents during the main growing period are 30% or greater.

Further research is needed to develop Fert N recommendations for PRG/WC swards based on the plant available N required to support herbage yield at specific time points in the season. The new Teagasc PRG/WC herbage growth model being developed currently could provide a good basis for developing Fert N recommendations for PRG/WC swards. The model needs to consider variables such as clover content, soil temperature, soil type, geographic location, legacy N from the previous autumn, manure N (slurry N and recycled N from grazing animals) herbage yield and soil N mineralization. This herbage growth model needs to be incorporated into PastureBase Ireland and could facilitate adoption of lower Fert N levels with some PRG/WC swards, without risking a deficit in early season growth.

Whilst there has been limited adoption of PRG/WC on dairy farms, uptake on beef and sheep farms has been much slower, despite the much lower levels of Fert N being used. Research at Athenry, Grange and Johnstown Castle has shown the potential of Grass/WC swards to increase animal performance and profitability under well managed rotational grazing, although lack of persistence of WC has been an issue in sheep grazing studies. Given the relatively limited use of rotational grazing on beef and sheep farms, further research is needed to examine the role of PRG/WC under alternative grazing systems.

Effects of white clover inclusion on herbage quality have generally been reflected in small increases in protein content in summer and autumn and reductions in NDF content, although in one Moorepark study, a CP content of 23% DM was observed for PRG + 250 kg Fert N/ha and PRG/WC +150 kg Fert N/ha swards across the full grazing season. The higher protein content in some PRG/WC swards is of concern as this is well in excess of nutrient requirements for mid/late lactation dairy cows and could result in increased N losses. In this context, development of a better profile of plant available N required to support grass growth over the growing season, coupled with more accurate models of N supply via N cycling within the soil is required in order to minimize N losses as ammonia, nitrous oxide to the atmosphere and nitrate to water with PRG/WC. It is also important to establish if BFN is less prone to loss than Fert N, given that there should be better synchrony between N supply from N fixation with white clover and N demand from grass roots, than is the case with periodic applications of high levels of Fert N.

Ceramic cups have been installed on most of the grazing study platforms in the last two years (Athenry, Clonakilty, Curtins, Grange and Moorepark) for the extraction of soil pore water in order to monitor nitrate concentrations and this should provide a detailed insight into impacts of PRG/WC systems on water quality.

- Persistency of PRG/WC swards.
  One of the main concerns regarding PRG/WC swards is consistency of sward performance over several years. Results from the Teagasc research programme have been equivocal in relation to clover persistency. In some studies, e.g. Moorepark, persistency has not been an issue whereas in others e.g. Grange, Clonakilty, Johnstown Castle and Athenry, lack of persistence has been a significant challenge.

  There also appear to be differences in approach to reseeding and over sowing between centres. For example, at Solohead, the policy is to reseed 10 % of the area annually, coupled with a further 10% of the area being oversown annually, whereas in Clonakilty the policy is to reseed 10% of the area with 20% of swards being oversown annually. Consideration needs to be given to the costs and potential environmental impacts of such an intensive reseeding strategy. In contrast, at Moorepark, excellent persistence of white clover has been achieved since establishment in 2012, with minimal reseeding or over sowing, other than when additional area is introduced into the study.

  Further research is needed on factors influencing persistency of white clover, building on the excellent work which has been undertaken on developing grazing management guidelines for PRG/WC swards during the grazing season and published in 'Management and Establishment of White Clover Swards' March, 2024 (Series 42). Reasons for particularly poor performance of PRG/WC swards in some years, e.g. the spring period in 2024, need to be better understood.

  There is some evidence of differences between clover varieties in N fixing ability and tolerance to competition within a mixed ryegrass/WC sward. Research is ongoing to develop a clover profit index which should assist in designing optimal PRG/WC seed mixes and this work should examine possible varietal differences in spring growth characteristics potentially related to onset of N fixation.

- Maintaining or enhancing animal performance and health.
  A comprehensive series of studies has been undertaken to examine performance of sheep, beef and dairy cattle offered PRG/WC swards. In general, animal performance has increased with inclusion of WC in the sward. There is evidence of higher DM intake (sheep and cattle studies), improved ADG in lambs with both red and white clover (Athenry), increased ADG in cattle (Grange and Johnstown Castle), higher milk yields (Ballyhaise) and higher milk solids yields (Clonakilty, Curtins Farm, Dairygold and Moorepark). In the Solohead studies, higher milk yields were also reported in one of the experiments with PRG/WC swards (6585 vs 6404 kg FPCM for PRG/WC and PRG + 266 kg Fert N/ha respectively, although cows on the PRG/WC swards had a higher EBI which would have contributed to this yield difference. The increased animal performance with PRG/WC swards is primarily driven by increased herbage intake, reflecting the higher protein and lower NDF content of PRG/WC swards relative to PRG swards. A comprehensive series of studies on milk composition at Moorepark has shown minimal differences in metabolome of rumen or milk, mineral content of milk or milk processing characteristics with milk produced from PRG/WC swards compared to PRG only swards with Fert N.

One of the major health concerns in relation to white clover swards is the risk of bloat. There has been remarkably little evidence that this is an issue across the Teagasc white clover research programme, with no bloat observed at Athenry, Curtins, Dairygold, Grange and limited evidence of issues across the Moorepark studies, although Ballyhaise, Clonakilty and Solohead have experienced some bloat issues from mid-summer onwards in recent years. Incidences of bloat have also been recorded at Johnstown Castle, particularly with high clover content swards under wet conditions. A number of strategies have been used to control bloat, including addition of bloat oil to drinking water, restricted grazing with high clover swards, longer rotations/higher covers in August/September and offering forage in the form of grass silage in the grazing paddocks in late season. Given that bloat remains a risk, there is a need for research to develop a better understanding of the risk factors and appropriate preventative measures.

- Reducing environmental impacts on air and water quality.
  One of the potential benefits of adopting PRG/WC swards is the opportunity to reduce environmental impacts on both air and water quality by replacing Fert N with BFN, but it is important to verify potential impacts. Teagasc research is investigating potential impacts of PRG/WC swards on air and water quality both in large scale systems studies and in detailed plot and laboratory studies, but many of these studies are ongoing and it is too early to draw definitive conclusions from the initial results.

Methane emissions

Athenry

Reductions in methane emissions per kg DMI in sheep with legume inclusion (27% reduction with WC using a fixed 75:25 PRG/Legume mix compared to PRG, and similar reduction with RC, Woodmartin et al., 2024).

Dairygold

Methane emissions similar per cow and per kg milk solids, but lower for PRG/WC + 250 kg Fert N/ha when expressed per kg DMI basis compared to PRG + 250 kg Fert N/ha (21.5 vs 24.5 g/kg DM intake respectively, Enriquez-Hidalgo et al., 2011).

Moorepark

Methane emissions similar with PRG/WC + 150 kg Fert N/ha and PRG +250 kg Fert N/ha, although in one study (Fitzpatrick PhD), methane emissions were 22% higher/kg of milk solids (400 vs 326 g methane/kg milk solids with PRG/WC compared to PRG only swards respectively) during an autumn measurement period. There is increasing evidence of greater enteric methane emissions per day with PRG/WC swards, but with no impact when expressed per kg DM intake, due to the higher intakes with PRG/WC swards.

