Department of Agriculture, Fisheries and Food
An Roinn Talmhaíochta, Iascaigh agus Bia

Research Stimulus Fund

Final Report

Productivity of clover-based grassland under organic management and nitrate losses to ground water

DAFM Project Ref No: RSF 07 511
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Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL ⟶ APPLIED/PRE COMMERCIAL

		X

Key words: *(max 4)*

Milk production, organic, white clover, nitrate leaching

NDP NATIONAL DEVELOPMENT PLAN

1. Rationale for Undertaking the Research

Ireland is a net importer of organic dairy products at processing and retail levels. This contrasts sharply with conventional dairy production where approximately 80% of Irish products are exported. In Ireland, a premium price is paid for milk produced on organic dairy farms if 50% of the milk is supplied during the autumn and winter (September to March). The prevalent conventional system of milk production in Ireland is seasonal, with >90% of dairy cows calving during spring and, hence, a high price premium is necessary to encourage farmers to produce milk during the winter. Grazing cows on clover-based grassland is a key component of profitable organic milk production. Ireland's climate is conducive to production from clover swards over a long growing season. Organic systems of production operate at low stocking rates compared with conventional systems. Low stocking rates offer the potential to extend the grazing season throughout the autumn, winter and early spring with the potential to substantially lower the cost of feed for organic winter milk production.

This project aimed at substantially lowering the cost of feed for organic winter milk production by supplying a large proportion (>50%) of the diet from grazed grass-clover during the autumn and winter. White clover (*Trifolium repens*) is the most important legume for grazing in temperate regions (Peyraud*, et al.*, 2009). The main attribute of white clover is that it facilitates biological nitrogen fixation (BNF) via associated *Rhizobia* bacteria. One of the main obstacles to achieving the benefits of clover in grazed grassland is difficulty in maintaining it in the sward at agronomically desirable levels (> 300 g kg^{-1} of herbage dry matter (DM)) from year to year (Frame and Newbould, 1986; Frame and Laidlaw, 1998; Rochon *, et al.*, 2004). Autumn, winter and early spring are critical times for clover as it has lower growth rates and is generally less competitive for light than perennial ryegrass over that period (Brock*, et al.*, 1989; Davies, 2001; Frame and Newbould, 1986; Hart, 1987; Woledge*, et al.*, 1989; Woledge*, et al.*, 1990). Lowering sward defoliation height has been shown to have a positive effect on clover content and herbage production in grass-clover swards during spring and summer (Acuña and Wilman, 1993; Frame and Boyd, 1987; Wilman and Acuña, 1993).

The objective of task 1 of this project was to investigate the productivity of white clover-based grassland under different management regimes for dairy production including a system where a large proportion (>50%) of the diet during the autumn and winter is grazed grass-clover swards. Furthermore the aim was to investigate the effects of grazing interval and post-grazing height during the autumn on herbage accumulation during the autumn, winter and following spring and to investigate trampling by dairy cows on soil properties and herbage production within this winter-grazing system on a soil with impeded drainage (task 2). Grazing during the winter, albeit at low stocking rates, carries the risk of losses of nitrate to groundwater. The objective of task 3 was to measure the impacts of this dairy production system involving grazing over the winter on nitrate losses to groundwater and nitrous oxide emissions to the air compared with more conventional systems on a poorly drained clay-loam soil with a high natural attenuation capacity at Solohead Research Farm (52°51'N, 08°21'W).

2. Research Approach

Fifty four primi- and multi-parous Holstein-Friesian dairy cows were used in a one factor experiment with 3 systems and repeated over two lactations (2008/09 and 2009/10). The three systems compared had: (i) a mean calving date of 17 February, stocking density of 2.15 dairy cows ha^{-1}, receiving 90 kg ha^{-1} of annual fertilizer N input (ES100N); (ii) a mean calving date of 17 February, stocking density of 1.6 dairy cows ha^{-1}, receiving no fertilizer N input (ES0N) and (iii) a mean calving date of 16 April, stocking density of 1.6 dairy cows ha^{-1} between calving and 1 September and stocking density of 1.2 dairy cows ha^{-1} between 1 September until dry-off in early February, receiving no fertilizer N input (LS0N).

