Legumes as a biological tool to address the sustainability of ruminant production systems

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Abstract:
Growing public concern regarding accelerated rates of climate change, the depletion and degradation of natural resources such as biodiversity water and soils, coupled with policy commitments to address these challenges, are placing increasing pressures to enhance sustainability metrics associated with agriculture in general, and ruminant production systems in particular.

At EU and indeed global scale, there has probably never before been so many potentially conflicting challenges for agriculture. On one hand, agricultural systems need to produce more, to feed the increasing global human population, while at the same time being much less reliant on economically and environmentally costly chemical inputs and protecting natural resources.

Within this paper we provide an overview of recent research that demonstrates the potential contributions that legume inclusion within grass swards can make to developing more sustainable and resilient ruminant productions systems.

Introduction:
From a European perspective, the ambitious goal of achieving climate neutrality by 2050 has been set out in the European Green Deal (EC, 2019) with the associated European Climate Law making this legally binding on EU Member States. Key to achieving this overarching goal will be successful implementation of the EU Farm to Fork (EC, 2020a), Biodiversity (EC, 2020b) and Soil (EC, 2021) Strategies together with the Common Agricultural Policy (CAP 2023-27). These Strategies set out numerous (many cross-cutting) targets to facilitate the development of a more resilient, sustainable European agriculture. Some high level targets contained within these strategies that will directly impact European farmers include: a) a 50% reduction in nutrient losses (particularly N and P), which will require a decrease of at least 20% in the use of fertilisers by 2030, while at the same time ensuring that there is no reduction in soil fertility; b) a 50% reduction in the use of and risk from pesticides; c) to have at least 10% of agricultural land under high diversity landscape features as part of the effort to ensure that European biodiversity is on the path to recovery by 2030; d) while simultaneously ensuring continued food security within the EU. Coupled with these environmental concerns and targets, economic challenges in the form of soaring global fertiliser prices and other input costs, represent a very significant, direct cost to farmers.

Lüscher et al. (2014) provided a particularly comprehensive review of the potential contributions legumes could make to livestock based agriculture in a European context. However, a significant body of research has been undertaken in this space since then. Within this paper we provide an overview of research predominantly, though not exclusively, undertaken since Lüscher et al (2014). Through this overview we hope to provide new insights into the role that legumes (clover in particular), inclusion in temperate grasslands can play in the development of more sustainable low input- high output pasture based systems. Where additional benefits are associated with further diversifying swards to multispecies swards i.e. swards consisting of at least three plant functional groups – grasses, legumes and forage herbs, these are also acknowledged.

Temperate agricultural grassland within the European Union:
Agricultural grasslands account for approximately 30% of Utilised Agricultural Area in the EU (Eurostat, 2023), making it a very significant land use across the territory. However, this masks much variability between Member States, with Ireland at 75.4% having by far the largest proportion of UAA under permanent grassland, while Malta and Finland have less than 2% UAA as permanent (Eurostat, 2023). Where permanent grassland accounts for a significant portion of UAA, this makes management decisions around these grasslands, and associated livestock, particularly important in terms of meeting environmental obligations and targets.

The benefits associated with legume and indeed, forage herb inclusion in temperate agricultural grasslands is reflected in their inclusion in seed mixtures developed during the early to mid 20th Century (Elliot, 1948; Newman Turner, 1955). However, over the following decades much grassland research in temperate regions focused on the homogenisation and simplification of swards, with significant emphasis on the use of perennial ryegrass (*Lolium perenne* L.) monocultures. The logic for this was based on good agronomic reasons, including its ability to produce high yields of good quality forage, adaptability to a range of growing conditions (McDonagh et al., 2016), ability to recover quickly following defoliation (Lee et al., 2010) and reliable germination. Coupled with this was the development of the synthetic fertiliser industry, which facilitated the widespread availability of relatively cheap fertiliser. However, for the reasons described above, over more recent years, such dependence on monocultures of a nitrogen hungry species has become less economically viable and socially acceptable.

