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

Research Stimulus Fund

Final Report

Farm-scale decision support systems: a DSS for sustainable nutrient management

DAFF Project Ref No: **07 502**
Start date: **01/02/2008**
End date: **31/01/2013**

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Prof Phil Jordan, University of Ulster

Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL ⟶ APPLIED/PRE COMMERCIAL

		✓

Key words: *(max 4)*

Slurry, Nutrient, Decision, Support

1. Rationale for Undertaking the Research

Irish agriculture uses >75% of land area, which is dominated by the livestock farming sector. The introduction of calendar limits to slurry spreading (S.I. 378, 2006) represented an effort to manage nutrients in order to improve water resource protection. Within this context there was a need to develop intelligent, environmentally responsive tools such as a decision support system (DSS) for sustainable nutrient management (SNM) that would allow for a proper balance to be struck between production requirements (optimum intensity), economic viability of the enterprise (farm livelihood) and environmental protection (minimum pollution).

2. Research Approach

This project developed a farm-scale sustainable nutrient management (SNM) decision support system (DSS) focusing on N and P management. There were two sub-projects: (1) theoretical development of the SNM-DSS; and (2) field-testing and evaluation of the SNM-DSS.

Theoretical development

This sub project was divided into 6 tasks:

1. Development of a slurry nutrient utilisation matrix was achieved by analysis of literature review and RSF 05 208 results to identify key controls for fertiliser replacement value with respect to application methods and weather.
2. Development of a slurry nutrient utilisation matrix was achieved by analysis of existing data.
3. The Hybrid Soil Moisture Deficit Model (HSMD) was further developed by consideration of how to extend to 2 dimensions. The approach taken was to integrate with Topographic Wetness Index data as these were of similar spatial resolution and allowed an estimate of the role of landscape position to be integrated into the model. The use of the HSMD model was also extended by calibrating for prediction of traffic damage during slurry spreading operations.
4. The HSMD model, management advise and weather data were integrated into a draft stand alone GIS based DSS using GRASS (an opensource GIS package), Python scripts (a language for coding calculations and MySQL (an open source database package).
5. Stakeholder input into the design and function of a nutrient management DSS was achieved by using diaries collected on 6 farms over 2 years and SMS messaging surveys with over 170 farmers over 12 months. Some focus group activities were also undertaken.
6. Dissemination was managed on a project wide basis with a view to presenting the results at scientific and farmer conferences, publishing in peer-reviewed journals and contribution to open days at Teagasc Centres.

Field testing

This sub project was divided into 4 tasks:

1. Seven farms were instrumented with weather stations and time domain reflectomotry (TDR) for monitoring soil water content. In addition periodic visits were made to sample the spatial distribution of soil water content during the monitoring period.
2. Data were collected for each farm for 24 months to generate a data set of soil water content at two depths, precipitation, and evapotranspiration (calculated).
3. The HSMD model / DSS was tested by comparing predicted and forecast SMD values against observed soil water content and farmer opinion.
4. Dissemination was managed on a project wide basis as described above.

