Animal & Grassland Research and Innovation Centre

Moorepark

Swards for the Future

Conference Proceedings

Thursday 8th September, 2022

Friday 9th September, 2022

Swards for the Future
CONFERENCE & WORKSHOP

Teagasc
Agriculture and Food Development Authority

An Roinn Talmhaíochta, Bia agus Mara
Department of Agriculture, Food and the Marine

Swards for the Future

Proceedings of the Swards for the Future Conference & Workshop

Teagasc Moorepark, Co. Cork, Ireland

8th and 9th September, 2022

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Foreword

Professor Michael O'Donovan

There are many new challenges facing Irish agriculture, such as achieving reductions in environmental emissions, reducing nitrogen fertiliser use, improving water quality and addressing rising costs of production. While grassland continues to be the lowest cost feed for milk and meat production systems in Ireland, it also offers other benefits including carbon sequestration and increased biodiversity. This conference and workshop will provide an overview of the latest research findings and current best practice in grass-white clover and multi-species swards for improvement in our environmental footprint and productivity. It is crucial that in the current environment of reduction in fertiliser usage that the incorporation of grazing and conservation legumes is completed seamlessly.

The agriculture sector as a whole accounted for 37.5% of national GHG emissions in 2021. On an individual farm basis, there is plenty of evidence that farmers have taken several steps over recent years to increase efficiency per unit of output as the carbon footprint of product from Ireland reduces. In July 2022, the Government agreed the agriculture sector will require a cut of 25% (5.77 Mt CO_2 eq) in its emissions by 2030, compared to 2018 levels. Implementation of both methane (CH_4) and nitrous oxide (N_2O) emissions reduction measures will be required to meet this target. This will be a significant challenge for agriculture as current technologies available to Irish farmers have the potential to reduce emissions by just over 50% of the target reduction. If the targets are to be achieved with current livestock numbers more ambition will be required around some of the technologies, as well as the incorporation of new technologies. Improving grassland management, better use of legumes and the use of protected urea are all key strategies in reducing national GHG emissions.

Previously, in 2010, Teagasc Moorepark hosted the 'Grasses for the Future' conference, from which there were many positive outcomes and industry impacts, including the development and adoption of the Pasture Profit Index (PPI). Sometimes we underestimate the importance of the interaction and usefulness of combining knowledge and skillsets of grassland farmers, advisors, industry personnel and researchers. Swards for the Future provides an opportunity to combine the best knowledge from each sector of the grassland industry to develop the future direction of grassland research, with particular emphasis on contributing to achieving emission reduction targets.

The role of clover and protected urea in meeting agriculture's Climate Action Plan targets

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Abstract

Irish agricultural emissions, as presented by the national greenhouse gas (GHG) emissions inventory, shows that agricultural emissions in 2021 (23.1 Mt CO_2 eq) are approximate to where they were in 1998 (22.9 Mt CO_2 eq; the historical high point). Emissions from agriculture decreased between 1998 and 2011, however they have gradually increased since 2011. All of these changes in emissions profiles have been as a result of changes in agricultural policy and supports whether at an EU or at a national level. Examples include the introduction of milk quotas in 1984, the introduction of direct payment support for beef brought about in 1992 and the relaxation of milk quotas in 2008 and their removal in 2015. Irish agriculture has been set a clear target in the Climate Bill to reduce emissions by 25% by 2030, while nationally the stated goal is for overall emissions to be climate neutral by 2050. There will be significant challenges in meeting those targets. The initial focus must be to implement technologies that are proven while research develops new solutions. Clover has a clear role in the facilitation of a reduction in chemical nitrogen (N) fertiliser use at farm and nationally. This paper shows that based on the 2018 national GHG emissions, reducing chemical N fertiliser applied to pastures and arable land by 30 and 15%, respectively, would reduce GHG emissions by 0.42 – 0.67 Mt CO_2 eq. The transition towards protected urea chemical fertilisers on pasture has potential to reduce national GHG emissions by 0.58 - 0.83 Mt CO_2 eq. In combination, reducing chemical N fertiliser through the incorporation of clover into pastures and the transition towards protected urea fertiliser has potential to mitigate 1.25 Mt CO_2 eq, 5.4% of the 25% reduction target set for the agricultural sector. Introducing clover into pastures and transitioning to protected urea fertilisers are clear strategies to be used at farm level to reduce chemical N and associated GHG emissions while not affecting overall grass production.

Introduction

The agriculture sector as a whole accounted for 37.5% of national greenhouse gas (GHG) emissions in 2021 (EPA, 2022a). On an individual farm basis, there is evidence that farmers have taken several steps over recent years to drive further carbon efficiency per unit of output as the carbon footprint of product from Ireland reduces. Taking the agricultural sector as a whole, the increase in agricultural output in recent years has contributed to increased GHG emissions. Under the Climate Action Plan 2021, the agriculture sector was required to reduce GHG emissions from the 2018 baseline of 23 Mt CO_2 eq to a range of 16-18 Mt CO_2 eq by 2030. This equated to a reduction of between 5 and 7 Mt CO_2 eq, or on percentage terms, a reduction of between 22% and 30% as set out in November 2021. In July 2022, the Government agreed ceilings for emissions from each sector of the economy that deliver a pathway towards a 51% reduction by 2023. The ceiling for the agriculture sector will require a cut of 25% (5.77 Mt CO_2 eq) in its emissions by 2030 compared to 2018 levels. Implementation of both methane (CH_4) and nitrous oxide (N_2O) emissions reduction measures will be required to meet this target. This will be a significant challenge for agriculture without affecting livestock numbers as current technologies available to Irish farmers have the potential to reduce emissions by just over 50% of the target reduction and if the targets are to be met with current livestock numbers will require more ambition around some of the technologies and new technologies. This paper evaluates the impact of clover and protected urea in reducing national GHG emissions.

Materials and Methods

Data

National annual fertiliser use per calendar year was obtained from the national informative inventory report (IIR) (EPA, 2022b). The objective of the IIR is to describe the methodologies, input data, background information and the entire process of inventory compilation for transboundary air pollutant emissions. The data is required to address well-known environmental problems such as urban pollution, acidification and tropospheric ozone formation. This analysis used national fertiliser usage in 2018 as it is the base year for the Climate Action Plan reduction target of 25%. Table 1 outlines the fertiliser usage in 2018.

Table 1. National fertiliser compound statistics in 2018 (EPA, 2022)

	Tonnes nitrogen	Proportion
Ammonium sulphate	1,881	0.5%
CAN	147,340	36.1%
NK mixtures	3,134	0.8%
NPK mixtures	198,050	48.5%
NP mixtures	1,969	0.5%
Other straight N compounds	863	0.2%
Urea	51,991	12.7%
Protected urea	3,265	0.8%
Total	**408,493**	

Emission factors

All GHG emissions associated with synthetic fertiliser in the national GHG inventory report were considered. The emission sources included were direct N_2O emissions following application, CO_2 emissions following the application of urea fertiliser, and indirect N_2O from ammonia emissions and nitrate leaching. Emission factors for each source are outlined in Table 2 and are consistent with the national inventory. In line with the EPA (2022a) Provisional Greenhouse Gas Emissions 1990-2021 report, IPCC AR5 global warming factors were applied.

Scenarios

An analysis was completed that evaluated the impact of reducing chemical N fertiliser application rates nationally. The analysis was completed based on two scenarios. In scenario 1, chemical N application rates to pastures were reduced by 30% based on the current profile of fertiliser use nationally and then the industry moved to displacing CAN and compounds with 100% protected urea. In scenario 2, it was assumed that the industry first moved to displacing CAN and compounds with 100% protected urea and then reduced chemical N application rates to pastures by 30% nationally. Synthetic N fertiliser use on arable land was reduced by 15% for both scenarios. In all scenarios it was assumed that most of the chemical N fertiliser reductions were achieved through the incorporation of clover into pastures, allowing atmospheric fixation of N.

Table 2. Emission factor applied in national inventory report 2022

Source	Unit	Emission factor
Direct N_2O - CAN/ammonium/NPK (arable)	kg N_2O-N/kg N	0.0149 (0.0035)
Direct N_2O – Urea (arable)	kg N_2O-N/kg N	0.0025 (0.0027)
Direct N_2O - Protected urea (arable)	kg N_2O-N/kg N	0.004 (0.002)
Direct CO_2 – urea application	kg CO_2/kg N	1.59
Indirect N_2O - CAN/compound	kg NH_3/kg N	0.012
Indirect N_2O – Urea	kg NH_3/kg N	0.155
Indirect N_2O - Protected urea	kg NH_3/kg N	0.033
Indirect N_2O – Nitrate leaching proportion	kg NO_3-N/kg N	0.1
Ammonia conversion	NH_3-N to N_2O-N	0.01
Nitrate conversion	NO_3-N to N_2O-N	0.011

Results and Discussions

Table 3. Effect of reducing chemical N fertiliser applied to pastures by 30% and displacing calcium ammonium nitrate (CAN) and compounds with protected urea

	Fertiliser (t N)	Protected % N	Total Mt CO_2 eq	Mt CO_2 eq saved
Baseline	408,493	0.8	2.3	-
Scenario 1				
Reduce fertiliser 30%	294,945	0.8	1.63	0.67
Protected urea	294,945	74.5	1.05	1.25
Scenario 2				
Protected urea	408,493	76.2	1.47	0.83
Reduce fertiliser 30%	294,945	74.5	1.05	1.25

The analysis (Table 3) shows that whether you move to protected urea first or reduce overall chemical N first, you end up at the same place in terms of the overall emissions reductions (i.e. a reduction in emissions from 2.3 Mt CO_2 eq associated with fertiliser use to 1.05 Mt CO_2 eq). The order of the movement has a dramatic impact on the advantages associated with reduced chemical N fertiliser compared to a movement to protected urea. The advantage financially, as well as from an emissions perspective, suggests that the focus at farm level across pasture-based systems should be to move to protected urea based N fertiliser at first and then focus on the N reductions. Table 3 shows that the reduction in GHG emissions associated with a reduction in fertiliser N is 0.42-0.67 Mt CO_2 eq annually. A Teagasc report published in 2021 (Dillon *et al.*, 2020) looked at different fertiliser reductions and shows that the reduction in fertiliser N application at farm level is associated with a reduction in profitability. Clover has a key role in replacing chemical N at farm level to ensure that there is not a reduction in profitability. Research by McClearn *et al.* (2020) has shown that the establishment and maintenance of clover will increase profitability by approximately €300/ha. The successful industry wide reduction of chemical N fertiliser use will be based on widespread establishment of clover on Irish farms. A key consideration around clover will also be the impact on enteric methane and nitrous oxide emissions at the animal level. Early indications are there is no impact on these components.

Conclusion

Clover established in grassland swards will help replace purchased chemical N while at the same time resulting in increased animal performance. A reduction in chemical N will reduce GHG emissions from Irish agriculture. The impact of this reduction will be dependent on the industry moving to protected urea, with the increase in proportion of protected urea in the national fertiliser use reducing the impact of chemical N reductions.

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Better management of dairy nitrogen with grass-white clover swards

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Abstract

The sustainability of Irish milk production systems is under pinned by the efficient conversion of grazed grass to milk and meat. Grass-based systems are reliant on nitrogen fertiliser for pasture production. Reductions in chemical N fertiliser application will have a negative impact on farm feed self-sufficiency. Incorporating white clover in grassland swards provides an opportunity to reduce or replace chemical N fertiliser in the case of enforced reduction in use. This paper discusses the results of recent Irish trials on the impact of incorporating white clover into pasture-based milk production systems with an emphasis on herbage production, milk solids production, N fertiliser reduction and farm-gate nitrogen use efficiency.

Introduction

Grass-based milk production systems are heavily reliant on nitrogen availability for pasture production. Sown pastures in Ireland and other temperate climates generally consist of perennial ryegrass (*Lolium perenne* L.) which requires chemical N fertiliser application to maximise there productivity. In the last 10-15 years, the use of chemical fertiliser nitrogen has received a lot of focus, particularly in terms of the negative impact of nitrogen on water quality as well as gaseous emissions, resulting in reductions in the permitted application rates. More recently, the increased cost of chemical fertiliser nitrogen has also resulted in an increased focus on reducing chemical fertiliser nitrogen as an input to pasture-based production systems. Ireland's milk production systems are predominantly spring calving, matching dairy cow feed demand to grass supply. The sustainability of Irish milk and meat production systems is under pinned by the efficient conversion of grazed grass to milk and meat (Hanrahan *et al.*, 2017). Irish grass-based milk production systems are amongst the most efficient in the world, converting a low cost, home grown feed source, grass, in to milk.

Reducing nitrogen fertiliser input

In Ireland, perennial ryegrass swards receiving 250 kg N/ha can grow 13-14 t DM/ha, sustaining stocking rates of ~2.5 livestock units/ha (O'Donovan *et al.*, 2020). Restrictions in N fertiliser use are of concern as reducing N fertiliser input can reduce grass production (Enriquez-Hidalgo *et al.*, 2018). In an analysis of the effect of reducing N fertiliser application rate across two soil types and weather scenarios, Ruelle *et al.* (2022) concluded that for pasture-based milk production systems stocked at 2.5 cows/ha and receiving 250 – 300 kg N/ha were self-sufficient in terms of grass-grown for spring to autumn grazing and winter feed. As N fertiliser input reduced, farm self-sufficiency declined. Ruelle *et al.* (2022) concluded that for every 50 kg N/ha reduction from 250 kg N/ha, stocking rate would have to be reduced by 0.18 LU/ha for systems to remain self-sufficient. To maintain herbage production in an environment with reduced chemical N fertiliser application, farmers must consider other options, including optimising soil fertility and introducing white clover (Dillon *et al.*, 2020).