Johnstown Castle

In simulated rumen studies (Khan et al., 2023) white clover monoculture +150 kg N/ha produced 36 and 48 % less methane/g OMD than PRG +150 and PRG + 300 kg N/ha respectively.

In summary, the effects of sward type on methane emissions is inconclusive. Ongoing and future research should provide more evidence on impacts when expressed per unit of animal output.

Nitrous oxide

Solohead

In a small plot study, (Cashman et al., 2025) lower N20 emissions were measured with a mixed sward of PRG/RC/WC (Zero Fert N) compared to PRG + 250 kg Fert N/ha with emissions of 3.1 and 12.2 kg N2O/ha respectively (CAN used as Fert N and clover contents of 43 % and 13.3 % with PRG/RC/WC and PRG +250 kg Fert N /ha respectively. The low rates of nitrous oxide emissions with the PRG/RC/WC sward were attributed to the N mineralised in the soil being taken up by the sward, lost via other pathways or fully denitrified to environmentally benign N2 gas. In an earlier study (Li et al., 2011) nitrous oxide emissions due to BNF and clover residual decomposition in a PRG/WC sward were found to be negligible. In this study N2O emissions were 7.82, 6.35 and 6.54 kg N/ha/year for PRG + 226 kg Fert N/ha, PRG/WC + 58 kg Fert N/ha and PRG/WC with zero Fert N respectively (CAN and urea being used as Fert N sources).

Johnstown Castle

N2O emissions were higher with monocultures of RC and WC, compared to PRG (Cummins et al., 2021) with nitrous oxide emissions of 144, 184 and 175 g nitrous oxide/ha/year/ t DM yield for PRG, RC and WC respectively, **when all sward types received 150 kg Fert N/ha as CAN**.

In summary, the results indicate that PRG/WC swards with low levels of Fert N produce lower nitrous oxide emissions compared to PRG only swards receiving Fert N. Further research is required using protected urea as the principal source of Fert N, with both PRG/WC and PRG swards.

Ammonia

Solohead

In a pilot scale, small plot study, short and limited assessments of ammonia emissions were measured on two occasions (June and September) using wind tunnels. Cumulative ammonia emissions of 1.52, 11.2 and 0.78 kg/ha were recorded with PRG (Zero Fert N), PRG + 250 kg Fert N/ha (urea) and a mixed sward of PRG/RC and WC (Cashman et al., 2025). The low ammonia emission with PRG/RC/WC swards was attributed to the fact that BFN takes place underground and at daily rates that are in line with capacity for uptake by the sward.

Further research on ammonia emissions is needed with PRG/WC swards at zero and moderate levels of Fert N applied as protected urea.

Farmgate N Surplus

Clonakilty

Farmgate surplus of 102 vs 201 kg N/ha for PRG/WC + 150 kg Fert N/ha and PRG + 250 kg Fert N/ha respectively (without BNF). Farmgate surplus of 245 vs 201 kg N/ha for PRG/WC + 150 kg Fert N/ha and PRG + 250 kg Fert N/ha respectively (with BNF included).

Clover 150

NUE increased from 31 to 39% and N surplus reduced from 194 to 140 kg N/ha for PRG +232 kg N/ha compared to PRG/WC + 156 -182 kg Fert N/ha.

Moorepark

Farm gate N surplus is reduced and NUE increased when WC is incorporated into swards and Fert N reduced, with N surplus of 156, 104 and 54 kg N and NUE of 37, 48 and 64% for PRG +200 Fert N/ha, PRG/WC +150 Fert N/ha and PRG/WC +100 Fert N/ha respectively (Note: BNF is not included in these calculations).

In summary, farmgate N surplus is reduced and NUE improved in PRG/WC swards with lower levels of Fert N, compared to PRG only swards. However, BFN needs to be included in assessments of N efficiency, as BFN contributes to the overall soil N pool.

Nitrate leaching

Solohead

No statistically significant differences were noted between PRG/WC (Zero Fert N) and PRG + Fert N levels up to 280 kg N/ha, with low nitrate-N levels (<4 mg/l) observed in drainage water from heavy clay soils over the period 2000 – 2022.

Clonakilty

Similar nitrate leaching with PRG/WC sward +75 kg Fert N/ha to PRG + 225 kg Fert N/ha.

Moorepark

Higher nitrate levels in drainage water with PRG/WC + 100 and + 150 kg Fert N/ha (14.4 and 11.2 mg nitrate/l respectively) compared to PRG + 250 kg Fert N/ha (9.4 mg nitrate/l), based on one year of measurement.

The Teagasc results are consistent with those of earlier studies (eg Jarvis et al., 1996) which concluded that nitrate leaching from grazed PRG/WC swards was similar to PRG only swards receiving the same input of Fert N as that biologically fixed by clover.

LCA C footprint

Grange

It was estimated that PRG/WC swards reduced GHG emissions per kg carcass weight by 5.5% compared to PRG swards (17.9 vs 16.9 kg CO2e/kg respectively).

Solohead

Yan et al., (2013) estimated that PRG/WC swards receiving between 80 – 99 kg Fert N/ha had between 11 to 23% lower C footprint/kg energy corrected milk than PRG swards receiving between 180 and 353 kg Fert N/ha, with average carbon footprints between 0.86 – 0.87 and 0.97 – 1.13 kg CO2 e/kg ECM respectively. The high levels of Fert N used in this study are no longer valid, and therefore the reduction in C footprint with PRG/WC compared to PRG + 250 kg N/ha is at the lower end of this range. Cashman et al., (2025) in a summary of 5 grazing experiments, estimated C footprints per kg FPCM of 0.90, 0.76 and 0.69 (Tier 2 emission factor) and 1.05, 0.80 and 0.73 (Higher Tier Emission Factor) for three systems of production – Intensive PRG + 266 kg Fert N/ha, Best Practice with 99 kg Fert N/ha and Best Practice with 3 kg Fert N/ha respectively. Clover contents averaged 5-15%, 20 -25 % and >25 % for the three systems and there were also differences in cow EBI and methods of slurry spreading between systems. The authors concluded that it was not possible to disaggregate the impacts of the different factors on overall GHG emissions.

Moorepark

7.9% reduction in GHG emissions per kg solids corrected milk for PRG/WC + 150 kg Fert N/ha compared to PRG + 250 kg Fert N/ha as a result of increased animal performance and reduced total emissions (CAN and urea were used as Fert N source, Herron et al., 2021).

Johnstown Castle

GHG emissions in the dairy beef grazing study were estimated for PRG +150 kg N/ha and PRG/RC/WC +75 kg Fert N/ha at 10.2 and 9.8 kg CO_{2e}/kg carcass respectively (JC submission).

In summary, there is evidence that inclusion of WC in swards, coupled with reductions in Fert N, can reduce GHG emissions by up to 11% when comparing PRG/WC + 150 kg Fert N/ha and PRG + 250 kg Fert N/ha, with CAN and urea used as the Fert N source. Given the lower nitrous oxide emissions with protected urea, compared to CAN, reductions in emissions are likely to be lower with PRG/WC swards when protected urea is the main Fert N source with PRG + Fert N swards.

- Maintaining or increasing overall farm profitability

  Athenry

  Reduced days to slaughter (19 days) with lambs grazing PRG/WC swards compared to PRG swards.

