SLURRY-MAX 2018

Holistic decision support for cattle slurry storage and treatment

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Photography: Shailesh Shrestha

Holistic decision-support for cattle slurry storage and treatment - techniques for maximum nutrient use efficiencies (SLURRY-MAX)

Acknowledgements

This research was funded in June 2016 by the Sustainable Agriculture Research and Innovation Club (SARIC) - a UK research council-industry collaboration administered by the Natural Environment Research Council (NERC). The research was designed as a SARIC 'translation project' in response to issues around slurry management and advice faced by the Agriculture and Horticulture Development Board (AHDB). Research lasted 18 months, beginning in November 2016 and ending in June 2018. We are grateful to the AHDB, SARIC and the NERC administrators who have provided context and advice during this research. We also want to thank John Williams and Lizzie Sagoo of ADAS for their expert advice on nutrient research throughout the project. Finally, the research team would like to thank all participants of the workshop that took place on the 5th December 2017 at Lancaster University. The results of that workshop have fed into this report and its recommendations.

Executive Summary

Slurry is a significant by-product of livestock agriculture in the United Kingdom. In 2016 an estimated 83 million tonnes fresh weight of livestock manure was produced during the housing period. Of this, 67 Mt (80%) came from cattle: 47% of this was estimated to be undiluted slurry and 53% solid, mainly straw-based farmyard manure (FYM) (Smith and Williams 2016).

Regional differences in cattle manure management mean that there is a predominance of slurry in South West Scotland, Northern Ireland and Wales, compared to the relative importance of straw-based FYM systems in England. Within England, slatted floor housing systems producing cattle slurry are more often found in the North and North-West.

It is well recognised that the way in which government and industry support good practice for handling and utilising slurry across the UK is important for business efficiencies as well as for farm, catchment and wider environmental sustainability.

The SLURRY-MAX research project was formed and designed in response to a problem statement put forward to SARIC by the Agriculture and Horticulture Development Board (AHDB): they were interested in understanding more about the 'provision of decision-support on organic slurry storage and treatment techniques'. The project was partly framed around the idea, prevalent among advisers and the agricultural industry, that 'there are really good decision support tools out there, but a significant number of people don't engage' (Interview with Farm Adviser, 2017). That is, despite much advice being available, farmers are still not managing slurries and manures effectively.

Aware that this 'information behaviour gap' is part of a broader set of issues around the effective storage and management of livestock, and particularly cattle, manures , the researchers designed the SLURRY-MAX project to evaluate and assess cattle slurry storage and treatment practices in a multi-disciplinary, holistic manner. During the research, the 'management' of slurry became a more important focus than 'treatment' per se.

Focusing specifically on the beef sector in the UK, the research found that:

- Most surveyed beef farmers do not currently use decision support tools
- By examining farm practices it is possible to understand why tools are not suited for the needs of farmers in the beef sector

The researchers have used their understanding of farm practices and the shortfalls of existing decision support tools to design a farmer-friendly prototype tool for slurry and nutrient management. No matter how good they might become, however, the researchers recommend that decision support tools should be seen as only one of many ways to support good slurry and nutrient management practices across the industry[1].

If institutions want to support better slurry and nutrient management practices we advocate a wider perspective, that:

- Resists a focus on individual farmers and their capabilities and looks, instead, at the whole system which influences and shapes better and worse slurry management practices on farms
- Does not only look towards the biggest slurry producers but also supports smaller farmers whose improved basic practices could make a difference economically and ecologically
- Understands that the solution is not purely technical but is 'socio-technical' in nature, involving wider issues such as - for example - the social relations on farms, the difficulties of changing farm infrastructures
- Considers partnership approaches that incorporate effective slurry management and use within the wider context of good nutrient management
- Acknowledges the wider problems of slurry: as a fertiliser with variable nutrient content; as a material that is difficult to store, handle and transport; as a material that can transmit disease; as a stressor for soil, freshwater and marine ecosystems; as a health and safety issue. These aspects of slurry require recognition so that support for farmers can be designed on multiple fronts

This project also considers available technologies that can be used in-field by farmers either to valorise the nutrient content of slurry or to reduce its potential negative effects and increase its usability. Some of these tools are still in development but hold promise for farmers in the future.

[1] This is now mandatory across England - e.g. through the 'New Farming Rules for Water' Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations which came into force on 2nd April 2018.

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Photography: Katrina Macintosh

Introduction: The SLURRY-MAX Project

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This project was designed, in part, to understand this 'information behaviour gap'. Two ways of thinking about this can be seen in the research approach.

- One assumption is that greater understanding of user-perspectives, generated by qualitative research with farmers themselves, might be used to enhance the decision-support available to farmers. It is possible that, by making tools easier to use, designing them in a way that answers practical agricultural questions and presenting them in a more straightforward way, farmers may be more likely to use them
- A second idea is that the provision of information through decision support tools alone may not be the answer to improving nutrient management practices on farm

These ideas, and their different implications, thread through the following report and we reflect on what they imply for the support of good nutrient management in the conclusion.

Project approach

In this report we consider the handling, storage and use of cattle slurry produced in beef farms across the United Kingdom. We set out our rationale and approach below, but first we outline a familiar problem – and one that has inspired the question that underpins this study.

It is well known that slurry can be a valuable, albeit limited, source of nutrients (phosphorus, nitrogen, sulphur, potassium and trace elements) if managed efficiently within the agricultural sector in the UK. Poor management, however results in the loss of these nutrients to water and air and the consequent pollution of wider ecosystems[2] through both point and diffuse pollution.

It is widely agreed that to ensure resilient and sustainable beef and dairy systems, which meet both economic and environmental objectives, better management of slurry is essential.

Yet although such things are widely agreed upon (as one of our research participants noted, "everyone knows that they should recognise the value of slurry"), readers may still be familiar with the sight of slurry being pumped from a tanker in a country lane over a nearby hedge on a wet winter's day. When this happens, it is clear that something has gone badly awry. A farmer has resorted to the practice of throwing valuable nutrients and organic matter over a hedge, at a time when seasonal and weather conditions mean it will not be utilised by their crops. No matter how strange and wasteful this may seem, there will be a number of reasons why.

This project has been designed to understand the everyday systems of farmers who produce and use slurry in the beef sector, and then to think through what can be done to support better on-farm practices. It has not taken a moral stance about the kinds of farm practice described above. Rather, it has deflected focus from 'the deficient farmer' in favour of engaging a far wider network of actors who might feasibly work together to improve the management and use of slurry in the UK.

[2] Farming is now the most significant source of water pollution and of ammonia emissions into the atmosphere in the UK. It accounts for 25% phosphate, 50% nitrate and 75% sediment loadings in the water environment, which harms ecosystems (The Impact of Agriculture on the Water Environment: summary of the evidence, Defra, 2014)

Objectives of the project

- To understand the varied reasons for continuing poor management of slurry
- To understand the varied reasons for poor take-up of existing slurry management decision-support tools from a farm-level perspective in the beef sector
- To understand better which kinds of decision-support and informational devices would be useful to a range of beef farmers
- To consider whether, and if so how, new knowledges and technologies could be brought into existing decision-support systems in ways that are useful to farmers on-the-ground
- To bring improved scientific understanding, not yet included in existing tools, into the decision-support environment

Where is slurry produced, and where is it a problem?

The SLURRY-MAX project has focused largely, but not solely, on slurry generated in the beef sector, including intensive beef farms and extensive mixed stock farms typically located in the north and western regions of England, the South West of Scotland, north Wales and eastern Northern Ireland.

The locations that we have focused upon seem to be uncontested: it is widely recognised that these are the regions of the UK where most slurry is produced, driven by the high number of cattle found there. However, our focus on the beef sector has seemed, to some, to be counter-intuitive. Slurry production is traditionally associated with dairy farming and it is the dairy sector that is assumed to produce and handle the highest volume of slurry[3].

So why did the researchers focus on beef farms? This decision was shaped by a number of factors. First, closer analysis of the numbers for slurry production showed that the idea that slurry is primarily a dairy issue, nationally, sends the wrong signals for some regions of the UK. This assumption can partly be put down to Anglo-centrism. Over 40% of the slurry produced in the UK, by weight, comes from beef, not dairy farms (Smith & Williams, 2016). Although only around 20% of handled manure produced in England's beef sector is slurry, for beef production in Wales, Scotland and Northern Ireland (NI), slurry makes up the majority of all handled manures (86%, 56% and 83% respectively; see Smith & Williams, 2016).

Second, the researchers recognised that this assumption has created an asymmetry of advice provision and decision support towards dairy, rather than beef. A keyword search of 'slurry' on the AHDB Dairy site, for example, gives 216 pages of results, including a dedicated and comprehensive slurry storage and management tool ('Slurry Wizard', embedded in the wider 'Dairy Wizard' package). AHDB Beef and Lamb, in comparison, turns up only seven pages of results relevant to 'slurry', many of which are tangential mentions. Slurry, of course, presents storage and management challenges regardless of the discrimination between dairy and beef slurry. Hence the research has focused on the sector in which these challenges exist but go relatively unheeded by key industry bodies.

Third, it is already known that beef farmers are far less likely than their dairy colleagues to have access to a professional farm advisor, or to make a nutrient management plan (Farm Practices Survey 2015). As our research has found, this is especially the case for smaller beef producing enterprises with relatively low profit margins.

Fourth, many of these smaller beef farms in the north and west of the UK can be found in Less Favoured Areas which include sensitive habitats and can often be located close to the headwaters of catchments. In the north and west of the UK, some of these small beef farms have derived from previous, marginally profitable dairy operations. In some cases this means that beef cattle will be overwintering indoors on a slatted housing system retained from the previous dairy operation. Where such farms fall outside of NVZs and Catchment Sensitive Areas a lack of nutrient management planning and good slurry and manure management may go unnoticed.

The Farm Practices Survey of 2015 found that grazing livestock farms in Less Favoured Areas are the least likely out of all farm types to take professional advice on nutrient management planning. These areas also tend to be distant from areas of arable cropping which could potentially benefit from the application of slurries and solid manures. This bundle of factors brings into focus the 'hard to reach' farms which have the least 'agency' (ability to change) and for which poor nutrient management is most likely to remain a problem.

[3] *An estimate of manure outputs from farm livestock, handled as undiluted slurry and solid manure across the UK, during the housing period and excluding grazing, reports that 17.73 million tonnes of slurry is produced annually in the dairy sector as opposed to 13.64 from the beef sector (Smith & Williams 2016).*

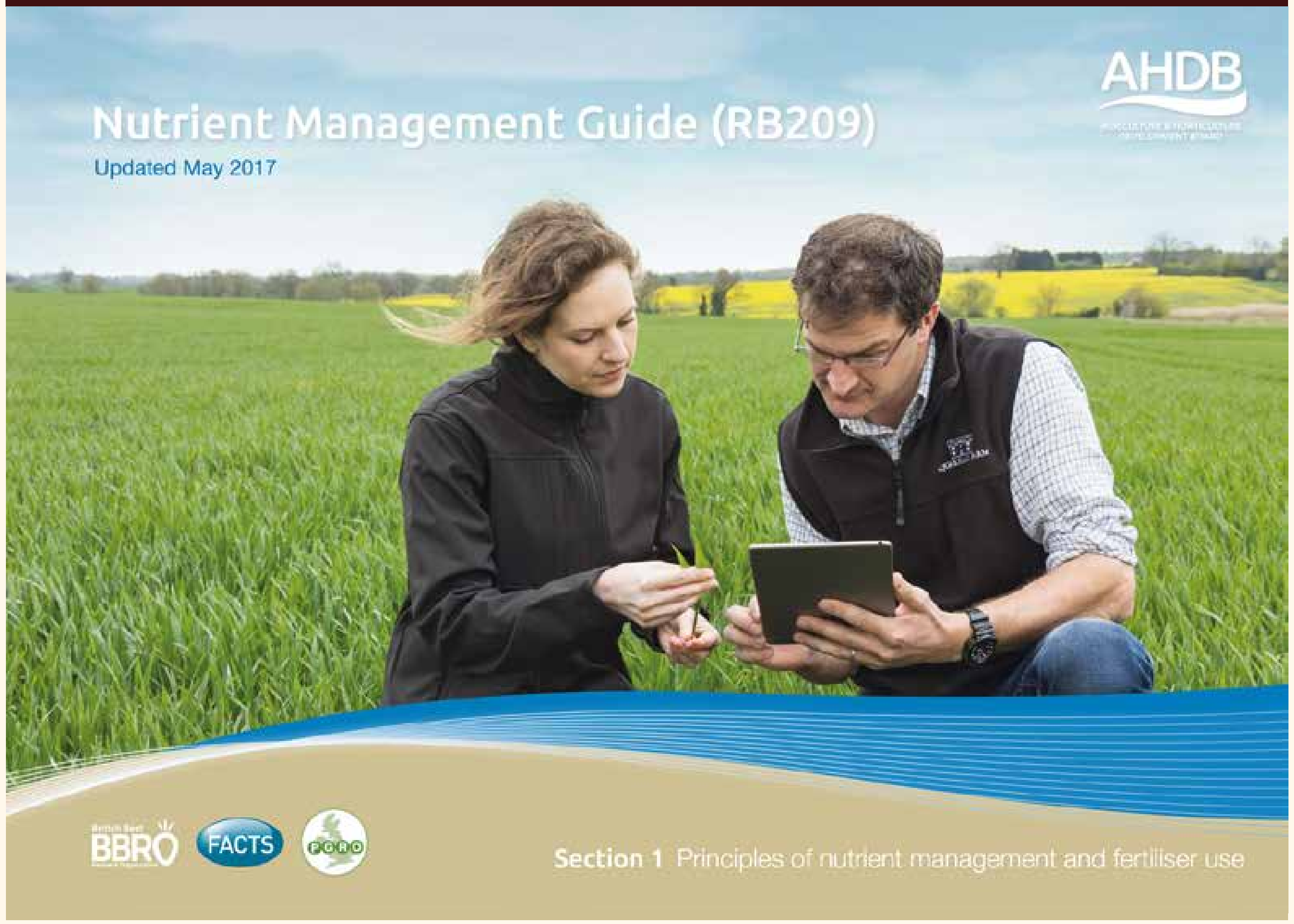
[4] *Slurry is defined as "FAECES and URINE produced by housed LIVESTOCK, usually mixed with some BEDDING material and some water during management to give a LIQUID MANURE with a DRY MATTER content in the range from about 1 – 10%". The definition of Livestock Manure is differentiated for LIQUID MANURE: "A general term that denotes any MANURE from housed LIVESTOCK that flows under gravity and can be pumped", and solid manure: "MANURE from housed LIVESTOCK that does not flow under gravity, cannot be pumped but can be stacked in a heap". (Pain, B. and Menzi, H., 2003).*

Fifth, the researchers have looked at the material of slurry itself. We have asked, "What is counted as slurry?" During our empirical research, we have seen and heard mention of increasingly liquid 'solid manure' stacks, and increasingly solid 'dirty water' run-off. The line between 'slurry' and 'solid manure[4]' is, often, on farms, somewhat blurred and this is important if we are to address the problem of good nutrient management. Furthermore, the ratio of solid manure to slurry production is subject to change.

If straw prices are driven upwards by poor weather conditions (as in the autumn of 2017) and there is competition from the biofuels and digestion sectors for straw, slurry production among English beef farmers is likely to increase. AHDB Beef and Lamb may see (in fact, are predicting) a significant need for advice on slurry infrastructure development in the beef sector in the near future. Previously solid manure-producing farms may be looking to switch to slatted-floor housing systems as they try to reduce their dependence on the competitive market for straw.

In sum:

- SLURRY-MAX research has found that a "dairy bias" in slurry management decision support has obscured the significance of slurry production in the beef sector
- Slurry and nutrient management advice is made (by industry bodies like the AHDB) much less visible for the beef farmer than it is for the dairy farmer
- Smaller beef farms that are not in NVZs, but are producing slurry in 'marginal' or 'less favoured' areas of the UK in sensitive habitats close to catchment headwaters, may be overlooked, and may also have the least ability to change their slurry and nutrient management practices
- Such small farms are least likely to be supported by advisers or good nutrient management planning
- Potential future trends towards the production of higher volumes of slurry, regardless of farm size and location, need to be on the radar for institutions with responsibilities for supporting good livestock and nutrient management



Objectives and Work Packages

The aims and objectives of the project, represented above, were covered through three main work-packages, as follows:

Work Package 1: Production of evidence based systematic review of existing decision support systems

Farmers have to make decisions about slurry storage (management and investment), application (rate, timing and method) and use all year round, and they do this within cross compliance and Nitrate Vulnerable Zone rules, where they apply. Numerous decision support tools have been designed to guide farmers to utilise the appropriate amount of slurry, in an appropriate way, in agricultural systems (e.g. The Fertiliser Manual, RB209; PLANET; MANNER-NPK). However, the uptake and use of these tools, like that of a whole range of tools designed to address farmer practices (Rose et al. 2016) is generally poor, as well as being uneven across the farming sector. Aware of this, the first task of this project was to create a systematic review of the decision support tools relevant to slurry, manure and nutrient management on livestock farms and to assess how useful they seemed to be. Here we have built on research which has evaluated the effectiveness of such tools (Rose et al. 2016; 2017; Rose et al 2018, Rose and Bruce 2018). We explain our own approach and the result of this review in section 1.

Work Package 2: Understanding social practices of farmers producing and using slurry

An overall aim of the project was to evaluate current slurry storage and management practices in an integrated multi-disciplinary manner. The second task for the researchers was to understand the varied reasons for poor take-up of existing slurry management decision-support tools from a farm-level perspective. We did this by meeting with farmers in four different locations – on their own farms, at cattle markets, at agricultural shows and in agricultural colleges. Through a range of qualitative methodologies in these sites, we were able to get the view of many farmers across the UK (in NI, Wales, Scotland and England) on their own slurry systems and on the decision support tools available to help farmers manage cattle slurry. We explain how we used qualitative methodologies with farmers and the kinds of understandings this generated in sections 2-4.

Work Package 3: Produce outputs that enable knowledges, practices and technologies to be brought into existing decision support systems in ways that are useful to farmers on the ground

The third task of the project was to consider whether, and if so how, new knowledges and technologies could be brought into existing decision-support systems in ways that are useful to farmers on-the-ground. The researchers wanted to see if the project could enhance the decision-support available to end-users in order to support resilience in agricultural production. This part of the research built on the insight generated from empirical fieldwork on farms and with farmers in Work Package 2, above. It therefore used knowledge of the whole context in which farmers have to manage their cattle slurries, not only that related to decision support tools. We report on our findings here in section 5.

The Team

This project drew on the expertise of a range of scientists from very different disciplines, all of whose work has relevance to slurry and livestock manure management practices.

Claire Waterton is Professor of Evironment and Culture in Sociology at Lancaster University. Her research looks at the way scientific knowledge is made, particularly in relation to environmental problems, and the roles that scientists, policymakers, the public and the material world play in these.