3. Research Achievements

Theoretical development

1. It was concluded that for P and K slurry offered a 1:1 replacement value. For N, regulation of the potential for ammonia loss after application was key, since ammonia emissions following slurry application to land is a major N loss pathway that reduces the fertiliser value of slurry. The slurry characteristics (N and DM content) and application method were considered constant in the model which forecast and recent weather were the critical variables that affected the N fertiliser replacement value. It was estimated using a model that fertilizer replacement values ranged from 5% to 30%, thus none achieved the legal assumption of 40%.
2. P efficiency is not affected by application timing provided runoff losses are controlled. Experiments comparing N fertilisers (calcium ammonium nitrate (CAN) and urea) showed that the relative efficacy of urea and CAN were affected by timing and weather. However, differences between fertiliser type were only significant on relatively few occasions, indicating that the perceived difference in efficiency between CAN and urea may not be as large as previously assumed in practice.
3. A land drainage classification method was developed to allow reliable classification of a field by HSMD soil drainage class. This was shown to be reproducible and reliable. The trafficablity experiment indicated that a threshold of soil moisture deficit (SMD) = 10 mm was most likely to minimise soil damage due to slurry spreading across all soil types. The best resolution for calculating topographic wetness index (TWI) was 20 m using the D-Infinity flow algorithm. TWI could be integrated with SMD by using it to modify the *Drain* term in the model to reflect landscape water flow processes.
4. A theoretical analysis indicated that when a transport vector is likely (i.e. SMD <=0) then spreading should not be recommended. If there is no transport vector then spreading is only recommended if storage capacity is not critical and fertiliser replacement value high. If storage is becoming critical, replacement value is ignored. A draft DSS was implemented to indicate how a sustainable nutrient

management decision support system SNM-DSS could be implemented given access to the correct data pipelines.
5. Stakeholder input was assessed in conjunction with DSS testing in the field testing sub-project.

Field testing

1. A database of field observations for testing the DSS were collected from seven sites over 24 months.
2. There was a very strong relationship between HSMD output and observed soil volumetric water content. This was found for all fields and farms monitored. This indicates that the HSMD model captures the correct trend in gravity moveable water availability in response to weather conditions. It is therefore suitable as the central model of a DSS.
3. There was a very strong relationship between farmer opinion of when it is safe to spread slurry and HSMD model output. The results supported the current legislative arrangement but perhaps indicated that the closed period should be extended to include February from a water quality protection point of view.

4. Impact of the Research

- The study resulted in a reliable and reproducible and geographically consistent method of forecasting field conditions and classifying land drainage. This will allow the HSMD model to be used in many ways by industry as tools are developed for decision support, including: trafficability, gaseous emissions, runoff losses, and nutrient management.
- This study also developed a scientific basis for supporting current legislation and a tool to analyse impacts of potential changes in legislation in terms of available spreading days in each month and likely impacts on farm nutrient management.
- The study has improved the understanding of the value and applied benefits of the HSMD model and its interpretation for various aspects of land management.
- Clear evidence has been shown of the similarity of scientific and farmer understanding of nutrient management and pollution issues.
- The study has demonstrated the value of new methods of stakeholder interaction, particularly the design of the SMS survey method.

5. Exploitation of the Research

There is no direct economic benefit of the research in terms of IP. The benefit will be for an individual farmer if a tool can be rolled out that allows more efficient nutrient management to be achieved. The study has shown a number of key outcomes that can be exploited by advisors and farmers when making nutrient management and slurry application decisions. These include:

- Optimising weather conditions at the time of slurry application is a means of maximising the fertiliser value of slurry and offsetting chemical fertiliser usage and cost.

- Slurry application is more restricted by the impact of soil damage by machinery traffic than by risk of a transport vector to convey nutrient losses to water. Soil damage by slurry application machinery has negative impacts on both soil structure and sward regrowth.
- The methods with which the HSMD model can be used in future have been developed and enhanced through the work of this project. The potential to apply this model in a range of DSS applications that combine weather and soil components has been demonstrated.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents
None

(b) Innovations adopted by industry
None

(c) Number of companies in receipt of information
In the public domain.

(d) Outcomes with economic potential
Not clear yet.

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

1. Improved fertiliser replacement value for farm organic nutrients
2. Clear evidence for reviewing the period of restricted slurry spreading into February
3. Demonstrated an excellent method for stakeholder interaction to get high response rate and participation

(f) Peer-reviewed publications, International Journal/Book chapters.
Acceptable Format: Walsh, D.R., Murphy, O., Cosgrave, J. (2008). Echinococcosis - an international public health issue. *Research in Veterinary Science* **774**, 891-902.