  Solohead

  Net margin with PRG/WC swards was higher than with PRG + 266 kg Fert N, with net margin per kg FPCM of €0.096 and €0.121 respectively and net margin/ha of €1579 and €2005 respectively. However, there were confounding effects within this study, with differences in EBI and method of slurry spreading (Cashman et al., 2024).

  Grange

  Net margin of beef production/ha increased by 16% with PRG/WC + 67-83 kg Fert N/ha compared to PRG + 134-156 kg Fert N/ha.

  Moorepark

  Increased profitability with PRG/WC +150 kg Fert N/ha with increase of €108/ha (Hurley PhD) compared to Grass +250 kg Fert N/ha. McClearn (2020) reported a €305/ha increase in profitability when comparing Grass/WC with Grass only, both receiving 250 kg Fert N/ha, and based on the lower N Fert prices which prevailed in 2022. Similarly, Murray et al., (2024) reported increased profit of €478/ha and €185/ha for PRG/WC +150 kg Fert N and PRG/WC +250 kg Fert N/ha treatments, respectively, compared to a PRG +250 kg Fert N/ha treatment.

  Johnstown Castle

  PRG/WC/RC +75 kg Fert N/ha swards generated an additional €284 net margin/ha and €76 net margin per head compared to PRG +150 kg Fert N/ha.

  In summary, Teagasc research has consistently shown increases in profitability per head and per ha when white clover is included in grazed swards as an alternative to chemical fertilizer N.

Multispecies Sward Research

- Research evidence on sward establishment.

  Athenry

  Research at Athenry investigated establishment of binary swards (McGrane et al., 2025). It was concluded that seed rates of 2.5, 3.5, 7.5 and 5.0 kg/ha were required for white clover, chicory, red clover and plantain respectively, within an overall seed rate of 25 kg/ha, in order to establish an effective binary sward (assessed over a two-year period). The seed rates recommended for plantain and chicory are considerably higher than those used in some of the Teagasc studies. The proportion of WC and plantain increased with tetraploid ryegrass varieties compared to diploid varieties, but this also resulted in an increased proportion of

unsown species. Given the high seed rates recommended in this initial study, a longer-term assessment should include an economic assessment.

Curtins Farm
An 8 species MSS was established at Curtins based on a seed rate of PRG 11, Timothy 2, Meadow Fescue 4, white clover 3, red clover 0.6, hybrid clover 3, chicory 0.4 and plantain 1 (all kg/ha).

Grange
A 6 species MSS has been established with a seed rate of PRG 11, Timothy 1.5, white clover 2.5, red clover 5.0, chicory 4 and plantain 6 (all kg/ha).

Moorepark
A series of small plot grazing studies were established using 2.5 kg/ha of seed from a range of alternative species within an overall seed rate of 30 kg/ha with a range of N Fert levels (0, 100, 150 and 200 kg N/ha). Over the period of the trial, sward chicory content declined significantly but plantain displayed sufficient sward persistency to suggest it could have a role in longer term grazed swards.

Johnstown Castle
The MSS established for the dairy beef study is based on a seed rate of PRG 19, white clover 3.5, red clover 3.5, chicory 2 and plantain 2 (all kg/ha). Average botanical composition of swards after establishment was PRG 46%, plantain 25%, clover 21%, chicory 6% and weeds 2%.

UCD
The MSS established at UCD have involved 6, 9 and 12 species mixes, with the 6 species mix comprising PRG, Timothy, WC, RC, chicory and plantain, with the 9 species mixes also containing cocksfoot, birdsfoot trefoil and yarrow and the 12 species mix also included sainfoin, salad burnet and sheep's parsley. In all studies the proportional contribution of herbs decreased significantly in the 2 years following establishment.

In summary, a number of MSS have been established across Teagasc research farms and UCD, although there appears to be a lack of consistency in both the composition of the seed mixtures used (differing number of species included) and the seed rate used (e.g. plantain levels from 1 – 6 kg/ha and chicory 0.4 – 4.0 kg/ha). It is worth noting that current Teagasc advice on MSS (https://www.teagasc.ie/publications/2022/establishing-multi-species-swards-on-your-farm.php) suggests a seeds mix based on PRG 16, Timothy 1.7, white clover 3.3, red clover 3.7, plantain 2.45 and chicory 1.71 (all kg/ha), although the research evidence to support the seed rates recommended has not been provided.

- Maintaining herbage yield and quality at lower Fert N levels.
  Teagasc Research has demonstrated that MSS (with at least one forage grass, one legume and one herb species) can enable significant reductions in Fert N use, whilst maintaining herbage yield and quality. A range of Fert N saving effects have been obtained with MSS whilst achieving a similar herbage DM yield to PRG + Fert N swards.

Curtins Farm
In the first three years following reseeding, similar DM yields were obtained with MSS + 125 kg Fert N/ha, PRG + 250 kg Fert N/ha and a PRG/WC sward +125 kg Fert N/ha. The MSS contained 16% legumes, 13% plantain and 4% chicory. Chicory content significantly declined over the three years and plantain content has also declined in year 3. Note 15% of MSS area oversown each year in this study. Despite considerable variation in the component species, nutritive values were relatively unaffected by sward type, with the exception of organic matter digestibility which was lower in the MSS compared to PRG +25O kg Fert N/ha and PRG/WC + 125kg Fert N/ha (788, 801 and 799 g/kg, respectively). It was concluded that increasing sward diversity and reducing the use of chemical N fertiliser maintained both grass yield and nutritive value at lower Fert N levels relative to PRG swards. These swards need to be evaluated over a further number of years to monitor longer term effects.

Grange
When grown for silage, multi-species swards had a greater yield advantage at zero or lower inputs of Fert N. Legumes made a greater contribution to dry matter yield than herbs. Multispecies swards comprising PRG/Timothy/RC/WC or PRG/Timothy/RC/Plantain/Chicory receiving 120 kg Fert N/ha produced the same herbage yield as PRG sward plus 360 kg Fert N/ha. Under grazing (Zero Fert N) and silage management (+70 – 80 kg Fert N/ha), MSS produced similar DM yields to a PRG/WC sward receiving similar Fert N levels. Herbage nutritive value in MSS was more influenced by legumes than herbs. Compared to a PRG only sward, MSS had a slower rate of decline in DMD in early season, but had lower DMD in mid-season.

Moorepark
Herbage production was similar for MSS and PRG/WC swards across a range of Fert N levels (0, 100, 150 and 200 kg N/ha) over five grazing seasons and addition of chicory or plantain did not increase seasonal or annual production in PRG/WC swards. The proportion of WC in MSS had the greatest effect on nutritive value, with WC increasing CP content and decreasing NDF content. No data were available for the effect of plantain inclusion on herbage quality in the MSS grazing study.

Johnstown Castle
Across a four-year dairy cow grazing study (Mattimoe et al., 2024), a 6 species MSS produced 12.8 t DM/ha, receiving on average 58 kg of Fert N/ha, compared to a PRG/WC sward which produced 13.9 t DM/ha receiving on average 162 kg Fert N/ha. In a dairy/beef grazing study, similar herbage yields were obtained for PRG, PRG/RC/WC and a 5 species MSS comprising PRG, RC, WC, chicory and plantain (11.9, 11.5 and 11.4 tonnes of DM/ha, respectively), despite an additional 75 kg Fert N/ha being applied to the PRG swards compared with the PRG/RC/WC sward and the MSS (150 vs. 75 kg Fert N/ha). Results of small plot studies have shown that MSS have potential to mitigate the negative effects of moderate drought on yield, with stronger resilience once soil moisture is restored after drought.