Role of white clover

White clover (*Trifolium repens* L.; hereafter referred to as clover) is the most important legume species in grazed grassland in temperate grassland regions, including Ireland. Clover grows well in association with grass, is tolerant of grazing, has high nutritional quality and can grow over a wide range of climatic conditions (Whitehead, 1995). Perennial ryegrass white clover swards can make an important contribution to the future sustainability of ruminant production systems in Western Europe (Peyraud *et al*., 2009). They have the potential to reduce N input from purchased chemical fertiliser through the fixation of atmospheric N, as well as reducing the energy required to manufacture and transport chemical N. In addition, there are herbage production and quality, and milk production benefits associated with the inclusion of clover in grass swards.

Sward white clover content

To achieve production benefits of clover inclusion in the sward, an average annual white clover content of approximately 20% is required. Sward clover content varies across the year. Clover growth is low in spring. Clover needs soil temperature of about 8°C for growth compared to about 5°C for grass. Sward clover content increases from approximately 0-5% in February to a peak of 35-50% in early September and then declines (Figure 1).

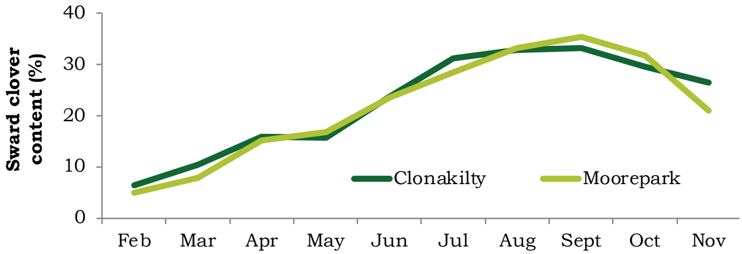

Figure 1. *Annual sward white clover content at Moorepark (8 years) and Clonakilty (4 years).*

Benefits of white clover

There are several benefits associated with the use of white clover in grass-based milk production systems.

Nitrogen fixation

As clover is a legume, it has the capacity to fix atmospheric nitrogen and make it available for plant growth. This occurs through a symbiotic relationship whereby rhizobia bacteria in the soil infect clover root hairs and form nodules. The clover then supplies the bacteria with energy through photosynthesis to fix nitrogen which the bacteria then makes available to the clover plant which uses this nitrogen for growth. Many experiments have been undertaken examining the quantity of nitrogen fixed in grass-white clover swards. In frequently grazed swards (8-10 times per year), up to 250 kg N/ha per year can be fixed. The rate of nitrogen fixation is influenced by the N fertiliser supply to the sward and the sward clover content. Generally, an average annual sward clover content of at least 20% is required for sufficient N fixation to occur to significantly reduce chemical N fertiliser application. In fertilised swards, as N fertiliser application rate increase, N fixation declines (Figure 2).

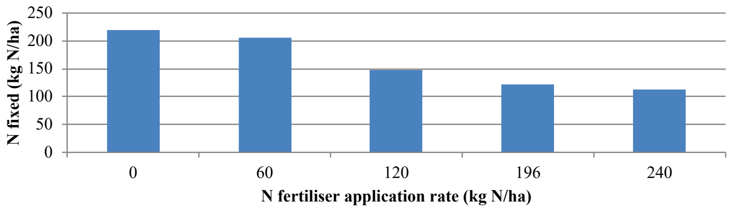

Figure 2. *Nitrogen fixation (kg N/ha) on grass clover swards receiving 0, 60, 120, 196 and 240 kg N fertiliser/ha over 3 years. Source: Enriquez-Hidalgo et al. (2018).*

Herbage production

Incorporating white clover into grazed grassland can increase herbage production, particularly at lower N application rates. Research from Clonakilty Agricultural College found that incorporating white clover into intensively managed swards increased annual herbage production by 1.5 t DM/ha, on average, relative to grass only swards (where both sward types received 250 kg N/ha) over a 4 year period where sward clover content was 23% (Guy *et al.*, 2018). Research at Moorepark shows that grass-white clover swards receiving 150 kg N/ha grew the same quantity of herbage as grass-only swards receiving 250 kg N/ha (13.4 t DM/ha) over an eight year period.

Milk production

Grass-white clover swards tend to be higher quality in mid-season compared to grass-only swards as sward clover content increases from May onwards. Clonakilty and Moorepark research both show increases in milk production and milk solids production ($P<0.05$) from grass-white clover swards compared to grass-only swards (Table 1).

Nitrogen use efficiency

Nitrogen use efficiency is hugely important in grazing systems as N is a key nutrient lost from these systems. It is influenced by many factors including N fertiliser application rate, quantity and crude protein content of concentrate fed, and N removed from the system in milk and meat. The farm-gate N use efficiency of a farm systems experiment undertaken at Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork from 2013 to 2016 was examined using a farm-gate N balance model. The experiment compared herbage and milk production from a grass-only sward receiving 250 kg N/ha per year (Grass250) and grass-clover swards receiving 150 kg N/ha per year (Clover150). Each treatment was stocked at 2.74 cows/ha. The N inputs were purchased concentrate, fertiliser and replacement animals, and the N outputs were milk and livestock. The N fixed by the clover was not included. The N use efficiency of the systems increased from 37% on Grass250 to 55% on Clover150 due to the reduction in N fertiliser application and the increase in milk production on that treatment.

Table 1. Effect of white clover inclusion on milk and milk solids yield in the Moorepark and Clonakilty grazing experiments

Moorepark Experiment			
	Grass-only 250 kg N/ha	Grass-clover 250 kg N/ha	Grass-clover 150 kg N/ha
Milk yield (kg/cow)	6,108	6,498	6,466
Milk solid yield (kg/cow)	460	496	493

Clonakilty experiment		
	Grass-only 250 kg N/ha	Grass-clover 250 kg N/ha
Milk yield (kg/cow)	5,222	5,818
Milk solid yield (kg/cow)	437	485

Long term research at Moorepark

Eight years (2013 - 2020) of research at Moorepark comparing the standard grass-only grazing system receiving 250 kg fertiliser N/ha with a grass-white clover system receiving 150 kg N/ha have been completed. Both systems were stocked at 2.74 cows/ha. The chemical N fertiliser application for each treatment is shown in Table 2. Cows were assigned to their respective system post-calving each spring and remained on that system until housing in late November each year.

Table 2. Nitrogen fertiliser application strategy by rotation on grass-only swards receiving 250 kg N/ha and grass-white clover swards receiving 150 kg N/ha		
Date (rotation)	Grass 250	Grass-white clover 150
Mid-late January	28	28
Mid March	28	28
April (2nd rotation)	33	28
Early-May (3rd rotation)	30	9
Late -May (4th rotation)	30	9
June (5th rotation)	17	9
Early-July (6th rotation)	17	9
Late-July (7th rotation)	17	9
August (8th rotation)	17	9
Mid-September	33	12

Herbage production was similar on the two sward types despite the 100 kg/ha reduction in N fertiliser used on the grass-clover swards. Approximately 75 kg DM/cow more silage were fed during lactation to the grass-clover cows, mostly in autumn. Neither system was self-sufficient in terms of herbage production due to the high stocking rate. Milk and milk solids yield were greater on the grass-clover system compared to grass-only. Reduced N fertiliser input and an increase in milk production contributed to increased net profit in the grass-white clover system compared to the grass-only system (Table 3). Average sward clover content was 22%.

Table 3. Average animal and sward production on grass-only swards receiving 250 kg N/ha and grass-white clover swards receiving 150 kg N/ha from 2013 - 2020			
	Grass-only 250 kg N/ha	Grass-white clover 150 kg N/ha	Difference
Stocking rate (cows/ha)	2.74	2.74	-
Annual herbage prod. (t DM/ha)	13.8	13.5	-0.3
Silage conserved (t DM/cow)	1.00	0.98	-0.02
Silage fed during lactation (kg DM/cow)	259	333	+74
Average sward clover content (%)	-	22.0	-
Milk yield per cow (kg)	6,068	6,331	+243
Milk solids yield per cow (kg)	490	510	+20
Concentrate fed (kg/cow)	438	438	-
Nitrogen use efficiency (%) (2013 – 2016)	40	58	+18
Net profit (€/ha) (2013 – 2016)	1,974	2,082	+108

Conclusion

Incorporating white clover into grassland swards is an effective way of maintaining herbage production when chemical nitrogen fertiliser application is reduced. Grass-clover swards receiving 150 kg N/ha have similar or greater herbage production than grass-only swards receiving 250 kg N/ha. The Moorepark long term clover research shows that milk solids production is greater on grass-clover swards compared to grass only-swards.

Acknowledgements

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Grass-white clover swards for drystock production

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Abstract

Ireland's competitive advantage in beef and lamb production is based on the efficient growth and utilisation of pasture. Challenges facing the agricultural sector are based on maintaining or improving current levels of production to support an economically viable sector but with an enhanced focus on environmental sustainability and a reduced dependence on chemical nitrogen fertiliser use. Incorporating white clover into sheep and beef grazing swards relative to perennial ryegrass alone has the potential to reduce age at slaughter (by 11 days), while maintaining similar levels of sward production at much reduced levels of chemical nitrogen fertiliser input, resulting in beef and lamb production systems of higher animal performance, improved economic return and reduced environmental impact.

Introduction

The ability of Irish beef and sheep production system to enjoy a long grazing season, where forage makes up 65% and 90-95% of beef cattle and lambs lifetime feed requirements on a DM basis, respectively (O'Donovan *et al.*, 2011), giving these systems both a competitive and comparative advantage over other nations. Ireland's competitive advantage in sheep meat production is based on efficient pasture production and utilisation. Perennial ryegrass is the most dominant forage grown in Ireland (DAFM, 2020). It can produce high dry matter yields, especially in spring and autumn, reducing the seasonality of production. It can, however, be difficult to maintain sward quality at certain times of the year, especially during the plants reproductive growth phase. It also requires relatively high levels of chemical nitrogen (N) application to maximise its growth potential. Challenges facing the agricultural sector are based on maintaining or improving current levels of production to support an economically viable sector but with an enhanced focus on environmental sustainability and a reduced dependence on chemical N fertiliser use (European Commission, 2020). The incorporation of white clover into pasture-based production systems can reduce the need for chemical N fertiliser application, and increases the N use efficiency of farm systems. The aim of this paper was to assess the influence of incorporating white clover into grazing swards on animal performance and pasture production.

Sheep grazing study

A grazing study was undertaken at the Sheep Research Demonstration Farm, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co. Galway, Ireland from March 2018 for three production years (2018-2020). The focus of the study was to assess the impact of incorporating white clover into sheep grazed swards on the productivity of pasture based lamb production systems with special focus on animal performance and the associated environmental and economic impacts. Three pasture treatments were investigated in the study: i) perennial ryegrass (PRG) only receiving 145 kg N/ha/yr (GO), ii) PRG plus white clover receiving 145 kg N/ha/yr (GCHN), and iii) PRG plus white clover receiving 90 kg N/ha/yr (GCLN). Within these systems detailed sward measurements and animal performance were recorded.

Animal performance

Results show that pasture treatment ($P<0.01$) had a significant effect on lamb lifetime ADG and days to slaughter (Table 1). Lambs in the perennial grass plus white clover treatments had a higher growth rate (+0.13 g/day) and lower days to slaughter (-11 days) compared to the perennial ryegrass only pasture treatment. Pasture treatment had no significant effect on carcass grade, fat score or dressing proportion.

Table 1. Effect of pasture treatment on lamb average daily gain (g/day), days to slaughter and slaughter characteristics

	GO	GCHN	GCLN	SEM	P-value
ADG[1] Lifetime (g/day)	211[a]	224[b]	219[b]	4.0	<0.01
Days to Slaughter	205[a]	194[b]	198[b]	5.23	<0.01
Carcass conformation	2.72	2.66	2.66	0.07	NS
Fat Score	2.97	2.98	2.9	0.08	NS
Dressing proportion	0.46	0.46	0.46	0.004	NS

[1]*ADG – average daily gain*

Sward production

There was no significant difference between pasture treatments in terms of sward DM production which averaged 12.7 tons DM/ha, as shown in Figure 1. Average sward white clover content across the grazing season was 12.3% and 14.3% for the GCHN and GCLN treatments, respectively.

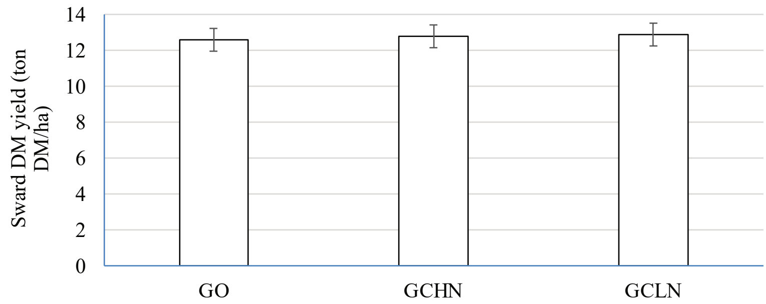

Figure 1. *Effect of pasture treatment on sward DM yield (tons DM/ha).*

Economics

From a financial point of view the lower costs associated with the low N clover treatment in the sheep grazing study resulted in a higher financial return for this system compared to the perennial ryegrass only or high chemical N fertiliser clover treatments (Figure 2). These calculations do not take into account the significant increases in the cost of fertiliser in 2022, which would have an even bigger impact.

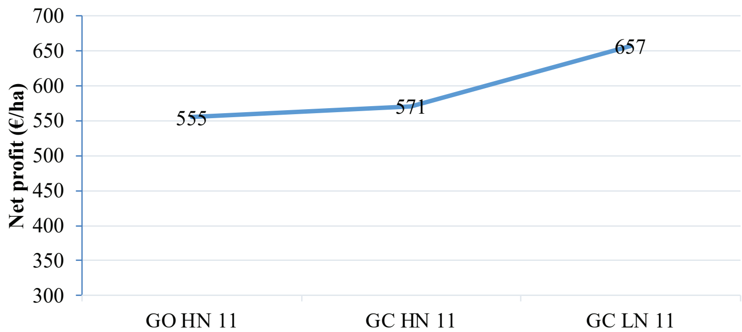

Figure 2. *Financial returns per hectare as influenced by sward type, stocking rate and nitrogen application rate (excluding direct payments and labour)*

Environmental footprint

Apart from the significant reductions in chemical N fertiliser use observed in the current study, in a separate companion study by Woodmartin *et al.* (2022) the effect of including white clover into sheep grazed swards on methane output was examined. When compared to lambs grazing perennial ryegrass only swards, the inclusion of white clover in the sward resulted in a 14% reduction in the ranking of methane output.