Ruben Sakrabani is a Senior Lecturer in Soil Chemistry at Cranfield University. HIs research explores nutrient dynamics and resource efficiency of compost, manure, slurry, biosolids, biochar and digestive application to soil to meet crop demands.

Katrina Macintosh is a researcher at Queen's University Belfast in the School of Biological Sciences and Institute for Global Food Security. Her research looks at phosphorus sustainability in terms of reuse, removal and recovery.

Dave Chadwick is a Professor of Sustainable Land Use Systems in the School of Environment, Natural Resources and Geography at Bangor University. His research looks at the management of nutrients in livestock manures and fertilisers, and how to optimise nutrient utilisation whilst minimising impacts on water and air quality.

Lisa Norton is an Ecologist at the Centre for Ecology and Hydrology at Lancaster Environment Centre. Her research looks at how different approaches to land management can produce different benefits in the form of ecosystem services.

James Gibbons is a Research Lecturer in Ecological Modelling in the School of Environment, Natural Resources and Geography at Bangor University. His research applies advanced statistical proceedures to farm level modelling, specifically the economic impact of policy change and effective adaptation to policy change.

Shailesh Shrestha is an Agricultural Policy Analyst at Scotland's Rural College (SRUC). His research applies farm level modelling and impact assessment to understand how big external changes in policies and environments impact individual farms.

Emma Cardwell is a Lecturer in Geography at Glasgow University. Her research looks at the sustainability of food production.


Photography: Shailesh Shrestha

Work Package 1: The Decision Support Landscape

This work package was focused on assessing the current status of available decision support tools for agriculture in the UK, and exploring their accessibility, user-requirements and ease of use. An exploration of those tools identified as particularly relevant to slurry management was carried out by the core research team in conjunction with ADAS and the AHDB. This meant that that a broad range of disciplines (economics/agronomy/ecology/biology/social science) examined the kinds of tools available with a view to probing the issues involved with their practical and effective use, from as holistic a perspective as possible.

1.1 Production of evidence-based systematic review of existing decision support systems

As the researchers began this review, they became aware of a recent paper by Rose et al. (2016) 'Decision Support Tools for Agriculture: Towards effective design and delivery' based on data collected within the Defra Sustainable Intensification Platform (SIP). This work was relevant to our research, comprising a review of decision support tools that could contribute to a farming decision (including business decisions) in the UK. The review was based on a broad definition of 'decision support tools' which included bespoke or generic software, email/text alerts, online calculators or guidance, phone apps, and paper-based guidance. The approach of Rose and colleagues was broader than our focus on slurry and manure management, but compatible, and so we first reviewed the tools they had covered to extract those potentially pertinent to the management of slurry and livestock manures.

There were a number of tools available which related in some way to slurry management, including software tools marketed by businesses (such as DairyCo housing), software tools developed for public use on phones and computers (FarmCrapApp, MANNER-NPK) and a range of leaflets and on-line advice material (including the SWARM Knowledge hub and AHDB Tried and Tested). Scotland has technical notes and an N-Max calculator, and Northern Ireland has the DAERA Nutrient Calculator (Northern Ireland) and the Nitrates Action Programme 2015-2018 and Phosphorus Regulation Guidance Booklets. Partly due to this administrative complexity, the UK tends to have more tools than elsewhere in Europe (see Table 1.1, Figures 1.1 & 1.2).

The SLURRY-MAX researchers gathered material about these tools, spoke to individuals involved in their development where possible, and came up with a final list of the core tools which they felt were aimed at influencing slurry management in the farm types on which the project was focused. These are summarised in Table 1.1. Of these, the tools in yellow became a key focus of the research because these are software-based tools designed for free farmer access and use. A number of commercial tools were also recognised as being influential within the sector, as the project progressed (e.g. Muddy Boots, Gatekeeper and MiFarm).

PLANET	FARMSCOPER	SWARM Knowledge hub*
The Farm Crap App	DairyCo – Slurry Wizard (housing)	Think Soils (EA)*
MANNER_NPK	RB209	Tried and Tested*
Managing nutrients for Better Returns (AHDB)*		
DAERA Nutrient Calculator (Northern Ireland)		
Scottish Government N Max Calculator (Scotland)		

Figure 1.1: DSTs considered most relevant for the management of slurry and livestock manures in beef systems. Tools in yellow became a key focus of the research. * indicates valuable for general information about slurry management

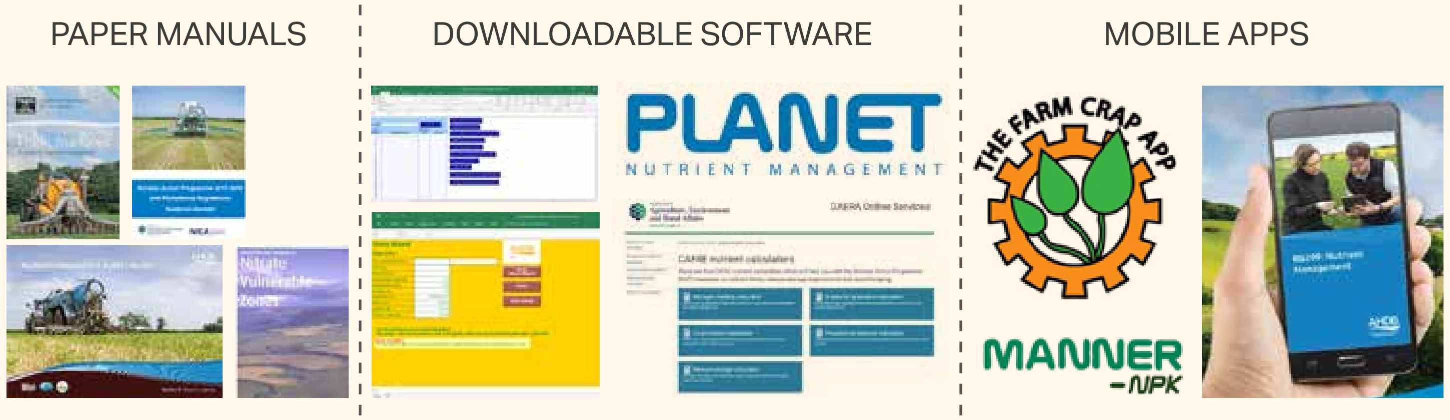


Figure 1.2: Mode of delivery of DSTs for the management of slurry and livestock manures.

Table 1.1: DSTs for the management of slurry and livestock manures

Decision Support Tools	Mode of delivery	Brief Description
Dairy Co. Housing, Parlour, Slurry Wizard	Excel, on-line, downloadable	The Dairy Wizard consists of three sections: Housing, Parlour and Slurry. Housing Wizard allows you to look at the cost implications of a range of housing options, look at existing structures, bedding arrangements and slurry storage options. Prepared with NVZ regulations and rising fertiliser costs in mind, Slurry Wizard calculates the slurry produced at a farm level and helps to highlight potential areas of improvement for managing storage capacity, including parlour washings, separation of clean and dirty water, yard run-off etc. It helps dairy farmers who are considering upgrading or replacing slurry storage, allowing them to work out their storage requirements and weigh up the cost-benefits of different ways to tackle under-capacity. And for farmers considering replacing or upgrading milking equipment and facilities the Parlour Wizard allows different parlour types and functionality to be compared and costed based on individual farm data including cow numbers, labour availability and input costs.
The Farm Crap App	Mobile App	The Farm Crap App is designed to help farmers make the most of their manure (slurry, FYM and poultry litter). The app contains three components; the calculator, the image library (to which you can add your own photos), and the record sheets. The calculator will determine the amount of crop-available key nutrients (N, P & K) within the manure at different spreading rates helping you decide how much to spread in order to meet the crop requirements, and also what this looks like.
FARMSCOPER	Downloadable software	Farmscoper is a decision support tool that can be used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm mitigation methods on these pollutants. The farm systems within the tool can be customised to reflect management and environmental conditions representative of farming across England and Wales. The tool contains over 100 mitigation methods, including many of those in the latest Defra Mitigation Method User Guide. FARMSCOPER was originally developed under Defra project WQ0106. It has now been expanded under Defra Project SCF0104 and includes additional pollutants and two new workbooks – one provides greater detail on the costs of mitigation method implementation, the other allows the tool to be applied at catchment to national scale. This tool is designed for policy support only, not direct farmer use.
MANNER-NPK	Downloadable software (or CD)	MANNER-NPK is a practical software tool that provides farmers and advisers with a quick estimate of crop available nitrogen, phosphate and potash supply from applications of organic manure. MANNER-NPK has been developed by ADAS with funding and support from AHDB (BPEX; Dairy Co; EBLEX; HGCA; Potato Council), CSF, DARD, Defra, EA, NE, SG, Tried and Tested and WRAP (see Nicholson et al. 2013). Inputs include farm and field details, manure type and nutrient content, manure application details (rate, method and soil incorporation). Financial value of applications is calculated based on fertiliser prices.
PLANET	Downloadable software	PLANET (Planning Land Applications of Nutrients for Efficiency and the Environment) is a nutrient management software tool that is freely available for use by farmers and their advisers. The tool has been developed and are supported by ADAS. PLANET takes into account NVZ rules when calculating nutrient loads. PLANET can be used to calculate the manure N capacity and the manure N loading of farms.
RB209	Paper or mobile app	This document underpins all nutrient advice provision in the UK. It is further discussed below (1.2).
Slurry Wizard (Dairy Co)	Online / downloadable	
SWARM Knowledge Hub (DUCHY)	Online hub	Extensive on line resource for waste management, includes; nutrient management planning, crap app, application methods, manure analysis, taking manure samples, organic farms, use of manure on crops, etc.
Tried and Tested	Paper / downloadable	Tools and resources to assist farmers and their advisers to improve whole farm nutrient management in an environmentally friendly cost effective and practical way.

1.2 Research Team Evaluation of the Tools

Table 1.1 shows that different DSTs for the management of slurries and manures vary, in their form (e.g. paper, software or 'app'), in their scope (e.g. targeted at waste management, or nutrient planning) and in their complexity.

Most, if not all, of these tools have drawn on a common resource - the scientific knowledge that is contained in the research-rich manual, RB209 (short for Research Booklet 209), formerly produced by MAFF/Defra (in collaboration with ADAS, Rothamsted Research Institute and the fertiliser industry). RB209 is used as the basis for the nutrient calculations made by the various tools and despite a proliferation of different tool types remains the common research core.

As we know from previous research, and as we shall see from our own empirical results with beef farmers (Sections 3 and 4) the uptake of these DSTs is 'disappointingly low' (Rose et al. 2016). David Rose and colleagues have identified 15 factors that they consider to influence DST uptake (Box 1.1). This list can be used to question the quality and performance of existing tools, for the farmer. It can also be used as a checklist that designers of new DSTs should consider and build into the development of new tools.

Below (table 1.2) we consider the slurry management tools highlighted as important in Fig 1.1, against these criteria. Tools have been scored in broad categories 1-3 in order to provide a way of comparing between tools. Our approach here is subjective: it is based on researchers' experience, both of interviewing farmers and of exploring the tools.

The total scores reflect the fact that for beef farms none of the digital tools appear to be particularly user friendly. The Think Manures publication was seen as very accessible for the farming type the study is focused on. Of the digital tools the Country level nutrient calculators (Scotland and NI) scored well, not least because of the 'public' impetus behind them which both makes them more apparent and ensures that they are supported by publicly funded training.

Box 1.1: Rose et al (2016) identified 15 factors thought to influence DST uptake:

1. **Performance** – does the tool perform a useful function and work well?
2. **Ease of use** – is the user interface easy to navigate?
3. **Peer recommendation** – how can we encourage peer-to-peer knowledge exchange?
4. **Trust** – is the tool evidence-based and do we have the trust of users?
5. **Cost** – is there a cost-benefit or is the initial cost too high?
6. **Habit** – does the tool match closely with existing habits of farmers?
7. **Relevance to user** – can the tool say something useful about individual farms?
8. **Farmer-adviser compatibility** – could the tool be targeted at advisers to encourage client uptake?
9. **Age** – does the tool match the skills and habits of different age groups?
10. **Scale of business** – how far is the tool applicable to all scales of farming?
11. **Farming type** – how far is the tool useful for different farming enterprises?
12. **IT education** – does the tool require good IT skills to use?
13. **Facilitating conditions** – can the tool be used effectively? i.e. is there internet access? Does it fit farmer workflows? Is there compatibility with use of existing devices?
14. **Compliance** – how can the tool help users to satisfy legislative and market requirements?
15. **Level of marketing** – how do we let users know about our tool?

Table 1.2: Slurry tools scored against factors identified by Rose et al (2016) as important for influencing DST uptake.

	PLANET	MANNER-NPK	Dairy-Co-Slurry Wizard	Farm Crap App	RB209	Think Manures (T & T)	DAERA Nutrient calc.	SG N Max Calc.
Performance	2	1	1	1	1	1	1	1
Ease of use	3	2	2	2	2	1	2	2
Peer recommendation	3	2	2	2	3	2	2	2
Trust	2	2	1	2	1	1	2	2
Cost (1 is no cost)	1	1	1	1	1	1	1	1
Habit	3	3	3	3	3	2	3	3
Relevance to User	2	2	2	2	2	1	2	2
Farmer adviser compatibility	2	2	1	2	2	1	1	1
Age (1 may appeal to younger farmers, 2 age neutral, 3 older)	2	1	1	1	2	3	1	1
Scale of business (1, smaller)	3	3	3	1	3	1	2	2
Farming type (3 not suitable, 1 ok)	3	2	2	1	3	1	2	2
IT education (has to be good 3, doesn't 2, or 1)	3	3	3	3	1	1	3	3
Facilitating conditions (training and help needed 3, needed and given 2, not needed 1)	2	3	3	2	3	1	2	2
Compliance (Yes 1, N/A 2, No 3)	1	1	1	1	1	1	1	1
Level of marketing (High 1, low 3)	2	3	2	2	3	2	1	1
Total	34	31	29	26	31	20	26	26

Scoring scale: tools with lower scores appear to be more user-friendly for UK beef farmers
1 Yes/it does this well
2 It is OK, but not that easy
3 It's very difficult.

What is already clear from recent research by Rose and colleagues is that, tools become much more useful and useable if they are developed in dialogue with users (Rose 2016, Rose and Bruce 2018). What is also clear is that, no matter how 'good' or scientifically rigorous the tool, there will still be farmers who will not use them due to other pressures such as lack of infrastructure being more pressing. Lack of infrastructural development on farms, in effect, removes the possibility of making informed 'decisions'. As Box 1.1 suggests, the tool itself is not always the reason for lack of uptake and use 'on the ground': social, organisational, legal and cultural factors are likely to be as important.

Rose et al (2016) and Rose and Bruce (2018) conclude that tool use needs to be made compulsory – through the obligatory keeping of nutrient management plans. The new "Farming Rules for Water" which came into effect on April 2nd 2018 mean that this compulsory element is now a reality for all farmers (The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018). Even this may not mean that all farmers begin to use DSTs for nutrient planning on farm. We have found that, even in a heavily regulated area such as NI, many farmers are not using the DAERA nutrient calculator[5].

[5] *Interview, Agricultural Adviser, CAFRE/ DAERA, Northern Ireland, 2017.*

1.3 European and global decision support and practice

The problem of slurry management/mismanagement is not unique to the UK, it is one shared by countries across the globe. A study by Teenstra et al. (2014) investigated livestock manure polices in 34 countries (in Asia, Africa and Latin America, Bangladesh, Vietnam, Ethiopia, Malawi, Argentina and Costa Rica) and assessed key barriers to improving integrated manure management. The study noted that while manure is a valuable source of nutrients its management is often poor. Reasons cited for this included: "1) a lack of awareness of manure's potential; (2) a lack of knowledge and a supporting knowledge infrastructure; (3) ineffective policies; (4) dispersed expertise; (5) a lack of resources and investments." The study called for 'integrated manure management' to encompass all aspects of manure production, storage, and utilisation and to include: collection, storage, treatment, transport, application and mitigation of losses, along the "manure chain".

Key barriers identified by the study which impair effective manure management globally included: a) lack of investment in infrastructure, b) labour availability, c) manure value is often not fully recognised, d) level of knowledge (farmer knowledge and also the knowledge infrastructure to support farmers[6]), e) economic issues, such as finance, incentives for investment (storage and equipment), particularly for small-scale farmers[7]. While this study was conducted in developing world countries, the issues raised in it are common to those identified in the SLURRY-MAX project and other related research in the UK.

Global DSTs

Illinois Manure Share[8] is a free program designed to benefit livestock owners, gardeners, landscapers and the environment. It is a manure exchange program that brings gardeners and landscapers searching for organic materials for use in composting or field applications in contact with livestock owners who have excess manure.

A study conducted in 1991-1992 on 'manure sharing' by the St. Clair Region Conservation Authority and the Ministry of the Environment in Ontario, surveyed 130 farmers about their practices and attitudes towards manure share, storage and spreading. The main reason for involvement in manure share was a lack of adequate storage: either when tanks are full or there was no available land for spreading. It was acknowledged that farmers should be self-sufficient in terms of storage. Crop farmers were most interested in receiving manures[9].

The Ohio nutrient management record keeper[10] is a computer-based record keeping system designed to allow farmers to record all applications of manure and fertiliser. The computer-based tool syncs with a smartphone or tablet so records can be made in the field. It is a free app that enables farmers to input farm and field information, plus weather information. The app was developed with input from OSU Extension Knox County, Ohio Farm Bureau, and Knox County Soil and Water Conservation District to comply with new state recordkeeping requirements[11].

No tools comparable to PLANET or the FarmCrapApp were found in the USA or Australia.

New Zealand has a decision support tool called OVERSEER (Watkins and Selbie 2015) to manage contaminant losses from land, but no tools to manage manures, this relates to the fact that cattle are not housed and therefore do not produce either slurry or FYM, but does cover effluent from yard and parlour washings. Nevertheless, livestock farming in New Zealand is now considering cattle housing to better control and manage nutrients.

OVERSEER[12] Nutrient Budgets is a decision support tool designed to manage P loss from farms via land and nutrient management practices (Gray et al 2016). It considers nutrient loss from: a) soil; b) fertiliser and effluent loss. It aims to improve nutrient use on-farm. It looks at nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and sodium (Na) and pH. It operates via a nutrient budget approach (inputs and outputs to a farm) and makes recommendations based on nutrient use efficiency and losses to the environment. Farmers input farm bio-physical attributes like climate (rainfall), soil type, topography; plant and animal types/numbers, production, as well as on-farm activities such as animal feeding regimes, fertiliser application, ploughing, irrigation and effluent application. The tool also provides: advice on fertiliser needs; estimates of nutrient losses to water; benchmarking and monitoring approaches and policy and limit setting as well as an education tool. It is primarily used by those with an understanding of farm systems who have received formal training.

