Making Science Work on the Farm

A Workshop on Decision Support Systems for Irish Agriculture

N. M. Holden, T. Hochstrasser,
R. P. O. Schulte, S. Walsh (Editors)

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Edited by

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on behalf of

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About ᴀʒᴍᴇᴄ

AGMET was founded in 1984 and has the full title of "Joint Working Group on Applied Agricultural Meteorology." Membership is open to anyone with an interest in the subject. Currently members are drawn from Met Éireann, Teagasc, Geological Survey of Ireland, Environmental Protection Agency, Office of Public Works, Universities, other third-level Colleges, Department of Agriculture and Food (Dublin) and Department of Agriculture and Rural Development, Northern Ireland. AGMET draws on the expertise of other organisations (e.g. RTÉ, IFA, ICMSA, The National Farm Centre, Bord Iascaigh Mhara) when topics of a specialist nature are under discussion and review.

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Foreword

AGMET organised this workshop to bring together interested parties to establish the best way to develop agricultural Decision Support Systems (DSS) services in Ireland. The purpose of the day was to consult with advisors, farmers, scientists and experienced DSS users to ensure that the DSS tools being developed in Ireland are based on high quality science and are useful at farm level.

Decision Support Systems have the capacity to assist farmers in making better-informed decisions for their businesses. Agro-Meteorology has to bring scientific knowledge to farmers and other end-users in the most practical way possible. The challenge is to develop DSS tools that are not only based on sound science but are also user friendly. This workshop gave an opportunity for participants to focus on how provision of DSS services to farmers might be offered, and to learn from the experiences gained in other countries.

Participants at the workshop were given the chance to use a number of the DSS tools already in operation and to provide useful feedback to Agmet on the most appropriate method of delivering these services to farmers and other interested parties. Communication options such as internet, phone and television were also explored, to ensure that whatever DSS are developed can be usefully applied.

The workshop met its aims by gaining the participation of farmers, advisors, scientists, agri-ICT specialists and consultants in order to formulate ideas and opinions on the type of information that is required and on user interface issues.

These proceedings detail results of a user survey, conducted on the day, which Agmet hopes will help inform debate on DSS and assist in formulating the best possible services for Irish farmers and related rural bioresource industries.

DECISION SUPPORT TOOLS: KEYS TO SUCCESS

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Abstract

This paper covers a number of principles that should, if applied, improve the prospects of success when constructing agricultural decision support tools. An intending decision support tool developer should:

- base the tool on the best-available science, and keep that science up to date
- expect to need a range of skills spanning scientific knowledge of the problem area, information and communications technology, and interaction with users
- consider carefully the kind of communication that will best support the intended intervention in farming practice, and design the tool accordingly
- plan to work through a formal project life cycle consisting of requirements definition, design, implementation, deployment and evaluation
- understand the importance of ongoing commitment to the tool by the host organization.

Introduction

In agriculture, decision support – like decision-making – is a complex business, and dealing with that complexity is vital to success. In this paper I will discuss some concepts and techniques that can be used to manage the building and deployment of agricultural decision support tools (henceforth DS tools), with an emphasis on general principles rather than on addressing a specific problem domain. The conceptual framework used in this paper owes much to an important paper by McCown (2002). The practical ideas are strongly influenced by the experiences of the GRAZPLAN research group in building models and decision support tools for Australian grassland agriculture (Donnelly *et al.* 2002; Moore 2005).
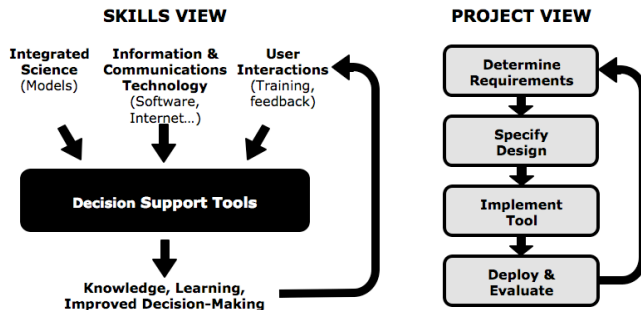
Figure 1. Two complementary views of agricultural decision support. The "skills" view emphasises that producing any but the simplest tool will require a team of people. The "project" view emphasises the importance of clear design processes and of reviewing outcomes.

Two threads that run through the paper are presented graphically in Figure 1. First, the construction of DS tools brings together scientific knowledge, information and communications technology, and an understanding of the users of the tool. The broad range of skills required means that a DS tool should generally be built by a team rather than an individual. Second, thinking of DS development in terms of a "project life cycle" is valuable, particularly because emphasis is then placed on the design steps relative to the implementation stage.

The first key to a successful DS effort is, of course, a sound scientific basis. Good science is fundamental to the reliability of the calculations that a DS tool makes, and hence to its credibility with users. Users' confidence in a DS tool will be enhanced if the science underlying it (including the limits of its application) is clearly documented.

Decision support: a process of communication

If it is to be effective, a DS tool must convey scientific knowledge to someone who can use it in making a decision. Decision support tools therefore operate within a process of human communication. The simplest form that this communication can take is shown in Figure 2, using the concepts of Shannon & Weaver (1949). The developer uses the decision support tool to communicate with a user who acts only as a receiver, in line with a "transfer of technology" extension approach. Such a one-way pattern of communication will work best when the purpose of the DS tool is to predict the consequences of a given action within a well-bounded, and usually small, problem domain (what McCown (2002) calls a "decision calculus"). Some examples are provided in Table 1.

"Decision calculus"

One-way communication of information is sometimes entirely appropriate. Many problems, however, require different kinds of communication; decision support tools that address these problems must therefore follow other modes of operation (Figure 3). When designing a DS project, it is important to be clear about what mode or modes of communication will be employed:

Figure 2. A simple pattern of communication through a decision support tool.

- **Information bases** operate in a similar way to a library. The knowledge to be communicated resides in documents rather than in a model, and users select which messages they will receive. These tools therefore support self-directed learning. The tool developer must construct and update the documents, but is relatively passive thereafter.

Table 1. A selection of decision support tools relevant to grasslands

Class of tool	Tool	Purpose & web site
Decision calculus	GrazFeed	Nutrition of sheep & cattle www.hzn.com.au/grazfeed.php
	NUTBAL	Nutrition of sheep & cattle cnrit.tamu.edu/ganlab
	EMA Fertilizer	Fertilizer & manure rates www.herts.ac.uk/natsci/Env/aeru/ema/
	N Decision Tools	N fertilizer rates www.nitrogen.unimelb.edu.au
	OVERSEER	Farm nutrient budgeting www.agresearch.co.nz/overseerweb/
	Greenhouse Accounting Tools	Calculate greenhouse emissions at farm scale www.greenhouse.crc.org.au/tools/calculators
	Pl@nteInfo	Yield prediction www.planteinfo.dk
Information base	Forage Information System	Extension, teaching & research information on forages forages.oregonstate.edu
	Agricultural Document Library	Variety of agriculture-related documents http://www.adlib.ac.uk
Constraint management	NMAN	Manure management www.omafra.gov.on.ca/english/nm/nman/default.htm
Consultancy	GrassGro	Evaluation of strategic and tactical management options for sheep and cattle enterprises www.hzn.com.au/grassgro.htm
	FARMAX	Farm planning service: flock and herd structure, seasonal paddock allocation, livestock trading. www.farmax.co.nz
Learning	MLA Feed Demand Calculator	Patterns of feed demand and supply through the year www.mla.com.au
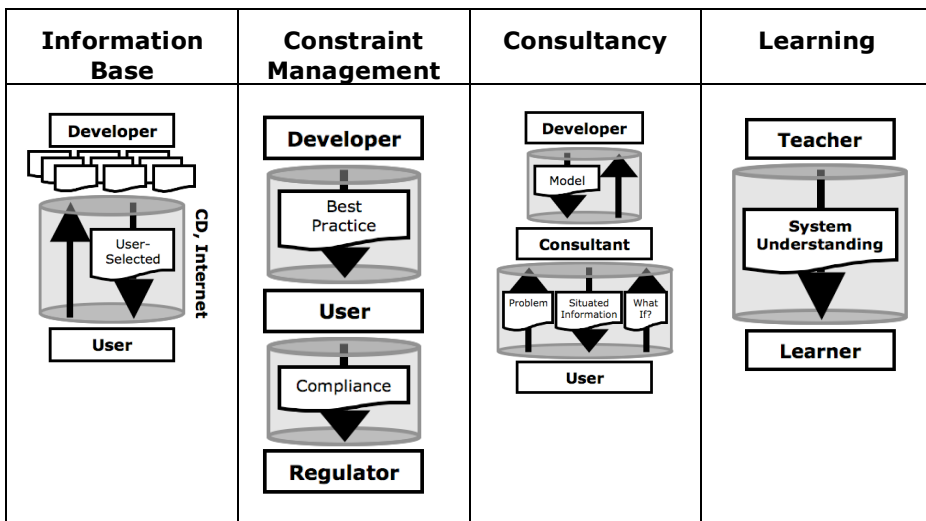
Figure 3. Four alternative modes of communication through decision support tools. Arrows denote information flows; grey cylinders denote the process of encoding, transmission and interpretation.

- **Constraint management tools** support a dual communication process, in which the tool developer communicates information about management practices to a user, and the user in turn uses the tool as a means of demonstrating that some externally-imposed requirement has been met. This "external" requirement may be imposed by senior managers in a large agricultural business (as with the SIRATAC tool; Hearn and Bange 2002). More commonly, external constraints will be set by society via regulations governing environmental conservation and safety. As a result of its dual purpose, this kind of DS tool must provide both technical information and also a facility for recording a manager's actions so that it can be demonstrated that acceptable practice has been followed.

  The DS tool developer and the regulatory agency are often the same organization (for example with the NMAN tool described in Table 1, which comes from the Ontario provincial government), but this need not be the case. The cottonLogic DS tools (Hearn and Bange 2002) demonstrate an alternative: in the Australian cotton industry, scientists and producers working together have successfully asserted what the standards of best practice should be.

- In **consultancy** mode, a problem is defined by the ultimate user (a producer, a policy maker, or some other actor). An advisor then uses the DS tool to apply a scientific model to the problem and its particular circumstances. The results obtained from analysis with the DS tool comprise context-specific information that is provided back to the user for consideration. Typically, this is an iterative process in which the results of a DS tool analysis prompt the important question, "What if...?" In this mode, the consultant acts as the point of interface between a "hard systems" and a "soft systems" approach.

  The consultancy-oriented DS tools in Table 1 are what McCown (2002) calls "versatile simulators". They are based on relatively complex simulation models, but they differ from traditional research modelling software in their primary intent. As McCown (2002) puts it: "the primary aim in making a simulator is not to mimic system process but rather system function and performance, and to do so cost-effectively. Flexibility and ease of specification are key simulator attributes."

- Finally, a DS tool can be used for **learning** purposes, in either a formal or an informal setting. In this case the DS tool (perhaps more properly described as a "learning support tool") conveys understanding about the biophysical system to a user. The consultancy and learning modes of communication combine because the questions "what if?" and "why" are often asked in parallel.

Some DS tools will support more than one of these modes of communication, especially as users have a habit of taking a tool designed for one purpose and putting it to another. The GrassGro DS tool (Moore *et al.* 1997; Moore 2005) provides an example. GrassGro is a DS tool that evaluates various strategic and tactical management options for broadacre sheep and cattle enterprises. It incorporates simulation models of the grazing ruminant, soil moisture, pasture growth and enterprise management. We designed GrassGro with the "consultancy" pattern of use in mind, but Professor J. Scott of the University of New England has driven a process

by which it has become widely used in "learning" mode in Australian universities (Daily *et al.* 2005).

It is also important to note that the pattern of communication determines the potential number of users, and hence the basis against which uptake of the tool should be measured. For example, the maximum number of direct users for a consultancy tool such as GrassGro is likely to be measured in hundreds, while an information base such as EMA (Table 1) is intended for many thousands of users.

Even in the simplest mode of communication (Figure 2), developers must encode their knowledge into a message, and users must then interpret that message before it can affect their behaviour. Using the right language to convey the message is therefore vital. DS tool developers need to consider whether concepts can be conveyed in terms that are familiar to their intended users or whether new language needs to be introduced via training.

The life cycle of a decision support project

Every decision support tool emerges from a development project, whether its builders realise it or not. Taking the "project view" of Figure 1 seriously is almost guaranteed to save time and to improve the end result. In particular, time spent on clarifying and writing down the requirements on a future DS tool, and then designing it to meet those requirements, will be time well invested.

Requirements stage

The first step should be to understand what will be required of a proposed DS tool and of the processes that will accompany it. What decisions are to be supported (i.e what is the *scope* of the tool)? Who makes them? Is the science adequate to improve decision-making, or will it become adequate by the time the tool is deployed? How context-specific do calculations need to be to be practically useful, and what does this imply about the set of inputs that will have to be provided? What are the constraints (e.g. time, finances, regulations) under which the decision-makers will operate even if well-informed? Are there well-established networks of decision-makers or advisors that can be used to deploy and promote the tool, or are they a population of rugged individualists who will have to be persuaded one by one to adopt it? The requirements stage is the time when the communication issues raised in the previous section should be addressed.

Consultation with potential users will be vital in answering these questions and conducting such consultations successfully is a specific skill that needs to be enlisted. It is possible however, to place too much reliance on users' views. For example, the successful GrazFeed tool was built because CSIRO scientists discerned an opportunity; the need for GrazFeed was only seen by the grazing industry after the tool had been built (Donnelly *et al.* 2002). The FEEDMAN tool for tactical grazing management, on the other hand, was developed using participative processes but failed anyway (Rickert 1998).

A further benefit of establishing and documenting the requirements for a DS tool is that it enables all stakeholders to be clear about what the end product is intended to achieve. Setting expectations in this way allows "success" to be defined clearly.

Design stage

Once the requirements for a DS tool have been agreed, it is time to specify how the tool will meet them. The usual end-point of this process is a document known as a "functional specification". This specification should answer questions such as: What kinds of human interaction will take place? What calculations will be carried out? What data sets will be required, and how will information flow from where it is stored to where it is used? What training will be required, and how will it be delivered?

Writing a good software design requires input both from specialists in the problem domain and from people with specific expertise in software development. Well-trained software developers possess skills in the *process* of developing and documenting specifications. Following these processes will improve the chances that all the important elements of a tool will be considered. In particular, a set of techniques embodied in the "Universal Modelling Language" (UML, Web 1) are helpful (e.g. Figure 4).
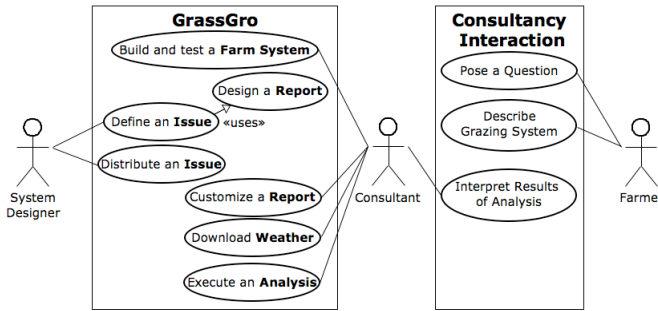
Figure 4. Universal Modelling Language being used to design the GrassGro decision support tool. This diagram documents "use cases", i.e. the kinds of actors that work with GrassGro and the tasks that they must perform.

Software professionals are also prone to finding ways of re-using existing databases and code, thereby lowering the cost – and risk – of building a DS tool. If a database (say of weather or soils information) needs to be constructed, it should be designed with future re-use in mind, thereby reducing the cost and risk of the *next* DS tool.

One of the choices to be made at this stage is that of the medium to be used in delivering the tool. Should it be a paper worksheet, a spreadsheet, software burnt onto CDs, a Web application, or something quite different? The decision on the delivery medium should be determined by the accessibility of the medium to the intended users, the complexity of the calculations and the quantity of information that needs to be provided to the user over time. For example, an application that is intended for technically-sophisticated users and also depends on large amounts of real-time weather data is likely to be a candidate for Web delivery.

Figure 1 oversimplifies the project life cycle in one important way: in reality, iterative revision of either the requirements or the functional specification is normal. For example the specification process may reveal that some requirements are mutually conflicting; or it may show an opportunity to increase the functionality of a tool at low cost. In either case, the discipline of documenting the requirements and the specification makes making such changes more manageable.

Implementation stage

Once a design has been agreed, responsibility for turning it into software should be assigned to software developers (or to technical writers if a different medium has been decided upon.) The primary role of science professionals at this stage of a project should be in quality assurance, i.e. testing that the calculations and the language used are correct.

The team should expect that arriving at the best user interface for a DS tool will require some trialling with prototypes and iterative refinement (Stuth *et al.* 1993). Testing the user interface to the tool should involve a group of users; if this is not possible it is desirable that someone in the project team take the role of "user representative". One side-effect of actively involving users at this stage is a risk of "feature creep", that is to say the informal addition of new functionality to the tool. A balance needs to be struck between being open to useful suggestions and losing sight of the primary purpose of the tool. This balance can be negotiated explicitly by requiring any additional feature to be documented and agreed as a change to the specification.

Deployment stage and evaluation

I tend to use the term "deployment" rather than "distribution" for the process of getting a DS tool out to its users, because it is seldom simply a matter of posting shrink-wrapped boxes. In particular, training of users is an essential part of deploying all but the simplest DS tool. The training requirements should be considered as an integral part of the design process. What level of on-screen help will be provided? Will it be restricted to operating instructions for the software, or will it seek to explain underlying concepts? Do the number and influence of the intended users, and the complexity of the tool, warrant workshop-style training? If so, what materials need to be prepared alongside the software?

Training materials and interactions are particularly important in conveying to users the level of precision that a DS tool can provide and the inevitable uncertainty associated with its calculations. Openness is the best policy here; producers and advisers are used to making decisions on the basis of imprecise information and will welcome a partial reduction in their uncertainty about the consequences of their actions.

There is a "Law of Unexpected Consequences" in agricultural decision support: "any successful tool will be used for purposes not expected by its developers". The history of the GrazFeed DS tool for sheep and cattle nutrition (Freer *et al.* 1997) illustrates both this rule and the importance of training (Donnelly *et al.* 2002). GrazFeed was

originally developed with southern Australian agricultural advisors in mind, i.e. a target market of perhaps 300-500 users. A group of advisors within the New South Wales Department of Primary Industries saw an opportunity to use GrazFeed in an extension program called PROGRAZE (Bell and Allen 2000). PROGRAZE exposed many graziers both to GrazFeed and to the skills in assessing pasture mass that are required to use it; as a result the user base shifted toward direct use by livestock producers, and the benefits accruing from the tool increased noticeably (Figure 5). Over 1300 copies of GrazFeed have now been distributed.
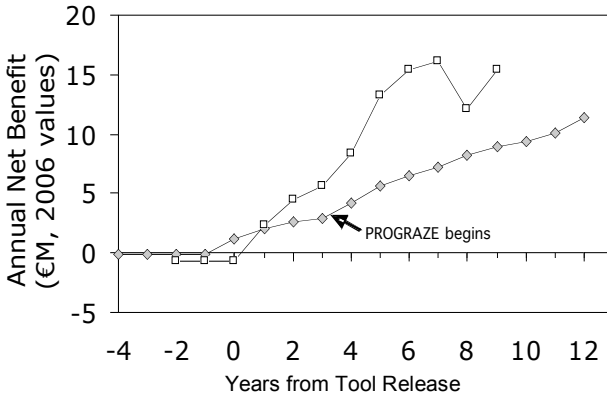
Figure 5. Independent cost-benefit analyses of two CSIRO agricultural decision support tools. The net benefit in each year is the estimated change in industry productivity relative to a hypothetical situation in which the tool was not released, less the costs of producing and maintaining the tool. ◇ GrazFeed (Freer *et al.* 1997, released in 1989); □ cottonLogic (Hearn and Bange 2002, released in 1994).

Both the science and the software in a DS tool need to be evaluated once the tool is released. Good scientific inputs will have been evaluated prior to release; but one of the virtues of a decision support effort is that it results in a widespread, if informal, test of the scientific understanding embodied in it. A need to update the science in response to users' experiences should be allowed for as part of the tool's maintenance budget. The metrics and methods used to evaluate the success a DS tool will depend on its intent and on the communication process it is supporting. A discussion of principles for evaluating DS outcomes can be found in Donnelly and Moore (1999).

Institutional issues

Ongoing commitment by a "host" organization is vital to the success of any DS tool in agriculture. Figure 5 illustrates a major reason why: the costs of agricultural DS tool are concentrated in the time before release, and the period during which benefits accrue is likely to be much longer than the development phase. During this time the tool requires ongoing support. Its software must be maintained, its scientific basis must be kept up-to-date, and new users must be trained if the potential benefits of the tool are to be realised.

The second DS tool that a team builds is likely to be produced more efficiently than the first, since skills and software can be re-used. For DS project leaders in the public sector it is sound strategy to plan beyond the first tool, and to aim for an initial success that can be converted into an ongoing commitment from management to DS tools as an element of their outreach.

When seeking to deploy a tool into another organization, it is a good idea to identify a "champion" for the tool who will act within that organization to persuade others of its utility. Of course a potential champion will have to be persuaded first! Neither the virtuous cycle between PROGRAZE and GrazFeed, nor the use of GrassGro for university teaching, would have developed as they did without this kind of support.

As with any provision of advice or information for decision-making, issues of liability for adverse outcomes must be considered before a DS tool is released. Our experience is that while written disclaimers and licence agreements can play a part in excluding liability, the critical policy for reducing liability is to train users so that they clearly understand the basis of our DS tools and their limitations. We emphasise the idea that even the best available information cannot be guaranteed to be correct in all circumstances. With our consultancy tool (GrassGro), this aspect of due diligence extends to ensuring that the users that we train understand that they must convey a corresponding appreciation of the strengths and weaknesses of the tool to their own clients.

Conclusions

The making of decision support tools is a complex activity. In my view, however, corresponding complexities will arise whenever one attempts to make scientific information available as a basis for decision-making; in formal decision support projects they can at least be dealt with explicitly.

To maximise the chances of success with a DS tool, take both a "skills view" and a "project view" while planning the tool. Plan to maintain the DS tool for long enough to recover the investment. Get the balance right between design, implementation & training, and re-use wherever possible. Expect the unexpected from your users, and evaluate to detect it. Above all, develop a DS tool by learning along the way. That is what the GRAZPLAN group has done and is still doing.

Acknowledgements

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Web 1. www.uml.org (date viewed, 1st November, 2006).

PL@NTEINFO – TEN YEARS OF ONLINE INFORMATION AND DECISION SUPPORT FOR CROP PRODUCTION IN DENMARK

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Abstract

The main objectives of PlanteInfo (www.planteinfo.dk) are to provide information derived from local, up to the hour weather data and weather forecasts, information derived from field observations by crop production advisers, and information derived from interactive decision support systems utilizing the aforementioned data. The main topics covered by PlanteInfo are weather information, plant protection, irrigation and variety selection. PlanteInfo has been on the Internet since 1996. In 2006 about 4% of Danish farmers and about 50% of Danish crop advisers were active PlantInfo users. This paper provides a description of PlanteInfo as it is in 2006 with references to scientific sources for each subject.

Introduction

PlanteInfo (www.planteinfo.dk) is a web site for Danish farmers and advisers. The main objectives are to provide information derived from local, up to the hour weather data and weather forecasts, information derived from field observations by crop production advisers, and information derived from interactive decision support systems utilizing the aforementioned data. The main topics covered by PlanteInfo are weather information, plant protection, irrigation and variety selection.

PlanteInfo has been on the Internet since 1996 and has thus been developed over a period of a decade. The general organisation and use of PlanteInfo were previously described by Jensen et al. (2000) and Jensen & Thysen (2002).

The purpose of this paper is to give a description of PlanteInfo as it is in 2006. The organization of the paper follows the structure of PlanteInfo with a section for each main subject on the web site. The descriptions of the web sit contents are quite brief but references to more informative articles are provided. The end-user uptake of PlanteInfo is illustrated by presentation of usage data for 2006.

Organisation

PlanteInfo is operated jointly by Faculty of Agricultural Sciences (FAS) and Danish Agricultural Advisory Centre (DAAC) on the basis of a formal agreement. Weather data are delivered by Danish Meteorological Institute (DMI) on basis of a annually renewed contract. The total costs per year for weather data are approximately €35,000.

PlanteInfo is running on a Microsoft Information Server. The scripting languages are Visual Basic embedded in Active Server Pages (ASP) and SAS delivered by SAS Intrnet 9.1. JavaScript is used for client-side interactivity. Data are stored on a Microsoft SQL server and in SAS data bases. SAS was chosen for the first versions of PlanteInfo in the 1990s because of its software for generating dynamic web pages including excellent facilities for producing graphics. The SAS Intrnet application for PlanteInfo is configured to serve multiple simultaneous requests, which ensures low response times even when the individual requests require relatively high computing time.