White clover in beef systems

PastureBase Ireland, our national grassland data base, shows that the top-twenty beef farms in 2021 grew 13.9 t DM/ha compared to 7.7 t DM/ha for the bottom-twenty farms, applying 174 kg and 92 kg N/ha, respectively. At these levels of grassland performance, white clover has the potential to support similar levels of DM production with a significantly lower chemical N fertiliser input while maintaining individual animal performance and live-weight/carcass output/ha from beef systems. Individual animal production benefits from grass-white clover swards remain unclear within beef systems. Previous research work has reported grass-white clover swards to have no effect (Moloney *et al.*, 2018) or increase (Yarrow and Penning, 2001) live-weight gain of beef cattle compared to grass-only swards, with previous studies from Teagasc Grange highlighting that carcass weight differences in favour of white clover were relatively small (O'Riordan and Travers, 1997). The variability between studies can be attributed to variability in white clover content across experiments. In continuous grazing systems, Yarrow and Penning (2001) reported that a white clover content of <30% has little effect on live-weight gain, and thus a white clover content of 30-45% is required to maximise live-weight gain from grass-white clover swards, which typically occurs in the second half of the grazing season (Yarrow and Penning, 2001). Similar to sheep systems, it was previously estimated that gross margin was 10% greater for forage legume (mainly white clover) beef systems when compared to grass only systems mainly due to a decrease in production costs rather than marginally increased animal performance (+ 6%) (Crosson *et al.*, 2016). Considering the lack of clarity on the impact of clover on beef animal performance in rotational grazing systems, future research at Teagasc Grange is investigating the impact of white and red clover incorporation in suckler calf-to-beef production systems on animal performance, sward production and economic and environmental sustainability.

Conclusions

Incorporating white clover into sheep and beef grazing swards relative to perennial ryegrass alone has the potential to support higher live-weight gains allowing for earlier age at slaughter while maintaining similar levels of sward production at much reduced levels of chemical N fertiliser input, resulting in higher animal performance, improved economic return and reduced environmental impact. It is acknowledged that further clover research is required in beef systems to gain a better understanding of the impact of clover on animal performance and age to slaughter.

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Economic value of grass and grass-white clover

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Abstract

The Teagasc Grange Feed Costing Model was used to review the cost of producing commonly used feeds on livestock farms in Ireland in 2022. Grazed grass is the lowest cost, high-quality feed source available, with white clover inclusion in swards providing further opportunities to reduce costs by reducing N application costs. The cost of producing and purchasing grass silage and concentrates were 3.3 and 5.2 times more expensive than grazed grass on an energy basis (excluding land charge), respectively, highlighting the importance of growing and efficiently utilising high-quality home-produced feed, rather than purchasing concentrates. Red clover silage can offer a further opportunity to reduce winter feed costs compared to grass silage in 2022. Establishing swards with optimum white clover proportions and utilising them efficiently needs to be a key objective to increase profitability on grassland farms.

Introduction

Unprecedented increases in prices of fertilizer, fuel and feed on global and Irish markets in 2022 has increased the cost of producing feed on livestock farms. The purpose of this analysis is to outline the cost of producing home-grown feeds on livestock farms in 2022 and to compare these with 1) the cost of purchased concentrate feeds, and 2) the cost of feed in 2021 in Ireland. Considering the price increase of fertilizer (CSO, 2022) it is also paramount to review the potential savings of incorporating nitrogen (N) fixing legumes into grassland-based systems.

Materials and Methods

An agro-economic simulation model "Grange Feed Costing Model" (GFCM) was developed to facilitate the impact of management, market and biological factors on the production costs of ruminant livestock feed (Finneran *et al.*, 2010). Previous iterations of the analysis identified yearly variations in crop yields and input prices as the major quantifiable measures of risk affecting feed costs. This model was used to re-evaluate the cost of feedstuffs in 2022 following surges in input prices (CSO, 2022). Table 1 lists the range of home produced feed crops evaluated and the assumed dry matter (DM) yields, DM concentration, energy content (Unitè Fourragère Lait (UFL)), DM digestibility and inorganic N fertilizer (kg N/ha) applied for each feedstuff, which were derived from Finneran *et al.* (2012).

Total feed cost includes accounting costs plus the opportunity cost of the resources employed (i.e. land charge – annual rental market price). The accounting cost includes all variable and fixed production costs, including processing, storage and feed-out costs associated with the feed crop, in addition to depreciation and interest on capital funding of fixed assets. Utilisation, harvesting losses etc. are also accounted for. Based on market prices in April 2022, Protected Urea was valued at €2.39/kg N, Calcium Ammonium Nitrate was valued at €3.33/kg N and rolled barley was valued at €390/tonne (t) fresh weight for the purpose of the analysis. Contracting costs were inputted based on the Farm and Forestry Contractors of Ireland (FCI) estimated costs 2022 publication (O'Donnell, 2022). Compared to recent years, on average contracting costs rose by 56% in April 2022 (e.g. pit silage = €419/ha, mowing = €72/ha, tedding €40/ha, baling (4 × 4) €9/bale, wrapping = €7.00/bale including plastic).

Table 1. Assumed dry matter (DM) yields (tonne, t DM/ha), DM percentage, energy content (Unitè Fourragère lait (UFL)), DM digestibility and inorganic N fertilizer (kg/ha) applied for each feedstuff.

	Grazed grass 13 t DM/ha	Grass -white clover 13 t DM/ha	Grass pit silage 10 t DM/ha (2 cuts)[1]	Grass baled silage 10 t DM/ha (2 cuts)[1]	Red clover pit silage 9.6 t DM/ha (2 cuts)	Maize silage 13 t DM/ha (no plastic)	Fodder beet 15 t DM/ha
DM yield (t/ha)	13	13	6 + 4	6 + 4	5.6 + 4.0	13	15
DM (%)	17.4	17.4	21.7	32.4	30.0	30.3	19.0
UFL/kg DM	1.03	1.02	0.82	0.82	0.82	0.80	1.12
DM digestibility (%)	82	81	73	73	73	68	86
Inorganic N fertilizer kg/ha[2]	225	100	87 + 69	87 + 69	0	112	114

[1]*First- and second-cut silage were assumed to be cut on 29 May and 17 July, respectively.*

[2]*Remainder of nitrogen requirement was fulfilled via slurry (organic N) application.*

Results and Discussion

The results of the estimated feed costs in September 2021 and April 2022 are presented in Table 2. Unless stated otherwise, prices described in the following text include land charges; prices excluding land charges are also presented in Table 2. Costs are presented in € per hectare, € per t DM grown, and a relativity to grazed perennial ryegrass swards on a unit energy basis (UFL) (which excludes land costs of home-produced feeds) (see Table 2).

It is well-established that grazed grass is the cheapest feed in Ireland and primarily for this reason, it underpins our ruminant production systems. Traditionally high grass yields have been supported by N application in the form of inorganic and organic N. At current prices, a grazed grass sward yielding 13 t of DM/ha and receiving 250 kg N/ha (225 kg Protected Urea N + 25 kg organic N) is estimated to cost €121/t DM (12.1 c/kg DM). This represents a 29% increase on 2021, inflated by the increases in N fertilizer prices.

Legume crops such as white clover have the ability to 'fix' N from the atmosphere, thereby replacing to a large extent the requirement for imported N fertilizer sources. In this analysis, we assume that clover fixes 125 kg atmospheric N/hectare and therefore, N application is reduced to 125 kg N/ha for a 13 t DM grazed grass-clover sward, reducing estimated total feed costs to €98/t DM. Successfully incorporating white clover onto farms can be a strategy for maintaining herbage production, with reduced fertilizer inputs. Perennial ryegrass-white clover swards are also characterised by additional benefits including increased digestibility and improved animal performance (+8% milk yield/cow) (Dineen *et al.*, 2018) but these benefits were not included in the analysis.

As grazed grass is not available at all times during the year in Ireland, alternative feedstuffs are produced to be offered to livestock housed indoors over the winter period. The most common winter feed is grass silage, traditionally produced from one or more harvests in the summer. The cost of producing grass silage (pit) in this analysis is €204/t DM and €238/t DM for first- and second-cut, respectively. On average across both cuts, harvested in late-May and mid-July, grass silage (pit) is estimated to cost €218/t DM (circa €47/t fresh weight), an increase of 27% when compared to 2021. Similarly, baled silage increased by 33% compared to 2021. On average baled silage costs increased from €25/bale in 2021 to €40/bale (exc. land charge) in 2022, respectively, with agricultural machinery contractor charges being the main expense (61% per bale), followed by fertilizer (27% per bale).

Red clover silage offers an alternative to reduce fertilizer N application, although red clover persistency in the sward is considerably low at 5 to 6 years (Clavin *et al.*, 2017) and therefore would require more frequent reseeding, raising fixed costs. At current fertilizer prices in 2022, red clover pit silage (2-cut) (€181/t DM) is more competitive than grass pit silage (€218/t DM). Additionally red clover silage swards are typically operated on a 3-cut silage system which raises the total cost to €207/t DM grown (pit) with the third harvest yielding 3.5 t DM/ha.

Feeds such as fodder beet and maize silage form an important part of the indoor feeding diet on many farms, particularly for beef finishers and winter milk systems, respectively. The cost/t DM of fodder beet (including washing and chopping) in 2022 are similar to grass silage at €246/t DM (ca. €47/t fresh weight), representing an increase of 32% when compared to 2021. Maize silage is marginally lower, costing €231/t DM grown (€70/t fresh weight), an increase of 41% when compared to 2021. Fodder beet (€272/1,000 UFL utilised) and maize silage (€330/1,000 UFL utilised) work out cheaper than grass silage (€341/1,000 UFL utilised) on a unit of energy basis. An important point to consider is that supplementary feeding costs, particularly those associated with indoor feeding such as mineral and protein supplementation (which is particularly important for fodder beet and maize silage) are not accounted for in the analysis.

While the cost of home-produced feed has increased substantially, the rising cost of purchased concentrate feeds is also noteworthy. For example, rolled barley has increased in price to €390/t fresh weight (€450 t/DM) in April 2022. This emphasizes the importance of (1) producing sufficient quantities of home-produce feeds, especially forages, and (2) ensuring that the quality of feed produced is suitable for the animal type to be fed. If these two objectives are not achieved, then supplementary concentrate feeding will be necessary at a higher cost than the home-produced alternative. Although it is acknowledged that concentrate supplementation is required in some winter systems (beef finishing, winter milk etc.) to obtain optimal animal performance, producing high quality winter forage can be a cost effective method to reduce concentrate supplementation.

Table 2. Estimated costs (€) to produce feed at current (April 2022) and previous (September 2021) market prices

	Grazed grass 13 t DM/ha	Grass -white clover 13 t DM/ha	Pit silage 10 t DM/ha	Baled silage 10 t DM/ha	Red clover pit silage 10 t DM/ha	Maize silage 13 t DM/ha	Fodder beet[1] 15 t DM/ha	Purchased rolled barley
September 2021								
Total costs/ha (incl. land costs)[2]	1,273	990	1,708	1,744	1,536	2,144	2,792	.
Total costs/ha (excl. land costs)	482	249	1,207	1,244	1,042	1,403	2,051	.
Total costs/t DM grown (incl. land costs)[2]	98	76	171	174	160	167	186	312
Total costs/t DM grown (excl. land costs)	37	19	121	124	108	110	137	329
Relative cost to grazed grass per energy utilised (UFL)[3]	1	0.5	3.8	3.6	3.5	3.1	3	5.7
April 2022								
Total costs/ha (incl. land costs) (€)[2]	1,577	1,269	2,175	2,517	1,742	2,953	3,685	.
Total costs/ha (excl. land costs) (€)	836	528	1,657	1,999	1,248	2,212	2,944	.
Total costs/t DM grown (incl. land costs) (€)[2]	121	98	218	252	181	231	246	450
Total costs/t DM grown (excl. land costs) (€)	64	41	166	200	130	173	196	450
Relative cost to grazed grass per energy utilised (UFL)[3]	1	0.6	3.3	3.7	2.7	3.2	2.8	5.2

DM = dry matter, t = tonnes.

[1]Fodder beet costs do not include the cost of additional protein supplementation required.

[2]Land charge is €741/ha (€300/acre).

[3]Excluding land charge associated with home-produced feeds.

Conclusion

The cost of all feeds have increased substantially in 2022. Home-produced feeds, and grazed grass in particular, remain our cheapest feed resource, with grass-clover pastures being particularly cost-effective. Incorporating legumes such as red clover into 'silage fields' can also be an effective method to reduce winter forage costs during high N price years. Purchased concentrates such as rolled barley remains an expensive feed resource, costing over five times the price of grazed grass (excluding land charge) on a unit of energy basis.

Prices quoted in this article are those prevailing at the time of the analysis (final week of April 2022) and are subject to high levels of volatility.

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The role of multispecies swards for livestock systems: an update from Irish research

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Introduction – the role of multispecies pastures in climate smart grazing systems

Among the main opportunities for grazing systems, there is a renewed focus on the incorporation of both legumes and herbs within intensive grassland-livestock systems. Grass-clover swards already encompass considerable benefits from having two species in a mixture. This paper focuses on recent Irish and international investigations of multispecies swards (MSS) typically comprising three main functional groups (grasses, legumes and herbs).