The effects of defoliation interval (INT: 21, 42, 56 or 84-days), defoliation height (DH: 2.7, 3.6, 5.3 or 6.0 cm) and final defoliation (closing) date (FIN: 23 September, 4 November or 16 December) on herbage production in a grass-clover sward were studied. Treatments were only imposed between July and December 2008, with all plots under a common management in the following March to June 2009.

A dense network of shallow groundwater piezometers was installed to determine groundwater flow direction and N spatial and temporal variation. Estimated vertical travel times through the unsaturated zone allowed the correlation of management with groundwater N within a short space of time.

3. Research Achievements

There were no (*P >0.05*) differences between systems in production of milk yields and milk composition or live-weight and body condition score (BCS) during or at the end of lactation. The LS0N system produced 48% of milk between 1 September and mid February, suggesting a later calving date than 16 April is necessary to produce 50% of annual milk between September and March. The LS0N system had no major effect on milk production and milk processing characteristics offering Irish dairy producers a viable option to produce organic milk sustainably.

Despite similar soil moisture levels, trampling in winter resulted in less of a reduction in pre-grazing herbage yield than trampling in spring due to lower soil surface deformation and longer recovery periods. During the main grazing season (April to September) trampling across the three systems increased soil bulk density, lowered air-filled soil porosity and lowered gravimetric water content. Soil susceptibility to trampling damage decreased with mean groundwater table depth to a nadir of 1 m ($P < 0.05$). Although trampling did not result in large changes in clover contents or clover stolon mass and roots it did reduce annual grass and clover herbage production by 5 to 14%. The reduction in herbage yield following each trampling event was significantly related to soil surface deformation and recovery period between grazing events which resulted in a greater effect of trampling with short recovery periods in spring than long recovery periods in winter despite similar soil moisture levels. There was substantial recovery before the next grazing season attributable to the high organic matter content and shrink-swell capacity of the soil. Grazing during the winter resulted in significant increases in clover content, herbage production and N-fixation estimates. The results show that grazing during the winter can increase clover content, BNF and herbage production and is therefore a useful management tool for maintaining or increasing clover contents of swards.

The 42-day INT achieved the highest total herbage yield. The 56 and 84-day INT reduced clover herbage yield whereas the 21-day INT reduced grass herbage yield. Lowering DH from 6.0 to 2.7 cm increased total herbage yield and resulted in higher sward clover content in the following June. FIN did not affect sward clover content or annual herbage yield. Spring-summer clover herbage yield was correlated with spring-summer clover stolon mass ($R^2 = 0.54$, $P < 0.001$) and light penetration of the sward in the previous winter ($R^2 = 0.16$, $P < 0.05$). A 42-day INT with low DH (2.7 to 3.5 cm) gave the highest annual (July to July) herbage production. Short (21-day) INT and long (5.3 to 6.0) DH should be avoided as they both reduced clover stolon mass in the following spring-summer. The 42-day rotation with a low cutting height (2.7 to 3.5 cm) in autumn gave the most desirable results in terms of herbage yield and stolon mass in the following spring/summer.

There were no relationships between grazing management and soil N dynamics in the soil profile or N concentrations in the groundwater due to high natural buffering capacity of the soils associated with heavy texture, high SOC, high soil pH, anaerobic conditions and presence of shallow groundwater. For this reason, grazing over the winter period on this site had no effect on N losses to groundwater. Mean concentrations of DON, NH_4-N, NO_2-N and NO_3-N were 2.16, 0.35, 0.01 and 0.37 mg L^{-1} respectively. Soil attenuation processes such as denitrification and DNRA resulted in increased NH_4-N levels. For this reason, DON and NH_4-N represented the highest proportion of N losses from the site. Some of the spatial and temporal variation of N concentrations was explained by correlations with selected chemical

and hydro-topographical parameters (NO_3–N/Cl− ratio, distance of the sampling point from the closest receptor, watertable depth, depth of sampling piezometer, DOC concentration). A high explanatory power of NO_3–N/Cl− ratio and the distance of the sampling point from the closest receptor indicated the influence of point sources and groundwater–surface water interactions.