UCD
Grace et al., (2018) observed annual herbage yields over a 2-year period of 9.9, 9.1, 10.3 and 9.9 t DM/ha for PRG +163 kg Fert N/ha, PRG/WC, a 6 species MSS and a 9 species MSS respectively, with the latter three swards receiving 90 kg Fert N/ha. All swards were grazed by sheep to a residual sward height of 4 cm. White clover content with the PRG/WC sward was very low (9 – 10%) over the two seasons, and legume content was also low with the 6 and 9 species swards (averaging 15.5 and 12% respectively).

In dairy calf to beef grazing studies, a 6 sp MSS + 92 kg Fert N/ha, grazed to 6 cm, outyielded both a PRG + 205 kg Fert N/ha sward and a PRG/WC + 92 kg Fert N/ha sward, both grazed to 4 cm, with DM yields of 12.6, 9.95 and 10.6 t DM/ha respectively (Baker et al., 2023).

In a two-year study with co-grazing cattle and sheep, annual herbage yields were greater for 6 and 12 sp MSS each receiving 70 kg Fert N/ha compared to a permanent pasture receiving 135 kg Fert N/ha or a PRG + 170 kg Fert N/ha sward, with yields of 13.8, 13.3, 8.5 and 11.4 respectively. However, pre grazing herbage allowances and post grazing residual sward heights were higher with the MSS than the permanent pasture and PRG swards (Beaucarne et al., 2025).

In summary, results indicate that, under cattle grazing, MSS produce similar yields to PRG/WC swards at the same Fert N level, with potential savings in Fert N use of up to 140 kg N/ha compared to PRG only swards. In the Teagasc studies there is no evidence that inclusion of additional grass and herb species with a PRG/WC sward has a beneficial effect on DM yield. Nutritive value with MSS swards is similar to PRG/WC swards with higher CP and lower NDF contents compared to PRG + Fert N swards (driven mainly by white clover content). There is a need for consistency across Teagasc research on MSS in relation to control treatments (PRG/WC or PRG + Fert N – preferably both) and in the levels of Fert N being used in order to enable comparisons across studies. In the UCD studies, higher yields have been obtained with MSS compared to PRG/WC swards (increases of up to 16%), but in one of the studies, WC contents in both the PRG/WC sward and the MSS were very low (9 – 10% and 12 – 15.5% respectively), studies have been of short duration (2 years) and in one study, different grazing management protocols were applied to MSS and PRG/WC swards.

- Persistency of MSS.
  One of the main concerns regarding MSS is consistency of sward performance over several years, with recent results highlighting marked reduction in herb content after 2-3 grazing seasons.

  Athenry
  Research at Athenry concluded that reliable establishment and lack of persistence of legume and herb-based swards remains a challenge under sheep grazing, with further long-term studies needed to optimise grazing management and sward composition.

  Curtins Farm
  The botanical composition of an 8 species MSS based on PRG, Timothy, Meadow Fescue, white clover, red clover, hybrid clover, chicory and plantain has been assessed over an initial three-year period after sowing. On average, the overall level of clover contribution was 13% and increased between year 1 and 2 (9 and 17%, respectively). Within the MSS, plantain made a consistent annual and seasonal contribution of 13% to total yield, whereas a significant reduction in chicory content was observed between year 1 and 2 (from 6% to 3%). In order to maintain species composition, 15% of the PRG/WC area was over-sown with 5 kg/ha of clover during May of each year, with 15% of the MSS area over-sown each year with a mix of 5 kg/ha of clover, 1 kg/ha of plantain, and 0.4 kg/ha of chicory

  Grange
  A 6 species MSS based on PRG, Timothy, white clover, red clover, chicory and plantain was monitored within and between years when the swards were grazed by beef cattle. Chicory exhibited greatest variation, with its presence greatly diminished in year two. Plantain exhibited a more stable presence in the sward, but was lower in the second year.

Moorepark
A series of swards were created with a range of alternative species included alongside PRG, e.g. PRG only; PRG/chicory; PRG/chicory/plantain; PRG/plantain; PRG/RC; PRG/WC; PRG/WC/plantain; PRG/WC/plantain/chicory; PRG/WC/RC; and PRG/WC/RC/plantain/chicory. Over the period of the trial (5 years), sward chicory content declined significantly with lower declines in plantain content. A dairy cow grazing trial is ongoing with a PRG/WC/plantain mix receiving 150 kg Fert N/ha. Swards are now 2.5 years old and plantain levels have declined.

Johnstown Castle
A MSS established for the dairy beef study is based on PRG, white clover, red clover, chicory and plantain. Average botanical composition of swards after establishment was PRG 46%, plantain 25%, clover 21%, chicory 6% and weeds 2%. Lack of persistency of MSS has been highlighted.

UCD
The herb content of MSS significantly declined in a 2-year grazing study with sheep, with herb content declining between years from 17 to 7% and 18 to 6 % in a 6 species and 9 species MSS respectively (Grace et al., 2019).

In summary, recent evidence indicates that lack of persistency of MSS is a major concern in the majority of studies, with particular challenges in maintaining chicory and plantain (under grazing conditions) whereas red clover appears to be more stable in the short term. Assuming there are other reasons to establish MSS (unrelated to DM yield and nutritive value of herbage), further research is needed to establish the optimal seeds mix and appropriate grazing management for beef, dairy cattle and sheep. This should examine the optimal number of species and specific compatibility characteristics of individual varieties under a range of environmental and grazing management conditions (e.g. sheep vs cattle grazing, wet vs dry conditions and effect of grazing severity e.g tight vs moderate grazing pressure).

- Maintaining or enhancing animal performance and health.
  Athenry
  Studies at Athenry using a 75/25 herbage ratio fed indoors to sheep have shown inclusion of either a legume or herb, alongside PRG increased DMI and lamb liveweight gain (12, 17, 9 and 17% increase in DLWG with WC, RC, Plantain and Chicory respectively) compared to PRG alone.

  Curtins farm
  Milk and milk solids yield per cow were highest with an 8 species MSS +125 kg Fert N/ha, intermediate with PRG/WC + 125 kg Fert N/ha and lowest with PRG +250 kg Fert N/ha (milk solids yields of 476, 463 and 452 kg/cow respectively), with no difference in milk solids yield per ha during the gazing season.

  Grange
  No differences in growth rate of beef cattle were observed over two grazing seasons when comparing MSS with PRG/WC swards, although cattle on MSS were leaner at slaughter.

  Moorepark
  No differences in animal performance were recorded between either a PRG/WC sward or a PRG/WC/Plantain sward over two grazing seasons.