Impacts of plant species diversity in sown pastures

There is unequivocal evidence that MSS (comprising a modest number of complementary species selected for their agronomic performance) can deliver similar or improved herbage DM yields when compared to *Lolium perenne* (perennial ryegrass; PRG), while requiring fewer inputs of nitrogen (N) fertiliser (Suter *et al.*, 2015). For example, across 31 international sites, Finn *et al.* (2013) found that four-species grass-legume swards yielded more than the best-performing monocultures in the majority of cases in conservation systems. In an Irish context, plot studies have consistently demonstrated the ability of MSS (consisting of PRG, *Phleum pratense* (timothy), *Trifolium repens* and or *T. pratense* (white and or red clover), *Cichorium intybus* (chicory) and *Plantago lanceolata* (ribwort plantain)) to produce similar or more herbage DM/ha/yr compared to PRG monocultures, while receiving only a fraction of the N fertiliser ((e.g. Grange *et al.*, 2021 (150 v's 300 kg N/ha/yr); Moloney *et al.*, 2021 (0 v's 360 kg N/ha/yr); Grace *et al.*, 2018a (90 v's 250 kg N/ha/yr)). In general, the yield benefits from MSS respond strongly to functional group diversity, and saturate at around four to eight species (Lüscher *et al.*, 2022). In a grazed plot experiment across three N levels, a mixture with three functional groups (PRG, white clover and plantain) yielded increased DM compared to either PRG monoculture or PRG-white clover binary swards (Hearn *et al.*, 2022). Recent and ongoing farmlet scale experiments to better understand the behaviour of MSS under grazing conditions have also shown similar findings (e.g. Baker *et al.*, 2022a (90 v's 205 kg N/ha/yr, beef steers); Shackleton *et al.*, 2022 (70 v's 170 kg N/ha/yr, beef heifers, ewes and lambs); Grace *et al.*, 2018b (90 v's 163 kg N/ha/yr, ewes and lambs)).

Multispecies swards are dynamic, changing in composition within season and between years. The maintenance of the legume component of the sward is key to achieving the N fertiliser replacement value associated with MSS (Nyfeler *et al.*, 2009; Grace *et al.*, 2018a). Increased N fertiliser rates generally lead to reduced sward legume content (Moloney *et al.*, 2021), and therefore, ensuring appropriate N fertiliser application rates and timings (early season) is essential to the maintenance of productive MSS. The factors influencing herb persistence in swards are less well understood, but studies generally indicate a decrease in herb content over time (Moloney *et al.*, 2020a; Grace *et al.*, 2019a, b). Given the lower DM content of MSS (Grace *et al.*, 2018a; Baker *et al.*, 2022b), silage made from these swards (particularly when herb and legume content is high), requires a greater period of wilting than PRG only swards. Once this is achieved, MSS make good quality silage (Moloney *et al.*, 2020b; 2021). While the nutritive value of MSS will change with the composition of the swards, in general, they have higher crude protein and ash, and lower neutral detergent fibre content than PRG (Grace *et al.*, 2018a; Baker *et al.*, 2022b).

Impacts on animal performance

In addition to their potential to produce higher DM yields from systems receiving fewer fertiliser N applications than PRG monocultures (Nyfeler *et al.*, 2009; Grace *et al.*, 2019a), the concurrent improvement in feeding value in MSS swards for grazing animals has also been documented (Dineen *et al.*, 2018; Grace *et al.*, 2018a). Until recently, there was a paucity of evidence on the performance of livestock grazing MSS under Irish conditions. Recent studies have begun to report the impacts of sward species diversity on the performance of animals within Irish grazing systems and a summary of emerging evidence are presented in Table 1.

The results presented are indicative of generally improved animal performance within more diverse swards compared to PRG monocultures. In the case of sheep and beef systems, the benefits of increased sward diversity are manifest in increased average daily gain (ADG) and a reduction in the number of days to slaughter. The situation with lactating dairy cows is currently less clear, albeit from fewer studies completed. McCarthy *et al.* (2022) reported an increase in daily milk production of 1.05 kg when cows were offered a six species MSS compared to PRG, although there was no difference in milk solids (MS; fat plus protein) production. Similarly, cows grazing a PRG-dominated sward or a 6 species mixture recorded similar milk and MS yields and milk fat and milk protein concentrations within an ongoing complete farm systems evaluation (Patton *et al.*, 2022). A recent two-year grazing experiment (with 75 kg N/ha/yr) in France also observed improved production of milk (+0.8 kg/day) and MS (+0.04 kg/day) when comparing PRG with a 5 species MSS (Roca-Fernández *et al.*, 2016) based on enhanced sward quality and increased DM intake (+1.5 kg DM/day). More generally, a meta-analysis review of international studies by McCarthy *et al.* (2020) reported increased daily milk (+1.2 kg) and MS (+0.06 kg) yields on MSS when compared to PRG only or PRG plus legume swards.

Table 1. Summary of animal performance studies comparing perennial ryegrass (PRG) control treatments with Multispecies swards (MSS)

Animal	Multispecies sward	Performance metric ***	Author
Lambs	6 species	ADG: increased by 10% DTS: reduced by 13 days	Grace *et al.* (2019b)
Lambs	5 species	Weaning weight: increased by 14%	Higgins *et al.* (2022)
Beef steers	6 species	ADG: increased by 24% DTS: reduced by 21 days	Boland *et al.* (2022)
Lambs/heifers	6 species	ADG: increased by 35% DTS: reduced by 50 days ADG: increased by 18%	Beaucarne *et al.* (2022)
Lambs	2 species**	ADG: increased by 13% DTS: reduced by 23 days	McGrane *et al.* (2022)
Dairy cows	6 species	MY: increased by 1.05 kg/day MS yield: no change	McCarthy *et al.* (2022)
Dairy cows	6 species	MY: no change Milk fat: % no change Milk protein: % no change	Patton *et al.* (2022)

**MSS: 5 species; PRG, white clover, red clover, chicory and plantain; 6 species: as 5 species plus Timothy. **Binary mixtures: PRG + one of white clover, red clover, chicory or plantain ; results presented are the mean of the binary mixes vs PRG. ***ADG = average daily gain, DTS = days to slaughter, MY = milk yield, MS yield = combined milk fat and protein yield.*

Impacts on environmental sustainability

Decoupling productivity and negative environmental impacts is a key objective for future agricultural systems expanding beyond traditional concerns (herbage quantity and animal production) to incorporate a wider set of attributes such as to reduce chemical inputs, protect soil physical and biological integrity, reduce losses of contaminants to water and air and preserve ecosystem services. Some of the recent ecosystem benefits of increased sward diversity reported in the literature include:

- reduced requirement for, and losses from, N fertilisation. The use of inorganic N fertilisers comes with high environmental costs, as their production needs large amounts of energy and their high level application can result in substantial N loss to the environment. By virtue of increased N fixation and reduced chemical N requirements, legume based MSS can reduce N loss from grazed systems by achieving better utilisation of N through increased pasture growth and increased animal performance (Dineen *et al.*, 2018; Roca-Fernandez *et al.*, 2016). In addition, the inclusion of forbs (e.g. chicory and plantain) reduces the N load of urine patches, thereby reducing the risk of N leaching (Vibart *et al.*, 2016)
- reduced greenhouse gas (GHG) emissions. Plant diversity had a strong effect on reducing GHG emissions intensity in grazing based systems. Both Bracken *et al.* (2020) and Cummins *et al.* (2021) have observed similar DM yield from the 6-species mixture compared to a PRG monoculture while reducing N_2O emissions by 41% and 24%, respectively. Compared to PRG, a dairy calf to beef steer production system had a 15% lower carbon (C) foot print per kg of beef produced when animals grazed a 6 species MSS from turnout to slaughter via reduced fertiliser N application (90 vs 205 kg/ha/yr) and a reduced lifetime to slaughter (- 21 days)(Boland *et al.*, 2022).
- increased C sequestration. The presence of species with differing functional traits has been shown to increase both soil C and N accumulation over time (Cong *et al.*, 2014; Buzhdygan *et al.*, 2020) due to increased root biomass (Fornara and Tilman, 2008) and increased function of soil microbial communities (Lange *et al.*, 2015).
- increased climate tolerance. Altered precipitation patterns and rising atmospheric temperatures are expected to cause an increase in the frequency and intensity of adverse weather events with a strong negative effect on biomass yield of extensively and intensively managed grassland ecosystems. Under adverse climatic conditions, MSS have achieved higher (or at least equal) forage yield and frequently attain a similar yield to monocultures under normal climatic conditions (Hofer *et al.*, 2016; Finn *et al.*, 2018; Haughey *et al.*, 2018; Grange *et al.*, 2021; Jaramillo *et al.*, 2021; Grange *et al.*, 2022).
- enhanced weed suppression and a reduced reliance on herbicides. MSS are more stable against weed invasion (Connolly *et al.*, 2018)
- enhanced biodiversity. There is a pressing need to modify current farming practice to improve biodiversity and soil health and function. Diverse grassland swards can enhance agro-ecosystem biodiversity, increase soil health and function and facilitate greater agro-ecosystem stability, which is essential in the context of managing pressures from future climate and environmental change (Fox *et al.*, 2020; Shnel *et al.*, 2021).

The studies reported here outline some opportunities to enhance the resilience of Irish livestock based systems to both adapt to, and mitigate, climate change by increasing diversity in sown grasslands. In addition, increasing plant species diversity can also be an effective strategy to increase the flexibility of management options for farmers compared to monocultures thereby achieving a greater convergence of agronomic, economic and environmental benefits.

Looking to the Future

With growing interest in MSS, pressing practical questions include how best to integrate such mixtures into an existing farming system and how best to subsequently manage such swards. There is need for more longer-term research platforms to best inform these questions and enhance successful adoption of MSS through evidence-based advice. This will include learning to respond and manage variability in MSS. Equally, the multiple additional attributes of livestock based grazing systems such as the impacts on nutrient losses to water, carbon sequestration, gaseous emissions and biodiversity need to be considered more frequently in future research studies. There is an important role for improved plant breeding and field-testing for better mixture performance, with persistence and complementarity among key traits requiring further evaluation and taking cognisance of local soil, weather and enterprise types and the need for adaptation to the challenges of more changeable climate in the future (see Lüscher *et al.*, 2022). Finally, although Irish research is ongoing on the implementation of MSS, there is a need to learn faster and benefit from lessons outside of research farm settings with new projects required to evaluate the adoption and integration of MSS on commercial farms.

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What does grazing do for carbon sequestration?

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Abstract

To improve and maintain soil carbon storage under grasslands is challenging due to numerous interacting factors affecting soil processes and carbon inputs to soil. Among most important factors are initial state of soil C stocks associated with the land use history, the local climate and soil conditions, age and botanical composition (number and nature of grassland species), as well as agricultural practices. In recent years several reviews highlighted the importance of grassland management for soil carbon storage (e.g. Conant *et al.*, 2001, 2017), where some of them focussed especially on grazing effects alone or together with climate conditions (e.g. Abdalla *et al.* 2018; Byrnes *et al.*, 2018). Agricultural practices are an important lever to be mobilized; i.e. objective of the 4 per 1,000 initiative by 2050 (Minasny *et al.*, 2017). Increases in soil C stocks were reported between 5 and 30% due an improvement of grassland practices (e.g. Ogle *et al.*, 2004). The objective of this contribution, is to outline a quick overview of the literature on the effect of grazing/stocking systems on soil carbon and the trade-offs with grassland production in temperate EU grasslands.

Context

The synthesis of Conant *et al.* (2017) shows that improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation tend to lead to increased soil C, at rates ranging from 0.105 to more than 1 Mg C/ha/yr (see Figure 1; Bai and Cotrufo 2022). Likewise, a comparison between grazing and mowing regimes showed that under comparable biomass exports grazed systems tend to sequester more C, in particular when moderately fertilised (Liu *et al.*, 2014), and in biodiverse pastures (Teixeira *et al.*, 2011). On the subject of grazing management only a few papers provide practicable (i.e. technical) recommendations.

Background

In grasslands the degree of sequestered C is primarily influenced by the difference between C inputs, via fixation of C from the atmosphere by plants (photosynthesis), and heterotrophic respiration, biomass removal (harvest, grazing), and losses by lixiviation and run-off. In other words, by plant productivity and the frequency and extent of disturbance (i.e. grassland ploughing and renovation). In general, grasslands have a higher soil organic matter level than croplands because there are no periods with bare soil and soil disturbance. In addition to disturbance, the nature, frequency and intensity of biomass exports play a key role in the C cycling and balance of grasslands. Likewise, grassland ecosystems are often characterized by substantial stocks of C located largely below ground in roots and soil (Jones and Donnelly, 2004).

Grazing has a large direct impact on grassland productivity, plant community structure and biogeochemical cycling. Grazing effects are driven by plant tissue removal (defoliation), excretion (urine and dung deposits) and trampling, which exerts mechanical pressure and causes physical damage to the vegetation where animals pass repeatedly. In grazed grasslands, much of the primary production is ingested by animals and returned to the soil in the form of faeces (non-digestible carbon; 25 to 40% of the intake, depending on the digestibility of diet); the remainder is returned to the soil in the form of plant litter (ungrazed leaves and roots) or root exudates. Grazing management strategies can either positively or negatively affect grasslands through changes in N cycling, in primary production, and in C flows and sequestration.

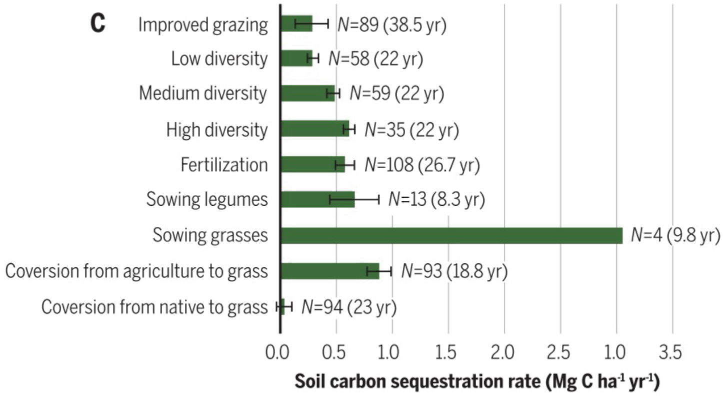

Figure 1. *Overview on impacts of improved management practices on SOC sequestration rate (mean ± standard error) by Bai and Cotrufo (2022). Number of studies (N) and the study duration (years) for each type of management*

Under medium to high grazing pressure, fast-growing, palatable species typical of nutrient-rich, managed grasslands have higher quality (lower C:N), promoting a rapid degradation by bacteria and thus short residence time of C in soil. Grasslands adapted to low grazing levels are generally characterized by slow-growing plant species and lower above-ground net primary productivity, a microbial community dominated by fungi, as well as greater N retention and C storage. Likewise, grazing animals promote spatial heterogeneity in CNP pools and fluxes via uneven patterns of defoliation and animal returns. Consequently, grazed grasslands can be considered as a mosaic of patches of variable vegetation height and feed quality, depending on the presence or absence of urine and dung.