The tool has nine management blocks: pastoral; fodder crop; crop; cut and carry; fruit crop; riparian, trees and scrub, wetland and house. It has compulsory and optimal data inputs and default values (that can be overridden). A number of databases are built into OVERSEER e.g. climate data (annual average rainfall); nutrient content of a range of fertiliser and lime products; nutrient content of imported feed supplements (now linking to FarmAX); soil property data; crop growth and nutrient uptake.

[6] *Teenstra et al., (2014) reported that 'knowledge development is not a one-off intervention, but requires continuous investment'.*

[7] *Teenstra et al., (2014) noted 'Proper integrated manure management is associated with high investments in capital, labour and knowledge which, on the short term, increases the costs of production'.*

[8] *http://web.extension.illinois.edu/manureshare*

[9] *http://agrienvarchive.ca/download/manure_sharing_study_91-92.pdf*

[10] *www.onmrk.com*

[11] *https://agcrops.osu.edu/newsletter/corn-newsletter/there's-app-nutrient-management-record-keeping*

[12] *www.overseer.org.nz*

[13] *www.overseer.org.nz/training-and-advice*

[14] *http://www.manureecomine.ugent.be/online-tool-pig-manure-processing-cost-flanders*

[15] *http://www.pigproducer.net/uploads/media/vermander.pdf).*

[16] *https://www.vcm-mestverwerking.be/en/anureprocessing/3892/manure-processing-in-flanders*

[17] *http://www.manurekiosk.org*

Tools outputs include: total nitrogen and phosphorus loss to water in kg/yr and kg/ha/yr units and areas of greatest loss; an overview of average nitrogen and phosphorus inputs and losses; pasture production reports; yield and fertilizer recommendations. Management options, which, are suggested to reduce losses of nutrients from fertilizer/effluent include: rate and timing; type of fertiliser used; method of application used. The tool assumes effluent is applied as per best practice recommendations and also that farmers follow good management practices. The tool acknowledges the wide range of farm types and that obtaining data for these is unrealistic, but continually gathering data reduces uncertainty.

Training in the use of OVERSEER is at Massey University[13] and Massey University, Lincoln University and Waikato University include OVERSEER as a part of their undergraduate agricultural degree courses.

European DSTs

In Europe, two primary pieces of legislation govern the legislation and management of manure: the Nitrates Directive and Water Framework Directive, both aim to improve water quality by addressing eutrophication (Liu et al., 2018; McDowell et al., 2016).

In general, there tend to be fewer DSTs for manure nutrient management across wider Europe than there are in the UK. In Europe, the focus is more on treatment and processing technologies. Treatment to separate the solid faction from the liquid in slurry is common in Europe to facilitate the export of nutrients. For example, ManureEcoMine[14] provides an online tool to assess the economic viability of differing manure treatment and nutrient recovery technologies for pig manures in Flanders. Manure is commonly processed in Flanders to meet Nitrate Directive obligations. Processes include, for example; drying and pelletising of pig and poultry manures; separation of pig and cattle manure; thermal drying or composting of solid fraction and anaerobic digestion[15]. Also in Flanders co-operatives exist between the Northern (livestock) and Southern (arable) provinces to improve supply and demand through effective transport of manure between the regions. Thermal drying of manures for transport has increased for poultry manure and for the solid fraction of pig and cattle manure. France remains the most important country for the export of Flemish manure processing products (mainly bio-thermally dried and limed manure): export to France increased from 49% in 2015 to 58% in 2016[16].

In 2014, The Manure Management Kiosk[17] was launched as a 'one-stop-shop for information and resources on manure management'. The aims of this kiosk were to reduce pollution (both air and water) and optimise crop production through improving nutrient utilisation and raising awareness and knowledge exchange. The Kiosk is a communication tool maintained by Wageningen Livestock Research. The kiosk addresses the 'whole chain' management of manure in terms of: housing; anaerobic digestion; storage, treatment, transport and application. An iKiosk operates as a knowledge repository for experiences and information from the network collaborators. Stakeholders include: farmers, industry, governments, multi-government organisations, NGOS.

The Cantogether Online Pig Manure Brokering Tool was funded as part of the FP7 Cantogether project in the Republic of Ireland, which also funded similar tools in Switzerland. The aim of this project was to establish an online brokering tool to promote and improve communication between pig farmers and recipient grassland/tillage farmers to improve manure utilisation and compliance with the Nitrates Directive N loading limits of 170kg N/ha. Pig farmers are able to use the tool to locate farmers who will receive pig manure, depending on factors such as distance, quantity of manure required and storage capacity. Tillage farmers can also search for pig manure sources. Furthermore, the tool also facilitates the exchange of grain between tillage and pig farmers. There is also the added benefit to tillage farmers of increased soil organic matter content from pig manure compared to using chemical fertiliser.

Acutis et al., (2014) reported on the ValorE project in Italy on an integrated and GIS-based decision support system for livestock manure management in the Lombardy region (northern Italy). Agricultural area consists of 62% NVZ. ValorE is described as 'a tool able to evaluate from the environmental, technical, agronomic and economic points of view the main components of manure management (production, storage, treatment and land application) for a variety of livestock types (i.e., cattle, swine, poultry, sheep, goats and horses), under different scenarios adopted at farm and territorial scale'. The tool consists of data management; model management and two versions of user interface: a) farm, b) territorial. The tools suggests manure management options at both farm and territorial scales.

1.4 The UK: A Shifting Tool Landscape

SLURRY-MAX empirical research, conducted in the UK, has found that the decision support landscape is in a state of flux and is complex. Several different agencies and companies are developing and promoting new applications and DSTs for nutrient management. In the last decade or so, a 'market' has emerged in decision support, meaning that users are not necessarily relying on government or statutory support for agricultural advice but gain this from within the agricultural industry itself. This is important, raising questions for the research, not only about tool accessibility and use, but also about the institutional maintenance and quality of the knowledge that sustains the development of information for practicing farmers.

The most relevant example here concerns the body of research known as RB209 (shorthand for 'Research Booklet 209'). This research-rich manual on nutrient management for agriculture was formerly produced by MAFF/Defra, in collaboration with the agricultural research community, and is seen by all industry actors as fundamental to the provision of advice on nutrient inputs from slurry and manure. The data contained within RB209 has, to date, supported all of the nutrient management tools - be they public or commercial - providing a consistent set of algorithms which underpin the calculations within different tools, thus providing a degree of standardization within the field. The research has found that, despite increasing flux within the decision tool landscape, RB209 remains the core source of information to date on nutrient planning.

Since 2013, however, the AHDB have relieved Defra of the custodianship of RB209 and taken on its management in their role as an industry-facing levy body. Because of this institutional shift, AHDB now have some influence over the continued use of tools that were historically also developed through ADAS and Defra and which drew specifically from the research underpinning RB209. Two significant and well-known information tools – 'MANNER-NPK' and 'PLANET' – are of special relevance here.

MANNER-NPK and PLANET are both seen as 'industry standards', supported by government science. They are seen to uphold the provision of quality information. A matter that has arisen as controversial within this research is the fact that AHDB are not planning to continue support for PLANET or MANNER-NPK in England and Wales, whereas the Scottish government will still support PLANET Scotland. The practical implication of this is that the space to develop a tool has been freed up for any organisation in England and Wales. This could potentially threaten future consistency in the nutrient management information provided across the industry.

The researchers have been agnostic as to the controversy outlined above and have evaluated MANNER-NPK and PLANET in the same way as for other slurry and nutrient management tools. However, this small controversy signals a wider point: that AHDB, whilst formally being an 'industry-focused' (private sector) institution, are now custodians of research and technologies that have derived from and have been designed to serve the public domain. The shift from a public to a private body inevitably provokes debate about the scope of institutional responsibilities, now and into the future. As readers will recognize, this kind of issue is by no means restricted to the domain of agricultural research and development – similar debates are being rehearsed across the health, environment, and education sectors to mention just a few. The question is the same for many areas: Can private institutions maintain the knowledges, technologies and practices that uphold the public good? We return to this question in our conclusion.


Photography: Shailesh Shrestha

Work Package 2: Social Practices of Farmers

2.1 Research Framing

To begin this section, we explain and justify the approach of this research.

- Why have we resisted the idea, implicit in the framing of the initial research question, and also found in much other research on farmers identities and actions (Hyland et al 2016, Story and Forsyth 2008, Sheeder and Lynne, 2011) that farmers and their individual behaviours are at the heart of the problem?
- Why, also, have we entered into this research somewhat sceptical of the idea that farmers need better advice and information to lead them to act in more sustainable ways (Hall and Wreford, 2012)?
- Why, instead, have the researchers looked in detail at the social practices of farmers?

These issues have been substantially debated in the social sciences of the environment. To put it briefly, many pro-environmental, or pro-efficiency initiatives have been framed—by business, international NGOs, and governments—in the last thirty or so years, in terms of a "language of individual behaviour and personal responsibility" (Shove 2010: 1274).

Elizabeth Shove pinpoints the underlying assumptions of this language in her work on the 'ABC' of policy (Shove 2010). In such initiatives, she suggests that social change "is thought to depend upon values and attitudes (the A), which are believed to drive the kinds of behaviour (the B) that individuals choose (the C) to adopt" (Shove 2010: 1275).

This ABC model, and its policy version, is derived from psychological literature grounded in theories of planned behaviour. The concept of choice embedded within it inspires policy makers to imagine different drivers—persuasion, pricing, advice, information—which will enable individuals to choose to act more rationally and responsibly. The underlying presumption (in sectors like agriculture, or transport, for example) is that, given better information or more appropriate incentives, individuals could choose to act more rationally and responsibly and could choose to adopt `pro-environmental' or 'pro-efficiency' behaviours.

This model/analysis of human behaviour has been rejected by many social science researchers in favour of analyses grounded in social theories of practice and social change. In brief, as Chatterton and Wilson put it (2014),

> "social practice theories take an approach that expressly moves away from the individual as the unit of enquiry and so also from psychological motivations and drivers".

Instead social practice theorists:

> "emphasise the way that patterns of behaviour are tied up in shared meanings and skills within inter-personal networks, communities and other social institutions"

But they are also interested in the way that the social and the technical work together, so in their attempt to understand social practices they need to understand:

> "how physical materials constrain, permit, enable and shape practices though technology, infrastructure and even the physical body".

Social practice research rarely focuses on discrete actions. Instead, it emphasises the way that patterns of behaviour are structured into the routines and rhythms of everyday life.

Translating this to the current research, instead of trying to understand farmer attitudes, behaviours and choices regarding slurry and manure use, we look at patterns of behaviour which are tied up in, and influenced by, wider networks and routines, and which are also shaped and constrained by physical infrastructures, bodies and technologies.

2.2 Fieldwork Conducted

The fieldwork took place within a short time-frame (12 months, from February 2017 to February 2018). As described in the introduction, the research team decided to focus on one sector: beef farmers producing slurry, in England, Wales, Scotland and Northern Ireland. Participants were recruited on a voluntary basis via agricultural colleges and at cattle markets and agricultural shows, and given an information sheet about the project and a copy of the interview questions. Interviewees could halt the interview process at any time and had the informed right to withdraw their responses for up to six weeks after the interview. All interview responses were anonymised.

Interviews with farmers:

- 11 in depth farmer interviews, conducted on-farm (1-2 hours)
- 3 in depth farmer interviews, conducted by telephone (1-2 hours)
- 5 focus groups at agricultural colleges in England, Wales, Northern Ireland and Scotland (15-28 students per group, 1-2 hours)
- Questionnaires at auction marts in England and Wales (short face-to-face surveys with 47 farmers)
- Questionnaires at agricultural shows in England and Northern Ireland (short face-to-face surveys with 37 farmers)
- Questionnaires at SRUC (18 agriculture students)

Further interviews with:

- 8 agricultural advisors/consultants
- 3 agricultural contractors
- 2 regulators
- Catchment sensitive farming officers (2 face-to-face interviews and 49 email consultations)
- 10 decision support tool developers

Researchers also attended four tool training sessions, two private (PLANET and Slurry Wizard) and two public (Slurry Wizard and Crap App).

Interview Technique

Each in-depth interview was semi-structured, with a defined set of questions based on the role of the interviewee (farmer, advisor, tool developer, etc. See annex 1). Interviews were then transcribed by the researcher and coded by theme using AtlasTi.

Shorter, face to face questionnaires were conducted at auction marts and shows (as well as 18 at SRUC). The questionnaires can be found in annex 2.

Table 2.1: Questionnaire respondents

Balmoral Show, Northern Ireland	34
Lancaster Auction Mart, England	12
Ruthin Auction Mart, Wales	11
Selby Auction Mart, England	9
Grassland & Muck Show, England	18
SRUC, Scotland	18

Tool Test Focus Groups

For a study of decision support tools, it was important for the researchers to see the tools in action, in order to evaluate user experience and identify any common bottlenecks in the tool work-flow that are likely to cause problems for users on the ground. Aware of the constraints of farmers' time, we did this by arranging a series of tool test focus groups in agricultural colleges. These targeted students from livestock (beef and dairy) backgrounds and were integrated into nutrient management curricula by course leaders.

We held five such focus-group tool tests, at four agricultural colleges (Newton Rigg College in England, SRUC in Scotland, Coleg Cambria (Llysfasi) in Wales and CAFRE (Greenmount) in Northern Ireland. Each focus group had between 15 and 28 students and lasted between one and two hours.

The aim of the groups was to recreate the first use of a tool on farm, to identify where unsupported users might struggle with the interface, the data inputs required, and how user experience could be improved. Students filled in standardized evaluation forms for the tools they tested, and focus groups were recorded, with notes later taken from these recordings by the research team, to catch any insights the standardized evaluation forms may have missed. After the tests, a group discussion was initiated, covering the tools and slurry management practices more generally. These discussions lasted approximately 30 minutes to one hour.

2.3 Analysis & Evaluation

All 38 interviews were transcribed and anonymised, and these, along with the notes from the tool tests and CSF email interviews, were then analysed using AtlasTi software. This allowed us to systematically code each interview by theme, noting how many times (and in which context) certain reoccurring issues (such as the availability of free advice provision, mistrust in the RB209 default values or the difficulty of handling slurry) were mentioned.

Using this analysis, the researchers then created a 'longlist' of topics for potential inclusion in the suite of recommendations arising from this project. This longlist was split into two categories: 1) suggestions for improvements to decision support tools; and 2) non-tool decision support, and wider slurry management contexts. For category 1, the research team developed ranking criteria to determine which topics should be taken forward, based on the following questions:

Suggested pathway for assessment/implementation:

- Does evidence exist to support the need to include this issue i.e. do farmers or other users express need?
- Should this be a high priority, i.e. is the need or potential benefits great?
- Does evidence exist to implement it, i.e. is it scientifically sufficiently understood?
- Is data available to implement the issue? Either available to all? Or available to specific tool developers?
- Do analysis methods/algorithms exist to implement the issue in an app? Or, is developer capacity available? Or is it trivial to implement?
- Is the interface already designed?
- Is it already available to users/farmers?

Applying these questions to our longlist of potential recommendations allowed us to narrow our scope to thirteen potential recommendations. These final recommendations are explored in detail in sections 3 & 4.

Alongside technical intervention in decision support tool provision, the research also revealed a number of non-tool specific ways in which the slurry management decision support landscape could be improved in the beef sector. These wider issues will be discussed in our next chapter.

2.4 Stakeholder Workshop

On the 5th December 2017, researchers held a stakeholder workshop for 22 key industry representatives, to discuss the emergent themes of the research, and optimal future directions (see attendance list in Annex 3).

In the workshop, the results of WP2 were presented to stakeholders, organized along the following five themes:

Theme 1: Interface and User Experience for Digital Tools[18]

Theme 2: Training, education and outreach[19]

Theme 3: Functionality: additions to existing tools[20]

Theme 4: Infrastructural innovation in slurry storage and treatment[21]

Theme 5: Support provision in the livestock sector[22]

For each theme, group discussions were scheduled, lasting between 45 minutes and one hour, with five questions for participants to collectively consider:

- What needs to change?
- Who would this change help? How?
- Who has the power to change this?
- What stands in the way?
- Action points for progress (for both the SLURRY-MAX team and the wider industry)

Groups assigned a scribe who took notes for each session, and the discussions were also recorded by the SLURRY-MAX team, who then listened back and noted any important points that had not been written down by the scribe. Based on the results of this workshop, the following actions were taken forward by the team:

1. The creation of a "paper prototype" for a narrative workflow for a decision support tool focusing on facilitating the production of a simple nutrient management plan for beef farmers, which would meet NVZ/Farm Assured/Agri-environment Scheme requirements
2. Facilitation of a knowledge exchange visit between DAERA/CAFRE and CSF
3. Recommendation of a holistic nutrient management support programme for the beef sector, led by AHDB Beef and Dairy, including tool provision (and the importance of ongoing technical support), the inclusion of agricultural colleges (following the DAERA/CAFRE model), face to face support (with CSF as best practice), with publicity and integration across the industry.
4. Provision of guidance on how cost benefit analysis for slurry storage and management on existing tools (e.g. Slurry Wizard, Crap-App, MANNER, PLANET Scotland) could be improved by integrating new costs.