Legumes - produce more using less:

Given the urgent need for farmers to reduce reliance on nitrogen (N) fertiliser, but achieving this without compromising sward productivity, legume inclusion in swards to facilitate biological nitrogen fixation would appear to represent an obvious solution. Plot scale studies have demonstrated the ability of grass-legume mixtures, with differing functional traits, to outyield in terms of kilograms herbage dry matter produced per hectare, and in some cases, transgressively outyield monocultures (Neyfeler et al. 2009; Finn et al. 2013, Grace, 2018). It is worth noting that in the case of Finn et al. (2013) these findings refer to a pan European experiment across thirty-one sites in seventeen different countries. These yield benefits can be achieved under much reduced N fertiliser inputs. For example, Neyfeler et al. (2009) showed that where legume proportion accounts for 50-70% of the sward, then grass-legume mixtures that receive 50 kg N ha^{-1} yr^{-1} can produce yields that are comparable as those achieved from grass monocultures fertilised at 450 kg N ha^{-1} yr^{-1}. Indeed, increasing N fertiliser rates to legume containing swards, generally reduces their legume content (Moloney et al., 2021).
However, evaluation of herbage production from such swards under actual grazing conditions is necessary. To this end, Egan et al. (2018), Baker et al. (2023) and Grace et al. (2018a) have shown that perennial ryegrass and white clover (*Trifolium repens*) swards produce similar herbage dry matter yields as perennial ryegrass monocultures when managed under dairy, beef and sheep systems respectively. This was achieved despite the legume containing swards while receiving significantly less fertiliser N ha^{-1} yr^{-1} (i.e. 60, 45 and 55% lower applications respectively) than their perennial ryegrass counterparts. When grazed swards are further diversified to include forage herbs i.e. multispecies swards (e.g. chicory *Cichorium intybus* and ribwort plantain *Plantago lanceolata*), this can result in significantly greater ($P<0.05$) herbage dry matter production compared to grass monocultures (Shackleton et al., 2022; Baker et al., 2023).

Weeds, or unsown species can cause significant loss of forage yield and/or quality in agricultural grasslands. Farmers have largely relied on herbicide application to achieve weed control over recent decades. However, Finn et al. (2013) and de Haas (2019) have reported the potential for mixtures (grasses and legumes) to suppress weed biomass production relative to monocultures.

From an animal performance perspective, it is critical that such maintenance / increase in herbage yield does not negatively impact on sward quality. While measures of sward quality are dependent on the level of legume present in swards, in general terms, legume inclusion increases the crude protein concentration of the herbage (McAuliffe, 2020; Baker et al., 2022) and may increase voluntary intake by grazing livestock relative to grass only swards (McCarthy et al., 2023). From a dairy perspective, how this translates in terms of milk production can be variable; for example, Roca-Fernández et al. (2016) reported an increase of +1.1kg day^{-1} in milk production relative to cows grazing perennial ryegrass only swards, while Enriquez-Hidalgo (2014) and McCarthy et al. (2023) and found no difference.

However, beef animals offered either perennial ryegrass and white clover or multispecies swards, had a higher average daily gain (ADG) ($P<0.05$) than animals offered perennial ryegrass only, and this in turn translated into a reduction of 21 days to slaughter (Boland et al., 2022). Where swards comprised of grasses, legumes and herbs, lambs grazing these had a higher ADG ($P<0.05$) and reduced period to slaughter compared to lambs grazing perennial ryegrass only swards (Grace et al., 2018b; Beaucarne et al., 2022). Similarly, beef heifers grazing a multispecies sward had a significantly greater ADG to those on perennial ryegrass monocultures (Beaucarne et al., 2022).