Guidelines for good management practices (grazing strategies) on regional, national and global levels may significantly influence soil function (see Teague *et al.*, 2013; Hennessy *et al.*, 2018). Grazing guidelines and grazing management systems have been developed in many regions and countries across Europe and those guidelines and systems vary widely in terms of complexity and adaptability. Adopting good grazing management practices through the use of appropriate guidelines can optimise herbage production, as well as ecosystem services, including C sequestration (e.g. Mosier *et al.*, 2021; Sandermann *et al.*, 2015). Many different types of grazing systems exist in Europe ranging from simple to complex and involving a range of sward types ranging from single species swards to multispecies swards. In addition, grazing systems occur across a range of soil types and climatic conditions.

Grazing strategies

Grazing strategies have received increasing national and global interest as potential "climate-smart" tools for sequestering C and enhancing soil health more broadly (e.g. Derner *et al.*, 2016). Grazed grasslands act either as potential sinks or source of C, ranging from -1.3 to more than 1 t C/ha/yr storing on average 0.26 ± 0.07 t C/ha/yr (mean of 11 literature references, e.g. Conant *et al.*, 2017; Sandermann *et al.*, 2015; Abdalla *et al.*, 2017; Franzluebbers and Stuedemann, 2009). Though there is increasing knowledge how climate, soil characteristics, vegetation (i.e. species composition, presence/absence of C3 or C4 grasses, etc.) influence C sequestration. There is little information on the appropriate grazing management for specific regions regarding intensity of biomass removal, animal stocking densities and amount of biomass consumed with respect to production.

At the present, literature synthesis (see Pellerin *et al.*, 2019), provide evidence that under intense herbage use improved grazing management include; reduction in animal stocking rates, periodical removal of grazing livestock, and adjustment of grazing period (e.g. rotational or short duration grazing, seasonal grazing, etc.). Such adjustments can increase the C sink by 0.12 to 0.86 Mg C/ha/yr.

Effect of grazing management depend thus on regrowth intervals/rest periods, being the length of the rest period between defoliation events. The rotation length depends on a range of factors including time of year/weather conditions, feed demand, sward species and grazing system. Adequate levels of recovery between two defoliation events generally requires elongation of the apical meristem and a minimum number of leaves (3-leave rule). If grazing is too intense or the period between successive grazing's is too short, the amount of live leaf can be reduced in the way that light interception falls and growth/carbon capture is reduced. In addition, some species may need to set seed, establish a desired structure (i.e. such as roots, which represent an important C input to soil), or establish seedlings and other measure of "growth/regrowth".

The ideal rotation length allows the sward to regrow and renew following defoliation but should not be so long that a deterioration in sward structure occurs.

Concepts such as "adaptive grazing management" that includes varing recovery periods that may be a full growing season or more in some years, depending on weather, different levels of defoliation according to the season, and timing of defoliation and fertilisation. Adaptive multi-paddock grazing showed on average 13% (i.e. 9 Mg C/ha1) more soil C and 9% (i.e. 1 Mg N/ha) more soil N compared to the conventional grazing (Monsier *et al.*, 2020).

What constitutes low/medium/high grazing pressure, varies between locations and over time; the lower the pasture growth, the lower the grazing pressure or longer the period between grazing events, and vice versa (e.g. Figure 2, Richie *et al.*, 2020). Likewise, the relationship between C storage and herbage use (i.e. ratio between produced biomass and biomass removal by grazing), often increases until an optimum beyond which the storage of C decreases (threshold of ~ 50 to 70% of biomass removed) (Klumpp and Graux, 2020).

Continuous and rotational grazing/stocking systems. The C sequestration increases with animal stocking rate and has a comparable pattern depending on site fertilisation (i.e. two maximums) and grazing/stocking system. Both continuous and rotational grazing/stocking systems have thresholds where C sequestration increases and declines. For a rotational grazing/stocking system, this is with a higher stocking rate than a continuous grazing/stocking system (Ma *et al.*, 2019). A possible explanation for this, is that rotational grazing/stocking system might provide a high C-sequestration due to short grazing periods (defoliation events) with a high animal stocking rate, allowing vegetation to recover. In continuous grazed systems, animal social behaviour and patch grazing (attraction to previously-grazed, nutrient-rich vegetation patches), result in patchy vegetation (re)cover (Bloor *et al.*, 2021). For instance, sheep grazing results in a higher selection of legumes and dicotyledonous species in mixed grasslands compared to cattle. Whereas, the smaller excretal patches of sheep have a faster nutrient turnover and generate smaller-scale patchy spatial patterns compared with the excreta of larger herbivores. Accordingly, under comparable annual grazing pressure (LSU/ha/yr) continuous grazing might in lower C sequestration than short term grazing events (e.g. rotational grazing).

Other benefits

Good grazing practices are a win-win situation since grazed grasslands allow a better coupling of C and N cycles within vegetation, soil organic matter and soil microbial biomass (Lemaire *et al.*, 2015), that favours plant growth, health and biodiversity. Environmental friendly grazing constitutes a compromise among biomass production, C sequestration and emissions (Soussana and Lemaire, 2014) and may enhance quality-adjusted yield and revenues similarly to increasing fertilization and cutting frequency (Schraub *et al.*, 2020).

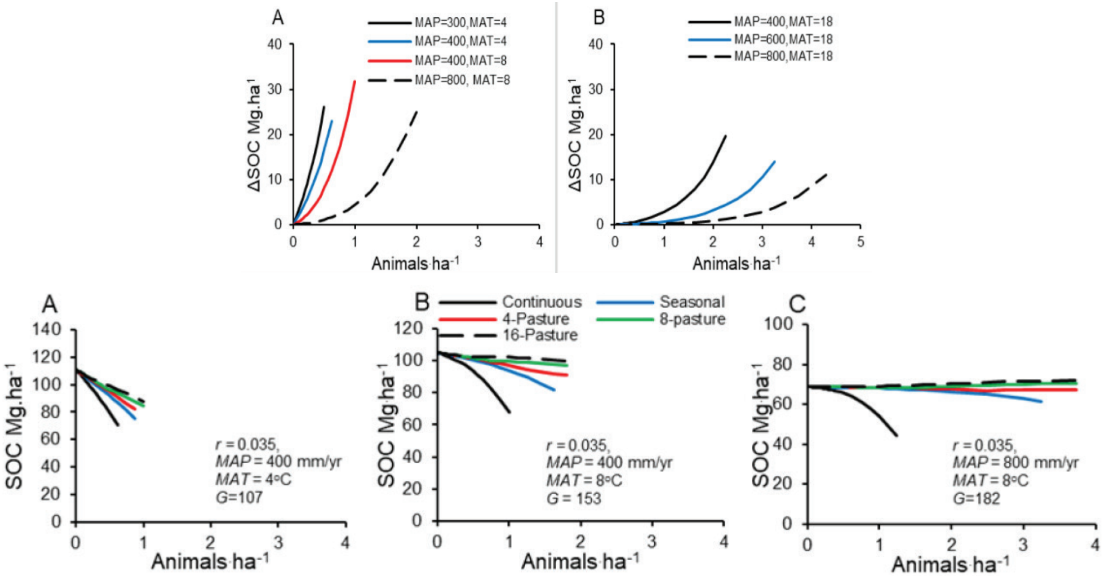

Figure 2. *Evolution of soil organic carbon (Mg/ha, to a depth of 30 cm for different for different grazing practices (multi-paddock grazing), and grazing days (G) of different climate zones (temperate conditions) (A-C). Relationship between stocking densities on soil organic carbon under different precipitation levels. Source: Ritchie (2020) Resources, 9, 49*

Trade-offs with other soil threats.

Grazing causes physical damage to the vegetation where animals pass repeatedly (Tate *et al.*, 2004). Accordingly, there are "bad effects" (risk of erosion, leaching) of grassland management related to high animal density combined with unfavourable climate conditions (i.e. dry and wet, respectively) and exposure (i.e. hilly lands). There are also trade-offs between production (biomass and livestock) and environmental services other than C sequestration, such as soil health and water quality (Soussana and Lemaire, 2014) and possible GHG emissions.

One are N_2O emissions and N losses at urine hotspots, which may become greater when soils are grazed under saturated soil water conditions (Schils *et al.*, 2012), or under short term rotational grazing events with high stocking densities; where more than 80% of biomass is removed in short grazing events.

Enteric CH_4 emissions related to feed production (i.e. grasslands and croplands) might be taken into account especially when an animal's diet is mixed, i.e. barn and occasional intense grazing. In these cases, grazing contributes to a nutrient returns N, P and C grassland stemming from feed not produced on the farm (i.e. nutrient decoupling of non-circular systems see Rumple *et al.* (2015)). Alike, grazing management has the capacity to modify enteric fermentation via changes in plant community composition in relation to grazing intensity; presence of legumes, leaf-to-stem ratio, and thus forage quality. For example, forage digestibility declines with an increase of stem in biomass (i.e. reduction in leaf-to-stem ratio) and across growth stages (vegetative, bud, flower); poor forage quality increases enteric CH_4 emissions. Feed processing such as drying, grinding are promising strategies to reduce enteric CH_4. There is a compromise between promoting animal production and promoting carbon sequestration (Soussana and Lemaire, 2014), and promoting the reduction in enteric CH_4, N_2O and C sequestration.

An application of decision rules based on climate impacts, sward composition, herbage quality and herbage mass targets are helpful to define grazing periods. Information on the nutritive value of forage quality by uses of phenological grass stages may help choose suitable grazing/harvesting times and stocking rates, try to achieve higher animal performance without vegetation damage and related decline in C sequestration potential, with subsequent increases in soil N_2O and enteric CH_4.

Climate Threats

Most grasslands are subject to marked seasonality of biomass production. Annual cycles of temperature or rainfall impose cycles of plant growth and phenology that result in cycles of biomass abundance and quality. Accordingly, un-normal climate events whose occurrence and magnitude you do not know are difficult to adapt to. The best strategy is to act with foresight and incorporate the risk into the grassland management, e.g. sward diversification. Some grass species can recover more easily than others from drought.

Species-poor, intensively managed temporary grassland is less resistant to drought and temperature fluctuations compared to semi-natural, more diverse grassland. A perennial vegetation dominated by grasses but also containing a proportion of dicotyledonous plants, including legumes, recovers from severe drought in periods ranging from a few weeks to several years.

Different root depths allow plants to use different soil layers over the seasons, some species can even compensate for the poor performance of others (Hernandez and Picon-Cochard, 2016). The combination of different species, e.g. very productive species that only produce over a short period of time might be a key factor in drought resilience.

Cocksfoot controls water loss well and shows good recovery after rainfall Dicotyledons with strong taproots, such as some yellow corms or chicory are able use deep soil moisture.

Some species such as lucerne, tall fescue, are well adapted to deep soils. Other ways may be the combination of fields differing in productivity (e.g. early meadows, late phenological stages, …different altitudes, that are less affected by drought and ensure later production).

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Where to next? Role of additional species in grass-white clover swards - production and environmental benefits

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Introduction (to the past)

Before attempting to foresee the future, it is essential to understand the present and often prudent to comprehend the past. In the mid-17th century, reseeding was pragmatically aimed at reproducing the most productive native meadows in hope of gaining new swards of equal performance. By the 18th century, however, simple mixtures of 'rye-grass', white clover (WC) and birdsfoot trefoil were sown in rotational leys. Come the 19th century, Sinclair (Woburn Abbey) was advocating complex species (Sp) mixtures again, with Elliot (Clifton Park) conducting possibly the first substantive agri-science studies. His first mixtures (Elliot, 1898) were complex compilations of common grasses, plus legumes (alsike, red/ and white clovers, kidney vetch and lucerne) and deep-rooting herbs (burnet, chicory, field parsnip, ribgrass/plantain, sheep's parsley, vetch, yarrow), (Table 1: later examples).