Most of the contents of PlanteInfo are delivered as personalized web pages requiring login. The user data base resides on a DAAC server and login to PlanteInfo is performed by a look-up procedure. PlanteInfo holds information on user geographical position and automatically provides web pages based on local weather observations and forecasts.

Weather

Weather data are delivered by DMI. Throughout the day new data are updated on a ftp server. A SAS program on the PlanteInfo server checks at short time intervals for updates, which then are downloaded and stored as SAS data sets. Several programs are run on the arrival of new data to generate intermediate data and graphics, thereby reducing the computing demands by individual requests to the web server. A watch dog program on a separate computer checks for proper operation of the weather data download programs, and warns PlanteInfo personnel by SMS in case of malfunctions.

The following five types of data are provided by DMI:
- Numerical weather forecasts from European Centre for Medium-range Weather Forecasts (ECMWF), daily
- Numerical weather forecasts from DMI-HIRLAM (Sass et al. 2000), every 6 hours
- Synoptic weather observation from Danish weather stations (Bødtker, 2003), every 3 hours
- Observations from voluntary rainfall stations in Denmark (Bødtker, 2003), daily
- Composite weather radar images from 4 Danish radars (Bødtker, 2003), every ten minutes.

The data in the first four categories are pre-processed by DMI on to the Agricultural Meteorological Information System (AMIS) grid of 632 10 x10 km cells covering Denmark (Hilden & Hansen, 1998). The weather parameter values in each grid cell are computed as inverse distance weighted averages of data from climate stations within a parameter dependent distance from the cell midpoint. Data from ECMWF are first calibrated to climate station positions by Kalman filtering and then interpolated to AMIS. Forecasts from DMI-HIRLAM are derived from model output on a 15 x15 km grid. Data from nearly 500 voluntary rainfall stations are reported every morning to DMI and included in AMIS interpolations.

The data in AMIS are daily precipitation, global radiation and reference evaporation, 3-hourly 2 m temperature and relative humidity, and 10 m wind speed (average and gusts) and direction. In addition, hourly observations of temperature at 20 cm above the soil surface and 10 cm below the soil surface are available from 16 climate stations.

The hourly precipitation forecasts from DMI-HIRLAM are divided as frontal and convective precipitation, which are presented by dark and light colours, respectively, in the graphical presentation. This reflects the differences in prediction accuracy of the two forms of precipitation, where there is much higher accuracy for rain produced by weather fronts compared to predictions for scattered clouds.

Weather forecasts and weather observations are presented mainly as dynamic graphics showing data from the AMIS grid cell corresponding to the user's localisation. Figure 1 shows the DMI-HIRLAM forecast. The ECMWF forecast is combined with observations from the previous week. Temperature 20 cm above the soil surface and 10 cm below the soil surface from each station are superimposed on a map of Denmark, showing current values, and linked to graphs with four weeks of historical data. Composite weather radar images are available for the past 24 hours with 1 to 6 images per hour. The images can be shown as a movie by a JavaScript program. A similar movie is available for rain forecasts, composed of the rainfall map for each hour from the DMI-HIRLAM forecast. Archived AMIS observations, which are available back to 2000 are presented in graphics for the AMIS grid cell selected by the user.
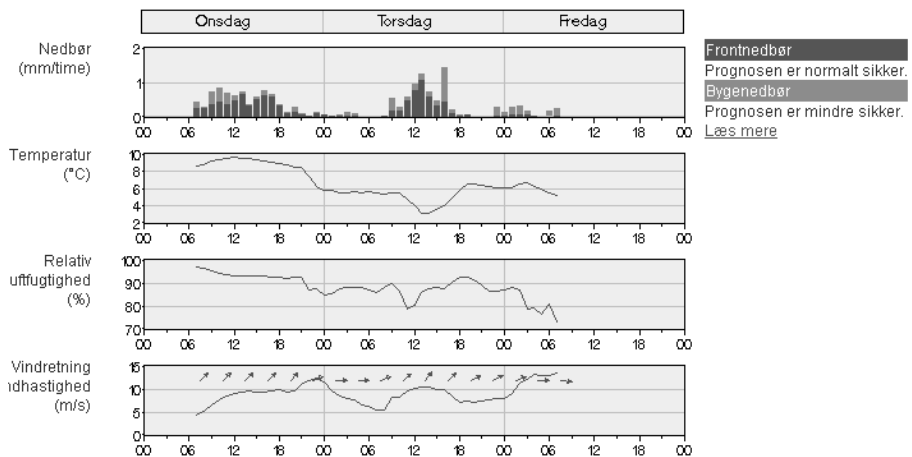
Figure 1. 2-day forecast by the DMI-HIRLAM model.

Other information presented in PlanteInfo weather section are climate data, and an annual FAS publication on the past year's weather in relation to agriculture. Finally, PlanteInfo offers online verification of recent weather forecasts versus observations

and analysis of possible bias in climate stations' measurement by comparisons to other, nearby stations.

The collaboration with DMI on weather data has led to agrometeorological studies by meteorologists at DMI. Hilden & Hansen (1998) analysed the quality of AMIS data, and Sattler et al. (2000) compared the accuracy of AMIS interpolations with grid cell data derived from the HIRLAM surface analysis scheme; AMIS interpolated observations were found to be sufficiently accurate, with the exception of relative humidity and precipitation, and the HIRLAM surface analysis scheme did not produce more accurate data, despite its inclusion of topographical information. Steffensen et al. (2001) and Steffensen & Vejen (2003) evaluated AMIS gridded observations and radar derived 24-hour accumulated precipitation; these studies showed a significant improvement in AMIS gridded precipitation by including data from nearly 500 voluntary rainfall stations as well as potential improvements by including radar data. The latter is not yet available on an operational basis in Denmark.

Numerical weather forecasts are potentially very useful for agrometeorological decision support. Studies by Detlefsen et al. (2001) and Detlefsen & Thysen (2003) on the use of forecasted relative humidity in decision support for control of potato late blight showed, however, unacceptable bias in the forecasts. An analysis by Detlefsen (2003) on DMI-HIRLAM data revealed frequent forecasts of precipitation not being realized in climate station measurements, possibly due to an area average nature of the forecast data in contrast to point data nature of the measurements. Work is in progress on translating the numerical precipitation forecasts into probability distributions for point realisations.

Weather forecasts are very popular among the PlanteInfo users. The availability of two sources of numerical forecasts by different models as well as different spatial and time scales has however created some confusion on which forecast to trust.

Crops

PlanteInfo provides information concerning common arable crops (spring and winter wheat, spring and winter barley, oat, winter rye, triticale, spring and winter rape, peas, sugar beets and potato), fodder crops (grass and maize), vegetables (carrots, cauliflower, cabbage, onions) and fruit (strawberry and apples). A great deal of the information concern plant protection and variety selection.

A specific project on horticultural crops (vegetables and fruits) developed comprehensive information, including growing guides, crop protection and variety information (Röhrig et al., 2000). A decision support tool for estimating emergence of carrot fly larvae from carrot fly catches and temperature was also developed. Another project on information for potato growers included, besides as usual crop protection and varieties, mechanical weed control, and timing of defoliation and harvest. In 2004, a model for grass growth depending on temperature and global radiation was

implemented in PlanteInfo to provide grass growth forecasts to dairy cattle producers. Another agrometeorological crop growth index for dairy cattle producers is the Ontario Heat Units, which can be used to estimate growth and development of maize.

Plant Protection

Plant protection is a very important subject for online decision support because efficient and environmentally friendly plant protection requires information on the current and projected state of crops as well as weeds, diseases and pests. PlanteInfo provides information based on weather data and on field recordings, and a comprehensive decision support system, Plant Protection Online, based on field inspections at the farm level.

Weather based plant protection
Warnings for pests include those for brassica pod midge in rape based on a temperature sum and cabbage root fly based on a soil temperature sum. The warnings are presented in maps of Denmark marked by green, yellow and red to visualize local risk levels and graphs of the temperature sums together with graphs from previous years and the risk threshold.

Warnings for fungal diseases in cereals are in Denmark based on number of rain days within a period related to the development cycle of the particular fungus. The warnings are presented in a GIS application used for presenting test field recordings (se next section), which resides on a server at DAAC; weather data (observations and forecasts) are transferred dynamically from PlanteInfo by XML.

Much attention has been paid to weather based decision support for potato late blight. Recent weather data and short term weather forecasts are combined into treatment advice on a daily basis, presented on maps of Denmark in green, yellow and red, with graphics of local weather data. In the decision support tool farmers can store data on previous treatments and crop susceptibility field by field, and have these data combined with weather data and interpreted as treatment advice (Hansen et al., 2003a). Bias in the forecasts of relative humidity (Detlefsen et al., 2001; Detlefsen & Thysen, 2003), the primary weather parameter for potato late blight risk assessment has caused a loss of end-user confidence in the advice.

Plant protection based on field recordings
DAAC operates a comprehensive system for testing varieties in cereals in trials conducted by local advisory officers. These trials include a weekly assessment of the level of fungal diseases; the data are recorded by use of PDAs and transferred electronically to a database at DAAC. The information is then available in PlanteInfo in a GIS application residing at DAAC. The observed disease levels are combined with a set of rules for recommending treatments depending on crop and variety susceptibility. The treatment recommendations are presented in the GIS application with green, yellow and red colours according to site-specific field recordings. Users

can select crop and variety of interest. General recommendations in plain text by DAAC's plant protection experts are automatically shown on the selection of a crop. Warnings on high observed levels of fungal diseases in cereals are also issued by SMS messages.

The DAAC also operates another system for monitoring crop diseases and pests, including sclerotinia, rape flea beetle, brassica pod midge, pea moth, pea aphid and potato aphid. The field inspections are done weekly by local advisory officers; the data are collected by DAAC and stored in spreadsheet files. A configuration spreadsheet file contains information on the locations of the fields inspected. The files are uploaded to the PlanteInfo web server, where the data are presented by relevant numbers at the proper places on maps of Denmark. The web pages contain expert recommendations by DAAC according to the current observations.
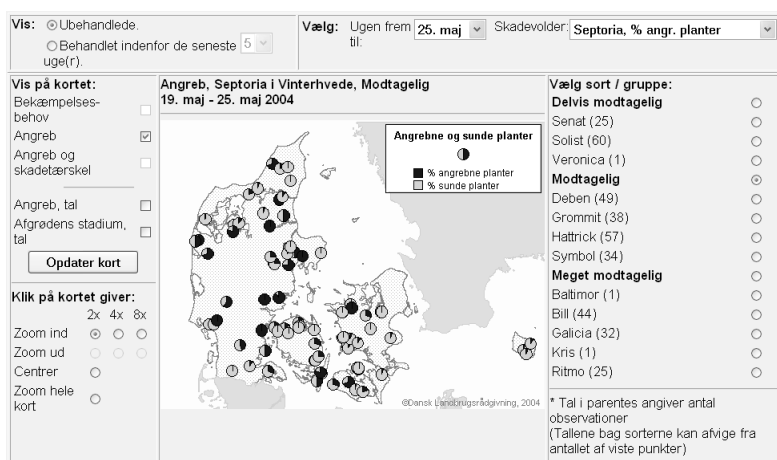
Figure 2. Percent registered attacks of septoria in winter wheat on May 25, 2004.

A third system was developed for monitoring the first findings of potato late blight. This system resides on the website www.web-blight.net, and it is also being used by the Nordic and Baltic countries; Web-blight also provides means for storing and analyzing potato late blight trial data (Hansen et al. 2002; Hansen et al. 2003b). In Demark, the collection of data is organized by DAAC. Data are uploaded by a client-side PC-program. Location, disease severity, crop variety and development stage are recorded, and the results are presented in maps and tables (Figure 2).

Plant protection decision support
Over a period of more than 15 years, work has been in progress at the FAS Department for Plant Protection on a decision support system for plant protection. The system was initially implemented as a standalone PC-program, PC Plant Protection, but has been further developed into a web-based system, Plant Protection Online, also available in PlanteInfo. Plant Protection Online covers weeds, diseases and pests. Recommendations are based on heuristic rules, which usually involve

observed data from the fields in question against treatment thresholds. Emphasis is on reduction of treatment intensity, reduced dosages and economical justification. The rules implemented in Plant Protection Online are extensively tested in experiments and field trials. Plant Protection Online has facilities for seasonal planning, weed, disease and pest identification, problem solving, pesticide database look-up, and formulation of mixtures of pesticides. For further information about Plant Protection Online, see Rydahl (2003) and Rydahl et al. (2003).

Varieties

Information on varieties is important for agricultural and horticultural producers. The data is produced by breeders, official variety testing regimes and farmers' / growers' organisations. By web-based applications linked to databases with variety data, the information is always up to date and a search for varieties with specific qualities is easily performed. PlanteInfo has applications for variety information on arable crops, and vegetables and fruits. In addition, results from the official variety testing are available in PlanteInfo.

SortInfo (Jensen, 2001) covers arable crops except potatoes, and includes comprehensive variety data in a database operated by DAAC. The system includes logics for computing annual indexes and summaries for the varieties from raw data in the database. The information on varieties is presented crop by crop in tables, which can be modified by the user with respect to search criteria, ranking criteria and data being presented. There is a very fast flow from data being recorded to availability on the net, allowing, for example, harvesting data to be used for variety selection in autumn sown crops the same year. SortInfo includes a facility to rank varieties using an overall profitability index, combining variety characteristics such as yield, disease susceptibility and product quality (Detlefsen & Jensen, 2004). The effect of disease susceptibility is represented by the likely costs for crop protection, which is calculated from each variety's observed disease resistance and a distribution of annual disease occurrences estimated from several years of variety trial data.

The data in PlanteInfo concerning variety information on potatoes, vegetable and fruit crops includes only aggregated variety data. The data are mainly provided by DAAC in spreadsheets, which are used to update the databases. The variety information is presented in tables with facilities to modify ranking, search criteria and inclusions of data. In some cases, graphical symbols are used instead of numbers.

The FAS Department of Variety Testing is responsible for the technical aspects of projects concerning the statutory variety testing of agricultural crops, lawn grasses and horticultural plants. Testing is carried out in accordance with the conditions and agreements necessary for acceptance to the official variety listings and to enable the protection of new plant varieties. The information available through PlanteInfo includes origin, breeder, maintainer, owner and Danish agent, and results from annual trials for testing new and currently used varieties.

Other Issues

Irrigation

Approximately 25% of Denmark's agricultural area is on sandy soils with a low water holding capacity. Irrigation in dry periods is therefore required for achieving high yields, especially for potatoes and fodder crops. Irrigation equipment is available on farms covering about 15% of the total agricultural area. Updated information on the water balance is thus an important issue in PlanteInfo.

The daily reference evaporation is calculated from the weather data in PlanteInfo, using Makkink's formula, as a study by Detlefsen & Plauborg (2001) showed less bias by this formula than by a modified Penman-Monteith formula. The spatial variation in daily precipitation and reference evaporation is presented on maps, and simple water balance calculations are available on a local scale (the AMIS 10 by 10 km grid) with a daily or weekly time resolution.

The most valuable information is provided by the irrigation decision support system Irrigation Manager, which is an Internet implementation of a previous PC-program. Irrigation Manager takes proper consideration of crop development and soil characteristics in model-based calculation of actual evaporation and water balance. Farmers can enter data on fields, crops, irrigation and precipitation and get field-specific information in return. The Irrigation Manager is described in detail by Thysen & Detlefsen (2006).

Nitrogen

PlanteInfo's section on nitrogen contains three interactive applications, one concerning ammonia volatilisation from manure and two specific to Danish regulations of nitrogen use in agriculture.

Concerning ammonia volatilisation, a model computes the total ammonia volatilisation in up to 3 days from manure application to fallow land or low crop (<10 cm). The amount of applied slurry is defined by slurry per hour and first and last hour. The model was developed by an EU-project and is based on data from several countries (Søgaard et al., 2001). The user can select certain input parameters, for example slurry type and application rate. Weather data from PlanteInfo's weather database is used. The results are presented in graphs (Figure 3).

The allowable amount of nitrogen fertilization in Denmark is regulated by regional norms. Farmers may, however, apply more nitrogen if they prove a higher need by soil analysis. PlanteInfo contains a tool for determining a new field-specific nitrogen norm from soil sample analysis and data concerning previous crops and cultivation methods. Advisers use this tool, and the end result is a document, which can be used as an application form to the authorities. The Danish nitrogen regulation includes a rule that farmers may apply more nitrogen, if previously applied nitrogen has vanished early in the growing season due to unusual weather. The farmer must provide documentation for the disappearance of nitrogen to get permission to

substitute. PlanteInfo can provide the required documentation by simulations using the soil-crop-atmosphere model Daisy (Hansen et al., 1990). Input to the model is five years of growing practice data for the field in question and the weather database. The end result is also a document that can be used as an application form. Technically, the simulation model is running in the background on input data generated by PlanteInfo (Thysen et al., 2003).
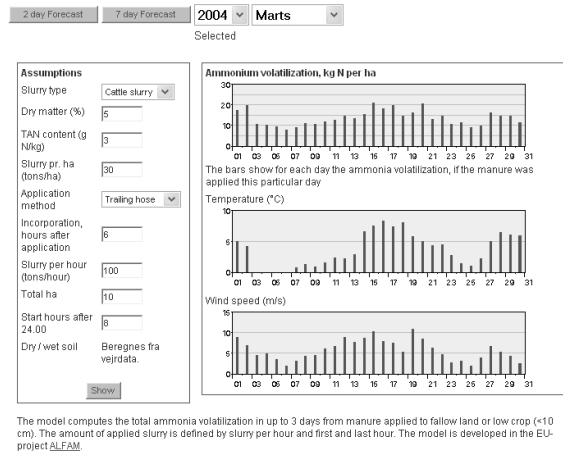
Figure 3. Ammonium volatilisation from manure applied to field, March 2004.

Bees

The FAS Department for Plant Protection performs statutory activities concerning prevention of diseases in honeybees. Information from this work is published in PlanteInfo. Most of the information is static pages concerning diseases affecting honeybees. The occurrence of American foulbrood (AFB) is monitored and the data are presented on maps of Denmark.

Mobile telephone applications

The use of mobile phones to acquire information is interesting for farmers because it enables access from the field and does not require use of computers. It has for some years been possible to receive some of the information from PlanteInfo by SMS (Short Messaging System) and recently also by browsers in new, advanced mobile phones. PlanteInfo contains a warning system where weather forecasts and plant protection warnings are communicated by SMS (Jensen & Thysen, 2003). The system has two types of warnings: Push-type warnings are sent regularly or when certain criteria are met, as specified by the user, while pull-type warnings are sent on the user's request by SMS. Furthermore, the Irrigation Manager (described in the water section), which requires frequent data updates by the user, has been enabled for operation by SMS.

In 2004, some of the most popular pages in PlanteInfo were enabled for access by web browsers implemented in new smartphones with larger screens (Jensen &

Thysen, 2004). From a technical point of view, it is very encouraging that mobile Internet can be developed with standard XHTML technology, which allows existing applications to be re-used with modification of the pages to fit the smaller screen size on mobile phones.

eAdvice

The eAdvice concept (Thysen et al., 2002) is aimed at bridging the information gaps and conflicts of interest between information providers, information users (farmers) and intermediates (local advisers). Uptake of ICT by farmers has been disappointing (Thysen, 2000), and one possible reason is an unwillingness to invest sufficient time in learning how to use technology. Local advisers may see Internet-based decision support as a competitor to their business of selling information to farmers. The basic idea in eAdvice is to offer a service, by which advisers can customize the farmer's account in PlanteInfo as a part of their normal business activities. The farmers can thereafter use PlanteInfo in their daily work with support from the adviser. The first version of eAdvice was launched in 2002. From 2003 to 2006, eAdvice attracted increased attention from local advisers in combination with the use of the Irrigation Manager. In 2006, the use of eAdvice increased dramatically due to new facilities for sending SMS messages to targeted groups of farmers.

User acceptance

During the period from 1 April to 30 September 2006, 4500 different users logged in to PlanteInfo. Many of these were only on very few occasions. By arbitrarily setting a lower limit of login on 4 different days during that period, the numbers of active users are, approximately, 1750 farmers, 300 crop production advisers and 310 others. A lower limit of login on 16 different days gives 1000 farmers, 210 crop production advisers and 170 others. There are about 50,000 farmers and 450 crop production advisers in Denmark. The Irrigation Manager was used actively by 266 farmers and 56 advisers in 2004, 334 farmers and 56 advisers in 2005 and 390 farmers and 60 advisers in 2005. There are nearly 10.000 farms in Denmark with facilities for irrigation. The most popular pages were those with weather forecasts, weather radar, irrigation, and plant protection. There was more interest among crop production advisers compared to farmers for pages with warnings and field data concerning crop pests and diseases. There was a relatively high interest among all user categories for ordering SMS services from PlanteInfo.

Discussion

The development of PlanteInfo over a 10 year period has resulted in a web site with a considerable amount of content directed at farmers and advisers. The main objectives are to provide information derived from local, up to the hour weather data and weather forecasts, information derived from field observations by crop production advisers, and information derived from interactive decision support systems utilizing the aforementioned data. The uptake of PlanteInfo amounts to approximately 4% of active users among Danish farmers, a disappointingly low figure though not

surprising in view of international experiences (Thysen, 2000; McCown, 2002). However, about 50% of registered Danish crop specialist advisers are using PlanteInfo regularly in the summer period, establishing PlanteInfo as a main source for advisory information communicated to farmers during the growing season. Through the on-going development of eAdvice, the direct use of PlanteInfo by farmers is being stimulated by establishing net-based collaboration between farmers and advisers.

PlanteInfo is developed and operated within the Danish agricultural research community, in a close collaboration with the Danish agricultural advisory system and with a high proportion of funding from Danish agriculture. The weather data are supplied by the Danish Meteorological Institute in an on-going collaboration also including development of new products. The stimulus for these efforts in applying information and communication technology in agriculture came from Danish Informatics Network for the Agricultural Sciences (DINA), which includes agricultural research institutes, universities and the advisory service (Flensted-Jensen et al., 2003). The Danish experience is now being utilized in a development programme for establishing similar systems in Poland, Lithuania, Latvia and Estonia (Høstgaard et al., 2003; Lassen et al., 2003). Similar opportunities could be developd elsewhere in the world.

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A SLURRY SPREADING DECISION SUPPORT SYSTEM FOR IRELAND

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Abstract

A slurry spreading decision support system (DSS) is described that is based on scientific research conducted in Ireland. Due to a lack of site-specific soil data, the DSS concept uses a generalised soil moisture deficit model, calibrated for well, moderately and poorly drained soils, driven by Numerical Weather Prediction weather forecast data to evaluate spreading conditions for the coming seven days. The model predicts whether there will be water available to transport nutrients from the field to other locations. It is up to the end-user to evaluate which set of forecast soil conditions is most applicable to their particular circumstances. The structure and function of the DSS are described and issues relating to its implementation are discussed.

Introduction

Bovine animal production systems in Ireland are usually based on rotational grass grazing, grass forage conservation, winter housing and indoor winter feeding. Animals are housed in the winter, but also under some conditions at other times, to allow controlled feeding of conserved forage and to protect soil resources from trampling damage. During the periods of animal housing, dung, urine and dirty water (rainfall and washing water contaminated by animal wastes) have to be collected in large tanks, generally referred to as slurry tanks, in order to prevent the animal houses and farm yards becoming sources of concentrated environmental pollution by the nutrients present in slurry. The material held in the slurry tanks is usually dispersed by land spreading during the grass growing season (April to October). If slurry is spread on fields when soils have a water content greater than field-capacity (the water content to which a soil will drain due to gravity) then the excess water can transport nutrients away from the field so that it becomes a source of pollution. For some farmers slurry disposal is seen as a waste management issue, while for others it is regarded as essential nutrient recycling.

Agriculture is estimated to contribute significantly to the eutrophication of Irish rivers and estuaries, with 70% of phosphorus loads and 82% of nitrogen loads, respectively, attributed to agricultural sources (anonymous, 2004; Stapleton et al., 2000). The loss of nutrients from farms, and the subsequent transport to water has been the subject of numerous studies, both in Ireland and internationally. Current European legislation such as the nitrate directive (Directive 91/676/EEC on nitrates from agricultural sources) means that it is necessary for member states to regulate the management of nitrate, and other nutrients, in order to ensure that pollution as a result of agricultural activity is minimised.

The idea behind developing a slurry spreading decision support system (DSS) is to:

(a) evaluate the science behind the pollution mechanisms associated with nutrient loss after slurry spreading in order to develop a robust approach to predicting when "safe" spreading periods occur. If this can be achieved it should be possible to develop a DSS that will inform farmers when the risk of causing pollution from slurry spreading is low; and

(b) to establish whether periods banning spreading are appropriate or whether it might be possible to regulate spreading to "safe" periods. If a robust method of predicting when spreading might be safe is developed, it can be applied to the climate archive in order to better establish when blanket bans are appropriate and when advice to spread is most appropriate.