Johnstown Castle
Similar milk yields and composition recorded across four years with a 6 species MSS + 58 kg Fert N/ha compared with PRG/WC + 162kg Fert N/ha. In the dairy-bred beef studies, animal performance was improved with more diverse pastures with ADG's of 0.61, 0.62 and 0.79 kg respectively for PRG + 150 kg Fert N/ha, PRG/RC/WC +75 kg Fert N/ha and MSS (5 species) +75 kg Fert N /ha in year 1 and 0.81, 0.92 and 0.87 kg respectively in year 2. Overall, lifetime growth rates were similar with PRG/WC/RC and MSS (0.78 and 0.79 kg/day respectively) and greater than those on the PRG only swards (0.74 kg/day). In year 3, there was an interaction between sward type and sire breed type for ADG. Early maturing heifers performed similarly on all forages whereas late maturing heifers on the PRG/WC/RC treatment had an increased ADG (+0.08 kg), compared to PRG and MSS swards.

UCD
Ewe performance improved on both a 6 and 9 species MSS, grazed over 2 years, with ewe weights at housing of 80.1, 81.8, 83.9 and 85.9 kg for PRG + 163 kg Fert N/ha and PRG/WC, 6 sp MSS and 9 sp MSS, with the latter three swards receiving 90 kg Fert N/ha. (Legume contents averaged 9.5%, 15.5 % and 12 % for PRG/WC, 6 sp MSS and 9 sp MSS respectively). Lambs grew faster on PRG/WC and MSS with birth to slaughter live weight gains of 227, 239, 242 and 244 g/day respectively for PRG +163 kg Fert N, PRG/WC, 6 sp MSS and 9 sp MSS respectively (Grace et al., 2019).

In dairy calf to beef systems, the ADG of both weanlings and yearlings was significantly greater with cattle grazing PRG/WC + 92 kg Fert N/ha swards and a 6 sp MSS + 92 kg Fert N/ha compared to those grazing PRG + 205 kg Fert N/ha swards with ADG's of 0.85, 0.82 and 0.70 for weanlings and 0.80. 0.82 and 0.70 kg/day for yearlings respectively (Boland et al., 2022).

In a two-year study with co-grazing cattle and sheep, ADG's were higher in both cattle and sheep for 6 and 12 sp MSS each receiving 70 kg Fert N/ha compared to a permanent pasture receiving 135 kg Fert N/ha or a PRG + 170 kg Fert N/ha sward, with ADG's of cattle of 1.09, 0.99, 0.92 and 0.92 kg respectively and ADG's of lambs of 393, 363, 292 and 305 g respectively. However, pre grazing herbage allowances and post grazing residual sward heights were higher with the MSS than the permanent pasture and PRG swards (Beaucarne et al., 2025).

In summary, improvements in animal performance have been recorded with MSS relative to PRG + Fert N swards with sheep and in some cattle grazing studies. However, in the majority of Teagasc studies, daily liveweight gain was similar with MSS and PRG/legume swards. Similarly, modest improvements in milk solids yield per cow have been obtained with MSS relative to PRG + Fert N, with similar performance between MSS and PRG/legume swards.

No bloat has been recorded at Athenry, Curtins Farm or in the Moorepark MSS studies. In contrast, bloat was a significant issue in the Grange beef study in the autumn of sward establishment, when naïve animals were exposed to the swards for the first time, with 3% of animals dying. Bloat has also been an issue in both the dairy cow and dairy heifer grazing studies at Johnstown Castle. Whilst no deaths have occurred with either study, on average, two incidents of bloat have occurred per year with dairy beef on the MSS treatment, mainly with high clover contents and wet conditions.

In Athenry studies, inclusion of red clover, white clover, chicory and plantain in binary mixtures alongside PRG had no effect on lamb faecal egg count (FEC). At Grange, no differences in level of worm infection or associated immune response were observed in cattle grazing either

Grass/WC or MSS swards. At UCD, FEC in sheep were lower with PRG/WC and a 6 sp MSS, with FEC of 422, 296, 293 and 399 eggs/g for PRG + 163 kg Fert N/ha, PRG/WC, 6 sp MSS and 9 sp MSS respectively. Grace et al., (2019) also showed a highly significant impact of sward type on the total anthelmintic treatments administered to lambs.

- Reducing environmental impacts on air and water quality.
  Teagasc research has investigated potential impacts of MSS on air and water quality both in large scale systems studies and in detailed plot and laboratory studies. Many of these studies are ongoing and it is too early to draw definitive conclusions from the initial results.

Methane emissions

Athenry

Binary diets containing herbs had lower methane emissions (g/kg DMI) than PRG only, with chicory approximately 13% lower and plantain 10% lower than PRG respectively using a fixed 75:25 Grass/herb mix. (This is around half the reduction noted with either WC or RC inclusion).

Curtins Farm

Results not yet available.

Grange

No difference in methane emissions in yearling beef cattle offered either a PRG/WC sward or a 6 species MSS (No Fert N applied to the grazing area).

Moorepark

Initial results from the 2023 grazing season indicate that methane emissions were 8% lower with a PRG/WC/plantain sward compared to a PRG/WC sward (both receiving 150 kg Fert N/ha), and this may reflect the fact that the WC content of the PRG/WC swards was higher.

Johnstown Castle

In simulated rumen studies Khan et al., (2023) observed that plantain, chicory and white clover monocultures gave lower CH4 production; with chicory producing 73% and 57% less methane than 300 N perennial ryegrass and 150 N perennial ryegrass respectively. However, methane production from a 6 species mix was similar to PRG, when both received 150 kg Fert N/ha (0.54 and 0.50 mmol methane/g OMD respectively). This analysis did not reflect sward persistency.

UCD

No results available

In summary, methane emissions from cattle grazing MSS are generally lower than those grazing PRG + Fert N, with some evidence of lower emissions relative to PRG/WC swards.

Nitrous oxide

Athenry

Inclusion of chicory in a fixed 75:25 Grass/herb mix increased urine output (smaller increase with plantain) and reduced urinary N concentration compared to PRG or PRG plus legume diets. This could potentially reduce nitrate leaching and nitrous oxide emissions.

Curtins Farm
Results not yet available.

Moorepark
Inclusion of plantain increased urine volume and reduced urine N concentration, resulting in lower N excretion. Implications of these changes on N2O emissions still to be assessed.

Johnstown Castle
N2O emissions were markedly lower with MSS swards, with DM yield scaled nitrous oxide emissions being 24% lower in a 6 species MSS compared to PRG, with both receiving 150 kg Fert N/ha (Cummins et al., 2021). The effect of MSS on nitrous oxide emissions was attributed to species identity effects and a net interspecific interaction that suppressed emissions intensity.

UCD
Model predicted nitrous oxide emissions following urea N Fert application increased in MSS as the proportion of legumes increased from 0 to 60% from 22.3 to 96.3 g N2O-N/ha and 59 to 219 g N2O-N/ha under ambient moisture and wet soil conditions respectively. Inclusion of plantain in MSS potentially inhibited nitrification (Bracken et al., 2020). Cumulative N2O emissions from MSS +45 kg Fert N/ha were 16% lower than from PRG + 250 kg Fert N/ha (Bracken et al., 2021)

In summary, N2O emissions are reduced with MSS relative to PRG only swards, with further research needed to compare MSS with PRG/WC swards.

Ammonia

Curtins Farm
Results not yet available.