Table 1. Example 'Clifton Park' and 'Cockle Park' seed mixture compilations

Table 1. Example 'Clifton Park' and 'Cockle Park' seed mixture compilations

Clifton Park (c.1943) Light Land Mixture		**Clifton Park** (c.1943) Soil Permeating Mixture		**Cockle Park** (current) 4-5 year Mixture	
GRASSES 53%		**GRASSES 59%**		**GRASSES 92%**	
Cocksfoot	21.3%	Cocksfoot	20.6%	PRG Early Dip	9.6%
Crested Dogstail	2.1%	Golden Oat Grass	1.0%	PRG Inter Tet	28.8%
Golden Oat Grass	2.1%	Hard Fescue	2.1%	PRG Late Dip	15.4%
Hard Fescue	4.3%	Italian Ryegrass	6.2%	PRG Late Tet	19.2%
Rough-stalked M. G.	2.1%	Meadow Fescue	10.3%	Cocksfoot	7.7%
Tall Fescue	10.6%	Rough-stalked M. G.	2.1%	Meadow Fescue	7.7%
Tall Oat Grass	10.6%	Smooth-stalked M.	2.1%	Timothy	3.8%
		Tall Fescue	8.2%	PRG = perennial ryegrass	
		Tall Oat Grass	6.2%	(PRG Tet = 48% of total)	
LEGUMES 17%		**LEGUMES 15%**		**LEGUMES 8%**	
Alsike Clover	2.1%	Alsike Clover	2.1%	Red Clover	3.8%
Kidney Vetch	6.4%	Kidney Vetch	5.2%	White Clover	3.8%
Red Clover (late)	4.3%	Red Clover (late)	4.1%		
White Clover	4.3%	White Clover	4.1%		
HERBS 30%		**HERBS 26%**			
Burnet	17.0%	Burnet	16.5%		
Chicory	8.5%	Chicory	6.2%		
Sheep's Parsley	2.1%	Sheep's Parsley	2.1%		
Yarrow	2.1%	Yarrow	1.0%		
Total 47 lbs/ac (c.21 kg/ac)		**Total 48 lbs/ac** (c.22kg/ac)		**Total 14 kg/ac** (c.31lb/ac)	

After further agronomic and persistence studies, the majority of these species were discarded for simpler designs as in Gilchrist's 'Cockle Park' mixes (Pawson, 1947), (Table 1: modern example). He also focused on variation in strains within species, which led to Stapleton's (Aberystwyth) ryegrass/WC breeding programme that Germinal Horizon continues today. From this grew the current breeding industry where the attributes of a few grasses and clovers have been greatly enhanced through breeding pipelines of new varieties. Each species is bred for specific conditions or management systems. From this came simple special-purpose mixtures of cocksfoot for dry regions, Timothy for wet or peaty land and ryegrass for good fertile soils, with white or red clover added for a wide range of uses.

The Present (perennial ryegrass/white clover; PRG/WC)

Currently, PRG is king in Ireland and until the recent surge in energy prices and Climate Change issues, relatively cheap mineral N fertilizer was the main production driver, even if WC was sown. More recently, Teagasc research has set high-level benchmarks for efficient, profitable grassland farming. PastureBase Ireland (PBI) farms, average just over 11 t DM/ha/year with a range of 8-16 t DM/ha/year, with an average utilisation target of 10 t DM/ha/year (Teagasc Grass10, 2017-2020) and an upper 12 t DM/ha/year goal. This is to support beef live weight gain (LWG) of 0.9 - 1.0 kg/day for a 300-550 kg animal and 1.2-1.5 kg/day for a 600 kg+ animal. For lowland lactating ewes the dry matter intake (DMI) target is 2.4 kg DM/day and LWG of 0.90 kg DM/day for lambs, for a carcass yield of c.280 kg/ha from grass. The dairy target is 5,000 L of milk from c.80% forage DM, of which c.75% is grazed. Recent energy price rises and environmental priorities have reinvigorated interest in WC and again Teagasc has defined the performance standards. To gain full benefits requires precision sward management to maintain a seasonal average content between 20-30% WC and a sward management strategy to offset the almost linear decline in fixation as applied fertiliser N rises (Figure 1).

As reviewed by Dineen *et al.* (2018), adding WC can raise milk yield and solids by 1.4 and 0.12 kg/cow, respectively, and although the 0.25 cows/ha lower stocking rate means output per ha is unchanged, these gains require 81 kg/ha less N fertilizer. This enhanced output is driven by a 10% higher crude protein (CP) and 13% less NDF and 4.5% less ADF. By adjusting stocking rates or rotation length and grazing to 1,400 -1,600 kg DM/ha (above 4 cm), the grass competition at higher N rates is offset, to deliver a higher yield per unit of N applied. Likewise, there is Irish evidence of up to 10% more LWG in cattle, 20% more milk from dairy cows and 25% more LWG in lambs (AFBI, 2018). Recent Teagasc research has confirmed these potential benefits, showing that at 150 kg N/ha/year, PRG/23% WC swards grew 13.4 t DM/ha, equalling grass alone at 250 kg N/ha/year (Hennessy *et al.*, 2022). In addition, milk/cow was 6% higher (6,466 kg/cow) with 7% more milk solids (493 kg/cow) and this increased N use efficiency by c.50% (from 37% to 55%). The associated CH_4 reductions were 12% per kg feed intake from PRG/>20-26%WC (vs PRG only), even up to 260 kg N/ha/year (Enriquez-Hidalgo *et al.*, 2014), but not if WC content falls (PRG/<21%WC at 150 kg N/ha/year, Fitzpatrick, Pers. Comm.). Grassland soils are also important carbon (C) sinks, storing c.0.35 Mg C/ha/year (35 g/cm/year) in 0-15 cm, able to offset 9-25% of GHG from an intensive system, (Fornara *et al.*, 2016). As a five-year reseeding cycle has a 50% higher carbon loss than a ten-year cycle (21 v's 14 Mg C/ha, respectively; Reinsch, 2018), the importance of PRG/WC perennialism is confirmed. It is against these PRG/WC benchmarks that novel species must be judged (not PRG alone).

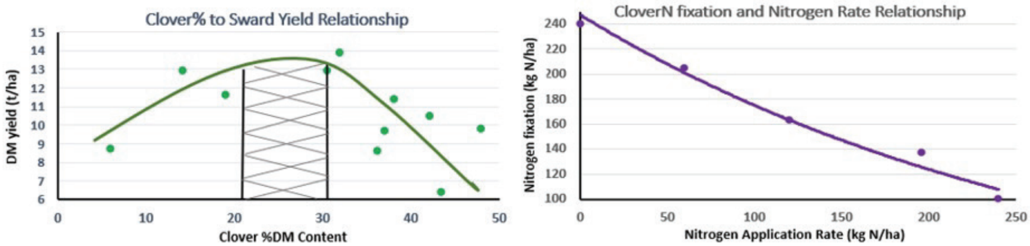

Figure 1. *Where clover production and N fixation relationships (modified Teagasc/AFBI data, 2022)*

Additional Species (the evidence)

Inflationary fertilizer costs and GHG issues are driving a revived interest in a wider range of herbage species. Initially this was created by EU-wide research (e.g. MultiSward, 2010, www.multisward.eu) but has subsequently been promoted by early adopter farmers, with researchers catching up. The perceived species benefits include greater drought tolerance for some grasses and several herb species, through deeper rooting (e.g. cocksfoot, tall fescue, chicory, plantain) and a different nutrient balance to PRG. Generally, herbs have a higher proportion of I and Se (soil/livestock deficiency risk), with high proportions of Ca, Fe and Mg in plantain (Raeside *et al.*, 2017a) and Cu, Co, Zn and Fe in legumes (Darch *et al.*, 2020a). Chicory and plantain have lower crude protein (171 and 191 g/kg DM, respectively) and a higher metabolisable energy (ME) than PRG (207 g/kg DM; Minnee *et al.*, 2017) and lower neutral (NDF) and acid (ADF) detergent fibre fractions (rises if plant stems develop; Rodriguez *et al.*, 2020). Grasses are highest in Mn, legumes (including WC) have higher CP and also lower NDF/ADF, while PRG has a higher water-soluble carbohydrate content than plantain, lucerne and WC (Raeside *et al.*, 2017a; Buxton and O'Kiely, 2003). Finally, grass DM% is consistently +7-8% higher than chicory and plantain (Minneé *et al.*, 2017), +3% greater than RC (Clavin *et al.*, 2017), but PRG/WC is similar to pure PRG.

The desire to fuse all these attributes into a multi-species sward (MSS) creates a push for complexity. In seeking superior productivity, nutritional value, climatic tolerance and biodiversity, some MSS now on farms are Clifton Park spin-offs (Table 2). Mix A is a high diversity MSS, comprising three functional groups (Grass/Legume/Herb: G/L/H) each in sizeable proportions, but several species are in such small amounts that a substantive contribution to the final sward is questionable. Even if adjusted for seed number, the fact that some are annual or short-lived limits their contribution, in comparison to a long term PRG/WC sward. Conversely, less complexity indicates a specific purpose for each component, as in Mix B, though the reason for the very low red clover seed number, the 50% plantain:chicory difference and a much higher Timothy seed number than normal practice, needs justification. Species with certain attributes can be used in mixtures designed to address limiting growing conditions (Mix C) or livestock health issues (Mix D) but must persist through the life of the sward. Even so, Haughey *et al.* (2018) and Woodward *et al.* (2013) report that yield stability is greater when species richness is high.

A body of scientific evidence is now building, as reviewed by Patterson (2022). Overall, MSS biomass yields in Ireland have been reported at 11.8 t DM/ha/year for a 6Sp MSS (Grange *et al.*, 2021) and 11.7 t DM/ha/year for a 5Sp mix (Moloney *et al.*, 2020), which equates to the PBI average for higher-N fed PRG swards. Individual on-farm reports from early adopters have exceeded these levels. Indeed, Finn *et al.* (2013), found that on average across 1 Canadian and 30 European sites, G/L mixtures exceeded the yield of the best monoculture by c.70% (1.18 transgressive overyielding) in conservation swards. The grass and legume species reflected each region's best adapted types but indicated improved resource complementarity overall and a robustness across a considerable range in conditions and proportions. Notably, Jing (2017) recorded higher OMD, NDF and CP and less ash for G/RC/WC compared to 10Sp - 12Sp MSS.

Table 2. Example Multi-species mixtures currently on farms in Ireland (% values = seed weight)

Mix A: Seventeen Species Mix. 10 kg/ac
Grass 49% • Legume 33.5% • Herb 17.5%

Grasses:	Legumes:	Herbs:
Perennial Ryegrass (tetraploid))-12%	Alsike Clover-1.5%	Plantain-1%
Perennial Ryegrass (diploid)-5%	Red Clover-5%	Chicory-4.5%
Cocksfoot-12%	Sweet Clover-4%	Burnet-7%
Timothy-11%	Vetch-2%	Yarrow-1%
Meadow Fescue-5%	Birdsfoot Trefoil-3%	Sheeps Parsley-4%
Tall Fescue-4%	Sainfoin-18%	(Wildflower: Knapweed -0.1%)

Mix B: Six Species Mix. 14 kg/ac
Grass 65% • Legume 15% • Herb 20%

Grasses:	Seed number ratio:
Perennial Ryegrass-55%	PRG-33%
Timothy-10%	Timothy-35%
	Red Clover-4%
	White Clover-14%

Legumes:	Herbs:
Red Clover-7%	Plantain-10%
White Clover-8%	Chicory-10%
	Plantain-6%
	Chicory-9%

Mix C: Drought Resistant Mix. 10 kg/ac
Grass 61.3%/Legume 22.2%/Herb 16.6%

Grasses:	Legumes:	Herbs:
Cocksfoot-39%	Red Clover-8.9%	Plantain-8.8%
Meadow Fescue-13%	White Clover-12%	Chicory-4.7%
Timothy-5.7%	Sainfoin -1.3%	Burnet-1.4%
Perennial Ryegrass-3.6%		Yarrow-0.3%
		Sheeps Parsley-1.4%

Mix D: Worming Mix. 15.5 kg/ac
Grass 19.4%/Legume 72.9%/Herb 7.7%

Grasses:	Legumes:	Herbs:
Meadow Fescue-12.9%	Sainfoin -64.5%	Plantain-3.2%
Timothy-6.5%	Birdsfoot Trefoil-8.4%	Chicory-4.5%

The evidence for stress resilience is more consistent. Grange *et al.* (2021) found that by using rainout shelters, a 6Sp (G/L/H) MSS+150 kg N/ha, had similar yields under drought to both the best-performing monoculture and a rainfed PRG+300 kg N/ha. When rainfed, the most diverse MSS outyielded the best monoculture and PRG, though a comparison with PRG/WC+150 kg N/ha was reported. As carbon sequestration needs 4-5+ years to build measurable changes there is limited research validation of early reports that deeper rooting herbs capture more carbon and impact soil structure long-term.

For livestock responses, a McCarthy *et al.* (2020) review showed evidence of an overall increase in daily milk yield (+1.20 kg/day, or +1.30 kg/day, energy corrected), and combined fat and protein (+0.06 kg/day) in dairy cattle grazing G/L/H MSS versus pure PRG, but with no change in DMI or urinary N excretion. Roca-Fernández *et al.* (2016), reported lower DM%, organic matter and NDF plus higher DM intake (+1.5 kg DM/day), milk yield (+0.8 kg/day) and milk solids (+0.04 kg/day) from G/L/H MSS compared to a G/L mixture. Mangwe (2019) found that cows grazing pure chicory or plantain had higher DM intake (17.7 kg/cow/day) and milk-solids yield (1.93 kg/cow/day), than those grazing PRG/WC (15.6 and 1.65 kg/cow/day). Boland Pers. Comm. reports that when grazing G/L/H MSS, lamb weaning weight rose by 2.5-4.0 kg/lamb, reaching slaughter weight 2-4 weeks earlier, with a 50% less need for anthelmintics. Likewise, dairy beef steers increased growth by 15-20%, and finished sooner. Benefits beyond PRG/WC are not always clearly evident. Raeside *et al.* (2017b), found no advantage for mixtures versus PRG/WC, Grace *et al.* (2019) found some gains for MSS containing herbs during lamb growth, including a need for fewer anthelmintic treatments, but no final change in average daily weight gain from birth to slaughter, and no improvement in slaughter weight or kill out percentage. They also reported that 6S and 9S MSS swards produced similar annual herbage DM to PRG/WC under intensive sheep grazing and, like Grace *et al.* (2018), the herbs (chicory/plantain/yarrow) declined substantially within two years. This may partly explain why researchers report evidence that increasing species complexity increases yield (Goh and Bruce, 2005; Kirwan *et al.*, 2007) and others do not (e.g. Nyfeler *et al.*, 2009; Patton *et al.*, 2022). None report progressive increases along a series of e.g. 6Sp-12Sp-17Sp MSS and PRG/WC is not always the base comparator. Possibly of relevance is the report of Moloney *et al.* (2020) that without inorganic N fertiliser application the largest yield increase from G to G/L to G/L/H MSS was from the inclusion of N-fixing legumes, with only a small additional benefit associated with the third functional group (herb).