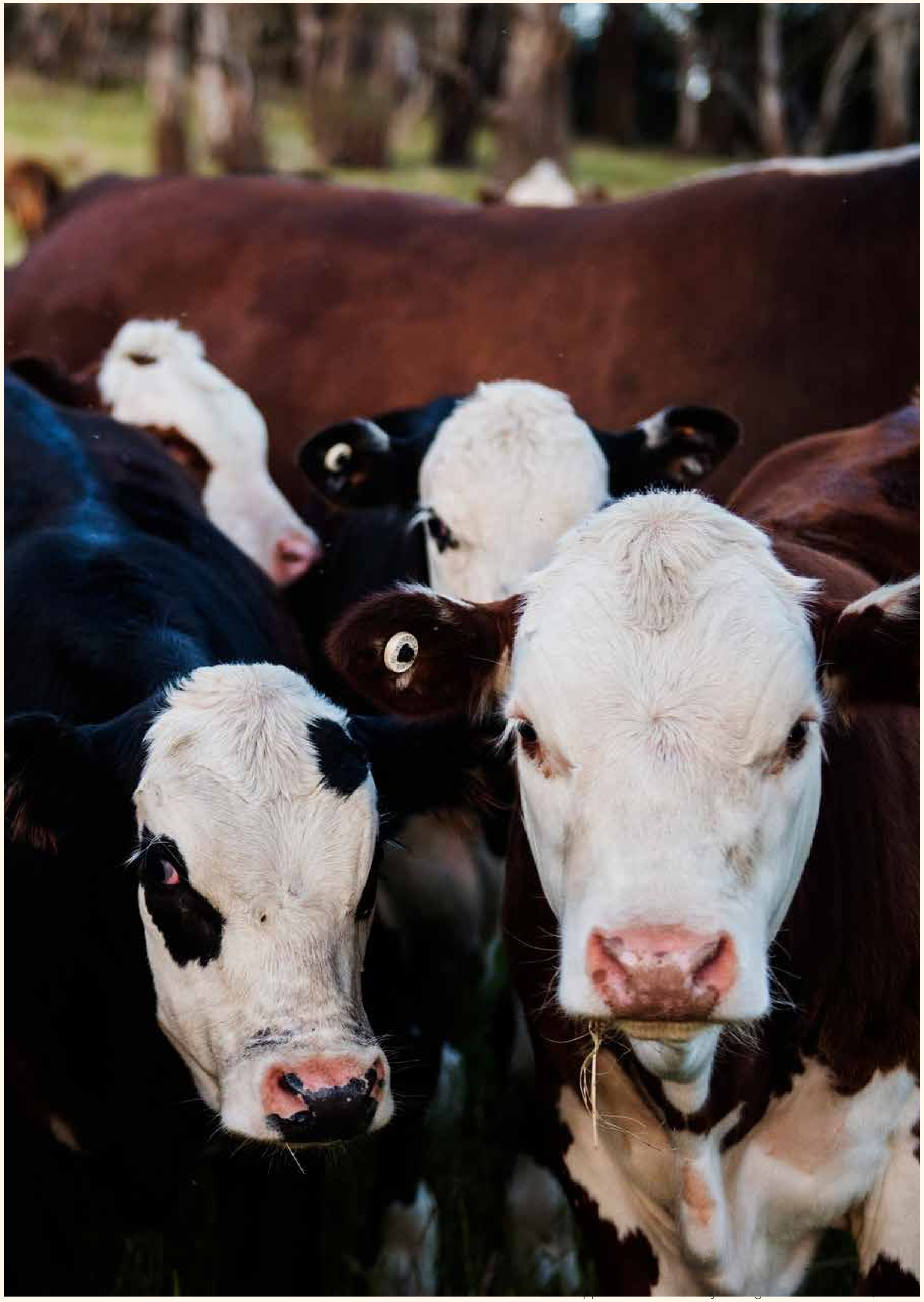
[18] *Clarity of question; narrative interface; mapping/importing data from elsewhere; inbuilt links to testing: either DIY or advisor.*

[19] *Official partnerships between tool developers and colleges; collaboratively developed teaching materials and worksheets; specialist training versions of the tools; continuing Professional Development; 'mini FACTS' for farmers, students and contractors.*

[20] *Integrate DIY, on farm testing into tools; link with RB209 API; Provide richer cost benefit analysis; Help farmers calculate an ecological footprint; Other (e.g. weather; precision agriculture; treatments) functionality additions*

[21] *Spur innovation in this area moving forward; Fund innovation in slurry storage and treatment; Discuss the feasibility of slurry (nutrient) re-distribution across farms; Find low-cost and flexible solutions to storage*

[22] *Who should bear the cost of good nutrient management? What is the current arrangement for advice provision in your country (NI, Wales, England, Scotland) and what could be done to make it better? Is there anything the SLURRY-MAX team can do to contribute to this?*



Photography: Shailesh Shrestha

Work Package 2: Results

3.1 Slurry Infrastructures

Int: When do the cows come in?

P: Here, it tends to be late September.

Int: that's quite early isn't it?

P: It is, but again it's a reflection of…

Int: I was reading about Orkney the other day, as an aside, and their cows come in in September and go out at the end of May. Such a long time.

Int: Yes, that's nine months.

P: Well, we aren't a lot different.

Int: When do yours go back out again?

P: May. You've seven month.

(Interview 1, Beef farmer, NW England)

As suggested in the Introduction to this chapter, rather than solely focusing on the discrete actions of farmers, the research takes a social practices approach. It investigates how practices are shared, the ways in which they are bound up with existing networks, communities, and institutions, and how practices are constrained by physical infrastructures, bodies and technologies.

Talking to farmers, as in the exchange above, slurry infrastructures recur as the most important determining factor of any ability to use slurry effectively (from both an economic and ecological perspective). The very first issue is having the right amount of storage, which is a matter of having a large enough tank or slurry store to hold up to 7 months' worth of slurry, for farmers in the colder, wetter regions. "There's a lot of farmers still haven't got sufficient storage," one farmer reflected (Interview 1, Beef Farmer, NW England).

It's not only the capacity of the store, but the type of infrastructure that is important. Farmers spoke to us about the whole infrastructural system that dictates whether solid manures or slurries were produced. Often, they were not able to change these infrastructures. When a system had been inherited, as seemed sometimes to be the case on smaller, less profitable farms, and on farms that are tenanted, this could be a constraint on the farmer. The farmer ends up working with a less-than-ideal system:

P: It's just the system. I haven't got facilities to handle slurry. It's always been byres, traditional byres, and straw bedding. And we haven't altered the system in the 36 years we've been there… we stack the straw muck in the midden, and then we tip the wet muck off the cubicles on top of it. It actually works like a weeping wall, where the water out of the slurry drains through the straw muck, breaks it down, and there's a collection tank underneath the midden, which collects the concentrated run off from the midden. We spread that as and when necessary. We used to do it three times a week before we covered the midden, and now we do it once a month.

Int: Big difference then?

P: yeah, the run off with the rainwater was absolutely unbelievable.

(Interview 2, Beef Farmer, NW England)

Insufficient storage infrastructure and wet weather were remarked to be the biggest issues for slurry management, according to our farmer surveys.

Table 3.1: Responses to the Question 'What is the biggest issue you face in your management of nutrients (slurry, solid manure or fertilizer)?

Respondents who self-identify as producing slurry	
Storage	17
Weather	16
Regulations	8
No Problems	8
Health & Safety	4
Cost of Fertilizer	4
Spreading	2
Weeds	1
Paperwork	1
Respondents who self-identify as producing solid manure	
No Problems	14
Spreading	5
Weather	4
Storage	3
Cost of Straw	2
Regulations	2
Cost of Fertiliser	2

Some farmers talked of people being desperate to get slurry on the land but the land being too wet. Many farmers and industry representatives recognised exactly the consequences are of having insufficient storage:

"In an ideal world I would love to have 6 months storage, but we go closed on grassland on sandy soils on the 30th August, so we have to stop spreading slurry from 1st September and legally we can go then again on the 1st January. So we've got September, October, November, December. So we can get away with that, but I'm not proud of spreading slurry at this time of year when there's not…the ground conditions are not fit, and the soil temperature is not warm enough for the grass to utilise that."

(Interview 25, Beef Farmer, Scotland)

The idea that farmers have choice over these infrastructure issues is not consistent with the farmers' responses. The first constraint is often money:

"Most farmers have got a grasp that you should use nutrients to their best possible effect, but as you have just said if your tank is full, your tank is full. What do you do? At the end of the day it's the cost of doing a new pit. As nearly every farmer would say, 'well, I'd like a new one, but where am I going to get forty grand from?'"

(Interview 26, Dairy Farmer, Wales).

Even where finances are made available (and research has suggested funds for infrastructure are very uneven across England, Scotland Wales and Northern Ireland) farm grants (FARG) to provide slurry store covers, for example, cannot always be taken up. One interviewee suggested that, despite the availability of grants, 'the majority' of farmers around his area in the north-west of England don't have covers on their stores. Under the grants:

"Every farm then gets a visit to see if the stores are suitable, and some aren't because of either age or shape or whatever."

(Interview 1, Beef Farmer, England)

We can see that the infrastructures that farmers already have on the farm are characterized by 'lock ins' whereby they constrain efforts to change to better or more efficient ones (Urry 2011; Shove 2010). This is one reason why social/infrastructural change around issues of sustainability is not simply an issue of choice. Technological systems already in place constrain change to more efficient systems.

When infrastructures are not fit for purpose, farmers have no choice but to resort to practices that are financially and ecologically detrimental:

"If it's too wet to get on the land…we have a side delivery and we shoot. We take it somewhere where there isn't immediate run-off…we can do it off the roadsides on our own land, we can do it on the fell, here on the tops, over the wall, the one inside, and the cow pasture at the front, it's free draining with no land drains hidden in it at all, it's just natural drainage, so it doesn't go direct to any water body…it's just a side chute, and it just shoots it over the hedge…You drive along so it soaks in."

(Interview 2, Beef Farmer, England)

3.2 Slurry is a Slippery Substance

As indicated in our introduction, the SLURRY-MAX project acknowledges that livestock slurry is a valuable source of nutrients and that better management of slurry would help bring about a more resilient and sustainable agricultural system. In this frame, slurry appears as a 'natural', benign substance. However, it is important to remember that this is not always the case (Bruce 2013). We relate here some of the difficulties of working with slurry that deserve reflection.

First, farmers have related how slurry is a difficult substance to work with:

"We can't mix slurry when the cows are on [the slats]. It kills them. Which is a downside, because there are times when you could spread slurry, eh?"

(Interview 4, Farmer, NW England)

Second, the research soon uncovered the relative merits of solid manure and slurry, suggesting that slurry was usually considered an inferior product, largely because of the difficulty of managing it:

Int: If you could choose, which would you rather spread on the land, slurry or manure?
P1: Manure, because it lasts longer.
P2: Manure is better for the environment. It doesn't let off as much gases.
P3: Slurry is fastest to respond, but I don't think it lasts long.
P4: Slurry seems to bring docks.

(Focus Group, Wales)

Int: So you do a muck for straw [swap]? So, people want muck?
P: It's like liquid gold.

Int: What about slurry?
P: Nobody really wants slurry.

Int: Why is that?
P: Basically, muck for straw, the lad who we export it to is just over the road here, he has a pile where he can stand the muck, he can move it about on the land—he's an arable man—so when he takes his crop off ,and before he puts his new crop in, he spreads muck on it. What do you do with slurry? It can't go on your crop when your crop is growing, so the only time you can put slurry on is when you take your crop off, before you put your new crop in.

(Interview 16, Beef Farmer, NE England)

Slurry brings with it risks – to the land as well as to cattle and to humans. Several farmers mentioned the risk of damaging soil organisms and hence the soil structure:

> P: well slurry kills the worms. I know that, because I know a contractor that reseeded some grass for a local dairy farmer that put slurry on his land, and when he was ploughing the field, somebody said to him, 'have you noticed what's different on this field?' and he said, 'What?' 'There's no seagulls or anything. Because there is no worms'.
>
> (Interview 16, Beef farmer, NE England)
>
> "It kills worms, when you inject it."
>
> "Yeah."
>
> "Then your ground is knackered, because you've killed all the worms."
>
> (Focus Group discussion, England)

The risks of slurry to people near to tanks and stores on farm premises also accompany talk of slurry:

> "I don't really like to be that close to slurry stores anyway, because you hear things, and I'm quite clumsy… when I first started three people had died. The dog had gone into the slurry, store and then the farmer went in and then the son, and they all died. It's horrible. To the actual extent that I've had nightmares about my dog running in to a slurry lagoon."
>
> (CSF officer, England).

The idea of slurry as a nutrient source is sometimes seen though rose-tinted spectacles. The chief executive of Natural England, for example, suggested to a recent House of Commons Inquiry on Nitrates (2018) that, in an ideal world, slurry generated in the west of the country could be transported over to the east where arable farmers are thought to need slurry for soil organic matter. The risks to soil alluded to above would cast doubt on this solution, as would the preference, perceived amongst our participants, that arable farmers preferred solid manure that could both be stored until the right window for application, and would offer greater organic matter to soils. So, also, would ideas about the risks of disease and weeds that slurry may carry and the fact that "it is so much easier to transport solids rather than liquid." (Interview 25, Beef Farmer, Scotland).

As another respondent suggested: "Slurry is a bit of an issue, isn't it? It's a pain." (Interview 23, Dairy Farmer, Wales). Farmers know that slurry is referred to as an asset and an important source of essential nutrients, but they also see it as a burden, and a liability. Slurry is a material that could bring serious problems to the already relatively precarious business of a typical upland beef farmer:

> "You've got to think about it because if you get caught with a pollution problem, you're in deep water. It could finish you."
>
> (Interview 3, Beef farmer, NW England)

3.3 The Importance of Face-to-Face Advice

Several of the decision support tools reviewed in Section 1 create, in effect, a nutrient management plan for the farmer. As we have already seen through the work of David Rose and colleagues, however, the mode of delivery and social context around such planning tools make a big difference to their use and usability. Research conducted in the Republic of Ireland has found that, even when such a plan is produced:

> "The plans on their own will not meet the farmer's needs and to increase their effectiveness advisory support is required to help with interpretation. To be most effective this support should extend to decisions on manure and fertiliser spreading regarding timing, soil type, application method and location."
>
> (Shortle and Jordan, 2017).

Similarly, Buckley et al (2015) found that contact with extension services were found to significantly influence adoption of nutrient management practices. Vrain and Lovett's (2016) study of the role of farm advisers for the uptake of farm measures to tackle diffuse pollution found that one-to-one advice delivery is best, but that this had to have follow up, feedback and progress monitoring. Advisors needed to build a relationship with farmers.

Interviews with advisors showed that they recognised the fact that to get 'their heads around' different software, farmers might actually require the additional support of advisory services. As they put it, much software is not 'farmer friendly'. However, some farmers struggle to afford advice:

> "I think that the bigger arable farms, the bigger units, will pay for agronomists or pay for commercial tools and help to use those tools. It's the smaller family farms, particularly extensive grassland farms, that maybe don't have that sort of cash flow, they are smaller businesses, that don't want to pay for that advice or pay someone to do it for them, they are using the free tools".
>
> (Interview 8, Tool Developer, England)

At an estimated £200.00/year to have a nutrient management plan created for a farm on an NVZ, several interviewees recognised the issue of affordability:

> "If you're a small beef farmer, you can't afford to have that done."
>
> (Interview 16, Beef Farmer, NE England)

Free advice, may, of course, come with feed and fertiliser purchase. But as one respondent suggested:

> "This is going to sound bad, but there is always an agenda, isn't there, trying to sell something? …I don't know how much talk there is around good practice…there's obviously a sale associated with that advice."
>
> (Interview 4, Tool Developer, England)

Within what many commentators have called a 'fragmented' advice landscape, the researchers found that the catchment Sensitive farming (CSF) programme offered a rare source of impartial, farmer-oriented, understandable and trustworthy advice. What was unusual about the one-to-one advice given was the amount of power given to the farmer through the CSF-farmer relationship:

> "[Farmers will] know best where the water flows on their farm. It's about empowering them, it's their decision, it's a voluntary scheme, it's totally up to them at the end of the day if they want to listen to me. I often put the ball back in their court and say you need to manage the details of how you're going to deal with the run off when we've concreted this, or you need to figure out if this roof needs cladding to keep the wind out. For me, they are just as much in charge of sorting these problems out… I always encourage my farmers to be open, spend the time with the advisor, make the most of it. Talk about the things that are an issue for you, really guide that visit."
>
> (CSF Officer, England)

Summing up this section, then, the issues surrounding farm advice are:

- Tools cannot stand in for good face-to-face advice;
- But advice giving is also complex;
- Advice must feel trustworthy;
- Advisors need to 'build a relationship';
- Advisory services from feed and fertiliser sales are assumed to carry an agenda;
- Not all farmers can afford regular advice;
- The Catchment Sensitive Farming programme offers an intelligent, farmer-facing advisory service that builds farmer trust and capabilities and could be a model for wider uptake in the UK.

3.4 Agricultural Colleges: an Overlooked Educational Opportunity

The tool developers we interviewed reported that it was very difficult to get farmers to attend tool training sessions. However, our experiences doing tool tests in agricultural colleges found that the industry often had poor links with these. This seems to be a missed opportunity – colleges are full of young farmers ready and willing to learn, and our interviews on farm suggested that sons and daughters were a common source of on-farm innovation later adopted by parents.

At the English, Scottish and Welsh colleges we visited, the lecturers made their own spreadsheet-based calculators for nutrient management, rather than using publicly available tools. Students were therefore not familiar with 'real' on-farm tools and had less confidence when they were presented with them.

> **Int: What would your dream tool be like?**
>
> P1: Simple and effective.
>
> P2: [tutor's homemade] tool. I've used it before and I know how to use it, so that's good for me.
>
> P1: Yeah. Something you know how to use.
>
> (Focus Group, Wales)

CAFRE/DAERA is a best practice example of training in agricultural colleges that we came across. In Northern Ireland students are trained on the publicly available CAFRE nutrient calculator, and the college (as with SRUC in Scotland) is fully integrated into ongoing professional development. It is worth noting that students in NI were generally very positive about the CAFRE nutrient calculator, which was included in our suite of tools for the focus group tool tests. All answered 'yes' to the question 'would this be useful on farm?', whereas reviews of the other tools were more mixed. This can be attributed to the fact that these students had been trained in the 'real' tool and were familiar with it. Both the DAERA (NI) and the Scottish tools for nutrient management scored well for usability (Table 1.2).

We would therefore recommend that tool developers work more closely with agricultural colleges, who can deliver training in a nutrient management tool, increasing uptake on farm. This could be achieved by making specialist 'educational' versions of tools (where students could, for example, experiment with the college farm file, without the original data being lost) and collaboratively developing teaching materials and worksheets.

For the broader industry, a certification of some sort (like a 'mini' version of FACTS) could be awarded for students training in nutrient management.

3.5 Governance & Support

As we have seen in Section 1.4, the provision of expert advice and decision support around nutrient planning has recently shifted, in England, from government (through Government support of RB209 and public payment of ADAS to develop and maintain PLANET) to an executive non-departmental body and the private sector (AHDB and many commercial companies). In addition, there has been a proliferation of different forms of decision support tools flooding the private sector, such that here are many apps, computer programmes, paper based and other information services available. Different advisors use different tools: costed advisory services for whole farm nutrient planning are now commonly available for around £200-400.

The governance and support of slurry and nutrient management advice differs across the devolved regions of the UK.

- In Northern Ireland CAFRE (College of Agriculture, Food and Rural Enterprise) has led a programme to host information and nutrient planning advice and digital decision support on the central '.gov' website. Nutrient management decision support is free to users and draws substantially on information already gathered by the state (e.g land holding maps).
- The Scottish government has pledged to financially support the free 'industry standard' nutrient management decision support system, PLANET, developed and maintained by ADAS, which for users in England will no longer be updated or maintained.
- In Wales, farmers are encouraged to make use of tools such as PLANET and MANNER-NPK, the Fertiliser Manual (RB209) and seek advice from a FACTS qualified advisor to help draw up a nutrient management plan. Through the Farming Connect advisory service farmers can access up to 80% funding towards Nutrient Management Planning.

Within this differentiated landscape, the AHDB is making it a priority to support the development of evidence-based information and tools, including the 'interactive crop Nutrient Management guide RB209', with the aim of helping levy payers become more competitive and sustainable (AHDB Annual Report 2017: 6).

Also relevant here is AHDB's commitment, under their second strategic priority, to focus on what is driving productivity and competitiveness to inform good decisions on farm and to try to speed up the adoption of innovation on farm through research and knowledge exchange.