Johnstown Castle
NH_3 emissions were assessed from soil following digestate application to grassland plots comprising either a PRG monoculture or an equi-proportional six species MSS of perennial ryegrass, timothy, red clover, white clover, chicory, ribwort plantain. Perennial ryegrass produced 11.4% higher ammonia emissions than the MSS (Ali Sultan Khan PhD).

Farmgate N Surplus/NUE

Athenry
NUE was not significantly affected by inclusion of chicory or plantain, in a fixed 75:25 PRG/herb mix, relative to PRG, but a PRG/chicory diet had a greater NUE than PRG/RC (possibly due to either higher passage rate or higher fermentable carbohydrate proportion in chicory relative to RC).

Curtins Farm
Results not yet available.

Moorepark
In a zero grazing trial, inclusion of plantain increased urine volume and reduced urine N concentration, with a 25% reduction in urine N output compared to PRG only. (The plantain treatment contained 50% plantain, 7% white clover and 38% PRG and received 25 kg Fert N compared to 50 kg Fert N with the PRG treatment). More N was partitioned to faeces and less to urine with the plantain treatment.

Nitrate leaching

Athenry

Inclusion of chicory, in a fixed 75:25 PRG/herb mix, increased urine output (smaller increase with plantain) and reduced urinary N concentration compared to PRG or PRG plus legume diets. This could potentially reduce nitrate leaching and nitrous oxide emissions. Effects are attributed to the diuretic effect of plantain and the lower DM content and higher ash content with chicory.

Curtins Farm

Results not yet available.

Moorepark

Results of the lysimeter studies demonstrated that nitrate leaching following autumn urine applications was reduced by 22% in an established monoculture sward of plantain compared to PRG (236 vs 303 kg TN/ha respectively).

Johnstown Castle

Across a range of soil types, inclusion of plantain in PRG/WC swards significantly reduced nitrate leaching, with a 30% plantain inclusion rate reducing nitrate leaching by 6% and 56% in poorly- and well-drained soils respectively in Year 1, and by over 96% in Year 2. Beneficial effects were attributed to deeper rooting activity, increased pasture growth, nitrification rate of applied N and mineralised or fixed N in the system. Deeper rooting allows more time for pastures to use the excess N in a urine patch therefore reducing N loss through leaching (Egan et al., 2025)

UCD

Nitrate leaching from MSS +45 kg Fert N/ha was similar to that from PRG + 250 kg Fert N/ha (Bracken et al., 2021).

In summary, initial results indicate that MSS containing plantain and/or chicory may have a role in reducing nitrate losses to drainage water as a result of effects on urinary N output coupled with deeper rooting activity.

LCA C footprint

Curtins Farm

Results not yet available.

Johnstown Castle

MSS with deep rooting systems may be a practical strategy to increase C cycling capacity in deeper soil layers within grassland thereby increasing C storage (Ryan et al., 2023). Higher concentrations of C in upper horizons of permanent pasture may limit C sequestration.

GHG emissions in the dairy beef grazing study were estimated for PRG +150 kg Fert N/ha, PRG/RC/WC +75 kg Fert N/ha and 5 species MSS +75 kg Fert N/ha at 10.2, 9.8 and 10.0 kg CO_{2e}/kg carcass respectively.

- Biodiversity and ecosystem function

Johnstown Castle

A six-species MSS had a significantly higher nematode diversity, maturity index, structure index and proportion of sensitive taxa (omnivore and predators) but a lower enrichment index (EI) than individual monocultures. Plant diversity enhanced nematode-based soil quality indices (Ikoyi et al., 2023). Compared to monocultures of forage plants, multi-species grasslands with

six species had a higher abundance of predatory nematodes, which can be beneficial for the biocontrol for plant pests. Conversely, there was a lower abundance of herbivorous nematodes in multi-species grasslands, the presence of which can negatively affect plant performance. MSS with 150 kg Fert N/ha had higher multifunctionality than a low-diversity, higher-nitrogen (300 kg Fert N/ha) PRG monoculture (Grange et al., 2024).

- Maintaining or increasing overall farm profitability
  Curtins Farm
  Economic assessments not yet available.

  Grange
  Economic assessments not yet available.

  Moorepark
  Economic assessments not yet available.

  Johnstown Castle
  Net margin per head was greater for MSS + 75 kg Fert N/ha compared to PRG + 150 kg Fert N/ha, but less than the margin for a PRG/RC/WC sward (€308, €257 and €334 respectively).

  UCD
  Results not yet available

Perennial ryegrass/red clover swards for silage

- Research evidence on sward establishment.
  PRG/RC Swards at Grange and Moorepark have been established using a full reseed, with current trials ongoing to evaluate a range of establishment methods and seed rates.

- Maintaining herbage yield and quality at lower Fert N levels.
  Over 2 seasons, yields of 13.3, 14.4 and 14.5 t DM/ha were obtained with PRG/RC swards receiving 0, 75 and 150 kg Fert N/ha respectively. Large varietal differences in DM yield and persistency were observed.

- Maintaining or enhancing animal performance and health.
  Higher DM intakes and growth rates were observed in dairy beef weanling steers offered PRG/RC silage compared to PRG silage with increases in intake and ADG of 1.4 and 0.12 kg/day respectively over the first winter period. However, the improved performance was not maintained over the second grazing season. In a second study, increased ADG (+ 0.08 kg/day) was observed with suckler calf weanlings offered PRG/RC silage compared to those offered PRG silage. In dairy cow studies, no difference in milk yield or milk solids yield was observed when PRG/RC or PRG silage was offered overnight in addition to daytime grazing, although cows on the PRG/RC silage had lower milk fat content.

- Reducing environmental impacts on air and water quality.
  No results available

- Maintaining or increasing farm profitability.
  Applying an agro-economic simulation model "Grange Feed Costing Model'' to silage costs indicates similar cost of a three cut PRG/RC silage to a two cut PRG silage with costs of €217 and €222 per t DM respectively.

References not included in Teagasc submission

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Jarvis, S.C., Wilkins, R.J. and Pain, B.F. 1996 Opportunities for reducing the environmental impact of dairy farming systems – a systems approach. *Grass and Forage Science* 51: 21-31.

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Sinclair Mayne 23 March, 2025

Section 6: Appendices

Appendix 1: Dr Sinclair Mayne – Brief Bio

Sinclair graduated with a First Class Honours Degree in Agriculture from Queen's University, Belfast in 1980 and undertook a PhD at the Agricultural Research Institute of Northern Ireland (ARINI), Hillsborough from 1980 to 1983. He was then appointed leader of the dairy research programme at the Grassland Research Institute in Devon, England, before returning to ARINI as Head of Dairy Research in 1987. He was appointed Director of ARINI in 2002 prior to its incorporation into the Agri Food and Biosciences Institute (AFBI) in 2006. He was appointed Departmental Scientific Adviser with the Department of Agriculture and Rural Development in 2009, and returned to AFBI in 2013 as Director of Sustainable Agri-Food Sciences Division. Sinclair was appointed CEO of AFBI in 2016 and retired in 2018 to form his own consultancy company. He has undertaken a range of contracts for industry, government, university and research organisations.