Environmental benefits include evidence from Cummins *et al.* (2021) that a 6Sp (G/L/H) MSS emitted 41% less N_2O/kg DM than pure PRG and as clover added extra N it had a higher emission value. Luo *et al.* (2018) found lower soil N_2O emissions from plantain than PRG or WC in autumn and winter after applying cow urine but not in summer (lucerne only lower in winter). Humphries *et al.* (2021a) achieved significant reductions in CH_4 emissions of Angus × Holstein and Holstein steers grazing three MSS (c.120 g/day; c.18 g/kg DMI) compared to those on PRG (190 g/day; 25.9 g/kg DMI), while Niderkorn *et al.* (2019) reported a 22% reduction, but only versus PRG. Importantly, WC also contains condensed tannins, shown to reduce CH_4 emissions in rumen fluid by up to 19.4% (Roldan *et al.*, 2022). Hence, when Loza *et al.* (2021a) compared CH_4 emissions of grazing Jersey cows on a 6Sp MSS, containing tannin-rich birdsfoot trefoil and burnet, they were 11% higher than those on PRG/WC, possibly because the herbs only made a minor contribution to herbage yields. Notably, they further reported CH_4 reductions up to 33%, with consistent species ranking (chicory highest), where the partner species in PRG/L or PRG/H mixes was at 67.5%, but was associated with lower forage digestibility (Loza *et al.* 2021b). Curiously, linear increases in L/H content did not give linear CH_4 responses. When fed as a pure diet, the diuretic effect of plantain reduced the urinary urea concentration of dairy cows by 48-62% compared to a pure PRG (Marshall *et al,* 2021). Similarly, when compared to a PRG/WC diet, Mangwe *et al.* (2019) reported a greater frequency of urination and lower urinary N concentration in dairy cows grazing chicory. Cheng *et al.* (2015) also found an increased frequency but not the concentration changes on a 50-100% chicory diet.

The Future (MSS or not?)

A comprehensive review of PRG/WC versus MSS was not possible in this short paper and biodiversity/ecosystem services that can justify complex MSS were not considered. Agronomically, a number of headline gains are reported, primarily MSS overyielding, enhanced animal performances, GHG reductions and climatic tolerance, some of which are supported by on-farm, early-adopter, reports (e.g. ARCZero, 2022). However, major agronomic instability concerns exist. Firstly, in line with seed merchant guidance, van

Barneveld (2019) found the herb content to fall to 10% or less after 3-4 years. Given that ploughing can emit carbon loses of 16-32 Mg C/ha (Necpálová *et al.*, 2013, Linsler *et al.*, 2017), a 10 yr reseeding cycle is the aim. Minimal-tillage/renovation methods can reduce losses while reinstating a single herb species (Raedts and Langworthy, 2020), but not to reconstruct a complex MSS. Secondly, the advice of longer rotations and more lax grazing (e.g. 5-10 cm defoliation/3 wk spring rotation and 5 wk summer/autumn rotations (Li *et al.*, 1997; Li and Kemp, 2005) and avoiding grazing heavy wet soils to reduce tap-root damage, is not best practice for optimising animal performance on PRG/WC swards. Thirdly, the inconsistency in the published delivery of MSS benefits versus PRG/WC is a likely symptom of MSS instability. Notably many published benefits are, as yet, only in years 1-3.

It seems likely that the future of MSS in Ireland will repeat history as good science replaces complexity for simplification. Clearly, research must take a focused approach, using optimally managed PRG/WC as the base comparator. For applied studies, the inclusion of a herb (or grass species change) must: A) include only species with benefits for that agronomic need/stress; B) use sufficiently high inclusion rates to contribute substantively; C) use mutually tolerant perennial species to gain stability over time. More basic research is also greatly required to study for mechanisms behind the reports of overyielding and inflationary animal performances from complex MSS. This work needs to determine if soil structure changes from deeper rooting boosts forage productivity; whether there are complementary interactions between functional groups above and below ground; whether these mixed diets are more optimal for rumen function; and whether the different micronutrient balances and condensed tannins are driving excess animal performances. Alternatives, such as reducing N rates and adding a balancing micronutrient fertilizer to give the same, but highly reliable yield responses (e.g. Micro-Match, 2022) also needs examination. Likewise, new opportunities to breed WC with higher tannin content (Caradus *et al.*, 2022), and so achieve similar benefits from a longer term, more sustainable platform, needs equal research investment.

Conclusion (foresight)

The blunderbuss approach where MSS are expected to do everything as they contain a little bit of everything is currently hard to vindicate scientifically. At present, therefore, given the extensive and definitive research evidence, the majority of Irish farmers on good organic soils with good grass growth potential, should optimise PRG/WC as their priority. Where there is a specific agronomic issue causing an acutely sub-optimal sward performance, then adding a herb or using a resilient grass, is possibly worth trying out. This paper began by claiming that an understanding of the past is valuable when plotting future paths. Interestingly, in 1941, Stapleton concluded that "even to this day there are adherents to the idea that the more species which are included in the seeds mixture, the better the resultant sward". His concern was "that only a few of the main species settle down and become real contributors to the sward, no matter how complex the mixture". As science evidence builds this wisdom appears to endure for agronomic goals. At present, most Irish swards will likely still have a PRG/WC core, designed for specific managements and conditions, and herbs added only if able to cure a specific issue. As Climate Change intensifies or if research studies show complexity in MSS creates stable 'over performances', "the more species the better the sward" may even become a proven fact.

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The agronomy and feeding value of red clover silage

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Abstract

Forage legumes, such as red clover (RC), can contribute substantially to organic, low-input and conventional animal production systems due to their ability to fix atmospheric N, reducing the system's reliance on chemical N fertilizer. Typically, RC is suited to silage production as frequent grazing can reduce its persistency. A number of studies have demonstrated the ability of RC grass silage (RCGS) swards receiving low or no chemical N fertilizer to achieve similar dry matter production to grass silage (GS) swards receiving >400 kg of chemical N fertilizer/ha annually. Animal performance is generally increased when animals consume RCGS compared with GS, primarily due to increased dry matter intake potential. Animal nitrogen-use-efficiency (NUE) is similar when consuming RCGS; however, some studies have observed a slight reduction in NUE. There is an opportunity to increase the NUE of animals consuming RCGS-based diets through understanding the role of polyphenol oxidase and protein-bound phenols, which are elevated when red clover silage (RCS) is fed. Current research is investigating the suitability of RCGS within pasture-based production systems and how to optimize its use.

Introduction

Given the increasing need to improve farm gate nitrogen (N) balance RC can offer significant benefits to Irish ruminant production systems, while enhancing economic and environmental efficiency. Improved N balance can be achieved through RC's biological N fixation ability and through its capacity to support higher animal performance. Swards with a high content of RC (75% on a dry matter (DM) basis) are capable of fixing 24-36 kg N/t DM produced (Peoples and Baldock, 2001; Peeters *et al.*, 2006), meaning swards of high clover proportion and DM production are potentially fixing in excess of 200 kg N/ha annually. The inclusion of RC in conserved GS swards can increase milk production and average daily live weight gain (ADG) compared to GS diets. Across 11 studies comparing the performance of dairy cows offered RCGS or GS, the inclusion of RC was found to significantly increase daily dry matter intake (DMI) by 1.2 kg and milk production by 1.4 kg (Steinshamn, 2010). Similarly, beef cattle offered RCGS were found to have an ADG of 1.04 kg, compared to GS which supported an ADG of 0.59 kg. Despite the many benefits of RC inclusion, it has had limited uptake on pasture-based production systems in Ireland. The poor uptake of RC is likely due to its more complex management requirements, unsuitability to frequent grazing, reduced DM yield stability and persistence giving a short term lifespan of approximately 3-4 years.

Agronomy

The breeding goals for RC varieties targeted to Irish producers is for improved DM production and persistence. Red clover varieties differ in their DM production potential and persistence under frequent cutting, with newer varieties offering improved persistence through better DM yield stability and plant survival over multiple harvest years (Marshall *et al.*, 2017). Unlike for perennial ryegrass (PRG) and white clover varieties, no Recommended List currently exists for RC varieties in Ireland, with Irish producers relying on information from the UK Recommended/National List (BSPB, 2022) to identify suitable varieties. Similar to PRG, RC varieties are categorised by heading date (early or late) and ploidy level (diploid or tetraploid). Early heading varieties typically flower 1-2 weeks sooner than late heading varieties while providing more vigorous regrowth and stable yields in a multi-cut system. Late heading varieties produce most of their annual yield in the first cut, with less vigorous regrowth than early varieties thereafter; however, late varieties store more energy reserves in their root system (Vleugels, 2013) and have increased growing points (Frame *et al.*, 1998) from the plant crown which contribute to improved persistence. Tetraploid varieties tend to be higher yielding, more disease resistant and persistent than diploid varieties (Frame *et al.*, 1998).

Red clover should be grown in rotation, allowing for a four year break to control diseases such as stem eelworm and Sclerotinia fungus (clover rot). Within Irish ruminant production systems this can be achieved by sowing RC with PRG varieties ranked highly on the Pasture Profit Index (PPI) and white clover, which will remain productive beyond the lifespan of RC. Typically 7.5 to 10 kg/ha of RC in addition to 20 to 22 kg/ha of PRG should be sown on well drained soils with a soil pH of 6.5 to 7. Depending on soil moisture and temperature, seedbed preparation and sowing, establishment may be slow but not necessarily a failure. Spring reseeds offer the greatest window of opportunity to optimise pre and post-sowing management.

Unlike white clover which has a stoloniferous growth habit, RC typically has a deep taproot, an erect growth habit, with larger shoots and a lower shoot density (Frame *et al.*, 1998). Stems are formed from the growing points located on the crown on top of the taproot. Reserves of carbohydrates and N are stored in the crown and taproot, where they are remobilised to fuel regrowth after defoliation. The crown/growing point of RC is solitary and exposed, making it vulnerable to physical damage by machinery and animals. This means that RC is less suitable to frequent and intensive grazing and is established more often as a silage crop; however, RC varieties with a more prostrate and stoloniferous growth habit have been developed for improved grazing tolerance (McKenna *et al.*, 2018). The morphology and physiology of RC make it best suited to silage making, with infrequent cuts which minimise damage to the crown and allow sufficient cutting intervals (6-8 weeks) for the canopy to intercept sunlight to replenish carbohydrate reserves (Black *et al.*, 2009). Red clover swards generally persist for 3-4 years under a multi-cut system, although well managed swards can persist somewhat longer (Clavin *et al.*, 2017).

Red clover swards have the ability to fix high levels of atmospheric N, making it available to plants in the soil, supplying in excess of 200 kg N/ha annually. Mixed RC and PRG swards receiving no chemical N were found to have similar annual DM production to PRG swards receiving up to 412 kg N/ha per year (Clavin *et al.*, 2017). The application of chemical N fertilizer to RC and PRG swards has antagonistic effects reducing the proportion of RC in the sward, annual DM production and persistence. A single application of chemical N fertilizer in March (50 kg N/ha) to mixed RC and PRG swards was found to reduce RC proportion by 13%, likely causing a lesser amount of atmospheric N fixation and lower annual yield (Clavin *et al.*, 2017). Red clover is best suited to a three cut silage system, with the first cut being harvested by mid-late May, which promotes higher clover proportions and DM production for the remainder of the growing season. Increasing the defoliation frequency beyond three cuts can reduce DM yield (Sheldrick *et al.*, 1986) due to insufficient replenishment of plant reserves and persistence. Due to the high buffering capacity of RC silages, 'late' silage harvests can also be difficult to ensile (insufficient wilting) and are of relatively low yield (Frame *et al.*, 1998) making it difficult to justify economically. To protect the crown of RC cutting height should be increased to 7 – 8 cm, compared to GS generally harvested at 5 cm. To increase DM concentration to 25-35%, RCGS generally requires wilting in dry conditions for 24 to 48 hours, while ensuring that the leaf is not damaged (shattered) as a result of over wilting and excessive machinery passes, including tedding and raking. Red clover has a lower water soluble carbohydrate concertation further reducing its ensilability therefore, the inclusion of PRG as a companion species will improve the overall ensilability of RCGS.

Feed value

For some time animals consuming mixtures of RCGS are known to have an increased DMI potential when compared with animals consuming GS (Castle and Watson, 1974; Steinshamn, 2010; Johansen *et al.*, 2018). As GS is substituted with RCS the digestibility of dry matter, organic matter and neutral detergent fibre (NDF) reduces (Moorby *et al.*, 2009; Johnston *et al.*, 2020), which is counter intuitive to the increased DMI. The reduced digestibility is likely due to RC's erect growth habit resulting in the harvesting of a substantial amount of stem material. While RCS is typically lower in NDF, it has been demonstrated to contain a greater ratio of indigestible NDF to NDF, than grass-silage (0.27 vs. 0.19, respectively; Halmenmies-Beauchet-Filleau *et al.*, 2014). While the extent of digestion is reduced for RCGS when compared with GS, the rate of digestion of the potentially digestible NDF is faster (Kuoppala *et al.*, 2009). Combined with legumes typical behaviour to break into smaller particles in the rumen, this likely increases the rate of passage of RCGS leading to lower rumen or physical fill (Dewhurst *et al.*, 2003a; Kuoppala *et al.*, 2009). These cell wall digestion characteristics and plant morphology attributes are the primary mechanisms hypothesised to lead to the increased DMI.