The AHDB is evidently aware of the pressures on all farmers, including those producing beef, to survive and thrive in a demanding and volatile post-Brexit situation, as well as the need to demonstrate return on its levy. Levy payer satisfaction of all farmers, standing at 37% in the 2015/16 annual survey, was reported to have increased by around 10% to 46.7% in the Autumn/Winter 2016 levy payer survey (AHDB Annual Report 2017). Despite this, it is unclear as to whether beef farmers, even if they are aware of the AHDB, really engage with the organisation or know what they receive in return for payment of their levy. As an AHDB employee suggested to us: "a lot of them [farmers] don't know how much they are paying," and, regarding smaller beef farmers: "there's a huge part of the industry that we don't talk to…we've just let them get on with it". This sentiment is backed up by our research: although many of our respondents had heard of the AHDB, they had not looked any further for support from them for any aspect of their business, including nutrient management.

A nutrient management plan costing £200-400 is considered by some to be affordable for the average British beef farmer, but our 84 survey interviews indicated that only half of those farmers purchase nutrient planning advice, many of them suggesting they couldn't afford such a service. It seems relevant now, then, to ask, what the AHDB's responsibilities to the smaller, less profitable beef farmer are, at a time when it is widely expected that these farmers will struggle under the coming uncertainties of Brexit. This question is particularly relevant in England where no farmer-friendly, publicly maintained tool aimed at the smaller, less profitable beef farmer exists.

Improving Decision Support Tools

Digital decision support tools – and the reasons why farmers do and do not use them – were a primary focus of SLURRY-MAX project.

The qualitative fieldwork undertaken in Work Package 2 discovered that the majority of farmers interviewed did not use a decision support tool. Just 12 of the 84 farmers surveyed used decision support tools (paper or software). Although some farmers were unaware of these tools, even among those that were aware of them, or had previously tried them out, their use remained unpopular. Of the eleven farmers we interviewed in depth, three had not heard of any of the digital nutrient management tools identified in work package one (such as PLANET, MANNER and Crap App) and eight were aware of and had tried the tools (PLANET being the most common) but chose not to use them.

The reasons given for this were almost universal, and the same reasoning was also repeated across all of our tool tests in agricultural colleges: that the tools were too difficult to use, and they required too much time and data input for not enough data return (see also Rose 2016, where the strongest reason for the lack of use of Decision Support Tools was not enough return on the effort required to use the tool).

Our interviews with tool developers showed that this argument was, to some extent, a familiar one. The response to it, however, tended to focus on factors beyond the tool developers' control: particularly, the argument that, 'they're not very good at record keeping, farmers', and that 'some of them aren't computer literate' (Interview, Tool Developer, England). This was the reasoning behind the production of paper tools, such as Tried and Tested, by the Professional Nutrient Management Group, a consortium of industry partners (AIC, BGS, CLA, Leaf and the NFU) looking to expand advice provision around nutrient management.

Our research, however, found a number of indications that ran counter to the 'computer illiterate farmer' argument. Although some farmers interviewed declared they did not use computers (three of eleven) a greater number were familiar with a range of digital tech, regularly using laptops, iPads or internet enabled smartphones; engaging with social media; and perhaps more interestingly, adopting digital farm management techniques, such as Shearwell animal identification systems or commercially provided herd management programmes.

It is particularly worth noting here that the British Cattle Movement Service, a compulsory cattle tracing system managed by the UK Government via the Rural Payments Agency, only allows farmers to register and change cattle passports online, via the Cattle Tracing System service. This means that every beef farm in the country must use a networked computer to process cattle data online. For 'computer illiterate' farmers, this system is likely to be managed by a family member. It is arguable, then, that if time and data requirements were not onerous, this same family member could also use a digital tool requiring equivalent computer literacy to the Cattle Tracing System to create a workable slurry/manure and nutrient management plan; especially where informed nutrient management decisions are a legal requirement (such as within an NVZ), or where failure to have a plan could potentially jeopardise Farm Assured status or lead to withdrawal of RPA or basic payments.

For us, then, the 'computer illiterate farmer' argument was insufficient to explain repeated complaints that decisions support tools were difficult to operate and time consuming. We therefore attempted to unpack the nutrient planning workflow across the suite of freely available tools identified in work package one, to work out how these could become more farmer friendly.

In response to this, many of our tool interventions focus on two central areas:

1. Simplifying the tool interface for clarity and ease of use,

and

2. Reducing the data input requirement by making use of existing digital farm records.

Our detailed responses to a range of tool issues are explored below.

4.1 The tool must answer a question a farmer is asking

It's perhaps stating the obvious to declare that tools must provide a service that farmers want, but it is worth re-iterating.

This is particularly important around decision support directed towards slurry and manure management, as farmers and students pointed out to us repeatedly that the timing and amount of slurry spread was, in most cases, not a 'decision' but driven by the amount of slurry in the tank, and the need to 'get it out':

> "If your slurry tank is full, it's just got to go out. You can't say, 'Oh, I'll just wait another month,' or whatever, because it would be flowing out." (Focus Group, England)
>
> Most people aren't bothered, because they've got that much slurry they're just, 'Get it in that tanker, get it out on the field.' How good it is or not doesn't matter, you just want rid of it. What are you going to do with it? You can't put it down the beck, can you? You're just going to fire it on, 2,000 gallons. You could test it, in an ideal world, but no-one's really like that. If your storage is full you just get it out. You've got no bloody choice, if your storage is full, you've got to have it gone. Regardless to how good it is."
>
> (Focus Group, England)

As discussed in section 3.1, infrastructure was the biggest driver of slurry spreading, not calculations of maximum nutrient take-up by the crop. Most farmers were aware that it was better to spread in spring, but still found themselves spreading in winter because of storage issues. Under those conditions, tools that help the user to decide when to spread slurry, and how much to spread, are superfluous to requirements.

A demand for decision support was evident, however, around two nutrient management questions.

The first of these only applied to users within an NVZ (which included all farmers in Northern Ireland), and, for these users, eclipsed all other concerns around nutrient management. This concerned ensuring that your farm complied with NVZ requirements, and that you could produce a nutrient management plan that would meet regulatory standards.

For these farmers operating under regulatory rules, the most important question a nutrient management tool should answer is:

How can I comply with my NVZ requirements?

> "[MANNER-NPK] gives the whole cost of it all, and I don't think that's really necessary. Just knowing how much to put on so you're under your Nitrates Regulations."
>
> (Focus Group, Northern Ireland)
>
> "I know a Defra inspector who's into Limousin cattle, and he did tell me, and I have read, that almost every farm they go on, or wherever there is a non-compliance, it is usually to NVZ… I've spoken to people about NVZs and how they manage it, biggish farmers, one's a dairy farmer and one's a contractor, they just pay someone to do it for them. These are big farmers, so obviously they can do it, because they could be big perpetrators with the legislation. So it's worth their while to pay someone. And I think I got a quote from someone, and it's like £200 a year. Whereas if you're a small beef farmer you can't afford to have this done… All I would say is there needs to be a simple tool, that's easy to use, plug and play, you don't need to have a degree to operate it, and whatever legislation they bring out about NVZs needs to be practical."
>
> (Interview 16, Beef Farmer, NE England)

Outside of NVZ requirements, participants were much more interested in a decision support tool that intervened not at the point of manure or slurry spreading (which was largely driven by external forces, rather than the need to make a nutrient management decision) but at the point of fertiliser spreading, which required two important decisions on the part of the farmer:

Which fertiliser should I buy, and how much?

> "It should be telling you how much fertiliser you should be using, when, and the rates. Manure, you have a set amount, and that's how much to go out, before next winter."
>
> (Focus Group, Wales)
>
> "[The CAFRE nutrient calculator] is a useful tool, but basic recommendations could be provided, for example some examples of a fert plan instead of trying to figure out on your own what fertilizers you need."
>
> (Focus Group, Northern Ireland)
>
> "It would be nice to see recommendations, so what you should have to do to improve your field."
>
> (Focus Group, England)

Although most tools provided recommendations on nutrient requirements, agriculture students testing tools indicated a desire for this to go one step further, and match requirements up to commonly available fertilisers, and application rates, rather than leaving that final step to the mental arithmetic of the user.

4.2 It should always be clear what the tool user has to do next

During tool tests, we observed that nearly all students spent the majority of their time looking at the tool interface and wondering what to do next. This generated an insecurity around tool use ("I don't know if I'm doing it right") that was a severe impediment to user satisfaction.

Table 4.2: Simplifying data input

Tool Used	Number of written focus group feedback submissions for each tool (participants did not submit feedback for each tool used)	Number of responses to the question "How do you think it could be improved?" saying data input should be simplified
PLANET	6	6
MANNER	11	10
Slurry Wizard	5	3
Crap App	15	10
CAFRE nutrient calculator	3	1
Scottish N-Max calculator	1	1

These observations were supported by discussion in the focus groups. For example:

> "I spent about ten minutes looking at the wrong bit…I think you'd struggle unless you were shown how to use it."
>
> (Focus Group, Wales)
>
> "There's so many sections you can click on, and knowing each one does, and the data you have to put into them, is quite a bit…"
>
> (Focus Group, England)
>
> **Int: What would make MANNER-NPK easier to use?**
> P: Make it easier to navigate through.
>
> (Focus Group Scotland)
>
> "It's confusing. I don't know what to click on. It's just a load of figures that mean nowt."
>
> (Focus Group, England)
>
> "It's good, but there's no instruction to it. There's a lot of information, but I don't know how to use the information."
>
> (Focus group, England)
>
> "Yeah, it could do with instructions on what to actually…what it actually wants."
>
> (Focus Group, Wales)

The most obvious answer to this problem is to replace the standard 'spreadsheet' interface used in nutrient management tools with a narrative interface – a "step-by-step approach" (Focus Group, Scotland). In a narrative interface, the user is given a clearly ordered set of commands, taking away the necessity for them to work out what they have to do next. Such a narrative approach is used across a range of digital tools that require the infrequent input of complex information by a diverse audience, the most obvious being HMRC's online tax self-assessment system.

Ideally, a tool should be immediately obvious to a user working unsupported at home and should not require training to operate. During tool tests, we found that even where help guides, and instructions were provided, users very rarely began by referring to these, instead going straight into the tool.

> "There's a guide at the start, but it's really long. I didn't want to read it."
>
> (Student, Wales, on Slurry Wizard)
>
> "Yeah, you have to sit through loads of information [in the help guide] to get to the bit you want."
>
> (Student, Wales, on PLANET)

In interviews, tool developers discussed how difficult it can be to get farmers to attend training events, and that providing training is expensive and time consuming. It is likely that only a small proportion of a tool's targeted users will ever attend formal training.

Furthermore, as nutrient planning is done relatively infrequently—it is likely the system will only be used once or twice a year—interviewees pointed out that even users who have been trained in a complex system (such as PLANET) have often forgotten this training when they come to use the software for their next round of planning. Therefore, it is vital that any software dealing in nutrient management is optimised for conditions of first use by an unsupported user. A narrative interface does this by clearly signposting what information is necessary for the user to provide, and in what order, reducing the cognitive load of the user and allowing them to focus on making the plan, rather than operating the tool.

Figure 4.1: An example of a narrative interface. There is only one data input category for the user to focus on, and the reasons the tool needs this data is clearly explained.

4.3 The tool should be integrated with existing farm-level data

Data input for nutrient management is extremely onerous and time consuming. In order to calculate an NVZ compliant nutrient management plan that incorporates both N-Max and N-Loading on PLANET, the farmer has to input all the following information:

- Farm Name
- Postcode
- STD Code
- Name of every field, individually inputted, with field areas, cropped areas and soil type
- Area of farm in NVZ; fields in NVZ
- Crop group and type for each harvest year for each field (minimum two years)
- Current sward, last year's sward and previous grass history for every field
- Defoliation sequences and grass management for every field (minimum two years)
- Application date, rate and type of organic manures, method of incorporation and delay to incorporation for this year and previous year
- Application date and type of fertiliser for this year and previous year
- Livestock group, types and average numbers per year
- Livestock occupancy as a %

Although changes in the most recent edition of RB209 have reduced some of this complexity (with input requirements for defoliation and grass management replaced by target yield) the nutrient management process is still data-hungry.

> "It's got to be easier, you don't want to be sat faffing when you could be doing something else."
>
> (Student, England, on Crap App.)
>
> "A lot of information is needed. It's confusing to put everything in."
>
> (Student, Northern Ireland, on Slurry Wizard.)
>
> "It was quite hard to use, it's quite complicated and you've got to fill a lot of information in."
>
> (Student, England, on MANNER.)
>
> "It was not an easy tool to understand and did not allow decisions to be made quickly and efficiently".
>
> (Student, Scotland, on Scottish Government's N-Max Calculator)

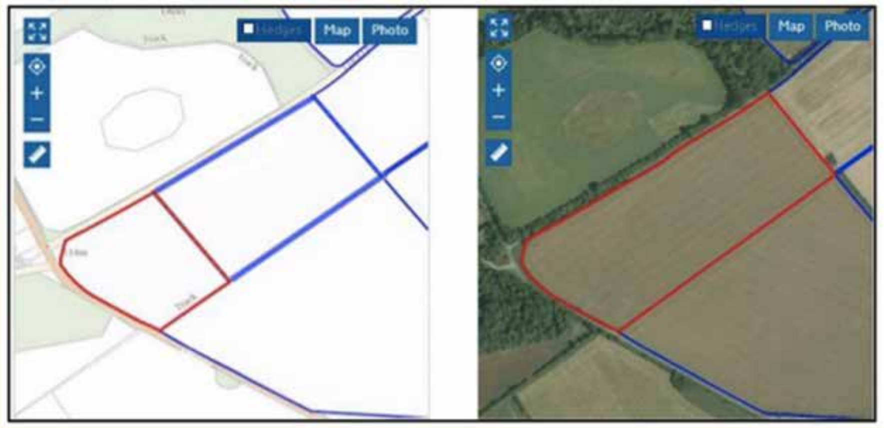
Many of the data inputs are not only onerous, but also deceptively complicated. To calculate N-Loading for NVZ compliance, for example, farmers must state the "average number per year" they have of cows of different types. This basically means how many cows they have within certain age/sex categories (e.g. calves younger than two months; beef cows or steers from 2 months and less than 12 months; non-breeding bulls 2 months and over; bulls for breeding from 2 to 24 months). But as this is an annual average, and cows get older throughout the year, this is a complex calculation to make: an heifer calf will only be under two months for 1/6th of the year: does that mean she should she go into the calf category, or the cow category? Should she be double counted in both? Should a complex fractional calculation be undertaken to establish the percentage of time she is a calf and the percentage of time a cow?

Uncertainty and frustration for users is compounded by the fact that the data they must manually input into the tool already exists digitally. Therefore, we would recommend that wherever possible, existing farm-level data be imported from other digital places, rather than requiring manual input. The two main data sources we recommend ensuring compatibility with are the following:

RPA land parcel maps

In England the Rural Payments Agency holds digital land maps that provide information on all the fields on a holding and their size, location, and land cover (arable, grassland, crops, non-agricultural areas). Devolved agencies hold similar data.

Figure 4.2: RPA's digital mapping service



According to the Rural Payments Agency, there has been some interest from farmers in accessing their spatial data to use in farm software packages. The RPA can issue the spatial data under a Public Sector Mapping Agreement[23] end user licence, provided it's used for Common Agricultural Policy purposes – which would be the case for nutrient management planning.

> **Int: What would make MANNER-NPK better?**
> P: Include aerial maps of the fields to help make the data linked. (Focus Group, Scotland)

RPA map data is held digitally, so there should be no issue in integrating this data with digital tools, and this has been done in Ireland and NI (e.g. for farmers entering the Environmental Farming Scheme in NI). Participants were generally in favour of a graphic interface over the more traditional spreadsheet presentation, and very positive about maps where they were used, in the newest version of Crap App. However, all found drawing their own field boundaries very difficult.

Cattle Tracing System

The Cattle Tracing System online contains a list of all cattle on a holding and their ages, sex and when they came onto the farm. It is already set up to allow compatible farm software packages to link straight through to the Cattle Tracing System via an internet connection.

Figure 4.3: CTS data can be downloaded in a simple .CSV file format

ANIMAL BREED	ANIMAL SEX	ANIMAL DOB	DATE MOVED ONTO HOLDING
LIM	F	08/04/2009	21/01/2012
LIM	F	26/04/2009	17/12/2014
LIM	F	08/04/2010	28/08/2016
LIM	F	19/07/2010	28/08/2016
BBX	F	16/01/2005	16/01/2005
LIM	F	08/04/2006	08/04/2006
LIM	F	11/04/2007	11/04/2007
LIM	F	26/07/2009	26/07/2009
LIM	F	07/11/2011	07/11/2011
LIM	F	01/06/2012	01/06/2012
LIM	F	01/06/2012	01/06/2012
LIM	F	03/03/2014	03/03/2014
LIM	F	06/09/2014	06/09/2014
LIM	F	27/09/2014	27/09/2014
LIM	F	01/08/2015	01/08/2015
LIM	F	12/09/2015	12/09/2015
LIM	F	19/09/2015	19/09/2015
LIM	F	06/10/2015	06/10/2015
LIM	F	10/03/2016	10/03/2016
LIM	F	29/03/2016	29/03/2016
LIM	F	26/04/2016	26/04/2016

[23]The Public Sector Mapping Agreement (PSMA) is a collective agreement between OS and the government. Its licence lets users access and share OS digital mapping.

4.4 The tool should be integrated with existing national-level data

The 'MAGIC' mapping service provides geographic information about the natural environment from across government. This includes a suite of useful information for farmers, including the location and environmental status of water courses, NVZ areas and local Countryside Stewardship priorities. According to a representative of the Environment Agency, the licensing of this data allows such use, it simply requires the correct interface to allow access to be provided. Again, this kind of model, where existing geographical data is brought into decision making around farm practices is used elsewhere, e.g. to assist in the choice of agri-environment options in NI and Wales.

Figure 4.4: Magic Map data layers showing Higher Level Stewardship target areas, and Countryside Stewardship targeting priorities. The system contains a wealth of environmental and legislative data.

4.5 The tool should be integrated with the wider decision support landscape

Study participants, in general, expressed a preference for face-to-face advice wherever that was possible. The optimum role for a tool was as supplement to this advice, or to use where the first-best option (face-to-face advice from a FACTS qualified advisor) was unavailable.

> "You'd be unsure. You might use one of those apps to put a load of nitrogen on, you might spend a lot of money, and you might put too much on. You don't know how accurate it is. You'd be always doubting it, wouldn't you? Whereas if you had a second opinion, a professional, you'd think well I've paid him, so you'd have a bit more trust in him." (Focus Group, England)

As best practice, decision support tools should recognise this preference, and present themselves as a part of a wider decision support landscape, rather than a replacement for face-to-face advice. The app should have links to the BASIS advisory register, for example, so users can access a local professional advisor at any time during their nutrient management process. The Magic Map data overlays can show a user whether they are in a Catchment Sensitive Farming area and eligible for free advice. It can also show if there is potential to join a stewardship scheme, and if so, what the regional priorities are.

Ideally, the app could contain real-time notifications of available grants (national or local) and upcoming regulatory changes.