Sinclair is recognised internationally for his research on grassland and milk production and is a past President of both the British Grassland Society (BGS) and the British Society of Animal Science (BSAS). He has published over 100 scientific papers and was awarded the Sir John Hammond Memorial Award from BSAS in 1996 and the BGS Award for outstanding contributions to grassland knowledge in 2001. He was awarded Fellowship of the Royal Agricultural Societies in 2004, received the Princess Royal Award in 2013 from the Royal Association of British Dairy Farmers and the Belfast Telegraph Cup from The Ulster Farmers Union in 2018.

Appendix 2: Schedule for on-site engagement

Day 1: Teagasc Oak Park, Wednesday February 26th 2025

9.00 – 9.15	**Welcome and briefing on Peer Assessment** Frank O'Mara/ Pat Dillon			
Time	**Research Programme**	**Researchers Involved** Lead (L) Supporting (S)	**Project Title and Years**	**Key Topics for Discussion**
9.15 - 10.15	**White Clover Research** Dairygold Research Farm	Deirdre Hennessy (L) Michael O'Donovan (S) Michael Egan (S)	Project MKGS-0252-6120 Strategies to increase white clover use in intensive dairy production systems; 2011 to 2014	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
10.15 – 10.45	**PAE deliberations/report writing**			
10.45 – 11.45	Moorepark Research Farm	Deirdre Hennessy (L) Michael O'Donovan (S) Deirdre Hennessy (L) Ben Lahart (S) Aine Murray (S)	Project MKGS-0255-6515 Strategies to increase white clover use in intensive dairy production systems. 2014 to 2018; MKGS-1386: Establishing and managing white clover for intensive pasture-based ruminant production systems. 2018 to 2022 Project 2322- Using Precision fertiliser management with perennial ryegrass/white clover swards to further increase the sustainability of dairy grazing systems. 2024 to 2028	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
11.45 – 12.15	**PAE deliberations/report writing**			
12.15 – 13.15	**Clover Research** Clonakilty Agriculture Collage	Brian McCarthy Aine Murray (S) Brian McCarthy (L)	Project MKGS-0252-6310 The effect of tetraploid and diploid swards with and without clover inclusion on the productivity of spring milk production systems- 2013 to 2017 Project MKGS-1350 In Identifying strategies to improve nitrogen use in grazing dairy systems 2021 to 2025	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
13.15 – 13.45		**Lunch**		
13.45 - 14.30	**PAE deliberations/report writing**			

14.30 – 15.30	**Clover Research** Solohead Research Farm	James Humphreys (L)	MKSD-0402-5783 Quantification of the potential of white clover to lower GHG emissions from Irish grassland-based dairy production; 2007 to 2011 MKSD-1101-5782 Productivity of clover-based grassland under organic management and nitrate losses to ground water;2007 to 2011 MKDC-0205-5676 Post grazing height and the productivity of white clover-based systems of dairy production; 2007 to 2011 MKLS- 1361: Developing a blueprint for low or zero nitrogen fertilizer use for low-emissions pasture-based dairy farming.2021 to 2026;	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
15.30 – 16.00	**PAE deliberations/report writing**			
16.00 – 17.00	**Clover & MS Research** Curtins Research Farm Ballyhaise Agriculture Collage	Brendan Horan (L) Ben Lahart (S) Brendan Horan (L) Donal Patton (S)	1384: Farm to Fork Dairy Systems: the evaluation of Low-Nitrogen pasture-based regenerative grazing systems 2021 to 2027 1405: Farm to Fork Dairy Systems: transitioning to low N dairy systems on a wetland soil type in the Border Western Region of Ireland. 2021 to 2026.	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
17.00 – 17.30	**PAE deliberations/report writing**			

Day 2: Teagasc Oak Park, Thursday February 27th 2025

Time	Programme	Researchers Lead (L) Supporting (S)	Project Title and Years	Key Topics for Discussion
9.00 – 9.45	**Clover & MS Research** Athenry Research Farm	Philip Creighton (L) Sarah Woodmartin (S)	Project 0118-An evaluation of incorporating white clover and other alternative forages into sheep grazed swards on the productivity of pasture based lamb production systems. 2017 to 2021 Project 1780: An investigation into reducing chemical N inputs and the environmental footprint of pasture based sheep production systems 2022 to 2027	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
9.45 -10.15	**PAE deliberations/report writing**			
10.15 – 11.15	**Clover & MS Research** Johnstown Castle	John Finn (L) Bridget Lynch (L) Michael Dineen (S) Patrick Forrestal (S) Karl Richards (S) Joe Patton (S) Nicky Byrne (L) Ellen Fitzpatrick (S)	Project 0806: Grassland mixtures: resource use efficiency and yield stability in farmlet-and plot-scale study at Johnstown Castle: 2019 to 2023 Project 1788: The development of low nitrogen grassland-based systems of integrated crop-livestock production 2022 to 2027. Project 2048: The role of animal maturity and sward type in achieving beef systems of reduced slaughter age.	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
11.15 -11.45	**PAE deliberations/report writing**			
11.45 – 12.45	**Clover & MS Research** Grange Research	Paul Crosson (L) Eddie ORiordan (S) Peter Doyle (L)	Project 1409: Effect of age at slaughter and feeding system on environmental sustainability and carcass traits for steer beef production; 2021 to 2026 Project 2022: Developing more sustainable suckler beef systems in the context of grass-clover swards and animal genetics; 2023 to 2027	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
12.45– 13.15	**PAE deliberations/report writing**			
13:15 – 13:45		**Lunch**		

Time	Programme	Researchers Lead (L) Supporting (S)	Project Title and Years	Key Topics for Discussion
13:45 – 14:45	**Stakeholder Session: On Farm Clover Research**	Michael Egan (L) Michael 0'Donovan (S)	Project 1369: Incorporating white clover on commercial grassland farms in Ireland 2021 to 2027	Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
14:45 – 15:00	**PAE deliberations/report writing**			
15:00 – 16:00	**Clover Research** Moorepark and Grange	Michael Dineen (L) Nicky Byrne (S) Michael Egan (S) Tomas Turbitt (S)	Project 1748 Investigating the efficacy of perennial ryegrass-red clover silage for Irish animal production systems. 2022-2028	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
16:00 – 16:15	**PAE deliberations/report writing**			
16:15 – 17:15	**Clover Research** Moorepark	Tomas Turbitt (L) Michael 0'Donovan (S) Tomas Turbitt/Michael O'Donovan (L) Michael Egan (L) Michael 0'Donovan (S)	Project 1147; Development of a Clover Profit Index. 2020-2024 Project 1386; Establishment of white clover and optimisation of nitrogen fertilizer use in pasture-based milk production systems.2021-2025 Project 2024: Increasing white clover proportion and persistence in perennial ryegrass swards; through improved establishment, fertiliser application strategy and grazing management practices in grazing swards. 2023-28.	Objectives & findings of research, key publications, personnel, resources, funding, and management of research streams. Are there research gaps? Are there clear advisory messages arising from the research and is the overall Teagasc advice consistent with the totality of the research?
17.15 – 17:45	**PAE deliberations** / closed discussion on the Peer Assessment between Evaluation Officer and PAE			Clarification of structure and content of end report.
17:45	**Close**			

Appendix 3: List of Scientific Publications Included in Review

Teagasc

Scientific publications

Bennett, P., McGee, M., O'Donovan, M., Kelly, A.K. and Doyle, P., IN REVIEW. Effect of grass-only and grass-clover based swards on the growth performance of suckler-bred heifers and steers finished at 19.5 months of age. *Advances in Animal Bioscience*.