Dietary N concentration, and correspondingly N intake, are important considerations when the objective is to optimise NUE and reduce N pollution. Dietary N concentration is generally increased with higher inclusion levels of RCS (Halmenmies-Beauchet-Filleau *et al.*, 2014; Lee *et al.*, 2019); however, some studies have shown no difference in N concentration (Moorby *et al.*, 2009). Many factors may influence dietary N concentration such as RC content, harvest/cut date, maturity and chemical fertilizer application level. Despite the increase in N intake, substituting GS with RCS has generally been shown to have no effect or only slightly reduces the NUE of lactating dairy cows (Dewhurst *et al.*, 2003b; Moorby *et al.*, 2009). This is likely due to lower degradability of RCS proteins, both in the silo and the rumen, which has been associated with polyphenol oxidase (PPO) and the protection of plant proteins it offers through the formation of protein-bound phenols (PBP; Lee *et al.*, 2019). These PBP have been suggested to reduce protein solubility and degradability resulting in reduced rumen ammonia-N release and a greater partitioning of excreted N into the faeces rather than the urine. Environmentally, this is more favourable as faecal N is converted to NH_3 less rapidly than urinary N increasing the probability of the N remaining in the soil. The formation of these PBP have also been suggested to alter the supply of metabolisable protein, increasing the contribution of undegraded feed and endogenous proteins while reducing the contribution of microbial protein (Vanhatalo *et al.*, 2009). Furthermore, PPO has been implicated in reducing plant mediated lipolysis in the silo and the biohydrogentation of C18 poly-unsaturated fatty acids (PUFA) in the rumen leading to increased levels of health promoting fatty acids in meat and milk (i.e. the n-3 fatty acid α-linolenic acid). In an effort to increase NUE and further improve the fatty acid profile of ruminant livestock products when RCGS is fed, Lee *et al.* (2019) compared two RC silages with low and high levels of PPO. The authors only observed small differences in N metabolism and C18 PUFA biohydrogenation suggesting that perhaps phenolic substrate supply and enzyme activity driving protein complexity may be the primary factors involved in protein protection rather than PPO concentrations. Further research is required to understand the mechanisms involved.

While reduced feed protein ruminal degradation is typically favourable, it is possible that the proteins could be over protected and reduce digestibility at the small intestine. This may specifically be the case for the sulphur containing amino acids (i.e. methionine and cysteine) which are likely to be phenol binding sites. Johansen *et al.* (2018) suggested that reduced bioavailability and plasma concentrations of methionine may explain the reduced milk protein concentration observed in their review of cows fed RCS when compared with GS. Vanhatalo *et al.* (2009) also observed an imbalance in the AA profile of digesta flowing out of the rumen. The outcome of reduced milk protein concentration has also been observed for milk fat concentration when cows are fed RCS (Steinshamn, 2010; Johansen *et al.*, 2018). The reduced milk fat concentration may be due to biohydrogenation intermediates escaping the rumen or increased supply of preformed fatty acids, which both inhibit de novo synthesis of milk fatty acids in the mammary gland. Nevertheless, the higher DMI achieved when cows consume RCGS compared with GS leads to increased animal performance despite the reduction in milk protein and fat concentrations. Future research is needed to develop strategies to overcome these reduced concentrations and further enhance animal performance when RCS is fed. Finally, RC contains favourable levels of magnesium and calcium in relation to potassium when compared with grasses (Frankow-Lindberg, 2017). Phosphorus concentrations can be low and it is important to consider when feeding cows in late pregnancy to reduce their risk of milk fever.

Current research

A new Teagasc research project is underway to investigate the suitability of RCGS within beef and dairy pasture-based systems. The project will undertake plot-scale studies, novel feed chemistry analysis, animal experiments and environmental emissions modelling to quantify the yield, persistency, animal production efficiency and environmental footprint of RCGS-based diets. The project also aims to identify the category of animal that can maximise the potential of RCGS (e.g. beef animals within the first winter or finishing period or weanling heifers in their first winter period). The effect of RCGS-based diets on milk and beef composition and functionality will also be investigated.

Conclusion

The inclusion of red clover into silage swards has potential across Irish pasture-based production systems of all intensities. These swards have an enhanced ability over grass only swards to maintain high levels of herbage DM production and animal performance from significantly lower levels of chemical N fertilizer. The use of red clover when combined with a range of other management and animal breeding technologies can future proof ruminant systems by enhancing N balance and ultimately economic and environmental efficiency. More research focus is required to identify optimum managements to successfully grow stable yields of red clover-grass silage in Ireland and to further understand the complex plant chemical and morphological characters which are believed to influence dry matter intake and animal performance potential.

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On-farm clover establishment and performance

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Abstract

An on-farm white clover programme, 'Clover150', was launched in 2021 with 36 grassland farmers from across the country participating. The aim of the programme is to successfully established a 20% clover sward on-farm, reduce chemical fertiliser use to <150 kg N/ha/year and reduce N surplus (to <130 kg N/ha/year), while maintaining herbage production. White clover was established on-farm by reseeding and over-sowing during the past two years. Clover content was assessed three times per year, with individual management guidelines (fertiliser and grazing) provided to farmers after each assessment. Average sward clover content was 16% on 56% of the grazing area, which resulted in a significant reduction in chemical N fertiliser application (-32 kg N/ha) with no reduction in herbage production. There was no variation in sward clover content between reseeding (19%) or over-sowing (18%) on commercial farms. White clover can be successfully established on commercial farms over a short period and reductions in fertiliser use can be achieved in line with an increase in clover content.

Introduction

White clover has an important role to play in reducing chemical nitrogen fertiliser use on grassland farms in Ireland. Recent research at Teagasc Moorepark has shown increases in milk (+30 kg milk solids/cow/year; Egan *et al.*, 2018) and herbage production (+1,100 kg DM/ha/year; McClearn, *et al.*, 2019) and reductions in N fertiliser by up to 100 kg N/ha from incorporating white clover into grass-swards in high stocking rate systems (Fitzpatrick *et al.*, 2022). To date the uptake of white clover incorporation in to grass swards on commercial farms has been low. There has been an increase in white cover use on farm this year due to increasing fertiliser prices and environmental concerns. Reseeding an entire farm to introduce white clover into pastures is impractical and costly and as such there needs be a two pronged approach (reseeding and over-sowing) to introducing white clover.

Establishing a white clover sward

Incorporating white clover in a full reseed is the most reliable method of establishing white clover and provides the best opportunity for weed control (Brock and Hay, 2001). Over-sowing is a simple and low cost method of introducing white clover into swards and can yield successful clover establishment; however, success is very much dependent on soil fertility, soil moisture content, post-sowing grazing management and competition from the existing sward (MacFarlane and Bonish, 1986). Suitable paddocks for over-sowing are those with good soil fertility index 3 or 4 for P & K, and a soil pH of 6.5+, high perennial ryegrass content and low weed content. When selecting clover cultivars to sow, use the DAFM recommended list. Small and medium leaved cultivars are best suited to intensive grazing systems, with large leaf white clover and red clover more suited to silage-based systems. White clover should be sown when soils are warm and moist – ideally in April/May. Sowing in the autumn can reduce the chances of a successful establishment as soil temperatures are on the decline so it is more difficult for clover to compete with the grass. If Irish farms are to successfully establish clover as part of their grazing system, a 3 to 4 year programme will have to be implemented and a combination of methods used.

White clover establishment blueprint

A targeted multi-year approach should be used in establishing a grass-white clover system through a combination of reseeding and over-sowing

- Reseed approx. 10% per year

- Over sow approx. 20% per year
  - Year 1 - reseed 10% & over sow 20% = 30%
  - Year 2 - reseed 10% & over sow 20% = 30% (60%)
  - Year 3 - reseed 10% & over sow 20% = 30% (90%)
  - Year 4 - remaining 10% + any ground where clover did not establish (100%)

Paddocks for a full reseed should be identified as early as possible in the process to avoid over-sowing clover on these.

Direct Reseeding (Key steps involved in a full reseed)

- Take a representative soil sample for analysis of P, K and pH; if ploughing take soil sample after ploughing
- Spray off the old pasture with glyphosate as per label recommendations; allow a minimum of 7 to 10 days after spraying before cultivating
- Avoid ploughing too deep (15 cm) as it can reduce soil fertility
- Prepare a fine, firm seedbed and apply lime, P and K as per soil test results
- Sow grass (34 kg/ha) and white clover (2.5 to 3.5 kg/ha) seed mix
- Avoid sowing white clover seed too deep; sowing depth – approx. 10 mm
- Ideally cover seeds and roll well to ensure good contact between the seed and the soil

Over-sowing (Key steps involved with over-sowing white clover)

- When over-sowing, the white clover seed can be broadcast onto the sward or stitched in using a suitable machine
- Best practice is to over-sow directly after grazing (≤ 4 cm post-grazing sward height) or after cutting the paddock for surplus bales – ideally only over-sow 3 to 4 paddocks at a time
- Control weeds before you consider over-sowing clover - some herbicides have a residue of up to 4 months – always check the residual time on the label of the product or seek advice on a suitable weed control product
- A slightly higher seeding rate (5 - 6 kg/ha) is recommended for over-sowing compared to a full reseed, to overcome the issues with slugs and a lower germination rate
- Sow with a fertiliser that contains P as this will favour establishment particularly if soil fertility is poor
  - 1 bag of 0-7-30 or 0-10-20/acre
  - If possible reduce N fertiliser post over-sowing
- Soil contact post over-sowing is one of the most crucial factors effecting germination
  - Roll paddocks post sowing to ensure soil contact
  - Apply watery slurry (if available) – ideally around 2,000 gallons/acre
- Ideally over-sow on well managed grassland – not suitable on old 'butty' swards with a low content of perennial ryegrass – if this is the case a full reseed is best practice
- If broadcasting with a fertiliser spreader
  - Mix clover seed with 0:7:30 fertiliser and only add clover to the spreader when you are in the field to avoid clover settling at the base of the spreader

On-farm white clover study - Clover150

In 2021, an on-farm study was launched by Teagasc Moorepark, the 'Clover150' programme. The focus of the programme is establishing white clover on commercial grassland farms, and the programme is currently in year 2 of a 6 year programme. A total of 36 farmers are involved in the project from across Ireland and a range of soil types and farming systems. The objectives of the programme are to increase sward clover content (>20%); reduce chemical N inputs (to approx. 150 kg N/ha/yr); and reduce N surplus (<130 kg N/ha/yr), while maintaining herbage production. All farms were provided with a detailed plan for clover establishment and post-sowing grazing and fertiliser management with clover establishment commencing in spring 2021. Sward clover content is visually accessed using the 'Teagasc Clover score card' three times per year (spring, summer and autumn); and farmers are then provided with tailored management guidelines for their farm. In newly established paddocks (reseeded or oversown) a pre-grazing herbage mass of <1,100 kg DM/ha is advised for up to four months and reduced levels of N fertiliser to reduce competition form the grass plant as well as maintaining a lower cover on these paddocks over the autumn and winter period. On paddocks that have an established annual sward clover content of ≥20%, N fertiliser is reduced by 50% from mid-May onwards. Additionally to facilitate a broader adoption and group learning, a discussion group was established with the 36 participating farms. The group meets 4 times a year, on member's farm to discuss shared experiences and improve their clover management. As part of this discussion group, a survey of the participants was carried out in May 2022 to obtain information on the establishment and clover management on their farms.

Results to date

Farm gate N surplus and nitrogen use efficiency (NUE) was estimated for the year 2021 for all farms involved in Clover 150. The average N surplus for the group was 179 kg N/ha/year with a range of 131 to 262 kg N/ha/year, and average NUE was 32%, with a range of 20 to 43%. Sward clover content in spring of 2022 (assessed in March/April) across the 36 farms was 15% (8 - 20%), and 40% of the farmed area had clover present. Within each individual farm there was a large variation in clover content between paddocks, ranging from 5% to 45%. From this data all farmers were provided with a list of paddocks that had a sward clover content ≥20% and advised to reduce chemical N fertiliser. Another sward clover content assessment was undertaken in June/June 2022. There was a significant increase in the area of the farm with clover from 40% to 56%, and average sward clover content was 16% (12 - 35%). The level of clover currently on farm is from a combination of over-sowing and reseeding, with over-sowing accounting for 50% more of the established area compared to reseeding. Previous studies have reported more success in establishing clover via reseeding compared to over-sowing, however in the current data set, there is no variation in average sward clover content (19 and 18%, respectively) where well implemented reseeding or over-sowing procedures and post-grazing management were applied.

There was a significant reduction in the level of total N applied on the paddocks with adequate clover, which resulted in a 32 kg N/ha chemical N fertiliser reduction across the entire grazing from 2021 to 2022 (January to July) (Table 1). There was an increase (+7 kg N/ha) in the level of organic fertiliser (slurry) applied to grazing swards from 2021 to 2022. Despite a reduction in the level of chemical N fertiliser applied, there was no reduction in cumulative grass grown for the same period in 2021 and 2022, 7,200 and 7,400 kg DM/ha, respectively. This is a hugely positive result for pasture-based systems. Where reductions in N fertiliser application are being targeted, it is imperative it is only done so in paddocks with adequate levels of clover content (>20% annually) so that herbage production is not reduced. While the average sward clover content on the current farm dataset was 16%, the 25 kg N/ha reduction in N fertiliser was achieved on swards that had a swards clover content of >20%.

Table 1. Cumulative herbage production and chemical nitrogen fertiliser applied from 1st January to 15th July in 2021 and 2022			
	2021	2022	Difference
Herbage production (kg DM/ha	7,200	7,400	+200
Total Nitrogen applied (kg N/ha)	168	143	-25
Total chemical nitrogen applied (kg N/ha)	150	118	-32
Total organic nitrogen applied (kg N/ha)	18	25	+7

Results from the survey carried out among the group show that establishment is the most difficult aspect of implementing a grass-white clover system on farm. Grazing at the correct pre-grazing herbage mass and managing overall farm cover were considered two of the most difficult elements in establishing clover. Both of these are hugely important in the establishment process. Another key outcome of the survey was the requirement to tailor the area to be reseeded/over-sown for individual farms to ensure that the correct management can be adhered too.

Conclusion

White clover is a vital element in grass based systems now and will continue to be into the future, a renewed focus on establishing grass-clover swards on farms is required. The results from the current on-farm Clover150 programme show that white clover can be successfully established on farm through a combination of reseeding and over-sowing with little variation in sward clover content between methods. The Clover150 programme will continue for the next 4-5 years, detailing how clover establishment and persistence can be achieved on commercial farms, as well as quantifying reductions in N fertiliser and N surplus. The role of red clover for silage swards will also be investigated.

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Notes

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