The risk of nutrient loss to water has been conceptualised as a pressure-pathway-receptor model (Ansell and Wharton, 1992; Haygarth et al., 2005), in which the risk of nutrient loss to water is greatest where pressure and pathway coincide, and there is a sensitive receptor. When applied to the issue of managing slurry spreading, the model can be recast in terms of a source (slurry spread), a transport vector (free water available to transport nutrient) and a target (surface or ground water). Figure 1 provides a schematic representation of the concept. In this situation if there is no transport vector to link the source and target then there is no pollution problem. In order for there to be a continuous transport vector there has to be sufficient soil water, combined with rainfall to bring the water content to an excess over field capacity, and this has to occur over the whole of the transport vector. The excess water results in "drainage" which can be either overland flow (runoff) or leaching. The physical properties of the soil (texture, structure, horizonation) will interact with landscape and other weather driven properties such as evapotranspiration (wind, relative humidity) to determine when the transport vector exists.
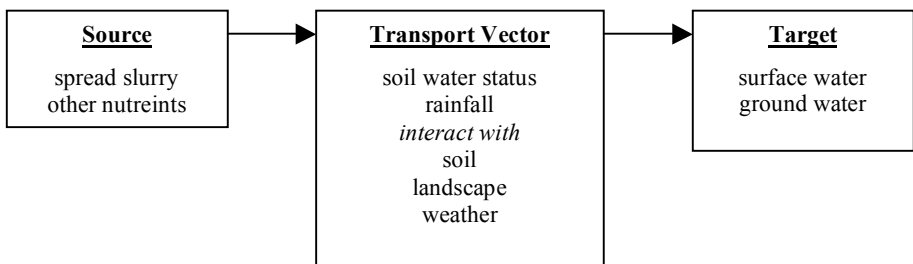
Figure 1. The conceptual model of nutrient pollution following slurry spreading.

Slurry will be transported from the target site by runoff (as a transport vector) if the combined volume of slurry and rain exceed either the infiltration rate or drainage rate of the soil (Parkes et al., 1997). McGechan and Wu (1998) and McGechan and Lewis (2000) outlined a range of criteria for determining a 'spreading day' or 'workday', for the application of organic manures (slurry spreading) with minimal environmental

risk based on the requirements that: (i) there is no snow cover and the ground is not frozen; (ii) the rainfall on the current day <2.5 mm; (iii) the air filled pore space in the soil profile is >15 mm; (iv) the forecast rainfall is less than a threshold on a set number of days after spreading; and (v) the soil water content in the upper soil is less than field capacity + 2%. In Ireland snow and frozen ground are rarely a problem, rainfall data are available from the Met Éireann database, and forecast estimates are good (Keane, 1996). However data for air-filled pore space and field capacity are soil dependent and not available at a suitable scale. This approach to the problem of forecasting when it is safe to spread slurry is however a good basis on which to develop a slurry spreading DSS.

A number of attempts have been made to estimate slurry-spreading opportunities from climate characteristics. Rounsevell and Jones (1993) used a simple model of plant root moisture extraction to predict actual evapotranspiration. Smith and Trafford (1976) used the same basic method combined with soil, environmental and management factors to predict storage requirements. A national scale estimate of regional spreading opportunity could only be guessed at using this approach however. A technique called "versatile soil moisture budget" (Baier and Robertson, 1966) estimates daily soil moisture fluxes. Rutledge and McHardy (1968) used a simplified version to estimate work and non-workday probabilities for seven locations in Alberta. They recommended estimated soil moisture content in excess of 95% of field capacity in the upper zone of the soil as criterion for a non-workday and that workdays should have no snow cover. Gardiner (1986 a,b) used a similar approach to examine Irish soils with respect to hydraulic loading and slurry spreading but only had data available for a limited number of locations. Holden et al. (2004) developed a method based on rainfall patterns over an 8-day period, but this was never field calibrated.

A lack of site-specific soil data at an appropriate scale makes it desirable to separate the spatially determined soil component of a slurry spreading DSS from the spatial weather component. Most of the methods described above have required close integration of soil and other environmental data with weather data because they were designed for site-specific analysis. In order to find an approach suitable for Ireland it is necessary to separate these components.

The approach taken when developing a slurry spreading DSS for Ireland was to use numerical weather prediction rainfall data to achieve both good spatial coverage over the country and a forecast element, and to make forecasts for soil types. In this case, soil is reduced to three categories and a soil water balance is calculated at each location for each soil category. In order to apply the output of the DSS it is then necessary for the farmer/advisor to determine which soil type most closely approximates the field conditions where slurry might be spread. This approach has two significant benefits: (a) it allows a system to be developed that accounts for spatial weather patterns but is not constrained by the lack of soil data in Ireland and (b) it allows the farmer/advisor to have a positive input into the decision making process. The DSS theory and structure will be described in the following section.

DSS Theory

The soil and landscape component

The soil moisture deficit concept. In order to predict when a volume of rainfall and/or slurry will result in an excess of free water that can be come a transport vector, it is necessary to estimate the soil's water content. Given the scarcity of soil data for Ireland, rather than considering soil water in terms of gravimetric (g g^{-1}) or volumetric (m^3 m^{-3}) water content, it can be quantified using the concept of the soil moisture deficit (SMD). SMD is defined as the amount of water (expressed as mm of rainfall) required to bring soil moisture levels to field-capacity (Keane, 2001), where field capacity means that macropores are air filled and all other pores are water filled (i.e. the water content to which a soil will drain due to gravity). This means SMD = 0 is field capacity, SMD < 0 the soil is approaching saturation (free water is available in the soil) and SMD > 0 the soil is drier than field capacity. SMD can be calculated directly as a soil water mass balance (e.g. Aslyng, 1965; Brereton et al., 1996; Keane, 2001) as:

$$SMD_t = SMD_{t-1} - Rain + ET_a + Drainage \qquad (1)$$

where SMD_t is today's SMD (mm), SMD_{t-1} (mm) is yesterday's SMD (there is a 24 hr or 1 day time step assumed), *Rain* is the rainfall since time t-1 (mm), ET_a is the actual evapotransiration since time t-1(mm) and *Drainage* is the vertical percolation plus surface runoff of free water since time t-1 (mm).

The model used by Brereton et al. (1996) predicts the SMD for well-drained soils only and assumes any water in excess of field capacity is instantly drained. The model used by Met Éireann until 2006 is summarised in Keane (2001) and assumes that water surpluses can accumulate during wet spells, thus predicting the SMD of poorly drained soils. Most of the models predicting SMD do not use Irish soil calibrations but adopt the parameters that were originally established for a soil in Denmark by Aslyng (1965). For the DSS a modified version of the SMD model was developed (Schulte et al., 2005) that could be calibrated for three generalised soil types. The objective was to formulate a predictive model with minimum requirements for input parameters, in order to maximise its practical applicability.

The Hybrid SMD model (Schulte et al., 2005). The Hybrid model is described in detail by Schulte et al. (2005). It main components can be most rapidly appreciated by considering how SMD interacts with evapotransiration (Figure 2A) and drainage (Figure 2B). The model has four critical parameters that can be calibrated by soil type (Table 1). SMD$_{max}$ is the water content (expressed as a SMD) at which no further evaporative loss is possible, which is also known as the wilting point. SMD$_{max}$ should be very similar for all soil types. SMD$_c$ is a critical SMD at which actual evapotranspiration becomes less than a predicted potential rate for a reference crop. When SMD exceeds SMD$_c$ the model is representing when grass leaf stomata close progressively to reduce the transpiration rate, which should be related to the soil water characteristic curve, and most importantly texture and structure. SMD$_{min}$ is the maximum water surplus (expressed as a negative SMD) that can occur. For a well

drained soil this is assumed to equal field capacity (SMD = 0), since, by definition, on these soils any water surplus in excess of field capacity is drained by infiltration within a day. For soils that can hold water until saturation without immediate drainage, SMD_{min} was calibrated as SMD = -10, assuming that any further precipitation is drained through overland flow. $Drain_{max}$ is the maximum rate at which free water can drain away from the soil through infiltration (mm d^{-1}), and is only applicable if $SMD_{min} < 0$. The model is operated with a daily time step, and $Drain_{max}$ refers to the total daily infiltration capacity. The instantaneous infiltration rate is not considered, therefore overland flow resulting from rainfall rates in excess of infiltration cannot be predicted.
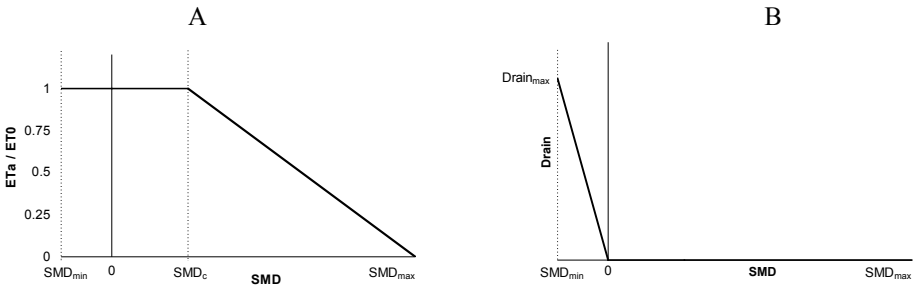
Figure 2. A. The actual evapotranspiration (ET_a), expressed as a proportion of the potential evapotranspiration (ET_0), graphed as generalised function of SMD (mm). B. The actual drainage rate, *Drainage* (mm), as a generalised function of SMD (mm) and $Drain_{max}$ (mm). Source: Schulte *et al.* (2005)

Table 1. Generalised parameter values for well drained, moderately drained and poorly drained soils in the Hybrid SMD model.

Parameter	Soil type		
	Well drained	Moderately drained	Poorly drained
SMD_{max}	110	110	110
SMD_c	0	0	10
SMD_{min}	0	-10	-10
$Drain_{max}$	N/A	>10	0.5

The Hybrid SMD model was calibrated and tested using data from three soils at Ballintemple Nursery, Co. Carlow, Clonroche Research Centre, Co. Wexford and Johnstown Castle Research Centre, Co. Wexford. The evaluation was conducted over multiple years at multiple locations and the results indicated that three distinct soil types could be defined using the model (Table 1). The three soil classes are: a) well-drained soils that remain at field-capacity on wet winter days, even during rainstorm events, and are never saturated; b) moderately-drained soils that carry water surpluses on wet winter days, and can reach saturation during rainstorm events, but will return to field-capacity on the first subsequent dry day; and c) poorly-drained soils that carry water surpluses on wet winter days, reach saturation during rainstorm events, and remain below field-capacity for a number of days, even when no further precipitation occurs..

<u>Landscape position</u>. In effect, the Hybrid model is a simple bucket model in which the only input of water comes from precipitation. However, the farming landscape is three dimensional and soil water is transported both laterally and vertically. As a result, soils in selected locations may receive significant amounts of water input from lateral flow, originating from higher ground. To account for this, the SMD calculation can be modified to simulate water draining from a higher elevation influencing a soil at a lower elevation, by assuming that the water transport (i.e. either the predicted infiltration or predicted overland flow) from higher to lower ground can be described with an exponential decay function.

Meteorological inputs: observations and forecasts
The Met Éireann synoptic observation network consists of fifteen stations which take readings of temperature, pressure, humidity, windspeed, sunshine/radiation and rainfall which are required for the calculation of potential evapotranspiration (ET_0) and SMD. These stations are a mix of manned and automatic stations so data are available in near to real time for use in DSS. In addition there are at present 12 TUCSON (The Unified Climate and Synoptic Observation Network) stations which also take the required meteorological readings, but these will not be available until a Quality Control System has been implemented. In the near future meteorological readings will be available from 25 locations, with a further expansion of the TUCSON network likely over a three to five year time-scale.

The DSS requires Numerical Weather Prediction (NWP) data for 7 days ahead, which requires forecast data from a global model. In effect, forecast data are required for 8 days ahead since the data are only available 10-12 hours after the model run. At the European Centre for Medium-range Weather Forecasts (ECMWF), a deterministic model is run to 10 days ahead at a resolution of 25 km, which produces an output for each parameter at each grid point. However, the accuracy of the forecast decreases with time, and the deterministic forecasts shows little accuracy after day 7. One of the main reasons for the fall-off in accuracy at longer time intervals is uncertainty in the model initial conditions, which has led to the development of the ensemble prediction system (EPS). In the EPS the model is run 50 times at a lower temporal resolution using different initial conditions, so for each grid point there are 50 forecast values for each parameter. The mean values of the EPS output might be better than the single value deterministic output, and the spread of the EPS output could be used to estimated the current 'predictability' of the atmosphere i.e. if the EPS spread is small there is little variance in the forecasts and the different initial conditions have little effect on the forecast, while a large spread means that the atmospheric model is particularly sensitive to initial conditions and is difficult to predict.

DSS system structure
The Hybrid SMD model, with landscape component is integrated with
- meteorological observation data (for daily evaluation of the SMD predicted by NWP data)
- NWP 7 day forecast data for predicting SMD over the coming days

- Data on SMD thresholds for estimating when there is a significant risk of the transport vector being established

Using data interpolated onto a grid over the country (the staring point is a 40 x 40 km grid) it is possible to make spatial estimates of pollution risk following slurry spreading for a forecast period of 7 days. A schematic representation of the data/information flow in the DSS is presented in Figure 3.
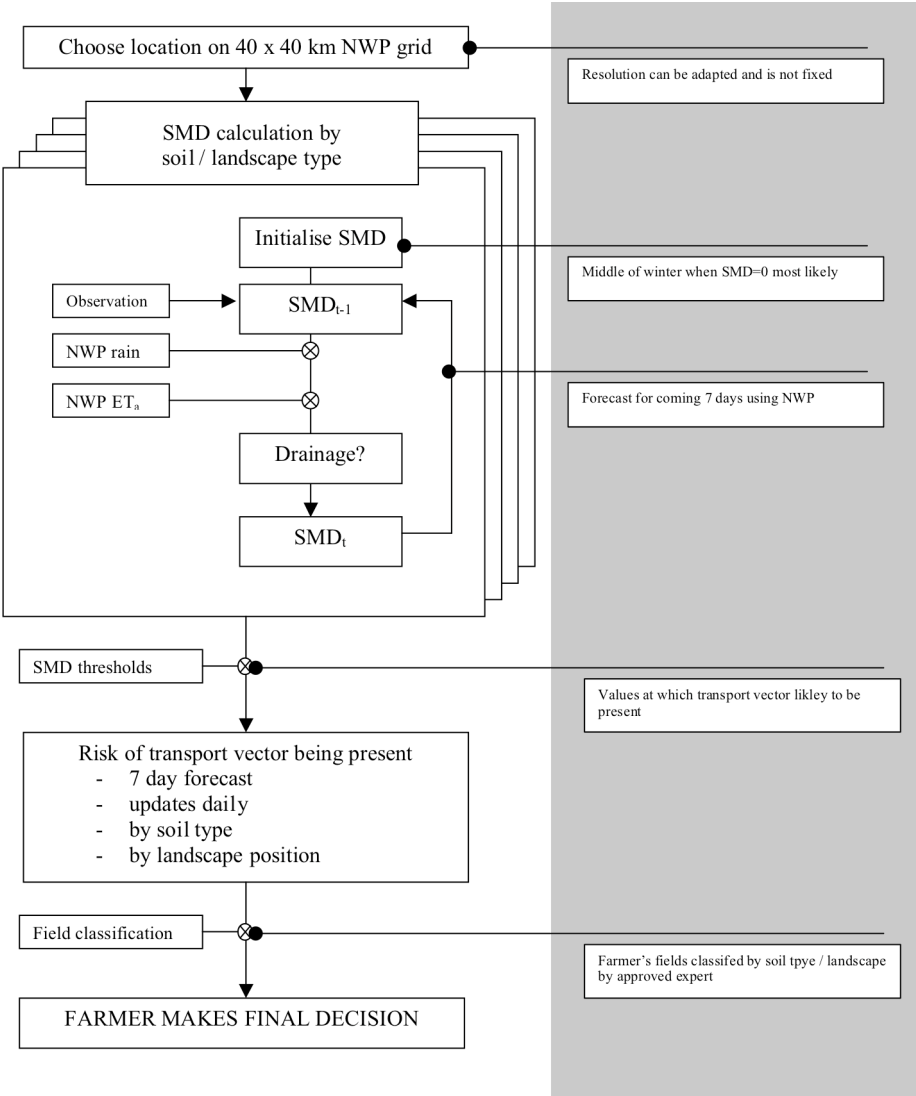
Figure 3. Flow diagram of the DSS processes leading to information to support farmers' decisions about when and where to spread slurry.

To use the risk forecast, the farmer / advisor has to classify individual fields by soil type / landscape (not integrated into the DSS structure), and choose the risk calculation most appropriate for the specific geographical situation. A degree of local knowledge can then be used to make the decision whether to spread or not.

DSS Implementation Issues

Resolution and application for farmers
The spatial resolution of the DSS as currently implemented is relatively coarse at 40 x 40 km. The forecast skill for rainfall was evaluated (Lancaster et al, in prep) and it was found that NWP rainfall offered a significantly ($p < 0.05$) better forecast than climate or persistence for a 7-day time horizon. Recent developments in NWP specification indicate that the resolution might be reduced to around 15 x 15 km in the coming years, but a re-evaluation of the forecast skill at this resolution will be required. It will probably never be possible to make dynamic interpolations or NWP predictions of rainfall data to a resolution compatible with farmers' fields, so given the lack of site-specific soil data, the system resolution as specified represents a good starting point for characterising local-scale climates, defined as mesoclimates by Holden and Ortiz (2003) as "…covering a scale of tens of kilometres,… reflected in the farmers view of the weather experienced in the region…". A field-by-field option could be implemented but it would still have to rely on meso-scale data from NWP and would need individual farmers to provide specification data for the local soil and landscape characteristics.

The question has arisen during DSS development whether the service should be made available directly to farmers or whether it should be presented via an extension service such as an accredited agricultural advisor. During system development it was envisaged that a farmer would subscribe to the system (the cost element was not evaluated) and in doing so would have each field or land unit allocated to a soil / landscape class by an accredited professional trained in using the system. This way, the farmer could then use output on a regular basis secure in the knowledge that it was being correctly interpreted and understood.

Interface technology options
The initial presentation of the DSS as a trial package is via Internet web pages. This is a technology that permits rapid development and extensive distribution. In the current Irish situation it is perhaps not the best option due to the lack of farms with Internet-connected PCs, and the difficulty in getting reliable broadband services in more remote rural situations. If the information output from the system is correctly presented a better option might be to specify all end-point web pages as mobile telephone compatible so that the high rate of mobile telephone penetration into Irish farms can be better utilised by the system. Two other alternatives are subscription SMS messages based on the 40 x 40 km cell that the farmer is located in or the use of television teletext pages. The latter would probably devalue the system by being perceived as old-fashioned.

Regulatory and legislative implications
At this stage of the DSS development it is necessary to ask two important questions: (1) who is ultimately responsible for field actions and any resulting pollution that may occur, and (2) are the developers or providers of the DSS liable for the consequences of decisions taken as a result of the DSS being available to farmers/advisors? The answer to both of these questions is of significant consequence for all agricultural DSS developers in Ireland. At this point in the DSS development the answers are not clear.

Conclusions

The slurry spreading DSS has been designed based on straight forward science adopted to overcome issues relating to a lack of site-specific data in Ireland. To date the core issues of the soil model and the NWP rainfall predictions have been tested and evaluated which leaves the testing of the landscape component and the overall system model. Once this has been completed we can be reasonably confident that the DSS will provide useful and valid information for assisting with the decision making process. The remaining issues are to get the delivery to end-users and user-interface(s) right and to ensure that the DSS has an accepted place in the management of slurry on Irish livestock farms.

Acknowledgements

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WORKSHOP SUMMARY: FEEDBACK FROM THE HANDS-ON SESSION

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Abstract

A 'hands-on' session to provide Workshop participants with experience using existing decision support systems (DSS) from all over the world was held in the afternoon of January 25th at the workshop *Making Science Work on the Farm*. Participants filled in questionnaires about their impressions from using the Internet-based tools provided. In this paper, we provide an analysis of the responses received and discuss these responses in the wider context of discussions held at the Workshop and in the scientific literature. The Workshop highlighted the need to consult with users about the information required for agricultural management and the need for minimizing costs to the user (both in terms of work time and technology investment) when developing DSS for agriculture. Currently, because of rapid changes in agricultural legislation in Ireland, expert advice is in particular demand in the field of nutrient management and agricultural policy and legislation. Participants highlighted at the Workshop that it must be clear to them how the information received was generated, such that the information will have an empowering effect. It is the challenge for future development of DSS for Irish agriculture to address pressing issues as well as to deliver information in an easy-to-use way.

Introduction

Decision support systems (DSS) are interactive software or internet-based tools that allow users to inform their management decisions with expert knowledge. The usefulness of DSS for making informed decisions in farming is going to increase in the future provided DSS are developed and deployed in a mutual understanding of the scientist and the farm manager (McCown 2002). A successful example of a comprehensive agricultural DSS used in Denmark (Planteinfo) was demonstrated at the Workshop (Thysen, this volume). The Planteinfo website allows farmers to access relevant weather information, disease warnings, variety selection for arable crops, and irrigation advice. A farmer told the audience that he could increase the yield of his arable crops significantly by using the system (T. Heisel at Workshop presentation). The hands-on session of the Workshop allowed Workshop participants to explore a number of existing DSS and their potential benefit for farm management.

The hands-on session was organized such that we could get feedback from users on existing DSS. A critical factor in the uptake of any DSS is the benefit of the system in comparison to its costs (I. Thysen at Workshop presentation, Alvarez and Nuthall 2006). Costs can be both in terms of the investment in the technological equipment required (e.g. the computer, internet access) and in terms of the work involved in

learning and parameterizing the system. Benefits to users arise when the requirements of users can be met both in terms of the kind of information delivered as well as in the format of delivery. If the system meets user requirements they will be more willing to put effort into learning how to use it. In this Workshop we evaluated the format of a number of internet-based DSS in terms of how they meet user needs.

One challenge in the design of DSS is communicating enough of the background on a given system without compromising its utility in terms of presenting information in a summarized way. The designer will have to decide on the level of detail that should be included in a DSS. Furthermore, science-based DSS have a certain level of uncertainty associated with them and the designer needs to decide how this uncertainty should be communicated to the user (Moore, this volume). The user of the system needs to know about this level of uncertainty in order to correctly use the information provided. We wanted to evaluate what level of detail users would like to see in DSS and if the systems evaluated allowed them to see the level of uncertainty of the information provided.

The aim of the hands-on session at the Workshop was to provide participants with experience in using a number of existing DSS. They were then asked to evaluate the systems from three points of view: (i) Ease of use; (ii) Usefulness of the information provided; and (iii) Level of detail and information on the accuracy of the system. Furthermore, participants were asked about their likely future use of decisions support systems.

Materials and Methods

The systems were chosen to cover a variety of interfaces, but they had to be simple enough to allow Workshop participants to use them in a short amount of time (max. 15 minutes) (see Table 1 for more information about the systems). Only DSS in English were chosen for the Workshop. The systems chosen were all designed to assist farmers to make decisions about a particular farming 'action' (McCown, 2002). Participants were given a brief introduction to the system by a trained helper and then were asked to perform a DSS-specific task to get the experience of navigating the system themselves. A questionnaire was provided that had two pages of general questions as to the participants' use of computers, mobile phones and DSS, as well as their preferences concerning content, detail and reliability of DSS (see the appendix to this volume). Furthermore, participants were asked to fill in at least 3 DSS-specific sections of the questionnaire.

Evaluation of the questionnaire
The responses to the questionnaire were entered into an Excel file. For yes/no questions the number of 'yes' responses and the number of 'no' responses was summed. For questions where the answer could be 'strongly agree', 'agree', 'neutral', 'disagree' and 'strongly disagree', the number of people giving a particular answer was calculated as a percentage of the total number of answers to that question. No statistical tests were performed on the data.

Table 1. Decision support systems selected for Workshop

Short title	Short description	Distributor	Web address
Met Éireann webpage	Met Éireann webpage	Met Éireann, Ireland	http://www.met.ie
GrazFeed	Feeding management for grazing animals DSS	Horizon Agriculture in association with CSIRO Plant industry, Australia	http://www.hzn.com.au
ProPlant expert	Decision support for insecticide, fungicide and growth regulator applications for crops	ProPlant Ltd., Muenster, Germany	http://www.proplantexpert.com
SEADSS	Southeastern Agroforestry DSS	University of Florida, Center for subtropical agroforestry, USA	http://cstaf.ifas.ufl.edu
Irish DSS	Irish Slurry Spreading DSS	AGMET (c/o Séamus Walsh at Met Éireann), Ireland	Unpublished prototype
Manure Manager	Part of an information package for developing a manure management plan	Agricultural Document Library, University of Hertfordshire, UK	http://www.adlib.ac.uk

Analysis of Participants Feedback

A total of 37 questionnaires were returned, 14 of them from researchers, 8 from farm advisors, 5 from farmers, 3 from civil servants, 3 from meteorologists and 4 of them from people, who did not disclose their profession. Most (34) of the respondents use the Windows operating system and most respondents (34) had broadband internet access. The majority of farmers in attendance did not have broadband internet access. Most (31) participants used text messaging on their mobile phones. 32 people filled in the DSS-specific part of the questionnaire for the Irish DSS and 13 people for SEADSS. All the other systems were evaluated by around 20 people each.