It would also be beneficial for the tool to have two modes: farmer, and advisor, with the requisite level of detail and ease of use for each. An advisor who is using a tool every day is likely to prefer functionality over simplicity. A farmer, on the other hand, needs a simple and accessible narrative at each stage of data input. Information should share easily and directly between these versions, allowing integrated management between farmer and advisor and facilitating both the provision and use of face-to-face advice, and explicitly recognising the collaborative nature of decision support (Suchman 2007; Castañeda and Such man 2014). The tool should also have functionality to allow data from other equipment (such as tractor-mounted GIS or N-sensors) to be imported if necessary.

Finally, it is vital that any tool have good, human-based technical support. This can be provided in a range of ways; via telephone (as ADAS provided for PLANET users before the support provision restructure and withdrawal of Defra funding), by online 'chat' (for best service this should be with a real operative, not an automated response) or, if neither of those professional support options can be provided, at the very least peer-to-peer support via social fora such as Facebook. Our research suggests that the vital role of ongoing, professional technical support should not be neglected in the provision of any support tool.

4.6 The tool should make testing as simple as possible

Soil testing is an extremely important aspect of good nutrient planning and was perceived very positively by participants. This was matched by a distrust of any default values used in calculations.

> "Well, there's no point in starting using PLANET or something unless you've got your basic information right, else you're…you might as well just carry on as you are. If you can't put it in, there's no point in guessing, because you might be totally wrong."
>
> (Interview 1, Farmer, NW England)
>
> "It's a waste of time putting fertilizer on if you don't test your soil, you might as well just put it in the river."
>
> (Focus Group, England)
>
> "You'd need your soil testing first. If you start from you don't actually know, you'll always be wrong."
>
> (Focus Group, England)
>
> "If you're going to tell us what to put on, we don't want a rough estimate, we want to know what it is."
>
> (Focus Group, England)

This mistrust of the default values seems largely justified. Slurry, especially, is extremely variable, with a coefficient of variation for N content, for example, of around 20% (Shepherd and Smith, 2003). For users that haven't tested their soils within the last four years, the app should allow you to either commission an advisor to come and do this or send off for a testing kit to do it yourself.

Our interviews with soil testing companies suggested that these tend to market mainly to advisors and agronomists and did not advertise to or engage directly with farmers. One advisor we spoke to said that he often encountered farmers who were unsure how to go about procuring testing kits and testing their fields. The app should endeavour to close this gap and make testing as easy as possible. Ideally, test results should either upload automatically into the app, or if not, the app should accept common test result formats for manual upload. This suggests the need for discussion between companies and app developers regarding standard formats – for soil test results and also for the data input fields required by apps.

4.7 If including cost-benefit analysis in the tool, this should be as complete as possible

A number of the tools we analysed included supplemental economic data on various costs or benefits of slurry spreading and storage. These are summarised in the table below:

Table 4.3: Economic Information Included in Tools

Tool	Economic Information
Slurry Wizard	Cost of building store
Cost of covering store	Fertiliser savings from applications of manure
MANNER	Fertiliser savings from applications of manure
Crap App	Fertiliser savings from applications of manure
PLANET	Fertiliser savings from applications of manure

Although farmers were interested in this cost-benefit information, other costs frequently came up in interviews and focus groups. One example is the fuel costs of spreading/transporting slurry. Covering your slurry tank to keep out rainwater, for example, can reduce the volume of your slurry significantly, meaning less trips with the spreader, saving both time and fuel. To integrate this into the cost benefit analysis, app developers would need to incorporate the distance to, and area of, fields to be spread (which could be provided via the map imported from the RPA), average rainfall (already accessed via postcode/STD code), volume and circumference of tank (already provided by the farmer for existing calculations). The only new information required would be the capacity of the spreader, which is easily accessible information for the user. With the addition of payment rate, this could also cover contractor costs (see Section 5.2).

Currently, the economic information already provided by the tools is discrete. This could also be integrated to give the user a better cost-benefit of improved slurry storage, taking into account the differing values of slurry during the winter and spring.

Photography: Katrina Macintosh

Photography: Katrina Macintosh

Work Package 3: Technological support for on-farm slurry management: current practices and prospects

5.1 Enhancing the RB209 grassland workflow

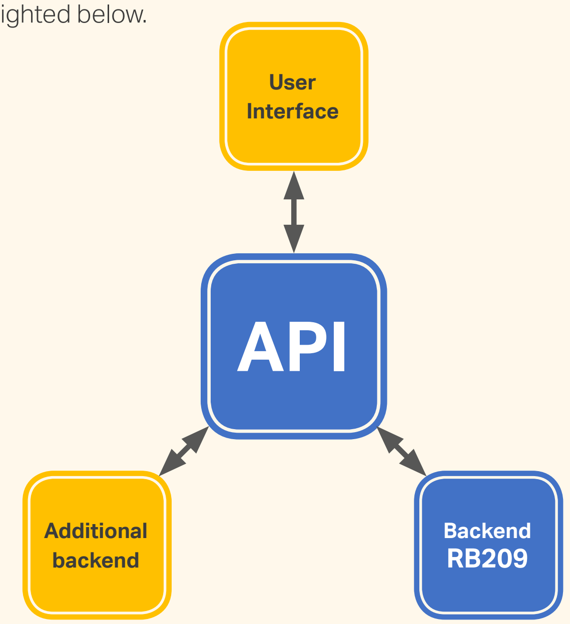
Figure 5.1: Summary of the RB209 workflow for a grassland farmer.

The RB209 approach to nutrient planning is summarised in Figure 5.1. For each field the farmer starts with a target annual pasture yield (in tonnes dry matter) and tested or estimated soil and manure nutrient properties. The farmer can then specify a manure application rate and estimate any nutrient deficit to be replaced with mineral fertiliser. Therefore, to calculate a farm-level nutrient management plan using RB209 the farmer must know i) target grass yield per field, ii) soil properties for each field, iii) manure properties and iv) total volume of manure available for spreading. The paper edition of RB209 provides supporting material on these and guidance on estimating pasture growth.

However, it is apparent from the results of the sociological research carried out as part of WP2 that for many of the beef farmers surveyed, their nutrient planning was driven by compliance, or even custom, rather than target pasture yield. In the words of an advisor present at the Newton Rigg focus group: "Most of the guys here rely on their fathers or grandfathers to say, 'Well, we put on 20,10,10. That's what it's been for 50 years".

This suggests that to increase adoption of DSTs more signposting is required around this part of the process and more practical, farmer-relevant support needs to be made available to farmers around pasture management. While Figure 5.1 implies there is an explicit order of data entry, many tools do not explain why these steps are necessary, and what they will accomplish for the person inputting the data. This has been highlighted by the social research as an area for improvement.

Figure 5.2: Summary of components of a complete farmer useable system.
Existing components in blue, missing components in yellow. Freely available user interface not currently implemented suggested structure is given below. Additional backend would be required to implement additional functionality highlighted below.



Starting with the existing RB209 approach and API (Figure 5.2) we have developed a prototype tool and workflow which may better support farmers in their nutrient planning. The prototype uses a narrative interface to guide the user through the nutrient planning process. The interface changes depending on the question being asked by the farmer.

We can categorise the prototype elements into 3 categories:

1. Functionality already exists in the API, i.e. simply pass data in and receive desired results.
2. Functionality can be implemented in the interface above the API (e.g. NVZ restrictions, fertilizer mix recommendations). This requires some post-processing of the API results, possibly combined with information provided by the user.
3. Functionality would require additional backend processing (e.g. calculation of slurry produced).

As described below there are existing AHDB tools and guidance that could be incorporated into the API that would substantially increase the functionality:

1. Slurry Wizard: to allow estimation of slurry production and storage requirement from on-farm livestock;
2. AHDB Beef & Lamb feed guidance: to allow estimation of target grazing and silage/hay yields which is a key driver for nitrogen requirements.

There is also a clear benefit of using existing map data to reduce the burden of setting up farm and field structure within any tool and providing e.g. data on watercourses. These data could be made available through RPA (individual farm/land maps) and Defra ('Magic'), (section 4.4).

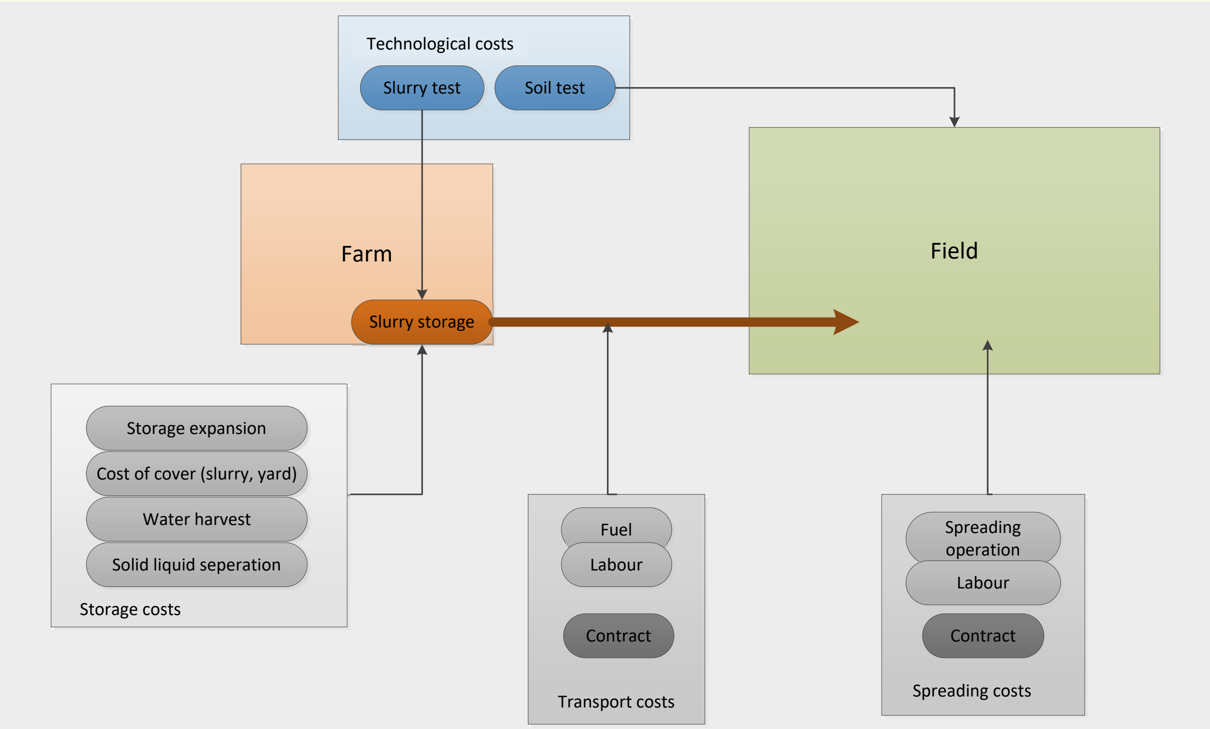
In addition to the import of map data, the incorporation of livestock tracing data would again relieve the burden on farmers to input complex estimations of cattle numbers. Data should be imported from the British Cattle Movement Service (BCMS) for this (section 4.3). A summary user pathway for a nutrient management tool showing potential data inputs can be found in Annex 4.

5.2 The processes and economics of slurry management

Slurry management is a labour and energy intensive activity that includes slurry collection, storage and spreading or distributing to a field (or slurry using plant such as anaerobic digester). Planning these activities optimally to the resources and need of the farms is required to manage slurry most cost-effectively on farms.

Slurry management on a farm can be divided into four stages based on the activities and costs associated with them. A brief description of each of these stages is provided below. A schematic diagram is presented in Figure 5.3 to show different stages of management activity and associated costs. A summary is provided in Table 5.1.

Figure 5.3: Activities under different stages of slurry management



Stage 1: Tests

This stage includes testing soil and/or slurry for nutrient contents. This allows the farmer to determine the potential nutrient supply from these sources more accurately and to plan their slurry management. As testing is central to accurate nutrient management, the integration of test results, and their clear interpretation, need to be incorporated into DST interfaces.

Stage 2: Storage

Slurry storage capacity is based on the volume of slurry which, as stated in the SSAFO Regulations, includes excreta produced by housed animals and run-off from solid manure stores, bedding, rain water and washings. If slurry storage is required in addition to existing storage capacity, this needs to be included in the cost benefit analysis. The costs of expanding slurry storage can be reduced by decreasing the volume of slurry through minimising rain water from roofs directly entering into slurry pits. This can be achieved by installing slurry covers, yard covers, fixing gutters and downpipes, as well as using a solid-liquid slurry separator. Different options for harvesting water can be included to reduce water costs.

One of the existing DST tools, Slurry Wizard, can determine slurry storage issues on farm and can be used to calculate the costs associated with different storage options. The data required to calculate costs under this stage are: the number of housed animals; annual rainfall, unit cost of slurry storage; slurry cover; yard cover and costs of a separator. The benefits of using storage covers and liquid separators can be translated (later in Stage 3) into savings made due to reduced volume of slurry. For example, one of the mechanical methods, Screw Press separator removes water from the slurry and can reduce spreading costs by 1/6th (Dairy Development Centre, 2012). Integrating Slurry Wizard into a broader manure management DST will allow farmers to more easily estimate production of manures and any changes of storage capacity required following management changes. Fully integrating slurry production and storage in decision planning creates the prospect of a fully optimised nutrient plan for the farm.

Stage 3: Transport

This stage includes moving slurry from storage to the fields to be spread (or to other points such as AD plants or other farms). The costs incurred in this stage are: costs of machinery; fuel; and labour costs. The machinery costs include depreciation and repair costs. Fuel and labour costs require current fuel price and labour hire price. The main factor that affects the overall cost is the volume of the slurry and distance of fields (or other sites) from the farm. As mentioned earlier, the volume of slurry produced is reduced if storage cover and liquid separators are used. These costs are combined with costs of spreading (Stage 4) if the farm owns machineries that are used in transport and spreading. Farms with no machinery, generally contract out these activities. In such case, contract costs need to be compared against other options (see section 4.7, above).

Stage 4: Spreading

This activity incurs the costs of machinery (combined with stage 3), fuel and labour. These costs are based on the size of the field where slurry is spread. There are a number of spreading methods for a farm to choose from and farmers can make decisions on a method that returns the best economic value to the farm. The direct benefit of slurry spreading is to replace inorganic fertiliser use and hence make savings on fertiliser purchase. The indirect benefits are improvements in soil quality with an increase in crop and grass production and hence increased farm revenues. The savings from fertiliser replacement have been included in some of the existing nutrient management tools (Crap App, PLANET, MANNER-NPK). Data on improvement of crop and grass production is scarce and limited to experimental trials (Livestock Northwest, 2011; Haynes and Naidu, 1998; Garg, et al., 2005; Ndayegamuiye and Côtè, 1988).

Table 5.1: Costs and benefits of different stages of slurry management on a farm

Stages	Costs	Benefits	Options and constraints
Stage 1 – slurry test and soil test	Costs of testing (on-farm and commercial laboratories)	Information on nutrient status which assist in planning more effectively. An on-farm testing tool may lower the costs of technicians and lab tests, but accuracy may be lower.	A number of testing tools are available The main constraint is the cost and ease of use.
Stage 2 – slurry storage	Storage costs Slurry cover Yard cover Water harvesting activity Solid liquid separator	Slurry and yard cover will minimise the water getting into slurry reducing volume A separator also reduces the volume of slurry by removing solids from the slurry store Additional benefits of covers- • Reduces ammonia and methane emissions • Reduces odour (a reduction up to 80% can be achieved by using impermeable cover (Van der Zaag et al., 2015)	Different types of storage, covers and separators exist. Costs can be the main constraint and costs will also vary with the amount of slurry produced on each farm.
Stage 3 – Slurry transport	Fuel costs Labour costs Depreciation cost of machineries used to transport slurry from storage to the field (or contract costs)	Identifying the most practical and cost-effective option	Options include different tractors, umbilical systems and/or contractors. Constraints include the distance from fields to slurry storage tanks, field size and tanker size.
Stage 4 – Slurry spreading	Machinery costs Fuel costs Labour (or contract costs)	Identifying the most practical and cost-effective option Improvement of grass/crop production and soil (potential yield changes/increase in soil organic carbon, less ammonia emissions if low trajectory spreading methods are used). Fertiliser replacement savings	Options include different spreading techniques and machinery. Constraints include cost of equipment and the size of farm.

Prospects for optimising the economics of manure management

If tools include an economic optimising section, making available a number of management options under each of the slurry management stages listed in Table 5.2, and if we assume that some farmers are able to change their existing management practices, farmers can select the most practical and cost-effective option through the use of the DS tool.

There are a number of economic methods that could be used to represent the optimisation of farm management systems that may assist decision making on farms. Economic optimisation can be carried out by configuring optimising farm level models (Glenk et al., 2017; Shrestha et al, 2007; Gibbons et al., 2005) or using the MACC method (Moran et al., 2010; Eory et al., 2013). However, these methods are data intensive and too complex to be included in existing DSTs for slurry management. A simple cost benefit analysis (CBA) or cost effectiveness analysis (CEA) could potentially identify the most economically optimal management system. This method has been used in much farm level research to determine optimal management strategies for different purposes (Berentsen et al., 1992; Bell et al., 2008; Bizoza and de Graaff, 2012; Schaap et al., 2013).

5.3 On Farm Technologies for supporting manure management and processing

Table 5.2 below provides a summary of technologies that are being used in managing slurry. The technologies have been divided into the role of the technology in either; 1) treatment or 2) measurement. Information is provided on the effectiveness of the treatment technologies for either separating out physical components and/or nutrients or changing the chemical and biological composition of slurry. The measurement technologies determine the physical or chemical properties of slurry to evaluate its nutrient content (using near infra-red or test kits to determine N, total P and total K content of slurry) or ease of application to land).