GHG emissions:

Irish agriculture accounted for approx. 38% of national GHG emissions in 2020 (EPA, 2022). As part of the National Climate Action Plan, the sector is required to deliver a 25% reduction in its emissions relative to 2018 levels, by 2030. Key to achieving this will be reducing methane (CH_4) and nitrous oxide (N_20) emissions arising from agricultural practices. For example among the key metrics listed in the Plan to deliver the necessary abatement in agriculture are: 1) a reduction in chemical N use; 2) earlier finishing of beef cattle (Govt. of Ireland, 2023). While Enriquez-Hidalgo et al. (2014) found no difference in the daily, or per-unit-of-output CH_4 emissions from cows on grass only or grass white clover swards. Such reductions in days to slaughter for other ruminants (as reported above) offers potential opportunities to reduce CH_4 emissions.

N_2O is a particularly potent greenhouse gas, and significant losses of it can be associated with fertiliser N application to agricultural grasslands (Harty et al., 2016). However, it must be acknowledged that reductions in fertiliser N application do not necessarily translate to equivalent reductions in N_2O emissions, and indeed legume inclusion in swards can be associated with increased N_2O emissions. However, once again, where legumes and herbs are included in combination with grasses to form multispecies swards, this has shown potential to significantly reduce N_2O emissions (Bracken et al., 2020; Cummins et al., 2021; Bracken et al., 2022).

Conclusions:

There is no silver bullet to address the significant sustainability challenges faced by ruminant based agriculture. However, the benefits associated with legumes demonstrate that they have an important role to play in addressing at least some of these challenges. When combined with forage herbs to form multispecies swards, these benefits appear to be even more pronounced.

References

Baker, S., Lynch, M.B., Godwin, F., Kelly, A., Boland, T., Evans, A.C.O., Murphy, P.N.C., Sheridan, H. 2022. Forage quality and structural characteristics of three sward types managed under a beef rotational grazing system. INTERCOL Conference Proceedings, Geneva, Switzerland, August 2022.

Baker, S., Lynch, M.B., Godwin, F., Boland, T.M., Kelly, A.K., Evans, A.C.O., Murphy, P.N.C., Sheridan, H. 2023. Multispecies swards outperform perennial ryegrass under intensive beef grazing. Agriculture, Ecosystems and Environment, 345, https://doi.org/10.1016/j.agee.2022.108335.

Beaucarne, G., Grace, C., Kennedy, J., Sheridan, H., Boland, T. 2022. Co-grazing of multispecies swards enhances growth performance of heifers and lambs. Book of Abstracts of the 73rd European Federation of Animal Science.

Boland, T.M., Sheridan, H., Lynch, M.B., Murphy, P., Baker, S., Godwin, F., Kelly, A.K. 2022. The impact of sward type on animal performance and the carbon footprint of beef production. Proceedings of the 8th International Greenhouse Gas and Animal Agriculture Conference, Orlando Florida, p. 72. Available from: https://conference.ifas.ufl.edu/ggaa/documents/GGAA-2022-Program-Abstracts-Online.pdf. Accessed 21-04-2023.

Bracken, C.J., Lanigan, G.J., Richards, K.G., Muller, C., Tracy, S.R., Grant, J., Krol, D.J., Sheridan, H., Lynch, M.B., Grace, C., Fritch, R., Murphy, P.N.C. 2020. Sward composition and soil moisture conditions affect nitrous oxide emissions and soil nitrogen dynamics following urea-nitrogen application. Science of the Total Environment, 722, https://doi.org/10.1016/j.scitotenv.2020.137780.

Bracken, C.J., Lanigan, G.J., Richards, K.G., Muller, C., Tracy, S.R., Murphy, P.N.C. 2022. Seasonal effects reveal potential mitigation strategies to reduce N2O emission and N leaching from grassland swards of differing composition (grass monoculture, grass/clover and multispecies). Agriculture, Ecosystems and Environment, 340, https://doi.org/10.1016/j.agee.2022.108187.