1. Kerebel A, Holden NM. 2012. Allocation of grass fields to Hybrid Soil Moisture Deficit model drainage classes using visual indicators. *Soil and Tillage Research*, **127**: 45-59
2. Kerebel A, Cassidy R, Jordan P, and Holden NM. Soil Moisture Deficit as a predictor of trend in soil water status of grass fields. *Soil Use and Management* **29**, 419-431
3. Kerebel A, Jordan P, Cassidy R, and Holden NM. Farmer perception of suitable conditions for slurry application compared with Decision Support System. *Agricultural Systems* 120, 49-60

S.E. Vero, D.L. Antille, S.T.J. Lalor and N.M. Holden. Field evaluation of soil moisture deficit thresholds for limits to trafficability with slurry spreading equipment on grassland. Submitted to *Soil Use and Management*, DOI: 10.1111/sum.12093

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

1. Hennesy, M., Holden, N.M., 2009. The slurry production component of a farm scale Decision Support System for Sustainable Nutrient Management in Ireland – a comparison of 3 slurry production methods. 7th World Congress of Computers in Agriculture, Reno, Nevada, US
2. Hennesy, M., Holden, N.M., 2009. The slurry production component of a farm scale Decision Support System for Sustainable Nutrient Management in Ireland – a comparison of 3 slurry production methods. American Society of Agricultural and Biological Engineers, Annual International Meeting2009.
3. Cassidy, R., Hennessy, M. N.M. Holden, P. Jordan, 2009. A comparison of SMD (soil moisture deficit) predictions using synoptic weather data with actual field data. Soil Quality = Environment Quality? Joint BSSS - SSSI meeting, 9-11 September 2009, Wexford, p73.
4. Holden, N.M., S. Lalor, P. Jordan, R. Schulte, B. Horan, M. Hennessy, P. Viola, A. Kerebel, R. Cassidy & N. Hoekstra, 2009. A farm-scale sustainable nutrient management decision support system, Soil Quality = Environment Quality? Joint BSSS - SSSI meeting, 9-11 September 2009, Wexford, p79
5. Piwowarczyk A, Giuliani G, Herbin T,Hennessy D, Lalor STJ, Creamer R, Richards K, Holden NM, 2009. How can soil quality be affected by grazing: A field study on contrasting grassland soils. In: Soil Quality = Envirtomental Quality? Joint BSSS - SSSI Autumn Meeting, Septemeber 2009, Johnstown Castle, Wexford, Ireland.
6. Lalor STJ and Lanigan GJ, 2010. The effect of application timing on ammonia emissions from cattle slurry in Ireland. Proceedings of the British Society of Animal Science and the Agricultural Research Forum, Belfast, p72.
7. Humphreys J, Li D, Yan M, Lalor STJ, Hyde B, Lanigan GJ, Holden N, and Watson C, 2010. The role of N-efficiency in lowering nitrous oxide emissions from agriculture in Ireland. Proceedings of 'A climate for change - Opportunities for carbon efficient farming.' 24-25 June 2010. Dublin. Teagasc GHG Working Group
8. Lalor, S. T. J., and Lanigan, G. J. (2010). The potential of application timing management to reduce ammonia emissions following cattle slurry application. In "14th International RAMIRAN Conference. Treatment and use of organic residues in agriculture: Challenges and opportunities towards sustainable management" (C. S. C. Cordovil and L. Ferreira, eds.). ISA Press, Lisboa, Portugal.
9. Hoekstra NJ and Lalor STJ 2011, Weather-based prediction of the nitrogen fertilizer replacement value of cattle slurry applied to grassland. Proceedings of Agricultural Research Forum, Tullamore. p35.
10. Herbin T, Piwowarcyzk A, Henness D, Giuliani G, Lalor STJ, Holden NM, and Richards KG, 2011, The impact of dairy cow grazing on physical indicators of soil compaction. Proceedings of Agricultural Research Forum,Tullamore. p37.