Table 5.2: Summary of technologies for managing slurry

Technology	Details	Advantages	Disadvantages	Key message	Reference
Treatment technologies					
(TRL = 3)	This is a novel method that involves ultrasound and electrolysis that separates the aqueous fraction of the slurry and nutrients. The equipment for this technique is expensive at the moment but shows promise in terms of using the liquid portion of the slurry for irrigation and nutrients as fertilisers.	Separates nutrients which can be stored Cost savings on fertilisers if the slurry derived nutrients can be stored and spread Possibly the liquid fraction if not used can be discharged (but need to confirm if nutrient levels are within the limits)	Expensive New and needs to be tested further in terms of its efficacy	A slurry dewatering and purification system that could reduce the volume of slurry by 80%, making it easier to store and spread.	Parrott, H (2018). New system could reduce slurry volume by 80%. Farmers Weekly. 12th February.
Acidification (TRL = 2)	Reducing the pH of slurry shifts the equilibrium of N towards the NH4+ state rather than the gaseous form which is NH_3	- H2SO4 is preferred as S is also needed as a nutrient but HCl, HNO3 have also been used. It is easy to obtain these acids commercially.	- High cost Acids corrosive so can affect slurry stores	Acidification reduces pH and minimises N loss in the form of NH3.	Fagueiro et al (2015). Acidification of animal slurry – a review. J. of Env Management 149 : 46-56
Mechanical separators (TRL = 9)	Separators either work by sweeping slurry across a screen, allowing liquid to drain and collecting solids or screws that exert more pressure on the material to extract more moisture	Affordable with evidence of efficiency.	Does it work for all kinds of slurry and slurry infrastructures?	Reduces volume of storage for solids by 20-30% and liquid can be applied by a low cost irrigation system.	James, D (2011). Farmers urged to see slurry as a cheap fertiliser. Farmers Weekly. 4th February, 2011.
Anaerobic digestion (TRL = 8-9)	Anaerobic process where bacterial culture metabolises feedstock and produces energy and digestate as a source of fertiliser. Digestate produced can be sometimes separated into liquor and fibre (solid fraction)	Feedstock can be utilised as a substrate to obtain a renewable source of energy and fertiliser	It is expensive to set up an anaerobic digestion plant – although some grants are available. There is a certification process such as PAS 110 or the Quality Protocol which measures/ensures the quality of digestate.	Anaerobic digestion is a well-established technique that can utilise feedstock such as slurry, usually in combination with other biowaste streams, to obtain energy and fertiliser. Anaerobic digestion does not help with the problem of the transport of slurry, however, since most farmers will not have an AD plant on-site and will need to export this material from the farm. Neither do AD plants help with the problem of volume of slurry/digestate. Most AD plants will require amounts of other organic material (e.g. straw, in addition to slurry) to keep the digester going. This requirement for mixed inputs has implications for the siting of digesters: not all farmers will find AD within practical distance from their own farm.	NNFCC, The Official Information Portal on Anaerobic Digestion: Official Biogas Plant Map. The National Non-Food Crops Centre, York, UK.
Measurement technologies					
Near infra-red (NIR) sensors L = 8-9)	Near infra-red spectra is a bespoke technology for measuring various parameters such as nitrogen, phosphorus and potassium in organic materials. Analysis of the spectra can be used to provide a quantitative measure of target analytes present in the sample.	NIR is easy to use and there are commercial software available that help in analysing the spectra to enumerate the quantity of target analysts in samples. Commercial laboratories use NIR routine to analyse samples. John Deere have developed a tractor mounted tool which measures slurry composition during spreading.	Many samples have to be used to establish a calibration curve against conventional methods. The calibration curve can be used routinely but only for samples of a specific composition and this cannot be used as a universal tool.	NIR is a simple and yet accurate tool that can be used to measure nutrients in slurry samples but needs to be verified against conventional methods.	Finzi A, Oberti R, Negri AS, Perazzolo F, Cocolo G, Tambone F, Cabassi G, Provolo G (2015). Effects of measurement technique and sample preparation on NIR spectroscopy analysis of livestock slurry and digestates (2015) Biosystems Engineering, 134 : 42-54.
On farm test-kits (TRL = 5-6)	Agros and Quantofix meters are commercially available tools to measure readily available N in slurry sample	Easy to use in field conditions to measure readily available nitrogen	This method of detection has many interferences of other analytes present in the sample and interpretation of data has to be considered in conjunction with conventional methods.	Reliability of these methods are dependent on the dry matter content of slurry. The use of these methods are not a universal solution and needs to be adopted to suit local conditions.	Environment Agency (2011). Tried & Tested – Think Manures a guide to manure management. Van Kessel JS and Reeves JB (2000). On-Farm Quick Tests for Estimating Nitrogen in Dairy Manure. Journal of Dairy Science. 83(8) , 1837 - 1844
Slurry hydrometers (TRL =9)	Hydrometer (measures specific gravity of solids suspended in liquid) is being used to determine dry matter content of slurry which is then linked to nutrient content.	Easy to use in field conditions and does not require a large storage area.	Calibration of the hydrometer has to be ensured at the start of each operation to ensure that the results obtained are reliable.	Dry matter content of slurry shows a consistent relationship with nutrient content and this can be valuable as an indicator to help choose suitable spreading tools (such as band spreading or trailing shoe)	AHDB Diary (2015) – Making the most of manures (https://dairy.ahdb.org.uk/news/technical-articles/june-2015/making-the-most-of-manures/#.Wvgd6JWpV2M)

Note: Some of the effects of treatments quoted in the column 'key message' are only applicable in certain circumstances and cannot be considered as universal. TRL = Technology Readiness Level.

Most of the technologies presented in Table 5.2 are well described in the cited literatures above but some new ones are being developed and further described in the factsheets below.

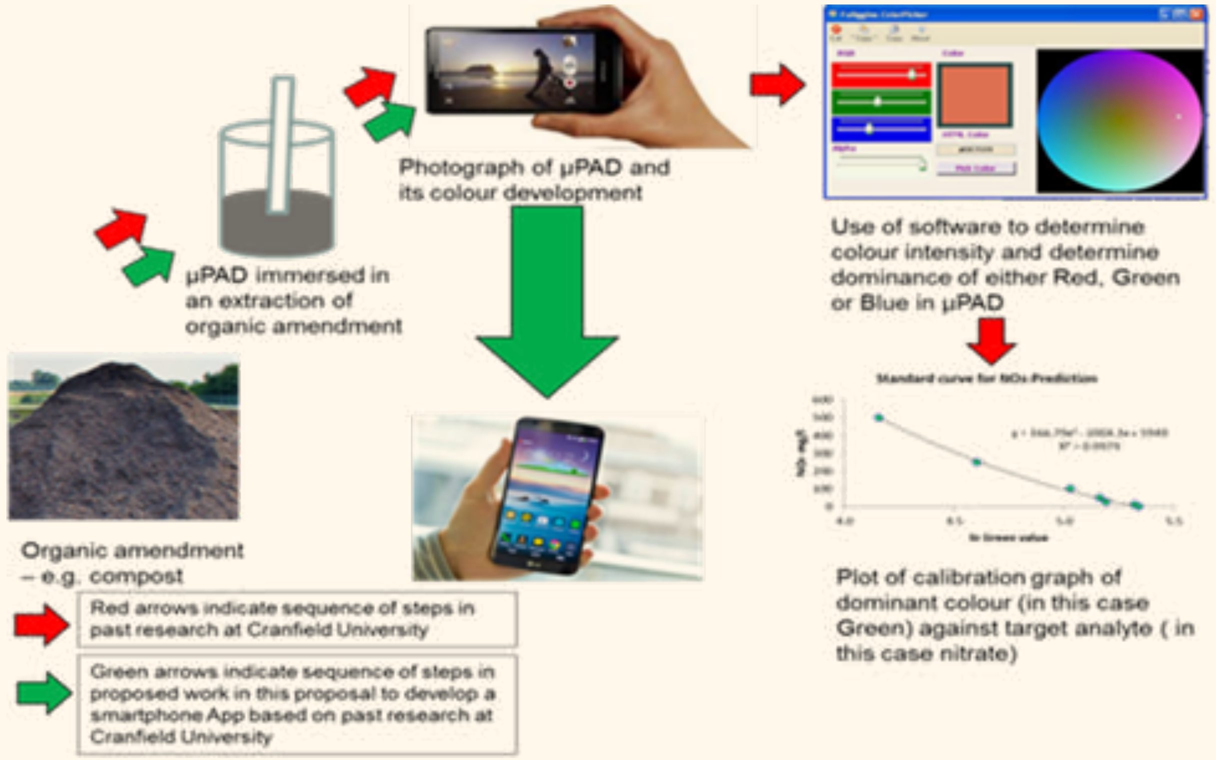
Micro paper analytical device (µPAD) - a quick method to determine nitrate and phosphate

An on-going project at Cranfield University is developing an in-field method to determine nitrate and phosphate in field samples of organic materials. Currently the samples include soil and compost but these can be extended to slurry, digestate and other suitable samples. This technology is based on using a specialist paper strip (known as microPaper Analytical Device – µPAD) that is impregnated with chemicals that becomes coloured in the presence of the target analyte. The µPAD changes colour when dipped into a solution. The intensity of colour indicates the concentration of target analyte present in a sample. The results will be compared with conventional laboratory methods. Figure 1 gives a summary of progress so far and proposed steps in the current proposal.

The paper strip is then photographed and a colour software determines the quantity of analyte present depending on the intensity of the colour. A mobile phone App is in development which will be used to provide in-field technology needed to assess the quantity of nutrients present in slurry samples.

There are challenges in using the paper strip as it is subject to many interferences in terms of other analytes present in the sample. The ambient environment (such as temperature, light intensity) where the photograph is taken can influence colour development of the paper strip and subsequently affect the interpretation of the amount of nutrients present in the sample. This method is being validated against a conventional laboratory analysis to assess its capacity to act as an in-field technique.

Figure 5.4: Steps involved in method development of in-field diagnostic tool and proposed option in current project.

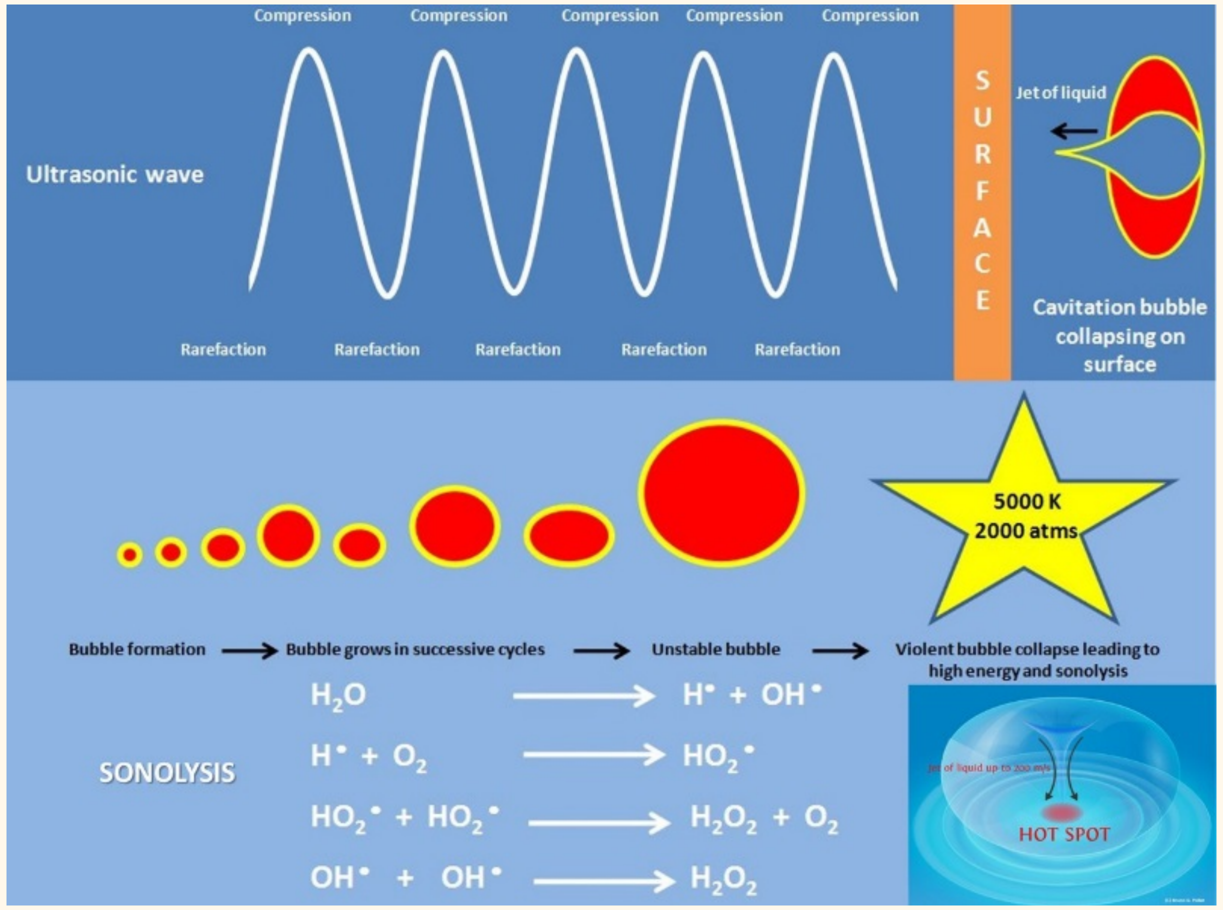


Electroflocculation

Power & Water and Coleg Sir Gar are adapting the recently developed a patented technology (Soneco™) which combines Power Ultrasound and Electrolysis for water treatment, a technology called 'Sonoelectrochemistry (www.sonoelectrochemistry.com) to tackle the ever increasing problem of livestock slurry. This enabling technology is at the core of the pilot processing system, and could be utilised in a further pilot plant in Malta.

This 'Proudly Welsh' innovative and ground-breaking technology is based on generating electrons and cavitation to accelerate the efficient removal of inorganic, organic and nutrient compounds as well as purifying the wastewater (and sludge) of pathogenic bacteria. Cavitation is the formation of vapour cavities in a liquid – i.e. small liquid-free zones ("bubbles" or "voids") – that are the consequence of forces acting upon the liquid. Cavitation caused by ultrasonic and hydrodynamic equipment and techniques have been used for catalysis of many known and well defined endothermic reaction traditionally implemented with high temperature/high pressure processes for many years. The advantage of cavitation is the effect of high pressure and temperatures achieved in the domain of effect near the collapsed bubble, the rate of heating being sufficient to start and sustain reactions in aqueous and other solutions.

Figure 5.5: Effect of ultrasound in liquids (© Bruno G. Pollet)



Two versions of the Soneco™ reactor will be deployed in the system to achieve: -

- Charge neutralisation through electrochemical dosing (converting soluble contaminants to an insoluble form – which is easily separated out)
- Advanced Oxidation Process (AOP) treatment – This mineralizes re-calcitricant organics, and breaks down ammonia

This technique is expensive at this stage and is being trialled as a prototype. It is showing promising results and anticipated that its cost may become more affordable in the future. From a practical standpoint, the electroflocculation technology may not serve the need for individual farmers but may be used as a central facility that can be used by a group of farmers. If this will be the case then several units may be setup in a region or catchment.

5.4 Prospects for incorporating farm foot-printing and LCA assessment within DST

Historically farm footprint tools focused on carbon emissions and the tools were largely derived from IPCC greenhouse gas (GHG) inventory accounting. This approach has been criticised on two grounds: first, that the existing inventory methods were not sensitive to on-farm management changes; and second, that GHG emissions are only part of the environmental footprint from farming.

The first criticism has in part been addressed by a revised inventory method developed as part of the Defra funded UK greenhouse gas platform and the second by including a broader range of indicators. The quality of carbon tools has also improved through certification through organisations such as The Carbon Trust. As with all model-based tools the precision and accuracy of the calculations depends on the detail and accuracy of the input data. However, management guidance can be given using relatively simple tools, for example the Bord Bia and Teagasc (the Irish National Agricultural Research & Farm Advisory Body) have developed a tool to audit >38,000 Irish beef farms using measures such as number of cattle and length of time spent grazing.

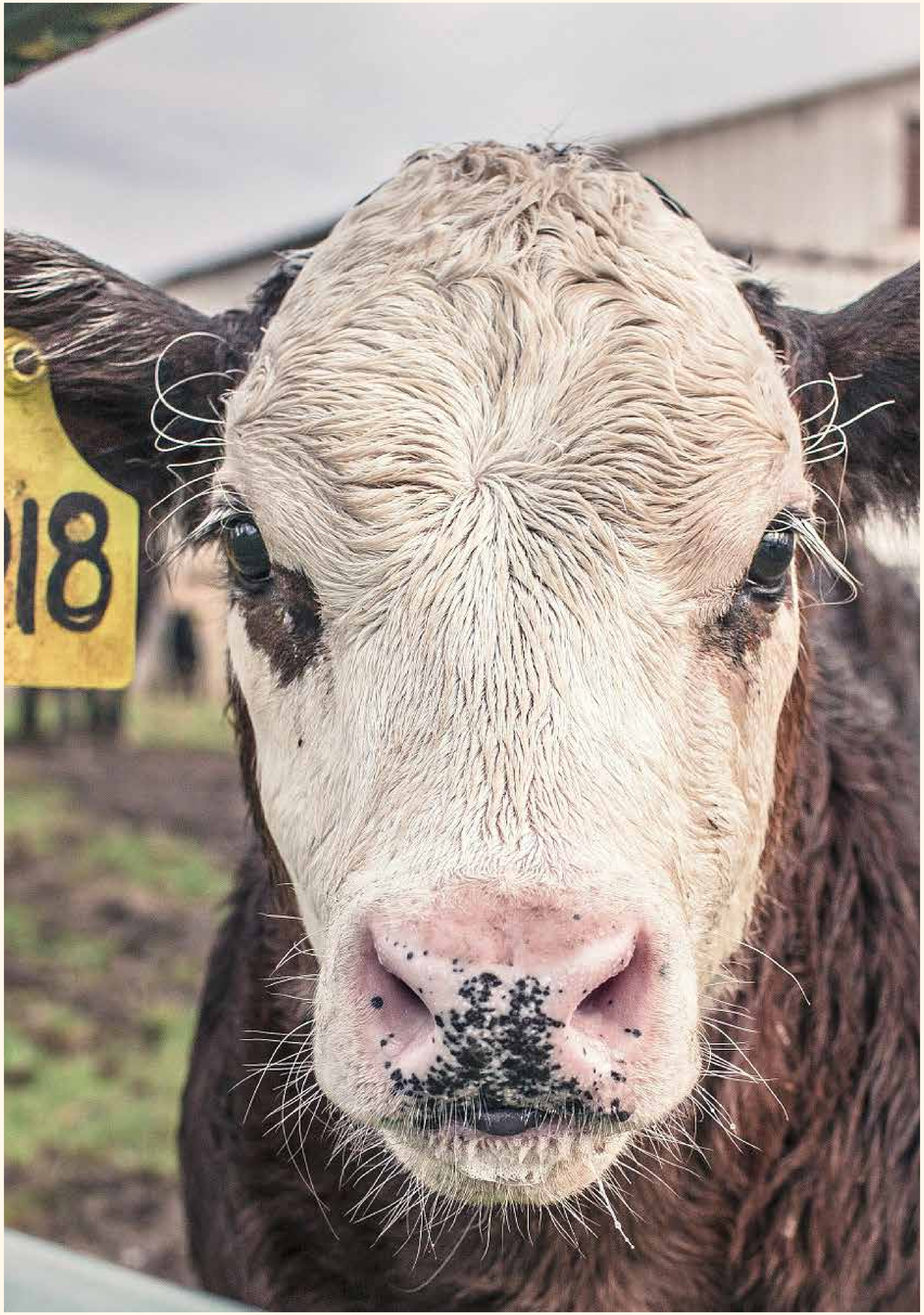
Milk and beef production contribute 1.42 and 2.91 Pg CO2e yr-1, respectively (9% in aggregate) to global GHG emissions (Opio et al., 2013). They contribute a large share of nutrient losses and ammonia (NH3) emissions that reduce water and air quality, cause soil degradation and depletion of finite phosphorus and fossil fuel reserves (Steinfeld et al., 2006). Life cycle assessment (LCA) provides a quantitative framework to assess the environmental efficiency of production systems in relation to multiple pressures on ecosystem services. LCA quantifies farm footprints in terms of greenhouse gas emissions, acidification, resource depletion and energy use. Usually the footprint is calculated per unit of output (litre of milk, kg of beef etc.). However, LCA approaches range in scope and system boundaries which can lead to different results.