1. Ease of use

Computer use amongst Workshop participants was high, with almost all (33 out of 35) respondents using computers on a regular basis. Workshop participants could therefore use systems with relatively little help. The two systems, which were easiest to use were the Met Éireann webpage and the Irish DSS. Seventy percent of the participants could use these with no help and they generally found the information they were looking for easily. These two systems were also the systems that looked the most attractive to users (Figure 1). The system that people needed the most help with was ProPlant Expert (70% of respondents needed sustained help), but once they had

found their way around it they thought it was relatively easy to find the information requested (60% agreed that the information was easy to find). This was similarly true for GrazFeed. The SEADSS and the manure manager needed an intermediate level of assistance (70% could do with little help), but people were also not sure if they had found the information that was requested in the DSS-specific task.
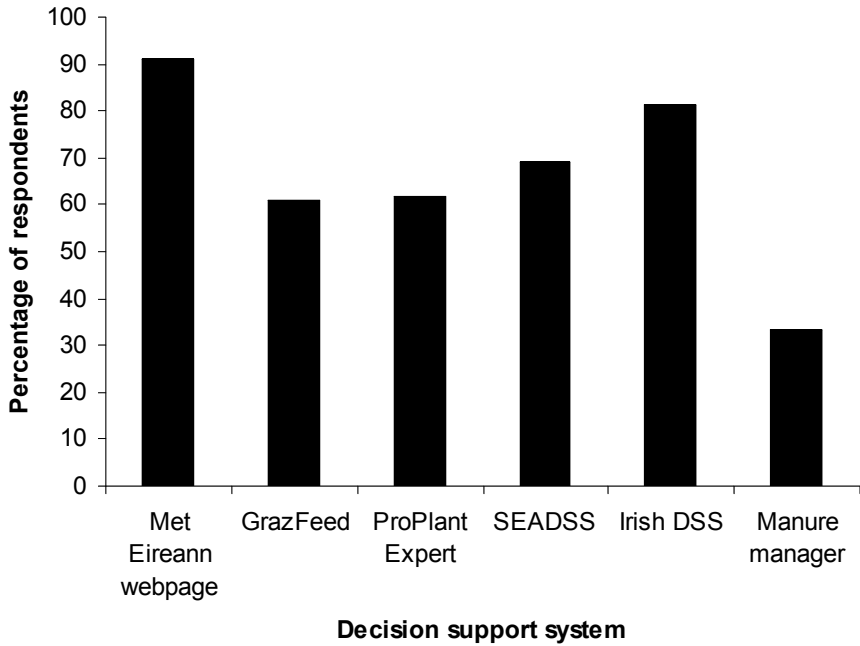
Figure 1. The percentage of respondents that either 'agreed' or 'strongly agreed' that the system they were evaluating looked attractive and made them curious about the system.

2. Usefulness of the information provided
Between 72% (for GrazFeed) and 85% (for the MetÉireann webpage) of the respondents thought that the information given by the systems was valuable. A detailed analysis of what aspects of farming Workshop participants thought they needed advice on follows below.

3. Level of detail and information on the accuracy of the system
In the case of the Met Éireann webpage and the SEADSS, over 60% of the users understood the data and information that was used to generate the advice. This percentage dropped to 50% for the Irish DSS and the manure manager. People were more unsure about GrazFeed and ProPlant expert as to what data these systems were using to generate advice. When asked about the level of detail users would like to know about a system they are using (general section of questionnaire), 50% of the respondents said they would like to know some detail, enough to know what the basic processes are that are incorporated in the model. Over a third of the people would

have liked to know the model in great detail, including a diagram of the model with all the equations. Only about 15% of the users would be satisfied with general information that would tell them when they can apply the model and how good the predictions are.

None of the models allowed the users to easily evaluate its accuracy (DSS-specific section). Most people either did not have an opinion about determining the accuracy of the model (neutral) or were unable to find out what the accuracy of the model is (disagree) (Figure 2). With the Irish DSS in particular over 45% of the users were unable to determine how accurate the model was (disagree). Less than 10% of the users were able to get a feel for the accuracy of the model (agree) in the case of the Irish DSS, SEADSS and the manure manager. This was a little better in the case of GrazFeed and ProPlant expert where between 20 and 25% of the people were able to determine the accuracy of the model, but in each of these cases there were also around 40% of the users who found it difficult to find information on accuracy. With the MetÉireann webpage 30% of the users felt that they had a means to evaluate the accuracy of the information, whereas 30% also thought they did not.
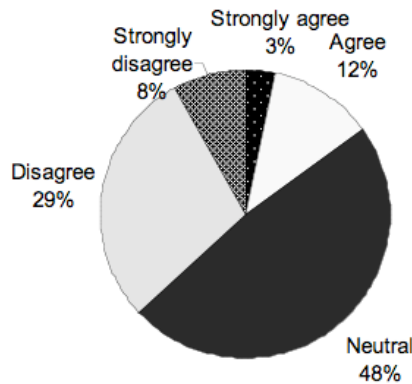
Figure 2. Answers to the question of whether it was easy to find how accurate model predictions were (question 6). Depicted is the average percentage of respondents in each category for all the DSS types demonstrated.

Despite this most (80-90%) people thought DSS were somewhat reliable (general section of questionnaire), i.e. they will mostly follow advice that they would get from a DSS. One farmer remarked that an opinion about the reliability of DSS could not be formed due to the lack of time to interact properly with the systems.

4. Differences between user groups
With the exception of the Met Éireann webpage, where user groups answered all questions in similar ways, user groups differed in aspects of their evaluation of the DSS presented. The Irish DSS and the manure manager were generally more difficult to navigate for farmers than all other user groups. In the case of the Irish DSS, everybody thought the system was user friendly, but farmers generally needed a bit of

help to use the system, whereas the other professional groups could generally use the system without help. Only one farmer used the manure manager, and found it very difficult to navigate, whereas most (70%) other participants found that they needed a little help to navigate the system, but were able to use it after that.

In terms of the information contained in the systems, opinions of user groups were different in the case of GrazFeed and the SEADSS. Farmers found it easier to understand the information GrazFeed used to give advice. In the case of SEADSS, researchers generally found the system more difficult to use to answer the question given and thought it was more difficult to understand what information the system was using to give advice than the other professional groups.

5. *Future use of decision support systems for farming operations*
About half of the respondents were farmers and farm advisors and their responses to the questions were very similar to the responses from all participants. Amongst the 11 respondents from farming (farmers and farm advisors) 7 would consider using DSS in their farming operations, with the others considering the use of DSS depending on their ease of use. The aspect of the farming operations that they need expert advice on varied and all aspects listed on the questionnaire were chosen by at least one person (Table 2). The main need for expert advice was perceived in nutrient management and slurry spreading as well as in agricultural policy and legislation.

Table 2. Number of people who indicated that expert advice might be useful for various aspects of farm management.

Aspect of farming operation	Number of people
Nutrient management	14
Agricultural policy and legislation	13
Slurry spreading	13
Crop systems	11
Grazing systems	10
Disease management	9
Pest management	8
Management of natural diversity	4
Drainage	3
Accounting	2
Forestry	2
Erosion	1
Fire management	1
Marketing	1

Discussion

Participation at the Workshop was very good and a varied audience attended. Participants were impressed by the potential of DSS for agricultural management and they thought DSS could make a significant contribution to farming operations in the

future. However, acceptance of DSS in agriculture has not always been a success (McCown 2002, Alvarez and Nuthall 2006, Thysen, this volume). Generally, information technology is more readily adopted in times of change, when new situations create new uncertainties (management problems) (McCown 2002). It was clear at the Workshop that the recent increase in agricultural legislation and the new restrictions on nutrient management have created a need for expert knowledge. This may translate into an uptake of information technology by the agriculture sector. Workshop participants showed great interest in expert advice that would allow them to manage nutrients more effectively, including the new Irish system (Holden et al., this volume). If this perception of usefulness can be combined with ease of use of the system the chances of uptake of the DSS are high (McCown 2002).

It was highlighted at the Workshop that DSS should be a means to empower farmers and farm advisors to make the right management decisions (also stressed in McCown 2002). Apart from management advice, Workshop participants highlighted the need for more basic data, such as better soils information and observed weather from the recent past. In general, Workshop participants understood that DSS could apply to a wide variety of farming operations. They thought if advice was available from a central location such as in the Danish system Planteinfo (Thysen, this volume), it would be easier to find and access. This central location needs to make the availability of the information known to potential users. It was remarked that the information from any DSS would only be used widely if there was some external incentive to use it, in particular legislation. However, DSS should not become a means of enforcing legislation. A better way to create incentives for farmers to use DSS would be to create awards for good management.

Generally the use of computers in agriculture is going to expand in the future. Even though results on computer use from the Workshop may be biased because mainly people with some interest in information technology attended the Workshop, the availability of computers does not seem a major hindrance to DSS deployment in general (Alvarez and Nuthall, 2006). In some cases, it may be enough for farm advisors to access computerized systems and then distribute the information by some other means (e.g. consultation with the farmer) (McCown, 2002; Moore, this volume). In order to improve DSS, it is necessary that users and scientists engage in dialogue that can lead to mutual understanding and learning (McCown 2002). This will increase the utility of DSS and contribute to a widespread acceptance.

Users wanted to know detail about the DSS they were using. Furthermore, the responses received during the Workshop indicated that it was difficult for users to identify the accuracy of the systems used. As mentioned at the Workshop, training plays a major role in DSS deployment (Moore, this volume). Training is important not only to provide users with the necessary background information, but also to inform them about uncertainties in the system. Training can also enhance the communication between users and developers and increase the utility of the DSS. In general, it seems that the complexity of the DSS should be adapted to its purpose (McCown 2002). For farm use, tools simple enough for the farmer to understand how

the advice was generated (and thus enabling the farmer to modify the information according to management context) will be more in demand than complex 'black box' models. Farmers are generally looking for real-time, localized information that supports day-to-day decision making in farm operations (McCown 2002, T. Heisel in Workshop presentation). The DSS demonstrated at the Workshop were able to satisfy this need to a certain extent as they were judged to be useful by most Workshop participants. It is a task for the future to develop such systems specifically for agriculture in Ireland.

Conclusions

The Workshop provided a unique opportunity to bring farmers, farm advisors, civil servants and scientists together to discuss needs and opportunities for information technology in agricultural contexts in Ireland. The Workshop was planned to be as interactive as possible in an attempt to realize mutual learning between all Workshop participants. The valuable feedback that Workshop organizers got from the participants and the broad range of responses testified that there is a strong interest in exploring information technology as a new conduit for the distribution of scientific knowledge. The organizers hope that this was only the beginning of a long-lasting dialogue.

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IDENTIFICATION OF OPTIMAL IRISH DAIRY SYSTEMS FOR CONTRASTING PRODUCTION ENVIRONMENTS

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Abstract

This paper presents an analysis of the impact of the Luxembourg Agreement on dairy systems in contrasting production environments with emphasis on the effects of site conditions on farm profitability. Two farm situations, Moorepark (MPK) and Kilmaley (KMY), represent extremes in terms of ability to utilise grazed grass in Irish milk production. Analysis was conducted through the development and application of the Irish Dairy Systems Optimising Model (IDSOM). IDSOM applies a comprehensive whole farm specification of Irish milk production systems and encompasses over 390 activities and 232 resource constraints. The model provides an optimising framework that permits the identification of optimal systems in terms of a measurable objective function and defined constraint set. The financial optimality of lower input systems compared to high input systems is evident when exposed to a reduction in milk price at both sites. Financial analysis indicates that the availability and utilization of grass exerts tremendous influence on Farm Family Income (FFI) and monetary returns as shown by the marked difference in MPK and KMY financial results.

It is concluded that the development, validation and application of IDSOM provides a framework for the evaluation of existing and prototype dairy production systems using recognised methodologies while simultaneously taking explicit consideration of resource levels, spatial factors and managerial performance.

Introduction

Agricultural systems are continuously being adapted to changing conditions in their external environment. Economic, institutional and technical developments drive and often necessitate adaptation of production systems. At the economic level, developments in the wider economy such as growth rates, income levels, and interest rates affect the opportunity costs of resources employed in agriculture and therefore have an important bearing on production decisions. Institutional changes are reflected in such developments as agricultural policy reform and environmental policy restrictions that dictate economic and legislative boundaries for farming activities. Finally, technological progress often generates specific challenges in terms of the timely adoption of appropriate technologies that enhance farm productivity and viability.

The Irish dairy industry constitutes one of the most important sectors of Irish agriculture with 79% of agricultural land devoted to grass. It accounts for 29% of agricultural output and contributed €1,417M to the economy from milk sales alone

(Department of Agriculture and Food, 2004). Both technical and institutional circumstances in Irish dairy farming are evolving continuously. For example, dairy producers are faced with specific challenges arising from policy reform and changing economic circumstances in the midst of development and growth in the wider Irish economy. To remain competitive, dairy farmers must adapt farming practices to best accommodate these developments in the external environment. It is widely acknowledged that more informed decisions are taken when greater pools of knowledge are available to decision makers. The advent and development of computer programmes and mathematical models as effective analytical tools can contribute significantly to improved decision making at farm level.

Grassland is a critical agricultural resource in Ireland and successful dairy farming relies to a great extent on the efficient conversion of grass to milk. Grazing represents the least cost method of grass utilisation and with present techniques grazed herbage is of higher nutritive value than conserved forage (Wilkins, 1990). However, according to Ryan (1974) and Shalloo et al., (2004), both soil type and climatic conditions have tremendous influence on production from grassland. The varying quality of land and the wide range in climatic factors is predominately responsible for the contrasting environments encountered on dairy farms in different parts of Ireland.

Two farm situations, Moorepark (MPK) and Kilmaley (KMY), chosen for the analysis reported in this paper represent extremes in terms of ability to utilise grazed grass in Irish milk production. Shalloo et al. (2004) provides a detailed description of production conditions at both sites. The objective of this paper was to model the effects of the Luxembourg Agreement (LA) on dairy systems in these contrasting production environments with emphasis on the potential profitability of each site. The LA represented the culmination of the Mid-Term Review of Agenda 2000. The agreement represented a radical reform of the Common Agricultural Policy (CAP) from an Irish perspective as it fully decoupled from production all direct payments for cattle, sheep and arable crops. From a dairying perspective, a 20% reduction in farm milk price was predicted (Breen and Hennessy, 2003) while a decline in male calf price was also projected.

Materials and Methods
The analysis was conducted using the Irish Dairy Systems Optimising Model (IDSOM). IDSOM is a static, single objective (profit maximisation) Linear Programming (LP) model which determines the optimal milk production system using GAMS/CPLEX software (Brooke et al., 1992). The farm model employs a deterministic modelling framework to represent the production activities and constraints of a dairy farm for a 12-month time horizon. Activities include forage production, dairy cow activities, subsidiary enterprises, purchase of inputs, sale of outputs, labour and borrowing capital. Constraints include land, housing, quota, nutritional requirements, labour and capital. The parameters of the model were selected to represent typical resource endowments for a relatively large-scale producer. Each farm was 40 ha with a milk quota of 467,482 kg.

Two scenarios were modelled for both sites reflecting pre-LA and post-LA conditions. Projected milk price, calf value and the opportunity cost of land were based on projections from FAPRI-Ireland (Breen and Hennessy, 2003). Eighty cow places and National Farm Survey fixed costs of €22,755 were assumed at both sites.

Results and Discussion

Table 1 presents a comparison of the key model solutions for each site both pre-LA and following the imposition of the policy amendments. Significant reductions in both farm output and consequently FFI were reported for both sites having imposed the policy changes. Total farm output reduced at the MPK site by €10,747 while KMY recorded a €11,124 reduction. While MPK variable costs were similar to those reported pre-LA, KMY costs reduced by €4,729 and the resulting FFI for KMY was €66,033 compared to €76,608 for MPK (Table 1). These figures represented an 11% decline in MPK FFI while KMY suffered a 9% reduction. Table 1 also details the annual net cash flow for both sites under both scenarios. The annual net cash flow shown for MPK following the policy imposition was €39,902 (16% reduction) while the KMY value was €31,933 (14% reduction).

In response to the policy imposition, average milk production per cow decreased at both sites with MPK averaging 5663 kg per cow while KMY output reduced to 6000 kg per cow. While both sites had spring calving herds, there were considerable differences in the proportions of grazed grass, grass silage and concentrate within the dairy cow diets of both locations. On average, 0.74 of the MPK diet was grazed grass while it was only 0.45 at the KMY site. Silage represented 0.39 of the diet at KMY compared with only 0.21 of the feed budget at the MPK site. Greater reliance was also placed on concentrate in the KMY diet. Concentrate constituted 0.16 of the KMY diet and only 0.05 of the MPK diet.

While both sites represented extremes in terms of ability to utilise grazed grass, the analysis identified consistent features which were observed in the optimal plans of both sites, namely larger herd sizes, moderate milk yields per cow and minimal levels of concentrate supplementation. The key difference between the two sites was the variable costs associated with the contrasting environments. The resulting plans highlight the importance of cost effective production in light of policy reform and market price reductions and in this respect the importance of grazed grass was particularly evident in all solutions for the MPK site. Spring calving systems were a stable feature of optimal plans throughout the analysis and this supports, from a producer point of view, the existing pattern of production within the Irish dairy sector. Optimal milk yields were also in line with observed data illustrating the effectiveness of current Irish systems of milk production.

Table 1. Optimal systems for both MPK and KMY pre and post Luxembourg Agreement Scenarios

	MPK		KMY	
	Pre -LA	LA	Pre -LA	LA
Level of N (Fertiliser + Organic) (kg/ha)				
Grazing	370	370	370	370
Silage	410	410	410	410
Fertiliser N purchased (kg/ha)	350	351	339	337
No. of Cows	79	80	67	75
Milk yield/cow (kg)	5697	5663	6750	6000
Month of Calving	46% Jan	35% Jan	65% Jan	38% Jan
	54% Mar	16% Feb	35% Mar	62% Mar
		49% Mar		
Dietary Intake:				
Grass (kg DM/cow)	3592	3594	2282	2329
Silage (kg DM/cow)	967	1008	2115	2020
Concentrate (kg DM/cow)	303	259	1106	816
S.R (LU/ha)	2.56	2.54	2.47	2.45
Total Farm Output	€145,647	€134,900	€149,723	€138,599
Variable Costs	€36,351	€35,537	€54,540	€49,811
Total Farm Gross Margin	€109,296	€99,363	€95,183	€88,788
Family Farm Income inc SFP*	€86,541	€76,608*	€72,428	€66,033*
Net Cash Flow	€47,604	€39,902	€37,198	€31,933

Conclusions

The farm-level effects of CAP reform were evaluated for two production sites that represented extremes in terms of ability to produce and utilise grass in Ireland. This contrast was useful for identifying how these systems may respond to policy change thus highlighting the need for tailored advice and site-specific adjustment. The results support the view that competitive Irish dairy systems rely strongly on the efficient conversion of grass to milk. The financial optimality of lower input systems compared to high input systems is particularly evident when systems are exposed to a reduction in milk price. The availability and ability to utilise grass efficiently exerts substantial influence on farm profitability as shown by the marked difference in MPK and KMY financial results.

The construction and validation of IDSOM has contributed to the existing pool of knowledge on Irish dairy systems modelling. The model has generated useful results that can be compared with the findings of the Moorepark Dairy Systems Model and *Dairy_sim* (Holden et al. this volume). The models serve to complement each other by exploring the effects of technical and institutional change on system configuration. The development, validation and application of such models provide a framework for the evaluation of existing and prototype dairy production systems using recognised methodologies while simultaneously taking explicit consideration of resource levels, spatial factors and managerial performance.

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POTATO BLIGHT FORECASTING IN NORTHERN IRELAND

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Abstract

Late blight is potentially the most important disease of potatoes in Northern Ireland and its control relies on frequent fungicide application. The risk of infection of crops by *Phytophthora infestans,* the causal pathogen, depends on the occurrence of suitable environmental conditions characterised by mild temperature and high humidity. In the UK, Infection Periods based on Smith's criteria are widely used and give a reasonably reliable indication of risk. The blight warning system in Northern Ireland described here uses daily counts of the number of risk hours (hours with temperature $\geq 10°C$ and relative humidity $\geq 90\%$): two days with 11 or more risk hours constitute an Infection Period which is a modified Smith Period. Information on Infection Periods and blight risk is made available to growers through the Department of Agriculture and Rural Development Blight-Net website, SMS messages, the Blightline telephone recorded information service, radio warnings and press releases.

Introduction

Late blight, caused by *Phytophthora infestans*, remains the most devastating disease of the potato crop wherever potatoes are cultivated commercially. In the past 25 years, world-wide changes in populations have been associated with increased problems in controlling blight on both potatoes and tomatoes. In the Republic of Ireland, trials over a 20 year period (1983-2002) showed an average loss in marketable yield of *c.* 23% when untreated plots were compared with those protected by fungicides (Dowley, L.J., personal communication). In Northern Ireland, in the early 1990s the annual crop loss due to blight was estimated to be 8% (Copeland *et al.*, 1993). Losses have been reduced over the past ten years by adoption of more effective control measures advocated by Department of Agriculture and Rural Development (DARD) and are now estimated to be the order of *c.* 5%. This has been achieved largely by increased usage of blight fungicides or by use of more effective, but more expensive products. Most seed crops now receive 8-9 applications of foliar fungicides and some receive as many as 14 sprays to protect them from foliar and tuber infection by *P. infestans* (Cooke, L. R., unpublished data). The value of fungicides applied to the Northern Ireland potato crop annually is estimated to approach £1 million (€1.5 million).

P. infestans can reproduce in two ways. Where the two mating types, known as A1 and A2, occur together, it can produce long-lived sexual oospores that may survive in the soil for up to 48 months. However, in Ireland, *P. infestans* relies on asexual reproduction, since at present the A2 mating type occurs very rarely (Griffin *et al.*,

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2002; Cooke *et al.*, 2006). The asexual sporangia are relatively short-lived and the pathogen must overwinter as mycelium in potato tubers. Each season, therefore, the primary infection sources are infected tubers which survive in seed stocks, dumps or as groundkeepers (volunteers) and then germinate to produce blighted plants. The devastating impact of blight is due to its very rapid spread from such infected plants under optimal conditions. Sporangia are produced in vast numbers on infected potato foliage in warm, humid weather and are then dispersed by wind and rain. When they alight on a potato plant, if conditions are suitable, they infect the foliage and develop into new sporulating lesions. The pathogen quickly spreads through the tissue causing the leaves and stems to blacken and die. Spores may also be washed into the soil and infect tubers, which develop a characteristic dry rusty brown rot and are predisposed to secondary bacterial soft rotting, which can lead to total crop loss. There is evidence that the latent phase (the time between infection and sporulation) of current *P. infestans* strains is shorter (74 – 94 h compared to 96-108 h) than that of the strains present before introduction of the new population (as defined by Spielman *et al.*, 1991) in the 1970s and 1980s. This may be one reason for the more severe late blight epidemics in Europe in recent years.

During the 1940s, it was recognised that, whereas there were always enough blighted plants to provide a primary infection source, blight was seldom widespread until later in the season. This led to attempts to determine the conditions needed for its spread and thus to define potential infection periods. The first effective system was developed empirically by Beaumont who formulated the Beaumont Period (Beaumont, 1947). This was later superseded by Smith Periods (Smith, 1956). An attempt to refine the system by Sparks (1980) was not successfully adopted and the Smith Period system continues in use in the UK to the present day. Alternative systems have been evaluated by the Ministry of Agriculture, Fisheries and Food (now the Department for Environment, Food and Rural Affairs, DEFRA) in England and Wales and by DARD in Northern Ireland, but Smith Periods have proved the most reliable indicator of blight risk (Taylor *et al.*, 2003).

A Smith Period is defined as two consecutive 24 hour periods, starting at 09:00 GMT, 10:00 British Summer Time (BST), in which the minimum temperature does not fall below 10°C (50°F) and there are at least 11 hours of 90% or greater relative humidity (RH) on each day (Smith, 1956). In Northern Ireland, the system currently in use provides an output of Infection Periods which are modified Smith Periods (see below). Such Infection Periods provide a general indication of blight risk, but do not predict the situation on an individual field basis. The blight forecasting system in Northern Ireland has been refined in recent years, but has not been formally evaluated. The system as currently used is described below.

Potato blight risk in Northern Ireland

In most years, weather conditions during the June-September period favour moderately severe or severe outbreaks of potato blight. The objectives of the current blight forecasting system are to:

- indicate to growers when to start spray programmes
- provide a local indication of blight risk
- inform growers when to modify spray interval.