11. A. Kerebel, T. Hochstrasser and N.M. Holden, 2011, Allocation of soil to drainage classes using visual or rapid soil indicators. 6th International Congress of the European Society for Soil Conservation, 9-14 May, 2011, Thessaloniki/Greece
12. A. Kerebel, T. Hochstrasser and N.M. Holden, 2011, Allocation of soil to drainage classes using simple visual indicators. ISTRO Working Group on Visual Soil Evaluation, 16-17 May, 2011, Slagelse, Denmark.
13. Antille, D.L., Hoekstra, N., Lalor, S.T.J., 2012. Efficiency of CAN, urea and urea + agrotain (n-butyl thiophosphoric triamide) in grassland – relative dry matter yields. Proceedings of the Ag Research Forum 2012.
14. Antille, D.L., Hoekstra, N., Lalor, S.T.J., 2012. Comparing the efficiency of CAN, urea and urea + agrotain (n-butyl thiophosphoric triamide) as N fertiliser in grassland. Proceedings of the 17th N Workshop, Teagasc.
15. Vero, S.E., Antille, D.L., Lalor, S.T.J., Holden, N., 2012. The effect of soil moisture deficit on the susceptibility of soil to compaction as a result of vehicle traffic. ASABE Paper No.: 121341063. ASABE, St. Joseph, Mich.: ASABE.
16. Kerebel A, Jordan P, Holden NM and Cassidy R. Estimating the contribution of soil moisture conditions and precipitation to the variations in Phosphorus fluxes. SESEH 2012. 20-25 August 2012, NUI Galway
17. Kerebel A, Cassidy R, Jordan P, and Holden NM. Evaluation of outputs from a 'Sustainable Nutrient Management Decision Support System' (SNM-DSS) compared to farmer opinion. EGU General Assembly 2012, 22-27 April 2012, Vienna, Austria.
18. Kerebel A and Holden NM. Farmer evaluation of slurry spreading conditions compared to predictions from the Hybrid Soil Moisture Deficit model. Environ 2012, 7-9 March, 2012, UCD, Dublin.
19. S.E. Vero D.L. Antille, S.T.J. Lalor, N.M. Holden (2012) The potential of soil moisture deficit as a predictor of soil compaction following machinery traffic. SESEH Galway.
20. Anthony kerebel, Nicholas M. Holden, Phil Jordan, Rachel Cassidy (2012): Estimating the contribution of soil moisture conditions and precipitation to the variations in Phosphorus fluxes. SESEH Galway
21. Gillian Lewis, Nicholas. M. Holden (2012): Grid-based computation methods of Topographic Wetness Index to account for elevation in conjunction with the Hybrid Soil Moisture Deficit Model. SESEH Galway

(h) National Report

1. Schulte RPO, Gibson N, Lalor STJ, and Hackett R, 2010. (Eds.) Independent review of the science, implementation and administration of the Draft European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 with associated proposals for amendments. Teagasc submission to Nitrates Directive Regulations review

(i) Popular non-scientific publications

1. Hoekstra, N.J., S. Lalor, N.M. Holden, P. Jordan, R. Schulte, B. Horan, M. Hennessy, P. Viola, A. Kerebel, R. Cassidy 2009. Farm-scale decision support systems: a DSS

for sustainable nutrient management. Ireland's Rural Environment: Research Highlights from Johnstown Castle, 2009, pp. 12-13