4. Impact of the Research

Producing organic milk at low cost over the winter to meet processor demand is an important objective of organic dairy farmers. Organic dairy farmers have shown a lot of interest in the approach developed in this project. On a broader front, new information is available on best management practices of white clover for pasture-based dairy production, which is of direct relevance to organic milk producers and, with the rapid increase in the cost of fertilizer N, is of increasing relevance grassland farmers in Ireland. New information on best management practices includes information on optimum rotation lengths, post-grazing heights, closing dates in the autumn and winter. The negative effect of poaching damage on herbage production was also quantified and recommendations made on how best to minimise impact. The above best management practices recommendations are of direct relevance all farmers to managing cows or cattle at pasture on white clover based swards during the late autumn and winter.

There have been very few studies of productivity and environmental impact of winter grazing by dairy cows. Grazing grass clover swards at a low stocking density of dairy cows over the winter had little impact on nitrate losses to water under the conditions at Solohead Research Farm. Nitrous oxide emissions were also minimal. The results indicate that grazing over the winter at low stocking densities typical of organic dairy farms in Ireland is likely to have minimal environmental impact in terms of N losses to water and nitrous emissions to the atmosphere

Two PhD theses, 9 papers submitted to peer-reviewed scientific journals and numerous conference papers (see below)

5. Exploitation of the Research

There are only 20 organic dairy farmers in Ireland and the potential economic impact from the perspective of organic milk production is limited. Over the last decade the price of fertilizer N has been increasing at an annual rate of 9% per year, whereas the farm-gate price for milk and beef have been relatively static. It seems likely that the rate of increase in the cost of fertilizer N is likely to continue. This has triggered a re-evaluation of fertilizer N practices and increasing interest in using white clover on farms, particularly on drystock farms. Between 1999 and 2009 national fertilizer N use has fallen by up to 30%. It is likely that clover-BNF will make an increasing contribution to the N economy of Irish grasslands in the future.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents

(b) Innovations adopted by industry

(c) Number of companies in receipt of information

(d) Outcomes with economic potential

(e) Outcomes with national/ policy/social/environmental potential

(f) Peer-reviewed publications, International Journal/Book chapters.

1. Necpalova M., Fenton O., Casey I.A. and Humphreys J. (2012) N leaching to groundwater from dairy production involving grazing over the winter on a clay-loam soil. *Science of the Total Environment* **432**, 159-172.

2. Humphreys J., Mihailescu E. and Casey I. A. (2012) An economic comparison of systems of dairy production based on N fertilized grass and grass-white clover grassland in a moist maritime environment. *Grass and Forage Science*, (in press)

3. Phelan P., Keogh B., Casey I.A., Necpalova M. and Humphreys J. (2012) The effects of treading by dairy cows on soil properties and herbage production in white clover based grazing systems on a clay loam soil. *Grass and Forage Science,* (in press)

4. Phelan P., Casey I.A. and Humphreys, J. (2012) The effects of simulated autumn and winter grazing management on herbage production and white clover persistence in a grass-clover sward. *Grass and Forage Science,* (accepted subject to changes)

5. Phelan P., Casey I.A. and Humphreys J. (2012) The effect of target post-grazing height treatment on herbage yields and dairy production from grass-white clover swards. *Journal of Dairy Science,* (accepted subject to changes)

6. Necpalova M., Li D., Lanigan G., Casey I.A., Burchill W. and Humphreys, J. (2012) Changes in soil organic carbon in clay-loam soil following ploughing and reseeding of permanent grassland under temperate moist climatic conditions. *Grass and Forage Science,* (submitted and under review).

7. Necpalova M., Casey I.A. and Humphreys J. (2012) Effect of ploughing and reseeding of permanent grassland on soil N, N leaching and nitrous oxide emissions from a clay-loam soil. *Nutrient Cycling in Agroecosystems,* (submitted and under review).