These limited objectives are governed by variation in weather conditions within Northern Ireland and within localities, and also variation in the environment within individual fields. The system cannot provide detailed guidance for an individual crop although it has been improved in recent years by increasing the number of meteorological stations to give more local advice to growers. In addition, the fungicides approved for potato blight control in the UK have limited curative activity and are not generally recommended for curative use. If curative applications are made too late, crop loss may occur and curative use may also encourage selection of fungicide resistant pathogen strains. This severely restricts the grower's window of opportunity to respond to a forecast risk of infection. The final consideration is that the frequent and extended periods of unsettled and wet weather which often occur in the growing period in Northern Ireland make it difficult for growers to apply sprays following a risk prediction. In the period 1994-1998, the incidence of Smith Periods in Northern Ireland was compared with the occurrence of blight outbreaks as reported by Potato Inspectors and Advisers and in each year, the first Smith Period pre-dated the first reported blight outbreak (Mercer *et al.*, 2001).

Inputs

Meteorological Data
Meteorological data are collected by a network of seven local weather stations (Co. Antrim: Dervock, Greenmount Campus, Agri-Food & Biosciences Institute (AFBI) Headquarters, Belfast; Co. Armagh: Moyallan; Co. Down: Ardglass; Co. Londonderry: Limavady; Co. Tyrone: Newtownstewart). Hourly records of temperature and RH are converted to "Risk Hours". These are hours in which the temperature is $\geq 10°C$ and the RH is $\geq 90\%$. The number of risk hours is expressed on a daily basis starting at 10:00 BST. A day with ≥ 11 risk hours is a half Infection Period (analogous to a half Smith Period) and two consecutive such 24 hour periods constitute a full Infection Period. This is analogous to a Smith Period, except that for Smith Period criteria to be satisfied the minimum temperature must not fall below 10°C at any time in the 48 hour period, whereas in the Northern Ireland system the minimum temperature may fall below 10°C during days with 11 or more risk hours.

Details of blight outbreaks from DARD inspectors and advisers
DARD Potato Inspectors and Crop Advisers report outbreaks of blight in Northern Ireland to Applied Plant Science Division (APSD), AFBI and these are used in Potato Blight Warnings. Potato Inspectors are also requested to provide samples of potato blight from crops in their areas (for use in the annual survey of phenylamide resistance in *P. infestans*) and the distribution of these provides an indication of the occurrence of infection.

Outputs

Internet: DARD Blight-Net website
Details of risk hours for the seven meteorological stations are provided to growers through the website DARD Blight-Net at: http://www.ruralni.gov.uk/index/ crops/potatoes/blight_net.htm, which is updated twice a week between June and September. A map shows the locations of the weather stations (Figure 1a), and for each site, risk hours are displayed graphically in the form of a bar graph showing the number of risk hours recorded each day (green bars for ≤ 10 risk hours and red bars for ≥ 11 risk hours; Figure 1b). This allows growers to visualise the risk easily and to see if, for example, conditions were only just below those required to give a full Infection Period in their locality. The guidance provided on the website states:

- "The risk of blight infection is low if there are fewer than 11 risk hours in a 24 hour period.
- There is an increased risk of blight infection if there are 11 or more risk hours in a 24 hour period.
- There is a high risk of blight infection if there are 2 or more consecutive 24 hour periods that contain 11 or more risk hours each. This corresponds to a Smith Period. Apply blight fungicides at the intervals recommended for high risk conditions over the duration of such periods."

In addition, a map showing recent and past blight outbreaks is provided to allow growers to see where these have occurred in relation to their own crops.

SMS Blight Warnings
Information on blight risk is also made available to growers via 'Blight alerts' sent directly to their mobile telephones. SMS text messages are sent to a grower whenever a full Infection Period has been recorded at the weather station closest to their farm. The alert is a direct warning to growers of the risk of blight in their area and the need to apply fungicides as recommended for high risk conditions. In 2006 'Blight alerts' were sent to 128 registered growers.

Blightline telephone service and other outputs
'*Blightline*', a 24 h recorded telephone information service on potato blight is operated by AFBI staff between June and August each year and is updated approximately twice weekly. The message informs growers of the occurrence of Infection Periods, with local detail on where they were recorded, and also includes information on recent blight outbreaks and topical advice on blight control. The number of calls received per season in the period 2001-2006 has ranged from 127 in 2001 to 41 in 2005, with an average of 88. In addition, Blight Warnings are given via local radio (e.g. Radio Ulster) and more general reports of blight risk through press releases issued to the local farming papers.

The range of different methods used for outputting blight risk data reflects evolving information transfer technologies and is intended to widen accessibility. The '*Blightline*' service was originally started in the early 1990s to supplement warnings on local radio, which are not always transmitted when requested. DARD Blight-Net

was initiated in 2001 to take advantage of the increasing availability of internet access, while the SMS text messaging service has been provided for the last two growing seasons. Growers' preferences in terms of the different communication methods have not been formally evaluated, but it is planned to do this in the future.
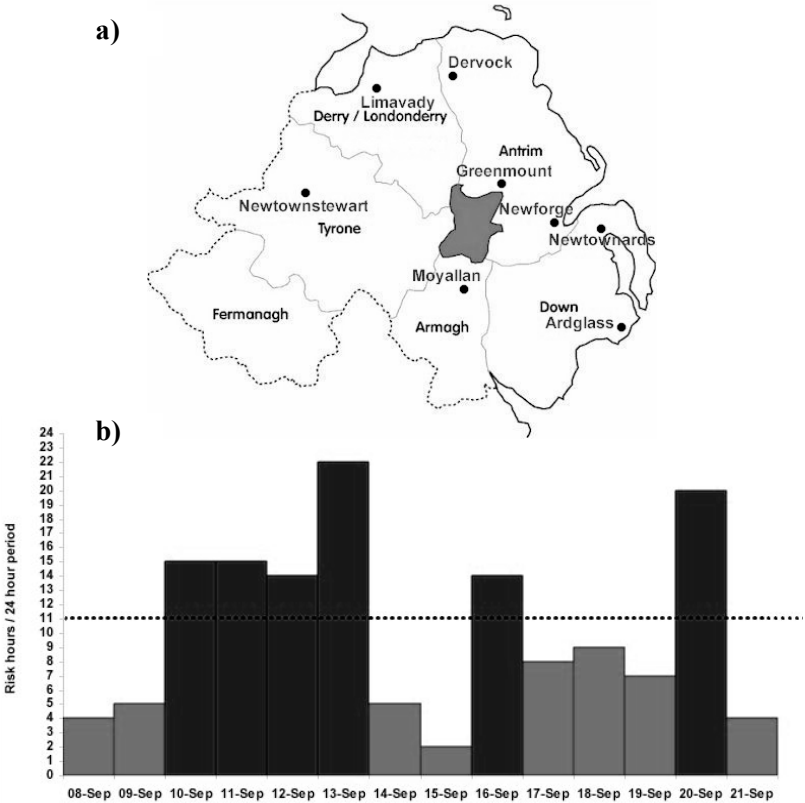
Figure 1. a) Locations of meteorological stations used in potato blight forecasting (the Newtownards site was not used in 2006), b) Graphical output of blight risk hours for Newforge site, 8-21 September 2006 [pale grey (green on the website) bars <11 h, darker grey (red on the website) bars ≥11 h – dotted line indicates the 11 h threshold].

Occurrence of Infection Periods in Northern Ireland, 2001-2005

Full Infection Periods were occasionally recorded as early as mid-May, but in most years the minimum temperature requirement prevented their occurrence before the start of June (Table 1). Infection Periods before the end of May were generally disregarded for the purposes of issuing blight warnings, since crops were not sufficiently advanced to be at risk. The majority of Infection Periods usually occurred during July and August and continued into September. Statutory haulm destruction dates are set for seed potato crops in Northern Ireland and these are usually before the

end of August. After this only foliage of ware crops may be infected by blight and by late September most of these are either burnt down or senescent.

Relationship between Infection Periods and initial blight outbreaks, 2001-2006

Initial blight outbreaks are most frequently detected in crops in Northern Ireland, although the occasional infected potato dump is reported. In each year from 2001-2006, Infection Periods occurred before blight was seen in crops (Table 1). In the four years 2002-2005, the initial blight outbreaks were 4-8 days after the first Infection Period and probably developed from infection at that time. However, in 2001 and 2006, Infection Periods occurred about a month before the first outbreaks observed in field crops, so they clearly did not result in infection.

Table 1. Occurrence of Infection Periods and initial blight outbreaks, 2001-2006

Year	First Infection Period (A)	First blight report from field crop (B)	Time (days) (A to B)
2001	25-28 May	2 July	35
2002	7-9 June	17 June	8
2003	26-29 May	5 June	7
2004	4-5 June*	9 June	4
2005	31 May-2 June	8 June	6
2006	16-18 June	17 July	29

* near miss

Table 2. Number of Infection Periods and foliage blight incidence, 2001-2006

Year	No. of "Risk days"	No. of Infection Periods*	No. of days in Infection Periods*	No. of reported outbreaks**	Seed crops (%) with >5% blight
2001	61	10	53	42	0.5
2002	29	8	23	55	17
2003	23	7	17	44	0.2
2004	35	7	28	24	0.1
2005	22	5	11	54	0
2006	23	4	12	20	0

* between 15 May and 31 August
** only outbreaks yielding viable *P. infestans* isolates are included

The current blight forecasting system in Northern Ireland has the objectives of indicating a start date for fungicide spray programmes (growers are advised to apply the first spray when a Blight Warning is issued or when plants touch within drills, whichever is earlier), to provide a local indication of blight risk and to inform growers when to modify the spray interval. Given these limited objectives, Infection Periods have performed moderately well in predicting the first field outbreaks and providing a start date for spray programmes. Within seasons, comparison of the numbers of "Risk Days" and Infection Periods and their duration with the number of reported blight outbreaks and the estimated level of infection in seed crops at the end of the season (Table 2) shows a lack of association, particularly in 2001 and 2002. In part this may be because the number of blight outbreaks also reflects the effectiveness of spray

programmes and this depends on the ability of growers to maintain protection of their crops. Summer 2001 had extended periods of high humidity, but rainfall during May-July was similar to the 30-year average so that conditions permitted fungicide application. Summer 2002 was exceptionally wet and rainfall and soil conditions made it very difficult to apply fungicides regularly, so blight control was more of problem and infection was widespread. It is therefore difficult to assess the value of Infection Period information to growers simply by examining the number of reports of blight.

Future prospects and conclusions

More sophisticated forecasting and decision support systems (DSS) potentially allow more precise targeting of fungicide applications. Field experiments at the Teagasc Crops Research Centre, Oak Park, Carlow, Ireland showed that the NegFry forecasting system allowed reduction in the number of fungicide applications while maintaining good blight control and marketable yield, and validation tests on five farms in 1999 and 2000 confirmed these findings (Leonard *et al.*, 2001). However, application of such DSS at farm level requires in-crop meteorological stations and considerable management input compared with routine fungicide application and uptake will be strongly influenced by external pressures such as fungicide costs, food retailer requirements, and Government and EU policy on reduction in pesticide use. In the UK, crop quality auditing systems ask growers for justification for the application of fungicides. For example the Assured Produce Scheme asks 'Are local weather conditions monitored and/or disease prediction programmes participated in?'. The suite of forecasting systems operating in Northern Ireland provides growers with justification for applying blight fungicides to help comply with quality assurance standards.

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THE GRANGE BEEF MODEL: A MATHEMATICAL MODEL OF IRISH SUCKLER BEEF PRODUCTION SYSTEMS

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Abstract

Circumstances in Irish beef farming are changing continuously. These changes are occurring at a time when increases in production costs coupled with relatively low beef prices are creating considerable financial challenges on Irish beef farms. To elucidate systems of production which are financially sustainable, a linear programming model of Irish spring-calving suckler beef production systems was developed and is presented here. This model, the Grange Beef Model, was subsequently used to investigate a number of alternatives available to Irish farmers including different beef prices, the opportunity to harvest maize and participation in an agri-environmental programme. Results indicate that beef price has a substantial impact on gross margin and that maize harvesting has the potential to increase gross margin relative to a base scenario where no maize is harvested. In addition, participation in an agri-environmental program (REPS) is important to maintain gross margin.

Introduction

Recent changes in European agricultural policy coupled with international currency fluctuations and the prospect of renewed World Trade Organisation (WTO) negotiations have created an unsettled situation within which a number of components influencing farm production are subject to change. More specifically, the Luxembourg Agreement resulted in a shift in farm supports from product specific payments to single farm payments (SFP) based, in Ireland's case, on historical farm support payments and area farmed. The reform returns the focus of producer decisions to market-based considerations, thereby reducing the distortions that have been caused by headage-based livestock subsidies.

Strategies used by farmers to sustain financial margins in the context of these changes may include adjustment of their animal and forage production systems, the use of different production technologies and/or participation in agri-environmental programmes. Mathematical models provide the opportunity to investigate beef production systems within a set of farm constraints and management alternatives. Ireland's situation within Europe with regard to soil type and climate promotes a long growing season and hence, grass-based systems of production. Thus an appropriate model with an emphasis on grassland-based beef production, the Grange Beef Model, was developed and used to investigate these alternatives.

Model Details

The Grange Beef Model is a linear programming model designed to identify optimal beef production systems given a range of resource and economic parameters (Crosson et al., 2006). The interaction of technical and financial components is a key element of the model. The model employs a single year steady-state design, is static and deterministic and utilises an empirical approach to describe biological relationships. Animal feed requirements and forage characteristics are based on well established biological functions (O'Kiely, 2004; Crowley, 2001; O'Mara et al., 1997; Jarrige, 1989). Nutritional specifications are described in terms of animal energy requirements subject to a maximum intake capacity. The energy requirements of growing and lactating animals are specified in UFL's (Feed Unit for lactation; Jarrige, 1989) and the energy requirements of finishing animals are specified in UFV's (Feed Unit for maintenance and meat production; Jarrige, 1989). The intake capacity of all animals are specified in CFU's (Fill Unit for cattle; Jarrige, 1989). The equations are specified in a Microsoft Excel spreadsheet and solved using the 'add-in' optimisation software "What's Best!" (Web 1). Budgets are formulated assigning a cost or revenue to each activity and based on these the model identifies the optimal beef production system. The objective function of the model maximises farm gross margin.

The model is constructed around a typical beef cow herd based on spring-calving Limousin x (Limousin x Friesian) cows (Drennan, 1999) with animal groups based on the average animal within that group. Expected liveweight changes of cows throughout the year are specified. A 20% replacement rate is assumed with replacement heifers purchased as one-month-old calves. The heifers are assumed to calve at 24 months of age. For growing animals, discrete growth rates (Drennan, 1999) are specified in the model. These can be changed within allowable limits at the input stage. All breeding cows and heifers are mated to a Charolais sire with the progeny taken to beef within an integrated calf to finish system. Trading options are specified facilitating sale of weanlings and stores. Male progeny can be finished as bulls at 16 months or as steers at 20, 22, 24, 26, 28 or 30 months. Female progeny can be finished at 20, 22 or 24 months.

Diets for animal groups are based on a combination of grazed grass, grass silage, concentrates and maize silage if available. All feeding activities are specified on a monthly basis to incorporate the seasonal variation in animal diets during the year. Grass growth is modelled on historical data from Teagasc, Grange Research Centre and is responsive to inorganic nitrogen (N) application rates with annual yields ranging from 6.2 t.ha^{-1} for 0 kgN.ha^{-1} to 13.3 t.ha^{-1} for 300 kgN.ha^{-1} for the grazing area. Thresholds for minimum pasture herbage cover regulate turnout and housing. Insufficient growth in the winter period compels the model to provide conserved forage and/or concentrates as the feed source. Yields and digestibility of maize silage are typical of those achieved under Irish conditions. Planned nutrient input recommendations for grass grown for pasture and silage production and for maize silage are those of Teagasc (2001). Within the model, environmental issues are considered by means of maximum organic and inorganic N application constraints.

Application

In the context of the challenges and opportunities facing Irish beef farmers, a number of scenarios were investigated. These scenarios are presented in Table 1. The first scenario is a base scenario and represents the conditions typically found on Irish beef farms in 2005. The second and third scenarios represent an increase and decrease in beef prices of 10%. The integration of maize silage into beef production systems and its potential to increase gross margin is then investigated. The value of REPS both in contributing to farm gross margin and in limiting N use is studied by including a scenario where non-participation is assumed. For all scenarios, land area owned is 40 ha with additional land available for rent at €210 ha^{-1}. Single Farm Payment receipts, which are received by farmers independent of production, are not considered in the results. All progeny are finished with steers finished at 24 months and heifers finished at 22 months.

Table 1: Description of the five scenarios investigated using the Grange Beef Model

Scenario		Beef price (€ kg^{-1} carcass)	Harvest maize	REPS
Base		290	No	Yes
Beef price	Increase	319	No	Yes
	Decrease	261	No	Yes
Harvest maize		290	Yes	Yes
No REPS		290	No	No

Results and Discussion

Table 2 presents the key results for all the scenarios investigated. Solutions indicate that changes in beef price could result in substantial adjustments to optimal beef production systems and lead to considerable variation in farm gross margins. A 10% increase in beef price resulted in a predicted intensification of production with regard to area farmed and animal numbers and a 42% increase in gross margin whereas a 10 % decrease in beef price was predicted to lead to more extensive production and a 27% decrease in gross margin.

The area of maize silage harvested in Ireland has increased in recent years largely due to improved earlier varieties and the widespread use of plastic mulch. With maize harvest included in the production system, land area farmed increases, concentrate feeding decreases and beef cow numbers increase compared to the base solution. In this scenario, the area rented was 12 ha. There was no grass silage harvested and all forage conserved was as maize silage with 16 ha grown. Gross margin increased by 39% relative to the base scenario. In this scenario 16 t DM of good quality maize silage (30% DM, 25% starch) per hectare was assumed. Deviations in yield and quality from these will have subsequent impacts on optimal systems.

The final scenario investigated the impact of not participating in REPS. The result was an intensification of production with an increase in animal numbers and area

farmed when compared to the base solution. Additional feed requirements were predicted to be met by an increase in N usage; in this instance N application rates were not limited by the REPS limit of 260 kg total N ha^{-1} and thus the total N application rate was 365 kg ha^{-1}. Gross margin was the lowest of all scenarios at 45% lower than the base scenario.

An important aspect of results was land availability. In each case where gross margin was greater than the base scenario, additional land area was rented. The area rented ranges from 12.1 ha in the maize harvesting scenario to 20.6 ha in the beef price increase scenario. Land rental prices in all scenarios were assumed to be €210 ha^{-1} and this price will be important in determining optimal systems.

Table 2: Selected results of the five scenarios investigated using the Grange Beef Model

SCENARIO	Base	Beef price		Harvest maize	No REPS
		Increase	Decrease		
Area farmed (ha)	40.0	60.6	40.0	52.1	50.6
Grass silage area (ha)	17.9	27.1	17.0	0.0	28.2
Maize silage area (ha)	0.0	0.0	0.0	16.0	0.0
Concentrates (tDM/cow unit)	0.8	0.8	0.8	0.3	0.8
Inorganic N (kg N.ha^{-1})	114.9	114.7	99.9	93.2	191.1
Organic N (kg N.ha^{-1})	145.1	145.3	138.5	166.8	173.5
Total N use (kg N.ha^{-1})	260.0	260.0	238.4	260.0	364.6
Suckler cow numbers	38.6	58.6	36.9	57.8	58.4
Animals finished	34.8	52.8	33.2	52.0	52.6
Financial results (€)					
Gross output[1]	51,096	80,224	44,789	72,716	65,609
Variable costs[2]	34,608	56,842	32,836	49,848	56,501
Gross margin	16,488	23,383	11,954	22,868	9,108

[1]Includes animal sales, interest received on monthly cash surpluses and REPS payments.
[2]Included grassland management and feed costs, animal expenses, interest paid on monthly deficits and land rental payments.

The single farm payments have not been considered in the gross margin analysis. The average SFP in 2005 on suckler farms in Ireland was €563 per ha (Connolly et al., 2006). Therefore, these payments have a considerable impact on family farm income. However, since the future of the SFP beyond 2013 is uncertain and its value will be diminished prior to this, it is important that farmers achieve adequate market-based margins to remain viable in the longer term.

Conclusions

Solutions indicate that changes in beef price can result in substantial adjustments to optimal beef production systems and lead to considerable variation in farm gross margins. In addition, the harvesting of maize silage rather than grass silage has the potential to increase gross margin relative to the base scenario. Agri-environmental

programmes, such as REPS, have proven attractive to farmers given that the income derived from such programmes can represent a sizable proportion of total farm revenue and this is reflected in model results. The Grange Beef Model has also been used to investigate development options available to Irish farmers and the environmental impact of optimal Irish beef production systems (awaiting publication). In the latter study the Grange Beef Model was used to identify optimal systems and a second beef production model, the Integrated Farm System Model (Rotz et al., 2005), was used to facilitate an environmental analysis of these optimal systems. It has been shown that the model can be used to analyse current or prospective scenarios of interest. Future changes in agricultural policy can be routinely investigated. The sensitivity of optimal systems to price changes can be analysed. Whilst much of the production data are based on performances obtained at Grange Research Centre, the parameters can be modified to reflect other situations. Further development on this model is anticipated with the key areas of interest being the investigation of alternative calving dates, animal breeds and the development of a robust environmental submodel.

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DEVELOPING MODELS FOR THE PREDICTION OF

FASCIOLOSIS IN IRELAND

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Abstract

Fasciolosis or liver fluke disease caused by *Fasciola hepatica* is one of the major impediments to economic production in ruminants in Ireland. In recent years there has been anecdotal evidence of an increase in the incidence of acute fasciolosis in sheep by mid-summer. In addition, up to a 12 fold increase in the incidence of fasciolosis has also been reported in some EU member states. These observations suggest that there has been a change in the epidemiology of liver fluke, perhaps as a consequence of changing weather patterns, in particular, milder winters. The mild wet winters recorded over the past few years may allow for increased survival of the snail intermediate host and the free-living stages of *F. hepatica* and hence increase the risk of liver fluke disease. Downscaled global climate models suggest that climatic variables of relevance to agriculture and farm animal diseases can be expected to change considerably, resulting in marked changes in the epidemiology of these diseases.

Currently, the Department of Agriculture and Food uses the Ollerenshaw index to predict the likely incidence of disease on a regional basis during the autumn and winter; however, these forecasts are inappropriate in assessing the severity of infection from overwintering larvae and when disease levels are low to medium. The use of more sophisticated technologies, such as Geographic Information Systems and remote sensing may be better able to provide risk assessment models as an aid to controlling fasciolosis in future. Personnel from a variety of research institutions are collaborating to develop a predictive spatial model to identify fasciolosis high risk areas, which could eventually be used to advise farmers and veterinarians on prevention of this important disease.

Introduction and objective

Fasciolosis or liver fluke disease is important because it causes serious economic losses in Irish cattle and sheep farming enterprises. The disease is caused by a trematode *Fasciola hepatica* which requires two hosts to complete its life cycle. It utilises the mud snail, *Lymnaea* (*Galba*) *truncatula*, as an intermediate host where, following penetration, the parasite reproduces asexually, resulting in the emergence of hundreds of motile cercariae from the snail which then encyst on herbage as infective metacercariae. The encysted metacercariae are ingested by cattle or sheep and after

extensive migration through the liver parenchyma the immature flukes reach the bile ducts where they mature and produce eggs that are excreted in the faeces of infected animals to start the next generation. Temperature and moisture levels affect the hatching of eggs, survival of snails and development of cercariae in the snail. The optimum environment for snails is slightly acidic, muddy areas of disturbed earth/soil with slow moving water. Snails do not occur in soils with pH <5.5 (Ollerenshaw, 1971). Environmental temperatures above 10 °C are essential for the snail to develop and breed, *Fasciola* eggs to embryonate and hatch, and also for the intermediate fluke stages to develop within the snail intermediate host. Thus liver fluke disease has a distinct seasonal pattern. In Ireland the number of infective metacercariae is greatest in late summer and autumn. Acute disease develops in sheep 4-12 weeks later during late autumn and early winter. Chronic disease is usually observed in cattle and sheep from the end of December onwards.

Due to the relationship with weather, several forecasting systems to predict acute outbreaks of liver fluke have been developed, such as the Ollerenshaw prediction model, the Stormont 'wet-day' system, and the McIlroy computer system (Ollerenshaw & Rowlands, 1959, Ollerenshaw, 1966; Ross, 1970; McIlroy *et al*, 1990). The Ollerenshaw index is currently used in Ireland to predict the incidence of liver fluke and consists of a monthly index derived from measured rainfall, number of raindays and calculated potential evapotranspiration for a given month, between May and October inclusive. The data used are from Irish synoptic weather stations. A monthly index is calculated and summed for the period, giving an overall value designed to predict risk from late August onwards. The effect of temperature on development of larval flukes is taken into account by halving the values for May and October. Correlation between the incidence of disease and index values suggests that when values are less than 300, little or no disease will occur, when values are 300 to 400 there will be moderate losses and when above 400 a high prevalence of disease is likely. The index suggests that the disease generally increases from south-east to north-west across the country (Murphy *et al*., 2004).