Boiani, M., Sundekilde, U., Bateman, L.M., McCarthy, D.G., Maguire, A.R., Gulati, A., Guinee, T.P., Fenelon, M., Hennessy, D., FitzGerald, R.J. and Kelly, P.M. (2019). Integration of high and low field 1H NMR to analyse the effects of bovine dietary regime on milk metabolomics and protein bound moisture characterisation of the resulting mozzarella cheeses during ripening, *International Dairy Journal,* **91**: 155-164. https://doi.org/10.1016/j.idairyj.2018.08.016

Boudon A., Horan B., Delaby L., Tobin J., Guinard-Flament J., Jezequel A., Graulet B., O'Donovan M., Maxin G., Gele M., Lemosquet S. and Hurtaud C. (2022). Effect of grazing dairy system and breed on monthly variation of milk minerals and heat stability. EAAP, Sep 2022, Porto, Portugal. Book of abstracts, 28, pp.339, Book of abstracts of the 73rd annual meeting of the European federation of animal science. https://hal.science/hal-03777031v1

Burchill W., James E.D., Li, D., Lanigan G.J., Williams M., Iannetta P.P.M. and Humphreys J. (2014). Comparisons of biological nitrogen fixation in association with white clover (*Trifolium repens* L.) under four fertiliser nitrogen inputs as measured using two ^{15}N techniques. *Plant and Soil*. doi: 10.1007/s11104-014-2199-1.

Burchill W., Lanigan G.J., Li, D., Williams M. and Humphreys J. (2016). A system N balance for a pasture-based system of dairy production under moist maritime climatic conditions. *Agriculture, Ecosystems and Environment*, **220**: 202–210.

Burchill W., Li, D., Lanigan G.J., Williams M. and Humphreys J. (2014). Inter annual variation in nitrous oxide emissions from perennial ryegrass/white clover grassland used for dairy production. *Global Change Biology*, doi:10.1111/gcb.12595.

Cashman, O., Casey, I. and Humphreys, J. (2024). The economic performance of grassland-based milk production using best practices to lower greenhouse gas and ammonia emissions. *Agricultural Systems*. https://doi.org/10.1016/j.agsy.2024.104105 .

Cashman, O., Casey, I.A., Sorley, M., Forrestal, P., Styles, D., Wall, D., Burchill, W. and Humphreys, J. (2025). Lowering the greenhouse gas and ammonia emissions from grassland-based dairy production. *Agricultural Systems*. https://doi.org/10.1016/j.agsy.2024.104151.

Clarke, H.J., Fitzpatrick, E., Hennessy, D., O'Sullivan, M.G., Kerry, J.P. and Kilcawley, K.N. (2022). The Influence of Pasture and Non-pasture-Based Feeding Systems on the Aroma of Raw Bovine Milk. *Frontiers in Nutrition*, 9, DOI=10.3389/fnut.2022.841454.

Clarke, H.J., Griffin, C., Hennessy, D., O'Callaghan, T.F., O'Sullivan M.G., Kerry, J.P., Kilcawley, K.N. (2021). Effect of bovine feeding system (pasture or concentrate) on the oxidative and sensory shelf life of whole milk powder. *Journal of Dairy Science*, https://doi.org/10.3168/jds.2021-20299.

Connolly, J., Sebastià, M. T., Kirwan, L., Finn, J. A., Llurba, R., Suter, M. and Lüscher, A. (2018). Weed suppression greatly increased by plant diversity in intensively managed grasslands: A continental-scale experiment. *Journal of Applied Ecology,* **55***:* 852-862.

Cummins, S., Finn, J.A., Richards, K.G., Lanigan, G.J., Grange, G., Brophy, C., Cardenas, L.M., Misselbrook, T.H., Reynolds, C.K. and Krol, D.J., (2021). Beneficial effects of multi-species mixtures on N2O emissions from intensively managed grassland swards. *Science of the Total Environment,* **792**, p.148-163.

Dineen, M., McCarthy B., Dillon P., Coughlan F., Galvin N., and Van Amburgh M.E. (2021). The effect of concentrate supplement type on milk production, nutrient intake, and total-tract nutrient digestion in mid-lactation, spring-calving dairy cows grazing perennial ryegrass (Lolium perenne L.) pasture. *Journal of Dairy Science*, **104**:11593-11608.

Dineen, M., Delaby L., Gilliland T., and McCarthy B. (2018). Meta-analysis of the effect of white clover inclusion in perennial ryegrass swards on milk production. Journal of Dairy Science, 101:1804-

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Egan A., Moloney T., Murphy J.B. and Forrestal P.J. (2025). Ribwort plantain inclusion reduces nitrate leaching from grass-clover swards; A multi-year five soil study. *Agriculture, Ecosystems & Environment.* https://doi.org/10.1016/j.agee.2024.109376.
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Egan, M., Galvin, N. and Hennessy, D. (2018). Incorporating white clover (*Trifolium repens* L.) into perennial ryegrass (*Lolium perenne* L.) swards receiving varying levels of nitrogen fertiliser: effects on milk and herbage production. *Journal of Dairy Science*, **101**:3412–3427. https://doi.org/10.3168/jds.2017-13233.
Enriquez-Hidalgo, D., Gilliland, T. and Hennessy, D. (2016). Herbage and nitrogen yields, fixation and transfer by white clover to companion grasses in grazed swards under different rates of nitrogen fertilization. *Grass and Forage Science*, **71**: 559-574. https://doi.org/10.1111/gfs.12201.
Enriquez-Hidalgo, D., Gilliland, T., O'Donovan, M., Deighton, M. and Hennessy, D. (2014). The effect of grass white clover swards on herbage production, herbage dry matter intake, enteric methane emissions and milk production of dairy cows. *Journal of Dairy Science*, **97**:1400 – 1412. https://doi.org/10.3168/jds.2013-7034.
Enriquez-Hidalgo, D., Gilliland, T.J., Egan, M. and Hennessy, D. (2018). Production and quality benefits of white clover inclusion into ryegrass swards at different nitrogen fertilizer rates. *Journal of Agricultural Science*, **156**: 378–386. https://doi.org/10.1017/S0021859618000370.
Enriquez-Hidalgo, D., Hennessy, D., Gilliland, T., Egan, M., Mee J.F. and Lewis, E. (2014). Effect of rotationally grazing perennial ryegrass white clover or perennial ryegrass only swards on dairy cow feeding behaviour, rumen characteristics and sward depletion patterns. *Livestock Science,* **169**: 48-62. https://doi.org/10.1016/j.livsci.2014.09.002.
Herron, J., Hennessy, D., Curran, T., Moloney, A. and O'Brien, D. (2021). The simulated environmental impact of incorporating white clover into pasture-based dairy production systems. *Journal of Dairy Science*, **104**: 7902-7918 https://doi.org/10.3168/jds.2020-19077.
Faulkner H., O'Callaghan T.F., McAuliffe S., Hennessy D., Stanton C., O'Sullivan M.G., Kerry J.P. and Kilcawley K.N. (2018). Effect of different forage types on the volatile and sensory properties of bovine milk. *Journal of Dairy Science*, **101**:1034-1047; doi https://doi.org/10.3168/jds.2017-13141.
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