8. Keogh B., O'Brien B., Phelan P., Casey I.A. and Humphreys J. (2012/3) The effect of organic management strategies on milk production and milk processability characteristics within an Irish clover-based grassland system. *Journal of Dairy Science*. (Submitted)

9. Necpalova M., Phelan P., Casey I.A. and Humphreys, J. (2012/3) Soil N balances and soil N dynamics in a clay-loam soil under Irish dairy production systems. *Soil Use and Management.* (Submitted)

10. Phelan P., Casey I.A. and Humphreys J. (2012/3) The effects of simulated summer grazing management on white clover flowering, herbage production and persistence in a grass-clover sward. In preparation for submission to the Irish Journal of Agriculture and Food Research.

(g) Scientific abstracts or articles including those presented at conferences

1. Necpalova M., Phelan P., Casey I.A., Humphreys J. (2012) Effect of non-fertilized winter grazing dairy production on soil N balances and soil N dynamics. In: Proceedings of the 63rd annual meeting of European Federation of Animal Science, Bratislava, 27-31 August 2012, p. 150.

2. Phelan P., Casey I. and Humphreys J. (2012). Predicting N-fixation in a grass-clover sward. *Grassland Science in Europe*, **17**, 154-156.

3. Necpalova M., Li D., Lanigan G., Casey I.A., Fitzgerald E., Burchill W., Humphreys J. (2012) Changes in soil organic carbon in clay-loam soil under permanent and cultivated grassland under temperate

moist climatic conditions *Grassland Science in Europe*, **17**, 583-585.

4. Humphreys J., Mihailescu E. and Casey I. A. (2012) An economic comparison of dairy production on N fertilized and white clover grassland. *Grassland Science in Europe*, **17**, 774-776.

5. Necpalova M., Phelan P., Casey I.A., Humphreys J. (2012) Effect of non-fertilized winter grazing dairy production on soil N balances and soil N dynamics in a clay-loam soil. In: *Proceedings from 17th international Nitrogen Workshop*, 26-29 June 2012, 309-310.

6. Necpalova M., Fenton O., Casey I.A., Humphreys J. (2012) Effect of non-fertilized winter grazing dairy production system based on clay-loam soil on N leaching to groundwater. In: *Proceedings from 17th international Nitrogen Workshop*, 26-29 June 2012, 311-312.

7. Necpalova M., Casey I.A., Humphreys J. (2012) Effect of ploughing and reseeding of permanent grassland on N leaching to groundwater and nitrous oxide emissions from a clay-loam soil. In: *Proceedings from 17th international Nitrogen Workshop*, 26-29 June 2012, 313-314.

8. Necpalova M., Li, D., Lanigan, G., Casey, I.A., Fitzgerald, E., Burchill, W. and Humphreys, J. (2011) Changes in soil organic carbon in clay loam soil under permanent and cultivated grassland in temperate moist climatic conditions. *Proceedings of the 10th research conference of the British Grassland Society*, 20th-21st September 2011, Belfast, 73-74.

9. Phelan P., Keogh B., Fitzgerald E., Casey I.A. and Humphreys J. (2011). The effect of trampling by dairy cows on a rotationally grazed grass-clover sward. *Proceedings of the 10th research conference of the British Grassland Society*, 20th-21st September 2011. Belfast. p7.

10. Necpalova, M., Casey, I.A., Fitzgerald, E. and Humphreys, J. (2011). Changes in soil organic C in a clay-loam soil under permanent and cultivated grassland. Agricultural Research Forum, p.28.

11. Phelan P., Keogh B., Fitzgerald E., Casey I.A. and Humphreys J. (2011). Effect of seasonal grazing system on productivity of a grass-clover sward. *The Agricultural Research Forum*. p84.

12. Mihailescu, E., Casey, I.A., Fitzgerald, E. and Humphreys, J. (2011). An economic comparison of white clover-based and N-fertilized grassland-based dairy systems under moist temperate climatic conditions. In: *Agricultural Research Forum*, p. 144

13. Necpalova M., Casey I.A., Fitzgerald E., Humphreys J. (2011) Changes in soil organic C in a clay-loam soil under permanent and cultivated grassland. In: Book of abstracts of the Research day 2011, Waterford Institute of Technology, 13 April 2011, Waterford, Ireland, p. 99.

14. Phelan P., Keogh B., Fitzgerald E., Casey I.A. and Humphreys J. (2011). Predicting Nitrogen fixation in grass-clover pastures. In: Book of abstracts of the Research day 2011, Waterford Institute of Technology, 13 April 2011, Waterford, Ireland, p. 105.