While this prediction model has proved useful, it is not comprehensive and was validated at a time when winters tended to be longer and colder. The Stormont 'wet-day' system, developed for use in Northern Ireland, is a simplified derivative of the Ollerenshaw system and is subject to the same disadvantage. The McIlroy computerised system takes into account weather data, together with estimations of the size of the fluke population based on liver condemnations and is therefore highly dependent on accurate data from abattoirs in addition to the correct integration of weather variables with fluke biology. On both counts this system is not applicable in many parts of the geographical range of fasciolosis. All three systems have the further limitation of not being able to take local conditions into account. According to the fundamental concepts of landscape epidemiology, diseases have natural habitats in the same way as a species; they are found in focal areas where the spatial distribution of the parasite, host vector and suitable environmental conditions coincide (Pavlovsky, 1966). Inside this distribution range there are favourable zones where high level of abundance is maintained. Although snail habitats are widely distributed

throughout Ireland, the incidence of clinical disease is low in eastern counties but is high elsewhere, especially the wetter counties of Kerry, Clare, Galway, Mayo, Sligo and Donegal on the Atlantic seaboard.

In recent years in Ireland there has been anecdotal evidence of an increase in the incidence of acute fasciolosis in sheep by mid-summer. In addition, up to a 12 fold increase in the incidence of fasciolosis has also been reported in some EU member states. These observations suggest that that there has been a change in the epidemiology of liver fluke, perhaps as a consequence of changing weather patterns, in particular, milder winters. Current forecasting models predict that winter temperatures in Ireland will increase with modest increases in precipitation (Holden *et al*, 2004). Increased rainfall could raise local water tables, thereby, permitting *L. truncatula* to extend its habitat, while higher temperatures during winter could prolong the development period. The objective of this study is to collect baseline data on the population dynamics of *L. truncatula* snails as well as the infections levels with *F. hepatica* in selected areas of Ireland with the overall objective of developing a local-scale, GIS-based risk model for fasciolosis in Ireland.

Materials and methods

The project commenced in 2006. Baseline epidemiological data that directly influence the prevalence and transmission of liver fluke are being collected at two locations; Mayo (high incidence of fasciolosis) and Wicklow (low incidence of fasciolosis). Data collection at these sites include snail abundance, level of infection in snail, level of infection in the ruminant host and other environmental factors that influence fluke biology (e.g. temperature and rainfall). With the data collected, and data from satellite images, GIS technology will be used to produce digital disease risk maps as described by Malone *et al* (1998) and Yilma & Malone (1998). Briefly, a GIS for the study areas will be constructed by importing agroclimatic variables into a GIS computer software programme (ArcGIS). Data collected on snail and *Fasciola* prevalences, climate, terrain and Normalized Difference Vegetation Index will be exported from Microsoft Excel files into ArcGIS as separate database layers, and linked to map units in order to permit georeferenced analysis and display of spatial data. Using growing degree day (GDD) values [average annual mean temperature of 10 °C base temperature for *F. hepatica*] and water budget analysis using the Penman method for calculating potential evapotranspiration, forecast indices will be calculated for *F. hepatica* according to a previously developed model (Malone *et al*, 1998).

Discussion and conclusions

Two factors are thought to be contributing to the increase in prevalence of liver fluke disease being reported, namely climate change which is affecting fluke biology and resistance to the drugs used for the treatment of liver fluke. Against this background and the limitations associated with forecast models currently available, the re-examination of liver fluke epidemiology is timely. Ultimately the use of GIS technology to facilitate the collation and analysis of data collected from a variety of sources will go towards the development of more refined disease model. This will

enable us to predict the likely incidence and severity of fasciolosis at both regional and local scales in order to develop better control / intervention strategies to be implemented.

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Towards A Decision Support System For Sustainable Grazing Management Regimes – Upscaling Lysimeter Results To Farm Level

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Abstract

Nitrate leaching from diffuse agricultural sources is a major issue in Europe, and the subject of increasingly stringent legislation. In order to devise both effective legislation and assess the effectiveness of current legislation it is necessary to accurately assess nitrate losses from different farming systems. In order to reduce nitrate leaching, the data collected must be relevant to farming systems and should feed into a decision support system for farmers. This paper outlines a methodology to determine leaching losses from urine and non-urine areas on three different soil types using lysimeters. The spatial and temporal distribution of urine patches under different stocking rates is also determined, and used to model nitrate leaching on a field scale. The model will then be used for scenario analysis to identify sustainable grazing management practices for a range of stocking rates and soil types. The model will be flexible, and future research into different situations can be incorporated to increase the range of scenarios that can be evaluated. Integration into a decision support system to optimise sustainable grassland farming systems that reach both production and environmental targets will be possible.

Introduction

Nitrate leaching is a serious issue for agriculture in Europe, and has been the subject of much debate in recent years. Nitrate leaching from soils can have serious environmental and public health implications, and is also an important issue for farmers, as nitrate leached may have to be replaced through fertiliser application. Legislation aimed at mitigating nitrate losses from agricultural sources has been implemented recently in Ireland, for example S.I. 378/2006 (Anon. 2006). However, the amount of nitrate loss can vary considerably between farms and within farms, depending on soil type and stocking rates (McLaren & Cameron, 1996). In order for farmers and policy makers to identify areas of high nitrate leaching risk and to assess methods to reduce leaching, accurate data as to where the zones of high nitrate loss occur are required.

Point measurements of nitrate leaching can be made in the field underneath grazed pasture through either grazed lysimeters or soil solution sampling with suction cups. However, often such measurements show high variability as suction cups and lysimeters in the field may be located in atypical areas, and could be either bypassed by drainage water with high nutrient loading or located in an area of high drainage

flow (Stark *et al.* this volume). Furthermore, these point measurements only give results relevant to one farming situation (stocking rate and soil type), and a large number of measurements would be required to assess leaching losses from different soil types and different farming systems. For an effective decision support system to be developed for farmers, accurate data are needed at the field scale, on a range of farming systems. In order to calculate field-scale leaching losses the spatial variability of soils, and of urine and faeces deposition have to be taken into account.

Nitrate loss at the field scale varies considerably in space. Within grazed grassland systems elevated nitrate leaching has been associated with urine patches, where there is a high concentration of nitrogen in the soil (Di and Cameron, 2002a; Haynes and Williams, 1993). A paddock can therefore be divided into two distinct regions (urine and non-urine) (Richards and Wolton, 1976), with markedly different nitrate leaching losses. In order to determine total leaching loss from the field, it is therefore important to assess what proportion of the field has received urine deposition. The major effect of stocking rate on nitrate leaching is to change the proportion of pasture that has had urine applied to it at various times of the year. On average a cow urinates 8-12 times per day, with an average volume of 1.6-3.5L (Whitehead, 1970). The area of soil covered by each urination ranges from 0.19-0.49 m^2, while the area of pasture that shows a growth response to this urine ranges from 0.89-3.52 m^2 (Nguyen and Goh, 1994). Based on the averages of these figures at 2.5 cows per hectare, over a year (assuming cows are housed for 3 months) a field could receive 6850 urinations, covering 2400 m^2 (24%) of the area of the field. However the seasonal distribution of this deposition in Ireland is currently unknown, and could vary greatly due to the pattern of water intake by cattle. The distribution will also be strongly affected by stocking rate, and other factors such as the length of time for which cows are housed.

Free-draining soils have a greater potential to leach nitrate than poorly drained soils (Decau *et al.*, 2003, Stark *et al.* this volume). A farm with free-draining soils will require different management to minimise nitrate losses than a farm with poorly drained soil. A decision support system must recognise this, and must consider accurate data on different soil types in its calculations. The time of application of urine is also very important. There is a greater risk of nitrate leaching losses from urine applied in autumn/winter than in spring/summer (Di and Cameron, 2002b, Stark *et al.* this volume), due in part to the higher drainage rates during this time of the year. A decision support system must be able to integrate the effects of management on urine timing (such as the dates animals are housed for). This shows that detailed data on urine patch distribution throughout the year are essential for accurate calculations.

This paper outlines a methodology that allows nitrate leaching from dairy farms with a range of stocking rates and soil types to be estimated. The authors are currently establishing a trial based on this methodology, and data collection will commence in February 2007. This information will be used to scale results from point measurements to the field scale and to develop decision support systems for dairy farmers, and possibly for beef cattle farmers.

Materials and Methods

Leaching of nitrate from urine / non-urine areas
Nitrate leaching losses from soils are determined using lysimeters (Stark *et al.*, this volume). The two essential treatments are as follows:

1) Nitrogen fertiliser only
2) Nitrogen fertiliser plus cow urine

To predict nitrate losses from a wider range of scenarios, more treatments can be used. These may include differing nitrogen fertiliser rates, different soil types, or urine applied at different times of the year. Recent work at Teagasc Johnstown Castle has measured the leaching losses on three different soil types representing three major drainage classes, forming a good base for leaching calculations (cf. Stark *et al.*, this volume).

Spatial and temporal distribution of urine
The area of pasture that has urine applied to it at different times of the year must be determined accurately for nitrate leaching losses from a field to be calculated. One simple and very accurate method of recording spatial data is using survey-grade (Real Time Kinematic, RTK) GPS equipment. This equipment allows precise recording of the location of urine patches in the field to within a few centimetres.

Field plots are established in pasture grazed by dairy cattle at a range of stocking rates. These plots are observed every two months, 10-15 days post-grazing. At this time, grass has recovered sufficiently from grazing for urine patches deposited over the previous two months to be easily identified as darker, vigorously growing patches of pasture ("response zones" – Figure 1). The precise location of the centre of each urine patch is recorded using RTK GPS equipment (Figure 2). The location of all observed dung patches is also recorded.

When the plot is observed again two months later, all observed urine and dung patches are again recorded. If a response zone centre is located within 10cm of the centre of a previously recorded urine or dung patch, it is assumed to be a response to the previous urine or dung deposition, not a new urine patch. Urine patches may show a response many months after application (Dennis, 2005), which is why the location of previously recorded urine patches in the plot needs to be identified. Otherwise response zones are assumed to represent new urine patches.

The average area of a urine patch (determined separately by artificial application of urine containing a marker) is superimposed on each recorded centre (Figure 2). This means

Figure 1. Urine patch response zone

that the proportion of the field covered in urine during each two-month period can be accurately determined. The distribution of urine and dung under dairy cattle in Ireland at different stocking rates is currently being determined by the authors of this paper.
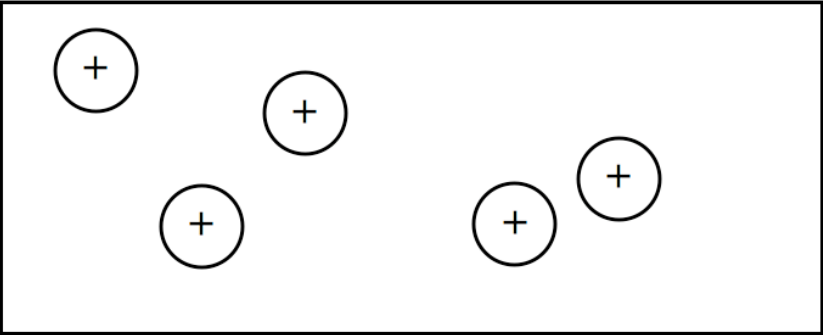
Figure 2. Spatial distribution of urine patches. Centre of urine patch recorded by GPS (+), average urine patch area (o).

Leaching losses from the field
Once the area of the field covered in urine at each time of the year is determined, the field-scale leaching losses can be calculated using an equation such as:

$$T = La(A) + Ls(S) + Ln(1 - (A + S))$$

Where:
T = Total annual leaching loss per hectare
A = Autumn/winter urine patch % coverage
S = Spring/summer urine patch % coverage
La = Annual leaching per hectare from autumn applied urine
Ls = Annual leaching per hectare from spring/summer applied urine
Ln = Annual leaching per hectare with no urine applied

Leaching losses (La, Ls and Ln) are determined from lysimeter data and are specific to soil type. Urine patch % coverages (A and S) are calculated from GPS measurements. For the purposes of this equation, autumn/winter urine patch % coverage is the sum of all percentage coverage determined during the autumn – winter period, which reflects the length of time cows are housed for over winter – the longer cows are housed, the lower the % urine patch coverage during this period.

A number of assumptions are being made in this calculation. The spatial distribution of urine patches under a given stocking rate is assumed to be the same across all soil types, a fairly reasonable assumption. The leaching loss of nitrogen from each urine patch is assumed to be the same average value determined with the lysimeter study (Stark *et al.*, this volume). Although this is most likely not the case, for the purposes of calculation it is a practical assumption that should yield valuable results.

The equation, or modified forms of it, can be used to estimate leaching losses from a range of situations. The lysimeter data from different soil types can be fed into the equation to determine leaching losses from soils of different drainage classes. Percentage coverage of urine from different stocking rates and management systems can be used to calculate leaching in specific farming situations. The same principles can be used to upscale other lysimeter data (such as gaseous emissions or pasture production) to a field scale.

Discussion

This methodology has great potential to provide valuable information on leaching losses from farmland. Leaching losses are calculated in a modular fashion, from both field level spatial data and lysimeter data. Field observations looking at three different stocking rates combined with a lysimeter trial looking at three different soil types, could yield leaching values for nine different situations at less cost than setting up a large field trial to look at each of the nine scenarios.

As we are assuming that for a given stocking rate the percent area affected by urine deposition remains constant on different soils and under different climate regimes, the measured relationship between stocking rate and urine deposition can be used to upscale lysimeter data to field-scale leaching losses, and determine the maximum acceptable stocking rate in a variety of situations. If a new situation needs to be assessed in the future, a minimum amount of lysimeter work is required to determine leaching losses. For example, to determine field scale leaching losses from farmland on a particular soil type under much higher rainfall than previous work, a lysimeter trial with that level of rainfall alone is sufficient to determine leaching losses from farms under the new climatic conditions.

Conclusions

The calculations behind this methodology could easily form the basis for a decision support system for farmers to reduce nitrate leaching losses. Future data can be added to the basic method, to provide a means of calculating leaching losses from many different situations throughout Ireland, and potentially other countries as well. The principles used can also be applied to other information, such as gaseous emissions or pasture production. This reduces the requirements for large, expensive field trials, and increases the number of different situations that can be assessed within a given budget.

Acknowledgements

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SEASONAL HERBAGE MANAGEMENT STRATEGY FOR IMPROVING N UTILISATION OF GRAZING BOVINES

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Abstract

Grazing during autumn, when grass growth rates and hence nitrogen uptake is low has been associated with increased risks of losses of Nitrogen (N) to water and air. Increasing the N utilisation of grazing animals may reduce risk of N loss. The quality of grass intake has a pronounced effect on both animal production and N utilisation. N utilisation may be improved by 1) reducing the concentration of protein in grass, and 2) increasing the ratio of water-soluble carbohydrates (WSC) to N in the intake. Herbage management has an impact on herbage quality with lower N application rates and longer rotation length both reducing the herbage N content and increasing the C:N ratio. Additionally, high sugar varieties increase the WSC content and subsequent C:N ratio. A herbage intake quality model for grazing bovines was developed, which showed that under grazing during late season, fertiliser N application rate has a relatively small impact on herbage N and WSC content. Instead, relative differences between high and low sugar varieties are largest during this period. A strategy is proposed in which: (i) during spring the focus is on silage production; (ii) in summer herbage cover is accumulated; so that (iii) in the autumn relatively long rotation lengths can be combined with low N application rates and high sugar varieties to minimise N losses to the environment. However, additional research is needed to evaluate the proposed strategy at farm level. The model and research may ultimately feed into a decision support system for grazing management, as a means to reduce the impact of grazing on N losses to the environment through seasonally optimizing herbage quality.

Introduction

In parts of Europe, a substantial proportion of bovine diet consists of grazed grass (Beever & Reynolds 1994; Lantinga et al. 1996; Lantinga & Groot 1996). Grazing is accompanied by localised deposition of nitrogen (N) in urine and dung patches. Grazing at times when grass growth rates and hence nitrogen uptake is low has been associated with increased risks of losses of N to water and air (e.g. McGechan & Topp 2004; Schulte et al. 2006). The quality of the grass intake has a pronounced effect on both animal production and N utilisation (Rearte 2005). Therefore, there is scope to reduce N excretion by increasing the N efficiency of grazing bovines through manipulation of the energy and N contents of the diet. N utilisation may be improved by 1) reducing the relatively high concentration of protein in grazed grass (Tamminga & Verstegen 1996), and 2) increasing the ratio of water soluble carbohydrate to N supplies in the diet (Beever & Reynolds 1994; Lantinga & Groot 1996). This reduces ammonia accumulation in the rumen, and subsequent excretion of urea through urine (Miller et al. 2001; Nocek & Russell 1988).

Hoekstra et al. (submitted) demonstrated how the levels of water-soluble carbohydrates (WSC) and N of perennial ryegrass (*Lolium perenne*) (two varieties: high-sugar and low-sugar) may be manipulated by herbage management. In general, they found that the high sugar variety had higher WSC content than the low sugar variety, with differences tending to be larger during the late season. Both the length of the regrowth period and N application rate strongly affected the WSC and N contents, with lower N application rates and longer rotation length both reducing the herbage N content and increasing the WSC:N ratio. Due to asymmetric grazing of animals between individual plant organs, the manipulation of bovine N efficiency through herbage management requires the prediction of the quality of the herbage intake, as opposed to the quality of the standing herbage, as a function of herbage management. Additionally, the local deposition of dung and urine during grazing has pronounced effects on local sward growth, herbage quality and grazing patterns (Brereton et al., 2005; Lantinga et al. 1987). Therefore, the spatial heterogeneity of herbage quality and grass morphology in the sward has to be taken into account. For this purpose a herbage intake quality model was developed to predict the proportion of lamina, sheath and inflorescence material in the intake of strip-grazing bovines. This simplified intake model was then connected to the empirical herbage quality model by Hoekstra et al. (submitted), to create an intake quality model. In the current paper this herbage intake quality model is applied to evaluate the potential of herbage management tools (ryegrass variety, N-application rates, rotation length, defoliation height) for affecting the N and WSC contents of the intake of grazing bovines throughout the grazing season.

Model description

The model is based on a cutting plot experiment which was conducted at Johnstown Castle during 2002 and 2003 (Hoekstra et al. submitted). The objective of the model is to predict the N and WSC concentration of herbage intake during grazing as a function of: 1) sward profile, specifically lamina/sheath ratio in the intake as predicted from the vertical distribution of lamina and sheath density, and their proportion in the total sward; 2) N and WSC concentration of lamina and sheath material as a function of season, length of regrowth period, N fertiliser application rate, and herbage variety (high sugar versus low sugar); and 3) proportion of pasture and intake affected by excreta as a function of animal grazing days. The pasture affected with excreta (fouled patches) was assumed to have received 390 kg N ha^{-1} yr^{-1} above which no agronomic response is expected (Coulter 2004). In this model, the stubble height for clean patches is an input variable. The stubble height for the fouled patched is then calculated based on the concept that fouled patches are grazed down to heights at which the lamina:sheath ratio in the upper layer is identical to the clean fraction (Garcia et al. 2003; Brereton et al., 2005). The model sequentially simulates three discrete periods of the growing season (early, mid and late season) (Hoekstra & Schulte submitted).

Model validation

The model was independently evaluated with two beef and two dairy herds, consisting of 15 animals each, grazing control (C) and high sugar (HS) swards at Johnstown Castle Research Centre (Table 1). The swards were closely monitored for 5

consecutive days during three periods, i.e. early (April), mid (June) and late (September) season during 2003. The N and WSC concentration in the intake during grazing was calculated by a) determining the lamina/sheath ratio of the pre- and post-grazing sward and b) measuring the actual WSC and N concentration of the herbage lamina and sheath material for clean patches and patches affected by excreta.

The model accurately predicted WSC content in intake ($R^2 = 76.4\%$, $p < 0.001$). Differences in the N content between laminae and sheaths and between clean patches and fouled patches were adequately simulated, though N-intake was over-predicted in early season and under-predicted during the late season.

Table 1. Validation experiment: herbage management for the dairy and beef high sugar (HS) and low sugar (LS) systems during early, mid and late season.

	Dairy HS			Dairy LS			Beef HS			Beef LS
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Late
Date	02/05	12/06	04/09	02/05	12/06	04/09	08/05	20/06	11/09	11/09
Total grazing area (ha)	3.7	4.8	6.2	4.2	4.8	5.4	2.2	3.0	4.4	4.9
N application (kg rotation^{-1})	30	25	20	40	40	30	30	20	20	30
Rotation length (days)	30	27	30	28	30	27	29	25	30	21
Defoliation heights clean (mm)	67	82	76	76	83	66	78	77	68	64

Model application

Herbage management for improving bovine N efficiency

The model was applied with the objective of assessing the impact of herbage management on the N and WSC concentration and the WSC:N ratio of the intake, which are directly related to bovine N utilisation. For the model initialization, the farm properties (grazing area, number of cows and dates) from the dairy HS system in the validation experiment were used (Table 1). Reduced N application rates and longer rotation lengths were shown to be effective for increasing the WSC:N ratio during early and mid season (Figure 1). However, during late season, the effect of N application rate was relatively small (Figure 1). This was caused by the large proportion of area affected by dung and urine (40% v 10% during early season). The differences between clean and fouled patches were greater at low compared to high N application rates. At low N application rates, the effect of the extra N from the dung and urine was more pronounced than at high N application rates. As a result, the effect of N application rate on the WSC and N contents in the intake became very small towards the end of the growing season. Instead, relative differences between high sugar and low sugar varieties were largest during this period (Figure 2). The magnitude of this difference was affected by two factors: 1) the difference in WSC content between high and low sugar varieties tended to increase with growing season; and 2) the difference was larger for lamina material than for sheath material (Hoekstra et al. submitted). Therefore, during the late season, the difference between high and low sugar varieties became more pronounced as the intake consisted of lamina only.
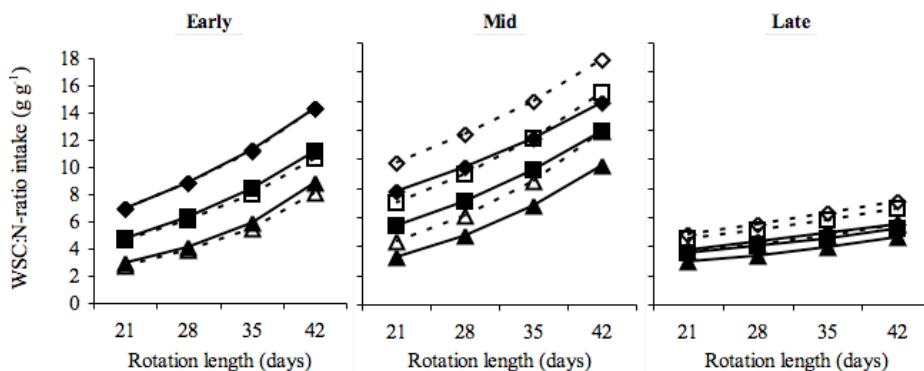
Figure 1. The effect of rotation length (days) N application rate (◆ 0, ■ 200, ▲ 390 kg ha^{-1} yr^{-1}) and *Lolium perenne* variety (○ low sugar, ● high sugar) on the WSC:N-ratio in herbage intake (g g^{-1}) during early, mid and late season.
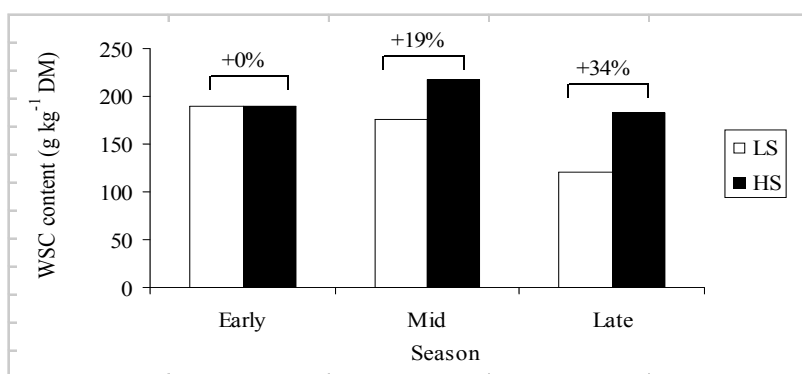
Figure 2. Predicted water soluble carbohydrate (WSC) concentration in herbage intake (g kg^{-1} DM) of the high sugar (HS) and low sugar (LS) variety during early, mid and late season (N application rate=150 kg ha^{-1} yr^{-1}, rotation length =25 days).