Cummins, S., Finn, J.A., Richards, K.G., Lanigan, G.J., Grange, G., Brophy, C., Cardenas, L.M., Misselbrook, T.H., Reynolds, C.K., Krol, D. 2021. Beneficial effects of multi-species mixtures on N_2O emissions from intensively managed grassland swards. Science of the Total Environment, 792. https://doi.org/10.1016/j.scitotenv.2021.148163.

de Haas, B.R., Hoekstra, N.J., van der Schoot, J.R., Visser, E.J.W., de Kroon, H., van Eekeren, N. 2019. Combining agro-ecological functions in grass-clover mixtures. AIMS Agriculture and Food, 4(3), 547-567. DOI: 10.3934/agrfood.2019.3.547

Egan, M., Galvin, N., Hennessy, D. 2018. Incorporating white clover (Trifolium repens L.) into perennial ryegrass (*Lolium perenne* L.) swards receiving varying levels of nitrogen fertiliser: Effects on milk and herbage production. Journal of Dairy Science, 101(4), 3412-3427. https://doi.org/10.3168/jds.2017-13233.

Elliot, R.H. 1948. The Clifton Park system of farming and laying down land to grass. A guide to landlords, tenants and land legislators, 5th Edn, 6th impression. Faber and Faber, London.

Enriquez-Hidalgo, D., Gilliland, T., Deighton, M.H., O'Donovan, M., Hennessy, D. 2014. Milk production and enteric methane emissions by dairy cows grazing fertilised perennial ryegrass pasture with or without inclusion of white clover. Journal of Dairy Science, 97 (3), 1400-1412. doi: 10.3168/jds.2013-7034.

Environmental Protection Agency (EPA) 2022. Ireland's Greenhouse Gas Emissions Projections 2021-2040. Available from: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/EPA-Ireland's-GHG-Projections-Report-2021-2040v4.pdf. Accessed 20-04-2023.

European Commission (EC) 2019. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal, Brussels, 11.12.2019 COM (2019) 640 final. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN. Accessed 10-12-2022.

European Commission (EC) 2020a. Farm to Fork Strategy – for a fair, healthy and environmentally-friendly food system. Available from: https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf. Accessed 10-12-2022.

European Commission (EC) 2020b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Biodiversity Strategy for 2030 Bringing Nature Back Into Our Lives. Brussels, 20.5.2020 COM (2020) 380 final. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380. Accessed 10-12-2022.

European Commission (EC) 2021. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Soil Strategy for 2030. Reaping the Benefits of Healthy Soils for People, Food, Nature and Climate. Brussels, 17.11.2021 COM (2021) 699 final. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699. Accessed 10-12-2022.

Eurostat, 2023. Agri-Environmental Indicator- Cropping Patterns. % Share of Utilised Agricultural Area, EU Countries 2020. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_cropping_patterns&oldid=587530#Analysis_of_cropping_patterns_at_country_level. Accessed 10-04-2023.

Finn, J.A., Kirwan, L., Connolly, J., Sebastià, M.T., Helgadottir, A. et al. 2013. Ecosystem function enhanced by combining four functional types of plant species in intensively managed grassland mixtures: a 3-year continental-scale field experiment. Journal of Applied Ecology, 50(2), 365-375. https://doi.org/10.1111/1365-2664.12041.

Government of Ireland. 2023. Climate Action Plan 2023 – Changing Ireland for the Better. Available from: https://www.gov.ie/en/publication/7bd8c-climate-action-plan-2023/. Accessed 20-04-2023.

Grace, C. 2018. The Potential of Multispecies Swards Compared to Perennial Ryegrass Only Swards on Dry Matter Yield, Chemical Composition and Animal Performance. Unpublished PhD Thesis submitted to the National University of Ireland, Dublin.

Grace, C., Boland, T.M., Sheridan, H., Lott, S., Brennan, E., Fritch, R., Lynch, M.B. 2018a. The effect of increasing pasture species on herbage production, chemical composition and utilization under intensive sheep grazing. Grass and Forage Science, 73(4), 852-864. https://doi.org/10.1111/gfs.12379.