2. Hoekstra, N., Richards, K., Schmidt, O., Lalor, S. and Schulte, R. (2010). The fate of slurry nitrogen in grassland. TResearch Vol 5, No 1 Spring ISSN 1649-8917
3. Lalor, S. (2010). How to get the best out of your slurry- Environment. Teagasc Advisory Newsletter Feb 2010
4. Lalor, S. (2010). Use slurry wisely. Irish Farmers Journal Vol 63 No 7, 13 Feb 2010
5. Lalor, S. (2010). Replacing fertilizers with slurry - Sucker Beef Open Day at Teagasc Grange. Open days/handouts/Teagasc literature 15 June 2010
6. Lalor STJ, 2011. Organic Fertilizers are a valuable commodity. Irish Farmers Journal (J3) Vol 64 No 2 (Jan 2011)
7. Lalor STJ, 2011. Organic Fertilizers are a valuable commodity. Western People, Tue 18 January 2011
8. Lalor STJ, 2011. Consider pig manure as a fertilizer. Irish Farmers Journal (J3) Vol 64 No 7 Feb 2011
9. Fenton O, Forristal D, Creamer R, Humphreys J, Richards K, Hennessy D, Lalor STJ, Tuohy P, Vero S, and Holden N, 2011. Every compaction has an equal and opposite reaction. Research, Vol. 6, No. 3. Autumn 2011. p14-15.

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

1. Holden, N. M. et al. 2009. Development of a sustainable nutrient management decision support system for Ireland. COST Action 869, Working Group 4: Evaluation of projects in example areas: The Swiss Midland Lakes. June 24 - 26, 2009, Nottwil (CH).
2. Tunney, H, Richards, K, Holden, N. M. 2009. Mitigation measures to reduce agricultural Nitrogen and Phosphorus losses in Ireland. COST Action 869, Working Group 4: Evaluation of projects in example areas: The Swiss Midland Lakes. June 24 - 26, 2009, Nottwil (CH). (presented by Holden)
3. Dowling C, Kirwan L, Lalor STJ, Hyde BP, Curran T, Lanigan GJ, 2009. Ammonia emission associated with landspreading cattle slurry: influence of application timing and method. In: Lalor STJ (Ed.). Efficient and reliable utilisation of manure nutrients - Manure Application Management Conference. 26th November 2009. Teagasc, Johnstown Castle, Wexford. pp. 9-20.
4. Schulte RPO, Creamer RE, Fealy R, Fenton O, Hoekstra NJ, Holden NM, Jordan P, Lalor STJ, Richards KG, Culleton N, 2009. Frontal waves: how agro-meteorological science is shaping agricultural and environmental policies. Proceedings of the Agmet conference: 25 years supporting Agricultural Meteorology in Ireland. Dublin Castle, 7 December 2009.
5. S. Lalor. 2010. Presentation on Organic Manures. DAFF Soils and nutrition training course. DAFF, Johnstown Castle. 30/3/2010
6. S. Lalor. 2010. Presentation to UCD Students and Slurry and soil nutrient management. UCD. 23/3/2010
7. S. Lalor. 2010. Seminar Presentation "Effective use of slurry within nutrient management planning' at ASA Technical Seminar, Portlaoise. 20/4/2010

8. S. Lalor 2010. Presentation at Farm Walk ("Efficient Use of Cattle slurry and Fertilizer FAQ's" - Clover and nutrient management event), Teagasc Grange. 28/4/2010
9. S. Lalor 2010. Presentation at Grange Suckler Beef Open Day ("Replacing fertilizers with slurry"). Teagasc Grange. 15/6/2010
10. Lalor S. 2011. Presentation on Organic Manures at Teagasc Crop Nutrition Management Course. Teagasc Johnstown Castle. 23/2/11
11. Lalor S. 2011. Presentation at Organic Manure Demonstration. Teagasc Oak Park. 23/2/2011
12. Lalor S. 2011. Presentations on Soil Fertility Management. Invited speaker at G-Lime soil fertility roadshow meetings. 15/3/11 (Mallow), 23/3/11 (Bunclody), 24/3/11 (Athy) and 31/3/11 (Athlone).
13. Lalor S. 2011. Presentation to WIT Developments in Grassland Course Students. Teagasc Johnstown Castle. 29/3/11
14. Lalor S. 2011. Presentation on Soil Fertility and Nutrients at Grassland Event, Teagasc, Athenry. 13/7/11
15. Lalor S. 2011. Presentation on manure and soil fertility management at Grassland event in Athenry. 1/7/2011
16. Kerebel A. 2012. Presentation to the Groundwater Research Group Seminar, Queen's University Belfast, Northern Ireland. 25/11/2012.
17. Kerebel A, Holden NM, 2011. Testing the Hybrid Soil Moisture Deficit model data as a key component for a decision support tool for sustainable nutrient management. COST Action 869, Working Group 4: Evaluation of projects in example areas: 12-14 October 2011. Keszthely, Hungary.
18. Antille, D.L., 2012. Presentation at the Inhibitors Workshop during the 17th N Workshop, Teagasc, on the use of nBTPT-coated urea in grassland.
19. Kerebel A, and Holden NM. 2012. Farmer evaluation of slurry spreading conditions compared to predictions using the Hybrid Soil Moisture Deficit model. Agmet day 2012, 29 February 2012, Custom House, Dublin.

7. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (months)	Average time contribution per permanent staff member
University College Dublin	1	3	3
Teagasc	4	9.44	2.36
University of Ulster	1	1.14	1.14
Total	**6**	**13.58**	**6.50**

8. Researchers Funded by RSF

Type of Researcher	Number	Total Time contribution (months)	Average time
Post Doctorates	0	0	0
Contract Researchers	4	56.1	14.0
PhD postgraduates	4	97.3	24.3
Masters postgraduates	2	39.0	19.5
Temporary researcher	0	0	0
Other	0	0	0
Total	**10**	**192.4**	**57.8**

9. Postgraduate Research

Total Number of PhD theses: 1

Anthony Kerebel. University College Dublin. Prediction of suitable conditions for slurry spreading using the Hybrid Soil Moisture Deficit model. November 2012.

Total Number of Masters theses: 2

Sara Vero. University College Dublin. The effect of soil moisture deficit on the susceptibility of grassland soil to compaction during slurry spreading. December 2012.

Gillian Lewis. University College Dublin. Improvement of the Hybrid Soil Moisture Deficit Model using Topographic Wetness Index on Irish Grassland. September 2013

10. Project Expenditure

Total expenditure of the project: €762,801.53

Total Award by RSF €796,417.62

Other sources of funding (specify) none

Breakdown of Total Expenditure

Category	UCD Institution 1	Teagasc Institution 2	UUlster Institution 3	Total
Contract staff	0.00	118,064.53	89,368.10	207,432.63
Temporary staff	0.00	0.00	0.00	0.00
Post doctorates	0.00	0.00	0.00	0.00
Post graduates	272,276.42	0.00	0.00	272,276.42
Consumables	12,286.96	9,811.46	8,838.17	30,936.59
Travel and subsistence	20,516.91	14,601.01	9,249.95	44,367.87
Sub total	305,080.29	142,477.00	107,456.22	555,013.51
Durable equipment	24,891.94	0.00	14,932.25	39,824.19
Other	2,984.84	0.00	0.00	2,984.84
Overheads	89,999.03	42,743.10	32,236.86	164,978.99
Total	**422,956.10**	**185.220.10**	**154,625.33**	**762,801.53**

11. Future Strategies

Results of this research will be used in a number of ways in future research and advisory initiatives, including:

- Initial comparisons of the agronomic efficiency of different N fertiliser types conducted in this study will be further investigated in other research projects. Future work will include measurements of gaseous emissions of reactive N in addition to grass growth effects.
- Research on the economic value of timing of slurry management with respect to yield, soil damage and storage capacity costs
- Advisory planning for slurry management strategies on farm

12. Industry Collaboration

Collaboration was with:

- 5 farmers (24 months monitoring of weather and soil water content on site)
- 175 farmers (SMS survey of spreading opportunities)
- ICMSA, IFA (stakeholder interaction on DSS design)