Herbage management strategy to minimise N losses to the environment

The model showed that during autumn, when the risk of N losses to the environment is greatest, around 40% of the grazing area is affected by dung and urine. Therefore applying large quantities of fertiliser N during this period is not a good tactic. Lower fertiliser N application rates will have a small impact on the WSC:N ratio of the herbage intake, but a decline in herbage yield may be expected on the areas not affected by dung and urine. Therefore, we propose the following strategy for early, mid and late season, which combines agronomic and environmental goals:

1) during spring, when risks of N losses to the environment are relatively low, the focus should be on maximising silage production, by maximising silage area. Fertiliser N application for silage should be aimed at a good silage yield, and the N application for grazing should be sufficient to allow grazing on a relatively small area;

2) during summer the focus should be on building up grass cover for the autumn by modifying the rotation length to building up cover; and

3) during autumn the grass cover built up in summer can be utilised, while minimising fertiliser N inputs. The longer rotation length will increase the WSC:N ratio in the herbage. High sugar grasses will be an important feature, especially during this time of the year, because the effect on herbage WSC content and WSC:N ratio is particularly pronounced during this season.

Current research aims to quantify the effect of herbage quality on animal N efficiency and additional research is needed to evaluate the proposed system on farm level.

Conclusions

The model predicted that reduced N application rates and longer rotation lengths could be an important tool for improving WSC:N ratio of intake during early and mid season, which has potential for improving bovine N utilisation. Towards the end of the season, the large proportion of area affected by dung and urine was predicted to result in high N and low WSC contents in the intake and a reduced effect of N application rate. The relative difference in WSC content between high and low sugar varieties was greatest in the late season. This suggests that high sugar varieties may be an important tool to increase bovine N-efficiency during the late season, when the risk of N-losses to the environment is largest. It is proposed that herbage management during spring should be aimed at silage production, during summer on herbage build up, so that in autumn N fertiliser inputs can be minimised. The model and research could ultimately feed into a grazing management decision support system for providing guidance on optimising herbage quality during different seasons and minimising the impact of grazing on N losses to the environment. For example, farmers could get a weekly / monthly advice on fertiliser N inputs, rotation length and silage area as a function of management history.

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A DYNAMIC DAIRY SYSTEM SIMULATION MODEL

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Abstract

Dairy_sim is a dynamic system simulation model that can be used to identify overall production strategy based on automated tactical decision making in response to daily weather data. It has been used to find appropriate strategic management for geographical locations in Ireland and to evaluate the impact of climate change on Irish dairy production. *Dairy_sim* has the potential to be used as a tool for improving real-time decision making on the farm. The main components of *Dairy_sim*, its logical structure and decision making rules are presented, along with an overview of test results that show how well the model performs with regard to finding good workable systems in response to soil drainage and local weather conditions.

Introduction

For successful dairy production in Ireland there are a large number of decisions that have to be made. These can be regarded as hierarchical in the form of *strategic, tactical* and *operational* decisions. A strategic decision is one that dictates the overall scope of the production system and cannot be changed at short notice. Strategic decisions include the choice between paddock or continuous grazing, summer or winter milk production, stocking rate, the type of cows to use (breed and genetic merit) leading to a target milk output, an overall fertiliser strategy (matched to expected feed demand throughout the production season) and a forage conservation strategy (to ensure year round supplies of feed). Tactical decisions are those that are necessary in order to make the strategy work over the duration of a production season and include decisions as to when to start and end the grazing season and whether to house animals in periods of grass shortage during the season, when to take silage cuts, interventions to ensure maximum sward quality and efficiency of production and when to dry cows off. Operational decisions are made for the day to day running of the dairy unit within the constraints of the tactics available to implement the strategy defined.

A static dairy production blueprint has been defined for Ireland (e.g. O'Donovan, 2000) and a static model based on economic and production factors has been developed and used to assess various production problems (e.g. Shalloo et al., 2004; Butler et al., this volume). In order to better understand the year-to-year variation in tactics that are necessary to implement a particular management strategy a dynamic system model is needed that is driven primarily by weather data but is also sensitive to other environmental considerations such as soil, atmosphere and water. A dynamic dairy system simulation model called *Dairy_sim* was developed to address these issues (Fitzgerald et al., 2005). The model allows a production strategy to be defined (number and area of paddocks, stocking rate, expected output per cow, a fertiliser

strategy and a silage management strategy) and as weather data become "known" to the model, it automatically chooses a tactical management to ensure that the target milk output is achieved with maximum grazing and minimum silage and concentrates fed. The model can be used to: (i) evaluate a particular strategy using historical climate data; (ii) evaluate a particular strategy in light of climate change forecasts; and (iii) provide day-to-day guidance as to how a dairy unit might be better managed given a reasonable forecast of what the weather is going to be like (using both seasonal and weekly forecasts). The model has been tested and applied for the first two situations and is being developed for the latter.

In this paper we will describe the components of the model, its structure and how it was tested. Results will be presented to indicate the ability of the model as a tool for production system design and management. Finally we will discuss further developments that are possible to enable the use of the model as a seasonal or weekly decision support tool.

Materials and Methods

Initially *Dairy_sim* was developed specifically for the case of low-cost, grass-based, rotational grazing for summer milk production on well drained soils, assuming a compact calving season in the late winter/early spring (Fitzgerald et al., 2005). It was later developed to include a soil water component in order to simulate production on less well-drained soils, and a CO_2 response model in order to be suitable for predicting climate change impacts. Facilities to permit simulation of winter milk production, strategic summer housing and beef production are integrated into the design but have not been calibrated or tested against field data. Further development possibilities include options to evaluate slurry management and liver fluke problems associated with the system.

System Components
In order to simulate the production component of the system, three main process models are required: *herd feed demand*, simulated using the British metabolisable energy (ME) system for allocating energy allowances for ruminants (MAFF, 1984); *grass production*, using a semi-empirical model (Brereton et al, 1996) based on the light use efficiency equation of Monteith (1972); and *grass utilization*, using a mechanistic model where, in a rotational system of pasture utilisation, the herbage in each paddock is progressively decreased by grazing over a period of days (Brereton et al, 2005). These were integrated using a number of strategic and tactical management controls, the details of which are presented in Fitzgerald et al. (2005) and are outlined in Figure 1 and Figure 2.

Moisture conditions are quantified in the model using soil moisture deficit (SMD) calculated by the Hybrid Model of Schulte et al. (2005) to account for differences in drainage between soil types. The SMD term was used to predict when saturation or drought would cause reductions in grass growth. With the SMD model it is possible to estimate when field access might be limited for traffic and animals due to

waterlogging. CO_2 response was initially simulated only for the period 2080 assuming an atmospheric CO_2 concentration of 650 vpm. Relationships between the CO_2 effect and sward were based on linear regressions of the fractional response of herbage dry matter growth to CO_2 enrichment on herbage growth rate (dry matter, kg ha^{-1} day^{-1}), on soil water deficit (mm) and on grass state (reproductive/vegetative). The data used in the regression analyses were derived from Figure 2 of Jones et al. (1996) and from Figure 2 of Casella et al. (1996). A continuous CO_2 response function is being implemented in *Dairy_sim* based on Special Report on Emissions Senarios (SRES) (Nakićenović et al, 2000) and the fractional response model already devised.
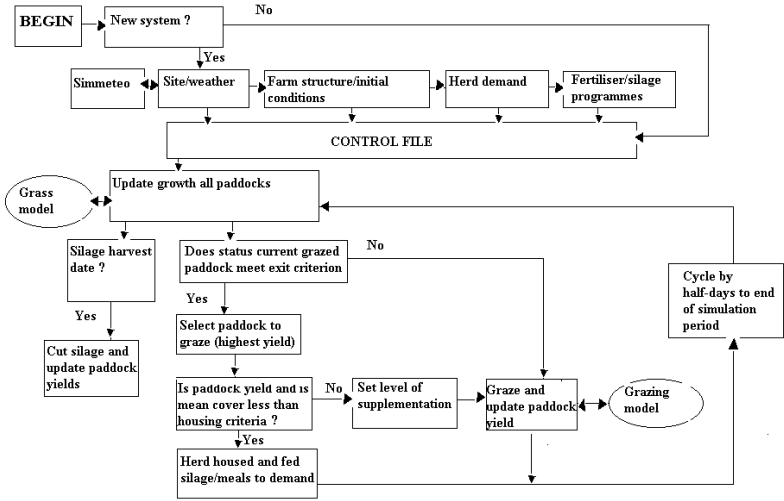
Figure 1. The logical structure of the calculations used in each cycle of *Dairy_sim*.
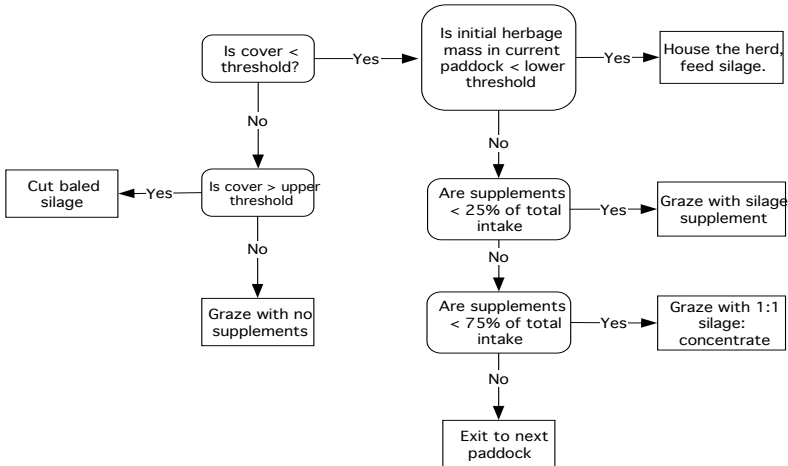
Figure 2. The tactical decision making process used in *Dairy_sim* to automate the decision making process in response to daily weather conditions

Testing and application of Dairy_sim

Dairy_sim was tested using a range of published data for Ireland. Initially it was set up and adjusted until there was good agreement between the outputs of the simulated system and the outputs of the system for well drained soil that was operated at the Teagasc research centre, Fermoy, Co. Cork (O'Donovan, 2000). The system simulation was then tested by comparison with field data from four system trials on well drained soil carried out at the Teagasc research farm at Solohead in Co. Tipperary (Humphreys *et al.*, 2002). The soil model influence on system optimisation was then investigated by comparison with data published for the Teagasc research farm at Kilmaley in Co. Clare. (Shalloo et al., 2004).

To date *Dairy_sim* has been used to evaluate:
- potential regional differences in the strategic detail for low-cost, grass based rotational dairy production due to agroclimatic differences in Ireland (Fitzgerald et al., 2005)
- the regional and inter-annual impact of poorly drained soil on dairy system strategies
- the nature of climate change impacts on dairy system strategy and viability by 2080 (considering whether balanced systems could be defined, issues relating to slurry management and field access and estimates of the change in liver fluke risk).

Results and Discussion

Example system test results
The inputs and outputs of the production system at Fermoy as described by O'Donovan (2000) and the average inputs and outputs of 30 years simulated by *Dairy_sim* were very similar (Table 1). All parameters had realistic values after calibration, and the simulation was a good reflection of dairy management practised in the Fermoy area of Co. Cork.

Overall there were very few differences between the optimised *Dairy_sim*-wet system and the Shalloo et al. (2004) system (Table 2). Some parameters for the soil were adjusted to reflect the effect on drainage of the gravel mole drains installed at Kilmaley compared to the central concept of a poorly drained soil as defined by Schulte et al. (2005). The growth restriction due to water logging was set to 0.25 of the full growth rate. The major differences were days grazing and intake from supplementary meals. The grazing days difference was caused by intermittent grazing days occurring at each end of the winter period. It is not currently possible to automate the management of these days but when accounted for the difference between the simulated and the field systems is much smaller.

The difference in meal intake can be attributed to the feeding of supplements late in the season at Kilmaley which was not simulated in *Dairy_sim*. Overall the wet soil component of *Dairy_sim* could be used reliably with the calibration established at Kilmaley.

Table 1. Comparison of calibrated *Dairy_sim* system with National Dairy Blueprint outputs

	Fermoy	*Dairy_sim*
Grazing management	20 paddocks	20 paddocks
Turnout	Early March	29 February
Close	mid-late November	26 November
Winter	100 days	98 days
Close for first silage cut	1 April	1 April
Date first-cut silage	28 May	28 May
Proportion of area for first-cut silage	0.45 (variable)	0.45
Date Second-cut silage	15 July	15 July
Proportion of area for second-cut silage	0.35	0.35
Concentrate (kg cow^{-1})	500	543
Milk (l cow^{-1})	6359	6400
Silage (t DM cow^{-1})	1.4	1.53
Total Herbage production (DM t ha^{-1})	12-15	13 (non-irrig.) 15.8 (irrig.)
Silage yield (DM t ha$^{-1-)}$)	5.4	4.8
Silage fed housed (kg DM cow^{-1})	------	1400
Silage supp. at pasture, (kg DM cow^{-1})	------	205
Nitrogen (mineral+organic) (kg N ha^{-1})	360	360

Table 2. Comparison between the Shalloo et al. (2004) data and the optimum systems produced for poorly drained (wet) and well-drained (dry) soils at the same site

	Dairy_sim-wet	Shalloo et al. (2004)	*Dairy_sim*-dry
Stocking rate (cows ha^{-1})	1.90	1.89	2.25
N application rate (kg ha^{-1})	236	238	236
Total DM (kg ha^{-1})	9438	9932	12303
Main silage DM (kg ha^{-1})	4821	4009	5349
Baled silage DM (kg ha^{-1})	913	-	560
Days grazing	177	149	194
Grazed intake (DM (Kg/cow)	1949	2121	2842
Silage intake (DM (Kg/cow)	2355	2375	1903
Meals intake (DM (Kg/cow)	455	759	463
Grazed intake fraction	0.41	0.40	0.55
Silage intake fraction	0.49	0.45	0.37
Meals intake fraction	0.10	0.13	0.09

Potential applications

The data presented here indicate that *Dairy_sim* can simulate real systems accurately and with reasonable precision. The dynamic nature of *Dairy_sim* means that it can be used to evaluate the *probability* of a particular strategic management system being workable at a given location and indicate the kind of problems that may arise and the tactical management responses that may be required. It is possible to examine the trends in nitrogen use, herbage supply and slurry management that can arise, and to investigate the proportion of years when problems might occur, such as lack of conserved forage or lack of opportunity for slurry disposal. As the model responds to the weather data available it is possible to use historical data to evaluate future

choices, but more importantly, the system can be modified to work with climate-based, seasonal and weekly weather forecasts in order to be converted from being a research tool to being an operational decision support tool.

Conclusions

When developing a system model it is necessary to address the critical issues that dictate system performance and to avoid consideration of secondary issues. In the case of *Dairy_sim* there is no mechanistic consideration of animal nutrition or biogeochemical cycles. The level of detail was specified as appropriate for strategic and tactical system design and climate change impact studies. This means the model cannot be used to assess issues such as nutrient recycling and carbon balance, rather it focuses on the core issues for which it was designed. Comparison with field data for various production systems indicates that there is sufficient detail in the model to capture the essential components of low-cost, grass-based rotational grazing systems as used in Ireland. As currently specified *Dairy_sim* is regionally constrained to the Atlantic-Arc of Europe and areas with similar climate, but there are no inherent limitations to developing the approach and testing the model for other systems of dairy or beef production.

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MONITORING AND MODELLING GROWTH IN A PROPOSED MANAGEMENT SUPPORT SYSTEM FOR GRASS-WHITE CLOVER SWARDS

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Abstract

Growth and clover content on sets of plots on 7 grass/white clover fields on 4 farms in Northern Ireland were evaluated in 2006. The data were used to test a model of grass/clover growth to forecast growth and clover content of swards within a management decision support system for improved management of grass/clover swards in Northern Ireland. The model predicts growth of grass and clover separately but takes account of interaction between them. It is driven mainly by daily photosynthetically active radiation, mean air temperature and rainfall while soil moisture status and soil mineral nitrogen concentration are estimated and used. Soil mineral nitrogen was not varied in the initial simulation and predictions of sward growth and clover content were poor. The model was rerun, adjusting seasonal concentration of available soil mineral nitrogen to reflect approximately the grass growth curve. The clover content was predicted reasonably well for each farm throughout the measurement period (March to end of August) with a mean slope of regression line 0.93 and R^2 ranging from 0.5 to 0.87, suggesting weather inputs to the model were adequate. In addition to minor changes to the model, practical considerations to be addressed before the model can be incorporated into a DSS include assessment of soil mineral nitrogen availability throughout the season.

Introduction

Increasing costs of nitrogen fertiliser, the prospect of restrictions on nitrogen use, limits to stocking rate in adherence to the Action Programme of the Nitrates Directive, increasing uptake of organic farming and entry into environmental protection schemes are all contributing to increased use of white clover in grassland farming. However, white clover's contribution to swards, both directly in production of clover herbage and indirectly through supplying transferred nitrogen to grass is difficult to predict. This lack of predictability is due to the influence of soil, weather and management on the complex interaction between grass and white clover. Clover content and growth of grass-clover swards vary not only within any year but also from year to year and from site to site. Regular up-to-date information from monitor plots interpreted to isolate effects of weather, stage in annual cycle, and soil could help farmers take decisions on the management of clover swards. Furthermore by using weather forecast information in a mathematical model likely trends in herbage growth and clover content could be predicted. This approach has already been

adopted in Northern Ireland in a management decision support system for intensively managed grassland called GrassCheck (Barrett and Laidlaw, 2005). This paper outlines progress made in developing a similar decision support system for grass-white clover swards, provisionally named CloverCheck.

Materials and Methods

Structure of CloverCheck
When fully developed CloverCheck will comprise weekly bulletins on growth rate, clover content and nutritive value from grass/clover plots grown at a range of sites, cut every 3 or 4 weeks and a forecast of growth and clover content. As nutritive value is required to be measured quickly to meet press deadlines it will be assessed by near infrared (NIR) spectroscopy on fresh herbage. To run the model basic meteorological data are required for the sites (mean daily temperature, photosynthetically active radiation (PAR) and precipitation) and account must be taken of soil water holding characteristics. Growth rates and clover contents estimated by the model will be compared with observations to aid interpretation of clover content and grass performance at the sites. The model will be rerun with forecasted weather data (from Web 1) for the following 2 weeks and the output presented as a forecast of herbage growth and clover content. Additional management guideline comments will be included in the bulletin.

Testing procedures for monitor plots
As a prelude to finalising monitoring of grass-clover swards, methods of harvesting and determining nutritive value of swards are being developed. Four organic farms were selected (three dairy and one beef) at contrasting sites throughout Northern Ireland in 2005. On each of three of the farms two grass-clover fields were selected while on the remaining farm one was selected, all normally grazed, while three plots were laid down on each and harvested every three weeks by cutting to 4-5 cm. Yield and clover content were determined. Data are presented here for 2006 until August as weather data from automatic logging stations sited in each area were only available for this period. All samples harvested and their grass and clover components were scanned using near infrared spectroscopy as fresh and dried samples, and milled for analyses of nutritive value to calibrate the NIR spectra output. In the DSS nutritive value of the harvested samples from monitor plots will be determined on the same day as harvesting (as currently happens for GrassCheck). Herbage from fields on which plots were sited has also been sampled and analysed as already described.

Development of a grass-clover model
The grass-clover model has been outlined in Laidlaw and Frame (2006) and is based on the grass growth model of Johnson and Thornley (1985) adapted for field conditions and incorporating white clover. Meteorological inputs are daily mean maximum and minimum air temperatures (^{o}C), PAR (MJ m^{-2}d^{-1}) and precipitation (mm d^{-1}). Other inputs include estimated initial conditions for herbage mass for grass, clover growing point density (m^{-2}), leaf area index (LAI) of grass after each

defoliation, soil mineral nitrogen in top 20 cm of soil (kg N kg^{-1} soil), availability of soil mineral nitrogen (kg N m^{-2} d^{-1}) and soil moisture deficit at which photosynthesis of both components and clover growing point density are adversely affected (dependent on water holding capacity of soil i.e. site dependent). Photosynthesis of both components (gross for grass and net for clover) depends on PAR, temperature (linear for grass, cubic relationship for clover), soil moisture deficit, and their relative contribution to canopy LAI, position within the canopy and photosynthetic efficiency. Clover LAI is determined by the product of the growing point density and net contribution of assimilate to leaf production per growing point. Respiration is temperature dependent; in grass account is taken of both maintenance and growth while losses for clover include respiration due to N_2-fixation, and senescence. Potential clover growing point density is considered to increase linearly from 1 May to 31 July but is influenced inversely by mean standing herbage mass from daily growth of grass and soil moisture deficit.

Results and Discussion

Data from plots and initial run of model
Farms are identified by the name of the closest town. They range from a heavy soil, with impeded drainage and high rainfall in the west to light, relatively shallow soil in a lower rainfall area in the south east of the Province. There were no major differences in meteorological conditions between areas over the growing season and the main factors influencing deviation for the standard herbage growing pattern for the Province were a cold early spring and a progressively developing soil moisture deficit which exceeded 60 mm in early July at the Strangford farm.

Growth rates varied between sites, ranging from plots at Coleraine with consistently the highest rates over the growing period and Kilrea the lowest, at least during midsummer (Figure 1). Strangford plots had the lowest rates in the second half of summer, reflecting the impact of the soil moisture deficit on herbage on the light soil. Clover content ranged from a maximum at Strangford of almost 70% (although the clover fraction comprised both red and white clover) to just over 25% (due to one of the two sets of plots on the farm having exceptionally low clover content) at Kilrea.

The model was originally run by setting initial clover growing point density, grass leaf mass and grass leaf area per unit area of ground at the beginning of the simulation (1 March) and threshold soil moisture deficit at which plant functions were influenced for the given soil. Hence only meteorological conditions and cutting dates were inputs after the start of the season. None of the relationships was a good fit, due mainly to the weak relationship between actual and model grass yield. The growth curve for the grass component was amended retrospectively by adjusting the available soil mineral nitrogen at a range of points during the growth season in the model iteratively until the curve approximated to that of measured growth rates. The general profile of soil mineral nitrogen availability in which availability is greater in the earlier part of the season in grass/clover plots agrees with an earlier study (Laidlaw and Frame 2006).

Clover content estimated by the model for the different farms, prior to taking account of soil mineral nitrogen availability, was variable. Regressing mean clover content at each cut on actual content, the slope and R^2 for the farms at Coleraine, Omagh, Kilrea and Strangford were 1.01 and 0.88, 1.18 and 0.43, 1.41 and 0.35, and 0.91 and 0.41, respectively. These were improved when the model was rerun to 0.94 and 0.84, 0.88 and 0.71, 0.84 and 0.50, and 1.06 and 0.87, respectively, for the four farms.
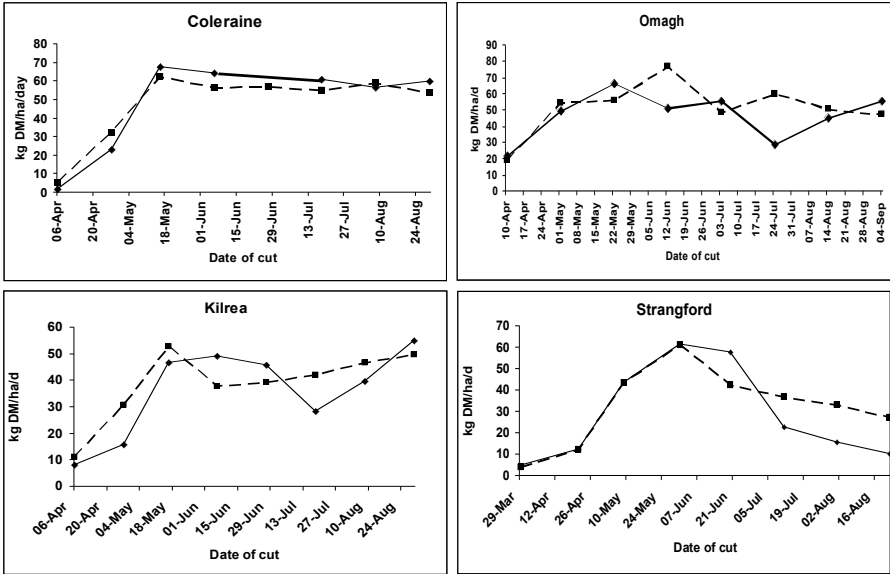
Figure 1. Actual (——) and model output (----) herbage growth rates on grass/clover plots on organic farms in Northern Ireland

Rerun of model addressing differences in soil mineral nitrogen availability
Measured and predicted growth rates show reasonable agreement (Figure 1) although an exception is the marked higher predicted than actual growth rate in August at Strangford, albeit that the predicted rate is still the lowest of the four sets of plots, possibly due to overestimation of water holding capacity of the soil. Although the same weather data were used as inputs for the Coleraine and Kilrea farms growth was generally higher at the former suggesting either microclimate may be important or factors identified by the model (e.g. soil mineral nitrogen) are implicated.