Grace, C., Lynch, M.B., Sheridan, H., Lott, S., Fritch, R., Boland, T.M. 2018b. Grazing multispecies swards improves ewe and lamb performance. Animal, 13(8), 1721-1729. doi:10.1017/S1751731118003245

Harty, M.A., Forrestal, P.J., Watson, C.J., McGeough, K.L., Carolan, R., Elliot, C., Krol, D., Laughlin, R.J., Richards, K.G., Lanigan, G.J. 2016. Reducing nitrous oxide emissions by changing N fertiliser use from calcium ammonium nitrate (CAN) to urea based formulations. Science of the Total Environment, 563, 576-586. https://doi.org/10.1016/j.scitotenv.2016.04.120

Lee, J.M., Donaghy, D.J., Sathish, P., Roche, J.R. 2010. Perennial ryegrass regrowth after defoliation – physiological and molecular changes. Proceedings of the New Zealand Grassland Association 72, pp 127-134.

Lüscher, A., Mueller-Harvey, I., Soussana, J.F., Rees, R.M., Peyraud, J.L. (2014) Potential of legume-based grassland-livestock systems in Europe: a review. Grass and Forage Science, 69, 206-228. doi: 10.1111/gfs.12124

McCarthy, K.M., Walsh, N., van Wylick, C., McDonald, M., Fahey, A.G., Lynch, M.B., Pierce, K.M., Boland, T. M., Sheridan, H., Markiewicz-Keszycka, M., Mulligan, F.J. 2023. The effect of a zero-grazed perennial ryegrass, perennial ryegrass and white clover, or multispecies forage on the dry matter intake, milk production and nitrogen utilization of dairy cows in mid-late lactation. Livestock Science, vol 272, https://doi.org/10.1016/j.livsci.2023.105234

McAuliffe, S. 2020. White Clover Inclusion in Intensive Dairy Production Systems. Unpublished PhD thesis submitted to Queen's University Belfast, Northern Ireland.

McDonagh, J., O'Donovan, M., McEvoy, M., Gilliland, T.J. 2016. Genetic gain in perennial ryegrass (*Lolium perenne*) varieties 1973-2013. Euphytica, 212:187-199.

Moloney, T., Sheridan, H., Grant, J., O'Riordan, E.G., O'Kiely, P. 2021. Conservation efficiency and nutritive value of silages made from grass-red clover and multi-species swards compared with grass monocultures. Irish Journal of Agricultural and Food Research, 59(1), 150-166. DOI:10.15212/ijafr-2020-0110.

Newman Turner, N. 1955. Fertility Pastures. Herbal leys as the basis of soil fertility and animal health. Faber and Faber Ltd, London. Available from URL: journeytoforever.org/farm_library/turner2/turner2.htm. Accessed 04-02-2023.

Nyfeler, D., Huguenin-Elie, O., Suter, M., Frossard, E., Connolly, J., Luscher, A. 2009. Strong mixture effects among four species in fertilised agricultural grassland led to persistent and consistent transgressive overyielding. Journal of Applied Ecology, 46(3), 683-691. https://doi.org/10.1111/j.1365-2664.2009.01653.x

Roca-Fernández, A.I., Peyraud, J.L., Delaby, L., Delagarde, R. 2016. Pasture intake and milk production of dairy cows rotationally grazing on multi-species swards. Animal, 10(9), 1448-1456. doi:10.1017/S1751731116000331

Shackleton, J., Kennedy, J., Grace, C., Beaucarne, G., Lynch, B., Boland, T., Schmidt, O., Hoffman, E., Sheridan, H. 2022. Grazing multispecies swards: The annual and seasonal dry matter production of four sward types under co-grazing of cattle and sheep. Abstract submitted to ISCRAES 2022: International Symposium on Climate Resilient Agri-Environmental Systems. August 2022, Dublin, RoI.