15. Phelan P., Casey I.A. and Humphreys J. (2011). Grazing management of white clover in grassland. Proceedings of the Teagasc Walsh Fellowship Seminar. Royal Dublin Society (RDS), Dublin. p55.

16. Humphreys, J. Keogh, B., Phelan, P., Necpalova, M., Fitzgerald, E. and Casey, I. A. (2010) Dairy production from clover-based grassland under different management strategies. Nordic Association of Agricultural Scientists Seminar 432, Hvanneyri, Iceland, 20- 22 June, 117 – 120.

17. Phelan, P. Keogh, B. Casey I.A. Fitzgerald E. and Humphreys J. (2010) Cutting height and interval in autumn and annual herbage production in a white clover-grass sward. Nordic Association of Agricultural Scientists Seminar 432, Hvanneyri, Iceland, 20- 22 June, 125 – 128.

18. Phelan P., Keogh B., Casey I.A. and Fitzgerald E. (2010). Impacts of autumn cutting height and interval on annual productivity of white clover-grass sward. *Grassland Science in Euorpe*, 15, 985-987.

19. Keogh, B., Humphreys, J., Phelan, P., Necpalova, M., Casey, I.A. and Fitzgerald, E. (2010). The effect of organic management strategies on dairy production in clover-based grassland. *Grassland Science in Euorpe*, 15, 907–909.

20. Necpalova, M., Keogh, B., Fitzgerald, E. and Humphreys, J. (2010) Effect of cultivation of clover based grassland on N losses to groundwater on a clay-loam soil. *Advances in Animal Biosciences*, 1, p. 90.

21. Keogh, B., Humphreys, J., Phelan, P., Necpalova, M., Casey, I. and Fitzgerald, E. (2010) Organic management strategies and its effect on clover-based grassland production. *Advances in Animal Biosciences*, 1, p. 147

22. Phelan, P., Keogh, B., Casey, I.A., Fitzgerald, E. and Humphreys, J**.** (2010). The effects of autumn rotation length and cutting height on a perennial ryegrass-white clover sward. *Advances in Animal Biosciences*, 1, p. 320.

23. Phelan P., Keogh B., Casey I.A. and Humphreys J. (2009) The effects of rotation length and cutting height in autumn on the productivity of a perennial ryegrass-white clover sward. Irish Journal of Agricultural and Food Research, 48 (2), p140.

24. Keogh B., Humphreys J., Phelan P., Necpalova M., Casey I.A. and Fitzgerald E. (2009) Organic management strategies and its effect on clover-based grassland production. *Irish Journal of Agricultural and Food Research*, **48**, p267.

25. Necpalova, M., Keogh, B., Fitzgerald, E. and Humphreys J. (2009) Effect of cultivation of clover based grassland on N losses to groundwater on a clay-loam soil. Research reports 2009, Teagasc, Moorepark dairy production research centre, Fermoy, Co. Cork, p. 81.

(h) National Report

(i) Popular non-scientific publications

1. Burchill W., Hennessy D., Boland A. and Humphreys, J. (2012) Role of white clover in grass based milk production at Solohead. Moorepark Dairy Levy Research Update, Series No. 19, 42–46.

2. Humphreys J., Keogh B., Murphy P. and Boland A. (2011) Clover helps you cope with costly N. Today's Farm, 22 (2)11-13.

3. Hennessy, D., Phelan, P., Boland, A. and Humphreys, J. (2011) Using white clover to increase profitability - Irish Dairying Planning for 2015, Moorepark'11 Open Day (29/6/11). Teagasc IE p. 76 - 77 ISBN 24967 B3

4. Humphreys J., Keogh B., McNamara, K., Barrett D. and Boland A. (2009) Dairy Systems Research at Solohead. Moorepark Dairy Levy Research Update, Series No. 11, 9 – 15.

(j) Workshops/seminars/ open days at which results were presented (excluding those in (g))

1. The results of this research will be presented at the Teagasc National Organic Conference at the Tullamore Court Hotel on 11 September 2012 http://www.teagasc.ie/events/2012/20120719.asp. The presentation entitled 'Clover research – latest update' will be given by Dr. Patrick Conaghan, Teagasc, Oakpark, Co. Carlow.