Audsley et al. (2009) estimate that land use change (LUC) outside the UK increases the carbon footprint of food consumed in the UK by 50%. Consequential LCA (CLCA) accounts for indirect effects of system changes via market signals (Weidema et al., 2008), e.g., indirect-LUC (ILUC) associated with an increase in demand for imported animal feed commodities (Schmidt, 2008). A recent study Styles et al. 2018) has shown that the interconnection between beef and dairy systems is important and apparent reductions in dairy footprint can only be achieved by also intensifying beef production and using spared land productively.

A recent study (Gunton et al. 2016) identifies two main difficulties in choosing sustainability indicators to measure/evaluate efficiency and footprint of production: i) that there a wide range of possible indicators and there is no consensus about which subset to use and at what scale (e.g. farm or region); and ii) that analytical tools are often unable to handle more than two indicators together, and how to combine and weight indicators is uncertain. The study also highlights indicators other that LCA such as biodiversity and the possible accounting for product quality (micro-nutrients, omega-3 fats, taste etc.) rather than just per unit of output.

The technology and knowhow exists for integrating farm foot-printing and LCA into existing or new DSTs. Simple approaches such as the Bord Bia carbon tool could be calculated without adding many more data requirements on farmers (although an explicit turn-out/housing dates would be required). However, this would only estimate a measure of greenhouse gas production which would be not responsive to many management changes known to affect these emissions. LCA could, in theory, benefit the farmer in terms of manure management - e.g. estimating NH3 emissions from each phase of the manure management chain, and gaining knowledge of the conserved NH4 in slurry at the time of spreading.

A more comprehensive LCA approach would require many more inputs and a more detailed representation of on-farm management, however. No farmers expressed a desire for this in the sociological research done for Workpackage 2, so any implementation would have to be driven by policy requirements.



Conclusions and Recommendations

The SLURRY-MAX project looked at a problem posed by the agricultural industry regarding decision-support on organic slurry storage and treatment. The project was partly framed around the idea, that 'there are really good decision support tools out there, but a significant number of people don't engage' (Interview, Farm Adviser, England, 2017). Institutions with responsibility for good agricultural practices (across government and industry) commonly worry that despite much advice being available, farmers are still not managing slurries and manures effectively.

The research has taken a holistic approach informed by economics, agronomy, ecology, biology, modelling and social science. We pose here our conclusions, followed by some recommendations oriented specifically to institutions – including Government and the AHDB – with responsibility for supporting good slurry and nutrient management.

Which producers need help?

- SLURRY-MAX has found that the dairy bias in slurry management decision support has obscured the significance of, and the need for support for, slurry storage and management issues in the beef sector.
- Smaller beef farms producing slurry are least likely to be supported by advisors, the levy board, or to have nutrient management plans in place.
- Good support to help these smaller beef farms manage their slurries more effectively (from both an agronomic and ecological perspective) could equally benefit all cattle slurry producers, large and small, dairy or beef.

Decision Support Tools (DSTs)

- There are several DSTs focused on the management of slurry, manures and nutrient planning.
- The empirical findings of SLURRY-MAX suggest that even when beef farmers producing slurry are aware of the available DSTs, the majority have decided not to use them because they require too much effort for too little return.
- Only 12 out of the 84 beef farmers surveyed at markets and shows said that they use Decision Support Tools (paper or software).
- 8 out of the 11 farmers interviewed for the study had heard of the Decision Support Tools available for nutrient planning and had tried them (PLANET being the most common) but all of those 8 farmers chose not to use such tools.
- Many of these DSTs do not perform well in regard to the factors, previously identified by Rose et al (2016) that encourage DST uptake and use.

Farmers and farm practices

- The focus on deficient farmers (often characterised as 'computer illiterate') needs to be broadened, to understand the ordinary practices of farmers who do not use DSTs, including the routines, rhythms, networks, communities, institutions, infrastructures and technologies that shape their current slurry and nutrient practices.
- Even obviously poor slurry and nutrient practices have a 'logic' for the farmer. Government and industry need to understand this logic in order to help support better practices.
- Only half of the 84 beef farmers surveyed at markets and shows had professional nutrient planning advice.
- Inadequate infrastructure poses a significant constraint on good nutrient management, effectively removing the ability to plan slurry applications.
- Slurry and nutrient management manuals and tools tend to portray slurry as a benign, beneficial nutrient source. Institutions responsible for creating these and for supporting good practice also need to recognize the difficulties and hazards, for farmers, of working with slurry.
- Young farmers should be introduced to 'real' nutrient planning DSTs, adapted for student use, through their agricultural college curricula.

Improvement of DSTs

- There is considerable scope to improve DSTs for slurry and nutrient management for beef farmers.
- A free (or cheap) well promoted and supported nutrient planning tool is needed (in England and potentially Wales) as many smaller beef farmers cannot afford a professional advisor, and farmers are less likely to use an agronomist for pasture than arable crops.
- DSTs must answer questions relevant to the farmer, or farmers will not use them.
- Tools need to guide the farmer through the interface through a step-by-step narrative.
- Existing farm-level data which the farmer has already provided should be imported as data input to any new farmer-friendly DST.
- Any new tool will require ongoing human technical support.
- Even the best DSTs cannot stand in for good face-to-face advice.
- A newly designed tool should support soil and slurry testing so that inputs to nutrient planning are farm-specific.
- A newly designed tool should include information about the costs and benefits of nutrient management options.

On-farm technologies

- Farmers have not expressed the need for any new technologies for the treatment or life-cycle analysis of slurry. Rather the technology they require is simple: adequate infrastructure which stores slurry safely and makes it accessible at the times when nutrients are needed by crops.
- Farmers have, however, shown support for testing and accurate measurements. Institutions responsible for supporting good slurry and nutrient management can consider a range of on-farm technical options for measuring nutrients, and they could make farmer networks more aware of these.
- Technologies that work to alleviate the 'storage problem' (such as flocculation) should be an investment priority.

SLURRY-MAX recommends

- Re-thinking publicity and campaigns to 're-brand' good slurry management as something that is supported not only in the dairy sector, but across all livestock farms.
- Applying a similar approach to Catchment Sensitive Farming (and expanding its currently limited geographical scope) to support knowledge and best-practice exchanges across England, and between England, Scotland, Wales and Northern Ireland, all of which have different strengths and weaknesses in nutrient management support.
- Embedding and supporting the use of the best, most farmer-friendly, free DSTs into agricultural college curricula across the UK.
- Development of a freely available, farmer-friendly, publicly maintained tool aimed at the smaller, less profitable farmers. This is important at the current time to help carry out (now mandatory) nutrient management planning. No such tool currently exists.
- More public-private partnership working and sharing of responsibility to support farmers is needed. Due to the fact that important forms of state support have now transferred to the private sector, discussions need to be held between Government and the agricultural industry (including AHDB). Such discussions need to address how to work together across the regulatory-advisory divide to support farmers to develop good nutrient management practices for the public good.

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Annex 1: Interview questions

Questions for Farmers

Farming Practices

1. What do you farm and what is the size of your herd/holding?
2. Do you own your farm or are you a tenant?
3. Do you produce slurry or FYM?
4. How is this stored?
5. How big is your store, if you have one?
6. How long are your cattle housed?
7. When do you spread your slurry/muck, and where? Do you use your muck for anything else?
8. Do you ever have too much/not enough slurry at spreading time?
9. Do you spread yourself, or using a contractor?
10. What spreading equipment do you (or your contractors) use?
11. How often do you calibrate your spreader?
12. How do you fertilise your fields?
13. Who do you buy fertilizer from?
14. How much approx. do you spend on fertilizer per year?
15. Do you sample the nutrient levels of the soil in your fields, or your slurry? If not, why not?
16. Are you in any certification schemes (e.g. Farm Assured) or legislative areas (e.g.NVZ)?
17. What do you think are the biggest issues you face in your management of muck and/or fertilizer?

Decision Support Tools

18. Do you keep written records of your muck and/or fertilizer management?
19. Do you get advice on nutrients (fertilizer/muck)?
20. Do you have a nutrient management plan?
21. Do you use software (e.g. PLANET, MANNER) to support your nutrient management? If so, which?
22. Have you looked at/downloaded this software?
23. Do you use paper tools (e.g. RB209, Tried and Tested) to support your nutrient management? If so, which?
24. Have you looked at/downloaded these documents?
25. What do these tools help you with?
26. If you don't use these, why not?
27. Do you think there is any value in these DSTs?
28. What other resources you use for farming information, and are these digital (on computer) or not?
29. What do you think of AHDB/Defra, and nutrient legislation? Do you trust these?

Use of IT

30. How much time do you spend on-line, on an average day? What websites do you visit?
31. Do you use a smart phone? Or a networked laptop? Or a networked PC?
32. Do you use any other digital tools to help you with farming?
33. How good is your broadband or your ability to connect to the internet using 3g or 4g?
34. Do you use any social media group tools such as 'Facebook' or 'whatsapp'?
35. Would you feel comfortable discussing your fertilizer/slurry management online (anonymously or not)?

Being part of farmer networks and community

1. Are you part of any social groups to do with farming? Which?
2. Do you meet informally with other farmers?
3. If so, do you discuss everyday problems such as muck spreading/fertilising?
4. Do you help each other out with these sorts of jobs? How?

Questions for Advisors

1. Who are your clients?
2. What advice do you give your clients? Do you advise on nutrient management?
3. How do you build a relationship with your clients?
4. What are your clients' priorities?
5. What drives farmer decisions (ie regulation, supermarket demands, etc)?
6. What kind of problems or issues are encountered by the farmers you advise?
7. How do you tailor your advice for different clients?
8. Do you feel your advice is always taken?
9. Do you soil/manure sample, or advise on soil/manure sampling?
10. Do you advise on any different treatments of slurry/manure? (e.g. covers; AD; enzymes)
11. Do you use any nutrient management tools?
12. How is advice changing?
13. Apart from yourself, where else can farmers get advice on nutrient management? What's the difference?
14. Do you think all farmers get professional (i.e. FACTS qualified) advice?
15. How do you think nutrient management should improve into the future?
16. What is important for farmers now?
17. How will your advice help farmers in the future?

Questions for Advisors NVZs

1. Can you explain the NVZ regulations?
2. What problem are NVZ regulations designed to address?
3. Has this problem stayed the same or has it changed over the time the NVZ regulations have been in place?
4. Do the regs and the required nvz practices address it fully/well?
5. What do you think are the best and worst things about the NVZ regulations?
6. How good do you think compliance is?
7. How are non-compliers identified?
8. Are any sectors/demographics more likely to struggle with compliance?
9. Have NVZs had an impact on water quality?
10. If money were no object, what do you think would be the most effective measure for improving NVZ compliance/water quality on farms?
11. What do you think is the biggest issue in keeping farms NVZ compliant?
12. Do you think nutrient management practices are significantly different on NVZ/non NVZ farms?

Phosphorus

13. Do NVZs cover phosphorus pollution?
14. Do you see phosphorus as an issue that needs to be regulated?
15. Do you think it will be regulated into the future?
16. Do you predict any other nutrient legislation that could be on the horizon? (e.g. Ammonia)

Tool Use & Advice

17. In your experience, do farmers use decision support tools to help them meet their NVZ compliance?
18. If so, are there any areas that you believe could be improved,

OR

19. If not, why not?
20. What do you think the best available tool for nutrient management is?
21. What would the ideal tool look like?
22. What is the value of face to face advice (e.g. from agronomists, fertiliser reps or CSF officers) are all these advice sources equally useful?

Final

23. Our research is looking at decision support for slurry storage and treatment. What do you think are the big issues for compliance in this area?
24. Is there anything that we could find out in the process of our research that would be of use to you?

Questions for Tool Developers

About the tool

1. Can you give a brief overview of your tool?
2. How and why did your tool come about?
3. What is the ultimate aim of your tool? (pollution/productivity)
4. How was the development of your tool funded?
5. How many editions has it had, and how has it been improved?
6. Who was involved in the development?
7. What do you think is the best thing about your tool, in comparison to other available tools?

Using the tool

8. What does your tool tell the user?
9. Can you demonstrate how to use your tool?
10. What are the data input requirements for your tool, and how flexible are these?
11. Which of these do you think are hardest to provide?
12. How are your default values set?
13. What do you think is the easiest thing about using your tool? And the hardest?
14. Is any of the inputted user data available to you, or other users?

Testing

15. How do you test your tools?
16. Who do you test your tools on? Where?
17. How is farmer feedback incorporated into design?

Marketing/Dissemination

18. How can potential users find your tool?
19. Is your tool advertised? If so, where?
20. Do you have any data on the number of users your tool has?
21. Where are your users?
22. Through the course of our fieldwork, is there any information we could gather that would be of use to you?

Annex 2: Questionnaires for shows and auction markets

1. Tell us about your farm (farm type/size etc).
2. What housing/bedding system do you have?
3. What do you do with your slurry/manure?
4. How is it stored?
5. When do you spread your slurry/manure?
6. Do you use a contractor to apply your slurry/manure?
7. Do you buy fertilizer? Which one?
8. Do you use any software or booklets to help with your nutrient management?
9. Does an advisor help you with this?
10. Do you test your soils or manures?
11. What do you think are the biggest issues for you in the management of nutrients (slurry/manures/fertilizers)?

Annex 3: Workshop Attendance

Tool Developers (public)

John Williams (ADAS)

David Ball (AHDB)

James Holmes (AHDB)

George Mathers (CAFRE)

Dave Freeman AIC (Tried and Tested)

Tool developers (private)

Clive Blacker (MyFarm/Precision Decisions)

Simon Penfold (Muddy Boots)

Abby Rose (Vidacycle)

Policy Makers

Neil Henderson (Scottish Government)

Andrew Penton (EA)

Lucy Dorey-Robinson (Defra)

Huw Williams (NRW)

Grainne McCarney (DAERA)

Other

Paul Flynn (Soil Association)

Andy Dyer (Newton Rigg/Askham Bryan)

Iain Clarke (Coleg Cambria)

John Owen (Coleg Sir Gar)

Melvyn Rutter (Yorkshire Ecological Solutions)

Sam Durham (NFU)

Michael Graham (CSF)

Aurelie Bovi (Agrometrics)

Phil Latham (NFU)

(Project Team)

Claire Waterton (Lancaster)

Lisa Norton (CEH)

Shailesh Shrestha (SRUC)

James Gibbons (Bangor)

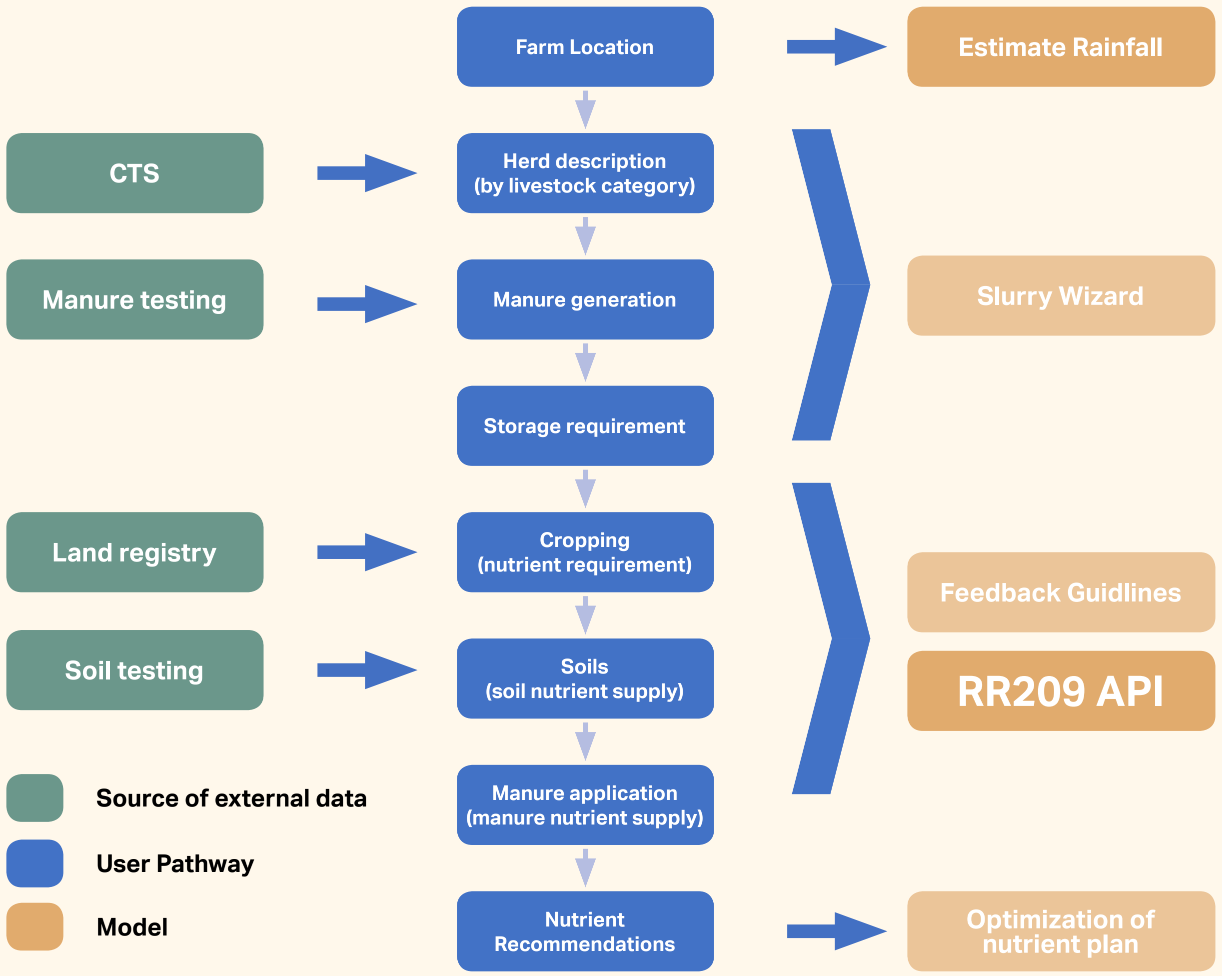
Ruben Sakrabani (Cranfield)

Katrina Macintosh (Queen's Belfast)

Dave Chadwick (Bangor)

Emma Cardwell (Glasgow)

Annex 4: Summary user pathway for nutrient management decision support tool



Summary of suggested user pathway indicating sources of data and model calculations for a fully optimised nutrient plan. Solid boxes indicate functionality already exists, partly filled boxes where there is potential to add functionality.

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