2. Findings from this research were presented at the openday at Solohead Research Farm on 12 July 2012. It was attended by approximately 1600 people.

3. Main findings were presented to international researchers at the Fourth General meeting of DAIRYMAN project at Solohead Research farm on 19 April 2011.

4. There were one presentation at the Teagasc Agri-environment Conference 2010 that was held at Ballykisteen Hotel and at Solohead Research Farm in September 2010. http://www.teagasc.ie/publications/2010/20100907/index.asp
5. There were presentations on the three tasks in this project at the international conference entitled 'Forage Legumes in Temperate Pasture-based systems' conference visit to Solohead Research Farm on 16 October 2009.
6. The results of the first year of this experiment were presented to the organic farmers' discussion group when they visited Solohead Research Farm with Pat Barry on 28 May 2009.
7. There was a major open-day held at Solohead Research Farm on 23 April 2009 entitled 'Using clover to cut costs on dairy and beef farms' Aspects of this research was highlighted. It was attended by approximately 1000 people.
8. Some results from this experiment were presented to Teagasc Dairy and Beef advisory specialists at Teagasc, Oakpark on 12 December 2008.
9. A description of this experiment and some initial data from this experiment was presented at the Teagasc National Organic Conference held at Tullamore Court Hotel on 2 December 2008.
10. Open day about organic dairy production from clover swards on Peter Young's (Irish Farmers Journal) farm on 2 September 2008

7. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (months)	Average time contribution per permanent staff member
Teagasc	6	44.16	4.36
WIT	2	4.92	2.46
Total	**8**	**49.08**	

8. Researchers Funded by RSF

Type of Researcher	Number	Total Time contribution (months)	Average time
Post Doctorates	0	0	0
Contract Researchers	1	33.84	33.84
PhD postgraduates	2	82.80	41.40
Masters postgraduates	0	0	0
Temporary researcher	0	0	0
Other	0	0	0
Total	**3**	**116.64**	

9. Postgraduate Research

Total Number of PhD theses: __2__

Magdalena Necpalova submitted her thesis entitled "Investigations into aspects of nitrogen and carbon dynamics in grassland used for dairy production on a clay loam soil" to the Waterford Institute of Technology for the Degree of Doctor of Philosophy on 26 June 2012 and passed her viva with minor changes on 18 September 2012. She is scheduled to graduate in January 2013.

Paul Phelan intends to submit his PhD thesis entitled "Investigations into aspects of grazing management to improve the productivity and persistence of white clover in Irish grassland" to the Waterford Institute of Technology for the Degree of Doctor of Philosophy in November 2012. His viva has not been scheduled yet.

Total Number of Masters theses: __0__

10. Project Expenditure

Total expenditure of the project: €416,613.15

Total Award by RSF €418,713.48

Other sources of funding (specify) €

Breakdown of Total Expenditure

Category	Teagasc Moorepark	WIT	Name Institution 3	Name Institution 4	Total
Contract staff	0.00	133,772.44			133,772.44
Temporary staff	0.00	0.00			0.00
Post doctorates	0.00	0.00			0.00
Post graduates	73,500	71,249.44			144,749.44
Consumables	35,266.22	0.00			35,266.22
Travel and subsistence	9,823.46	233.17			10,056.63
Sub total	**118,589.68**	**205,255.05**			**323,844.73**
Durable equipment	5,456.75	0.00			5,456.75
Other	15,390.00	0.00			15,390.00
Overheads	24,660.00	47,261.67			71,921.66
Total	**164,096.43**	**252,516.72**			**416,613.15**

11. Future Strategies

The results of this research are being used to improve the effectiveness of recommendations for managing white clover swards at farm level presented, for example, at the openday at Solohead Research Farm on 12 July 2012, which was attended by approximately 1600 farmers and advisors. We aim to continually improve the effectiveness of these recommendations.

Research by Teagasc into organic farming practices is being cut back due to the financial crisis.

12. Industry Collaboration

There was no industry collaboration in this project.