Implications of results for DSS
The anticipated application of CloverCheck is for it to be similar to GrassCheck in that weekly bulletins of current and predicted herbage growth will be published to aid farmers in budgeting feed resources. Farmers (mainly dairy) benefit from GrassCheck, especially in cold springs and during periods of soil moisture stress when grass growth departs from the norm. The farmer funded AgriSearch (Web 2) provides financial support for its operation and so is an endorsement of its practical value. However a criticism expressed by farmers in the west of the Province is that especially in dry summers GrassCheck overemphasises the adverse impact of drought

as herbage growth and meteorological data are only collected in the drier east of the Province. In CloverCheck (and also in a proposed revision of GrassCheck) growth and meteorological data will be monitored at a range of sites.

A positive outcome from this study is the ability of the model to reflect site differences in herbage growth and clover content. CloverCheck offers a learning experience for farmers who are not familiar with the typical seasonal curve of either grass/white clover growth or of clover content. For farmers who are already relying on white clover it will help them to make decisions not only on feed budgeting but also on whether remedial action is necessary either to encourage or control clover contribution. So Clovercheck will be a benchmark for them to judge their own swards. In a DSS farmers may need photographs to help them to classify the clover status of their swards so that they can relate them to the clover status classes used in the DSS. No attempt was made to reset the model for any departures from measured clover growth during the season which would be possible when used in a DSS. So in this respect the test was more rigorous than was necessary but increases confidence in its use. The findings from this study cannot be directly related to fields. The annual mean clover content for the plots was 31.9% clover (s.d 13.45) compared to 12.1% (s.d. 4.19) for the fields. So some interpretation of data from plots will be necessary for application to fields. Nevertheless due to their standard management, data from plots allow comparisons to be made across regions and years and so the results can be used as relative standards on which farmers can base decisions. Models are likely to be developed that can be used for direct application to grass/clover fields. The grass component poses more of a problem in grass/clover systems. The apparent variable availability of soil mineral Nitrogen throughout the growing season needs to be taken into account and requires further investigation, including methods to gauge seasonal contribution early in the year.

Conclusions

The role to soil conditions (water holding capacity and soil mineral nitrogen status) and state of the sward (e.g. amount of clover early in the season) are as important in determining sward growth and clover content in mixed swards as weather, although, the interaction between these cannot be ignored. The output, especially relating to the clover component, from the quite basic model used in this study is encouraging. Hence by building up experience and data bases over a range of seasons and sites, more reliance may be placed on model output and less on resource demanding monitoring of plots. However more information of the profile of availability of soil mineral Nitrogen in grass-clover swards is required.

Acknowledgements

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IMPROVING NITROGEN RECOVERY EFFICIENCY FROM CATTLE SLURRY APPLIED TO GRASSLAND

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Abstract

Current agronomic advice for cattle slurry applied to grassland in Ireland suggests that of the total nitrogen applied in cattle slurry, 25% is available if applied in the spring, and 5% is available if applied in the summer. Almost 100% of slurry in Ireland is applied with a splashplate applicator, and only 34% of cattle slurry is applied in the spring. Reductions in the levels of ammonia emissions from landspreading of cattle slurry of 73% for shallow injection, 57% for trailing shoe, and 26% for band spreading compared to conventional splashplate application are reported. Such reductions in gaseous ammonia losses are considered to result in a higher proportion of slurry nitrogen being available for plant uptake. The trailing shoe is considered to be the most promising application method for Ireland, as it should overcome the increased draught power requirement and soil type compatibility problems experienced with shallow injection, while minimising the sward contamination effects of the bandspreader and splashplate applicators. The trailing shoe should also provide more flexibility of application date on heavier soils, as application can be delayed in order to achieve optimal soil trafficability conditions, without increasing sward contamination. There is no reduction in silage quality as a result of applying slurry to taller swards with a trailing shoe applicator. An assessment of the increased slurry nitrogen recovery of the trailing shoe application system at field-scale under Irish conditions is being undertaken in order to evaluate whether an adoption of this more expensive slurry application technology is justified at farm level. The objective of this work is to find the optimum interaction of application method with timing and soil conditions that will result in maximising N recovery from cattle slurry on grassland. This work has the potential to feed into a decision support system that would predict the nitrogen fertiliser replacement value of slurry for a range of soil types, application methods and application timings.

Introduction

In 2003, the national cattle herd of 6.3 million animals produced 37 million tonnes of manure during the winter housing period. 29.3 million tonnes of this was produced as slurry, with the remainder being solid manure (Hyde and Carton, 2005). Using the standard value of nitrogen in cattle slurry of 5 kg per tonne of slurry, as quoted in the nitrates action plan (Anon, 2006), this slurry contains 146,500 tonnes of nitrogen. The objective of this paper is to establish the current usage of this source of potentially available nitrogen, and describe an experiment currently underway at Teagasc, Johnstown Castle, that aims to maximise the recovery of slurry nitrogen applied to grassland in Ireland.

Current usage of slurry in Ireland

Current agronomic advice available in Ireland states that the recovery of slurry nitrogen is 25% if applied in the spring, and 5% if applied in the summer (Coulter, 2004). Statistics on slurry management show that only 34% of slurry is being applied in the spring (Hyde and Carton, 2005). This means that 66% of slurry is being applied at a time when recovery of nitrogen is poor. The poorer recovery from summer application has been attributed to gaseous nitrogen emissions. Approximately 50% of the total nitrogen contained in slurry is in the form of ammonium (Stevens *et al.*, 1997). This ammonium (NH_4^+) is readily converted to ammonia (NH_3), which can then be volatilised to the air. The extent to which volatilisation occurs is controlled by temperature and wind speed, hence, gaseous ammonia losses are higher in the summer time when air and soil temperatures at their highest (ALFAM, 2001).

Almost 100% of slurry in Ireland is applied using a splashplate application system (Hyde and Carton, 2005). This method of application involves the pressurised expulsion of the slurry from the rear of the machine through a rubber nozzle of approximately 50-75 mm diameter. The slurry is projected onto a plate which then distributes the slurry as a fine layer to the entire surface spreading width. A consequence of this application system is that the surface area of slurry exposed to the air is very large relative to slurry volume applied, resulting in a high potential for ammonia volatilisation (Ryan, 2005).

Alternative application methods available

Alternative low emission application techniques have been shown to reduce ammonia emissions from field-applied slurry. The basic principle behind low emission application is that the slurry is applied in lines rather than being broadcast. This results in a reduced surface area for exposure to the air, thereby reducing the potential for ammonia loss (ALFAM, 2001, Malgeryd, 1998, Mattila, 1998, Misselbrook *et al.*, 2002, Smith *et al.*, 2000). Among the variations in this technology that are commercially available are the: (i) shallow injector which cuts a slit in the soil approximately 50 mm deep and deposits the slurry in lines below the soil surface; (ii) bandspreader which distributes the slurry in lines at the crop surface by way of a series of 50 mm pipes across the spreading width of the machine; and (iii) trailing shoe which applies slurry in lines at the soil surface by way of 'shoe' coulters that separate the grass canopy and apply slurry at the base of the sward (Figure 1).
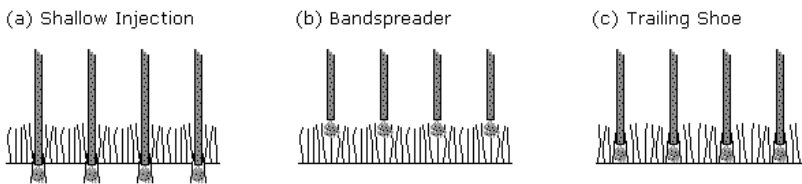

Figure 1. Schematic representation of slurry being applied with (a) Shallow injection – slurry applied below soil surface in 50mm deep slit, (b) Bandspreader – slurry applied in lines to crop, and (c) Trailing shoe – slurry applied in lines at the soil surface through 'shoe' coulters which part the crop canopy.

Numerous experiments report that low emission application techniques show a significant reduction in ammonia emissions (Malgeryd, 1998, Mattila, 1998, Misselbrook *et al.*, 2002, Smith *et al.*, 2000). The reduction in ammonia emissions is dependent on the application system. Misselbrook *et al* (2002) showed a reduction in ammonia emissions compared to splashplate application of slurry to grassland of 73, 57 and 26% for the shallow injector, trailing shoe and bandspreader respectively. Smith *et al* (2000) showed reductions of 57, 43 and 39% using the same respective comparisons.

Alternative application method for Ireland
While shallow injection is seen as the most effective slurry application technique for reducing ammonia emissions from slurry application to grassland, it must be noted that not all soil types are suited to shallow injection. The draught requirement for injection systems is higher for soils with high clay contents than for sandy soils (Huijsmans *et al.*, 1998). Injection systems are not deemed to perform well on compacted or stony soils as the reduction in gaseous ammonia loss is dependent on effective closure of the injection slit. Soils with high clay or stone contents result in greater disturbance around the injection slit, and poorer slit closure as a result (ALFAM, 2001). The mineral soils of Ireland are principally derived from glacial deposits of till and drift, and the soils are highly variable in terms of texture, drainage, and stone content as a result (Gardiner and Radford, 1980). Irish soils also tend to be quite wet. The number of days in a wet year during which soil moisture deficits are greater than 10 mm, and therefore deemed potentially safe for trafficking, ranges from 120 days in the east to 25 days in the west (Schulte *et al.*, 2006). Therefore, the scope for the adoption of shallow injection as a low emission application method in Ireland is limited.

Based on these considerations, the trailing shoe is viewed as a more promising option than bandspreading for Irish grassland. While both systems apply slurry in lines, the trailing shoe has the additional benefit of applying below the grass canopy, thereby avoiding contamination of the sward. Laws *et al* (2002) showed that slurry can be applied with a trailing shoe to taller swards without fear of negative effects on silage fermentation. This is vital when considering that slurry nitrogen recovery is greatest with spring application. Spring application is limited due to soil trafficability issues outlined by Schulte *et al* (2006). The correspondence of a period in the spring when soil conditions can be trafficked with a period when grass covers are low enough to avoid grass contamination with conventional splashplate application is often limiting. However, the trailing shoe application system could provide a wider spreading window for spring application, as the slurry could be applied to a higher grass canopy. Slurry application in spring may therefore be better timed to intervals which minimise soil damage due to machinery traffic.

While there is strong evidence supporting the reduced ammonia emissions of the trailing shoe system, there is little knowledge of the impact of application method on herbage yield and nitrogen uptake, and how these factors are influenced by soil type, timing of application and grass height at time of application. An experiment is

underway to compare the effects of the trailing shoe application system over the conventional splashplate system. The experiment aims to establish whether nitrogen recovery and fertiliser replacement value of slurry nitrogen is dependent on (i) application method (splashplate and trailing shoe) (ii) application timing (spring and summer) and (iii) site (well, moderately and poorly drained soils). The experiment also aims to establish the effect of grass height at the time of slurry application with the trailing shoe on recovery of slurry nitrogen.

Materials and Methods

The experiment is being conducted on three sites of varying soil drainage: (i) Moorepark, Co. Cork: well drained; (ii) Johnstown Castle, Co. Wexford: moderately drained; and (iii) Kilmaley, Co. Clare: poorly drained. The experiment is being carried out on permanent pasture, in which *Lolium perenne* is the dominant species. Each site is tested in the spring for soil phosphorus and potassium status, and blanket applications of fertiliser phosphorus and potassium as recommended for silage are applied to the whole site based on these results. A nitrogen response curve is established for each site and for each timing of slurry application. Nitrogen fertiliser (calcium ammoniacal nitrate) is applied at rates of 0, 30, 60, 90, 120 or 150 kg N ha^{-1} to plots 6 m long and 1.5 m wide. The slurry is being applied at two application timings (early April and early June) corresponding to the timings when fertiliser or slurry would normally be applied for first or second cut silage crops respectively. The slurry is being applied using a custom designed, farm-scale, experimental tanker. This machine is adjustable to apply slurry with splashplate or trailing shoe system over a 6 m spreading width. Slurry is sampled from the tanker prior to each load being spread and analysed for dry matter, total nitrogen, ammonium, phosphorus and potassium. Slurry is applied at rate of 33 m^3 ha^{-1}, which corresponds to a total nitrogen application of approximately 120 kg ha^{-1}.

There are three slurry application treatments. Two treatments compare splashplate (SP) and trailing shoe (TS1) application methods when applied on the same day. The third treatment (TS2) involves a trailing shoe application two weeks later. This treatment aims to compare the effect of grass height on nitrogen recovery from slurry applied with the trailing shoe. In order to establish if slurry nitrogen recovery is affected by additional chemical nitrogen fertiliser, each slurry treatment plot is further split into two sub-plots, each receiving a different rate (0 or 60 kg ha^{-1}) of nitrogen fertiliser. Plots receiving slurry in spring are harvested using a Haldrup plot harvester on three occasions (late May, mid July and early September). Plots receiving slurry in summer are harvested on two occasions (Mid July and early September). Extended harvesting beyond the first crop after application will allow for investigation of any residual uptake of nitrogen from the slurry. Dry matter yield and nitrogen uptake are measured for each plot at each harvest. The experiment within each site is laid out as a randomised block design, with split plots. Each block contains eight main-plots. Four main-plots are used for spring application of slurry (one for each of the three slurry treatments, and one for the nitrogen response curve treatments) and four are used for summer application of slurry. Each main-plot is split into sub-plots onto which the different chemical nitrogen fertiliser rates are applied. Each block is

replicated six times, resulting in six blocks on each site. The experiment is being conducted over three years, 2006 to 2008.

Results and Discussion

It is expected that the results of this project will provide useful information to allow more accurate predictions of how slurry nitrogen recovery in grassland is affected by soil type, application timing and application method. An expected outcome is that agronomic recommendations can be made more specific to soil type or location and application timing and method, rather than current practice of applying blanket assumptions on nitrogen recovery from slurry for all soil types.

Applying results to a decision support system
A decision support system that could predict the fertiliser value of slurry depending on soil type, application method, application timing and forecasted weather conditions could be of great benefit in optimising farm efficiency. The results produced by this project could provide the basis for such a system, whereby a farmer, while knowing the total nitrogen requirement of a crop, could adjust the fertiliser nitrogen supplement according to a specific prediction of slurry nitrogen availability.

Conclusions

Current utilisation of slurry nitrogen in Ireland is poor as a result of the relatively low proportion of slurry that is applied in the spring, and the use of the splashplate application system, giving rise to high gaseous ammonia losses. The trailing shoe application system is viewed as being a suitable alternative to the conventional splashplate applicator due to a reduction in ammonia losses and increased flexibility of spreading timing. This project aims to quantify to what extent the reduction in the ammonia emissions results in increased nitrogen recovery in the herbage, and has the potential to feed into a decision support system which would increase the reliability of slurry nitrogen recovery in grassland.

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THE POTENTIAL IMPACT OF CLIMATE CHANGE ON AGRICULTURE, HORTICULTURE AND FORESTRY IN THE NORTH OF IRELAND

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Abstract

Land based industries such as agriculture, horticulture and forestry are particularly dependent on climate for their operation and are potentially vulnerable to climate change. Creating experimental scenarios which predict the likely responses of these industries and components of them to a range of climate change scenarios is very difficult and resource demanding. A scoping exercise was undertaken whereby a range of scientists, geographers, industry practitioners and their representatives, policymakers, regulators, NGO's in the environmental sector, secondary producers were (1) presented with a pack containing a summary of the current most likely change scenario, and (2) summaries of scientific work on likely component responses to climate change. They were then interviewed in depth to seek their informed opinion on likely impact on their sector and to suggest mitigation measures. Their responses were aggregated and synthesised and it was concluded that: Climate change in other parts of the world would likely have a greater impact on the profitability of agri-industries in the north of Ireland; more opportunity for diversification would be created in the arable and energy cropping sectors; livestock farming would become more difficult though arable substitution would help; new opportunities in horticulture e.g. apple production would emerge; forestry would have to change radically – shallow rooting conifers in the uplands would need to be replaced by a wider range of trees with the ability to deliver ecosystem services. Overall, in the medium to long term climate change would bring net benefit to land-based industries in the north of Ireland.

Introduction

Predicted climate change for Northern Ireland is characterised by warming, increased precipitation and potential evapotranspiration, but seasonal and annual effects are inconsistent and year-to-year variation may confound overall trends. Overall winter gale frequency may decline, although very severe winter gales may increase. Improved models and estimates of the spatial and temporal patterns of climate change will provide more details of change (Hulme and Jenkins, 1998, SNIFFER, 2002). There is a need to investigate the likely impacts of climate change on the environment, economy, natural resources and land use of Northern Ireland particularly considering the effect of inter-annual variability and climate extremes. There is also a need to assess awareness of change, the opportunity for adapting to and mitigating effects of change.

The main land use sectors are agriculture and forestry and within an overall investigation of the impacts of climate change for Northern Ireland there is a need to

determine the awareness and predict the likely effects in the sectors to form strategy development, particularly in the government policy sector. This paper outlines such a scoping exercise.

Materials and Methods

Key experts and stakeholders in the agricultural, horticultural and forestry industries (Table 1) were presented with a list of predicted climate change scenarios based on the UK Climate Impacts Programme (UKCIP) (Table 2) and a series of questions as follows: -

- What climate change policy exists already in your organisation, if any?
- What climate change policy might emerge in response to the impacts and responses discussed above?
- Is climate change (and policy responses to it) always perceived negatively? In what ways is it perceived positively?
- What are your reflections on the significance of climate change impacts as an issue for Northern Ireland?
- What level of interest would your organisation have in a broader-scale research initiative on climate change impacts in Northern Ireland? What should be the focus of such a study?

Table 1. Expert and Stakeholder consultation list (by organisation)

School of Geosciences, Queens University, Belfast
Department of Agriculture and Rural Development-
a.   Environmental Policy Branch
b.   Countryside Management Branch
c.   Forest Service
d.   Science Service
Environment and Heritage Service– Biodiversity Unit
Department of the Environment– Environmental Policy
Premier Woodlands
Ulster Farmers Union
N.I. Agricultural Producers Association
Non Governmental Organisations – Royal Society for the Protection of Birds, Ulster Wildlife Trust, Northern Ireland Environment Link
Individual Farmers
The Woodland Trust

Table 2. Climate change scenarios presented to experts and stakeholders (UKCIP – Hulme and Jenkins, 1998).

Annual mean temperature + 0.8 to 2.0°C by 2050
Winter warming 1 – 2.9°C; Summer 1.1 – 2.5°C by 2080
Rainfall up by 5% by 2050 and 13% by 2080
Winter rainfall up by 13% Summer rainfall down 8%. Increased intensity
Accumulated degree days >25°C trebles by 2080
Accumulated degree days >5.5°C increases 5% per 10 years
More extreme storms

Additionally workshops and discussions for stakeholders were hosted by Queens University Belfast in June and August 2001 to enhance understanding and enable final additional issues to be raised.

All the information given by experts and stakeholders was synthesised by aggregating them under a series of sub-headings and weighting according to the frequency of occurrence of each response. Broad conclusions were made on predicted impact by sector and appropriate remedial and mitigation measures.

Results and Discussion

Overall there was broad agreement that:
a. Impact of climate change will be slow when set against main policy drivers (e.g. EU agricultural policy and CAP reform).
b. Change in other parts of the world that currently trade with Northern Ireland will have an impact on markets and eventually have more effect than climate change.
c. Change will impact on all the main land use activities in different ways.

Impact on the arable sector
- Generally will increase opportunity for expansion
- Wider range of crops can be grown e.g. Alfalfa, Sunflower, Maize, Lupin – will impact on livestock sector
- Potatoes could cease to be viable without irrigation
- Imported feed substitution, landscape changes
- Move from winter to spring cereals – biodiversity impact
- Increased pest and disease problems – migration
- Greater need for agrochemicals – new strategies for crop protection required
- Greater opportunity for industrial/energy crops e.g. willow, hemp
- Increased CO_2 but decreased summer rainfall could work both ways for energy cropping
- General prediction is increased arable area at expense of livestock
- Could favour return to mixed farming – landscape and countryside implications

The arable sector could adapt and produce more locally grown fodder (this would create a need for less silage) and this is an opportunity to expand the area of energy cropping . Lower pesticide and fertiliser use (and hence crop yields) are likely and there may be a role for breeding new varieties targeted towards these scenarios.

Impact on the livestock sector
- May increase potential for grass growth but will make utilisation more difficult
- Soil poaching problems anticipated
- Wetter spring could exacerbate slurry disposal difficulties – water quality effects
- Maize silage will gradually replace grass silage

- Current grass varieties not suitable for climate change
- Knock-on effects e.g. water quality and nutrient management will be a big issue – more regulation – affects type of varieties needed
- Upland conditions may be ameliorated
- Grazing season extended but weather extremes can have a serious negative impact
- Could affect EU designations e.g. 'Less Favoured Area' concept through a policy-driven decision
- Impact on agri-environment schemes and reduction of intensification
- Livestock farming will be more difficult in the west and easier (diversified arable impact) in the east
- Traditional low-intensity livestock farming will be more difficult
- There will be impact on the rural economy and rural communities

Utilising will be more important than producing and livestock numbers will continue to decline. Water quality will be a major constraint. As with the arable sector there could be a need for breeding new varieties that are drought and flood resistant (Stern, 2006).

Impacts on forestry and woodland
- Catastrophic events have major impacts
- Increase in frost damage, arthropod pests & fungal diseases
- Native trees with long cold-season requirement (e.g. ash) will decline
- Ancient heritage and native woodlands under greater threat
- Longer growing season results in more productivity
- Wider range of species available
- Carbon storage opportunities
- More scope on the 'margins' – i.e. land use systems which can adapt better, enhance landscape and biodiversity
- Biomass, scrublands and agroforestry could become more important land use options

In the forestry sector, there will be a move from conifers on peat to broadleaved woodlands and more novel ways to introduce trees into farmed landscape. Issues such as connectivity and expansion of native and heritage woodlands, contingency plans for catastrophes and broadening the species base will all arise. There are considerable opportunities for forestry and energy cropping though the current land use policy will need to radically change.

Impacts on horticulture
- Not likely to change much
- Strong influence of growing conditions elsewhere
- Apples – disease implications; late frost occurrences
- Mushrooms – adverse effect of warm summers will need better circulation, more dust and spores if drier summers
- Vegetables – not likely to be much change

Some niche market expansion in horticulture may be possible and apple growing could expand.

Socioeconomic impacts
- Livestock farming in Less Favoured Areas will come under greatest pressure
- Farmers already notice problems associated with climate change – wetter winters eating further into the summer
- More beneficial to consumers than producers (short term)
- In longer term, world market conditions will have a greater effect e.g. catastrophes elsewhere favour producers here
- Food prices will rise – decrease in cheap, unsustainable food production elsewhere (apart from EU)
- Producers here will have to 'ride out' a period of world over-production until balance shifts in their favour
- Moving away from subsidy-dependent culture but agriculture supplies more than food
- Government investment to sustain rural communities essential
- Need for agri-environment funding and diversified business support

Future Strategies
Eventually climate change will make farming a more viable business. Related factors such as renewable energy increases and upturn in tourism could impact as well. There is a need for young people to be involved in the sectors and to improve the general level of skills and training particularly for part-time farmers to cope with change. An east/west split in farming and rural land use could be exacerbated. Issues such as risk and insurance will increase operational costs.

Conclusions

The north of Ireland is very vulnerable to factors beyond its control and this will increase in a climate change scenario. Farming will be affected by conditions elsewhere in the world. In the long term farming could significantly benefit from climate change. There will be gradual changes in farming infrastructure and in land use. The use of trees should expand to meet opportunities in landscape, carbon storage, timber, recreation and renewable energy.

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SPATIAL AND TEMPORAL ISSUES IN THE DEVELOPMENT OF A MICROBIAL RISK ASSESSMENT MODEL FOR CRYPTOSPORIDIOSIS

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Abstract

A microbial risk assessment model is being developed using GIS for municipal water systems to identify when potable water is at high risk of being contaminated with zoonotic enteric pathogens via surface pathways. *Cryptosporidium spp.* oocysts are being used as the indicator organism. The spatial data layers in the GIS include: soils; geology; stock density; animal husbandry; farm storage of animal wastes; animal waste disposal practices; data from biological surveillance of the environment; and meteorological data. Field monitoring will provide temporal estimates for probability of oocyst prevalence and survival along the transport vector and geo-spatial analysis within the GIS will be used to estimate probability of the transport vector being active from source to target. Monte Carlo simulation will be used to determine the risk of contamination of potable water in the trial area. This paper reports on spatial and temporal issues being considered.

Introduction

Cryptosporidiosis is a pathogenic disease that develops in humans after the ingestion of *Cryptosporidium* parasites, usually from contaminated drinking water. Some of the resulting, and possibly protracted, effects of *Cryptosporidiosis* on humans are fever, diarrhoea and vomitting. The disease is also potentially fatal to the very young, the elderly and immunodeficient patients such as organ transplant recipients. *Cryptosporidiosis* is now deemed a notifiable disease whereby all known cases must be reported to the Health Protection Surveillance Centre (HPSC). The *Cryptosporidium* species that commonly infects beef and dairy calves may also cause disease in humans (de Graaf et al, 1999). The parasite is about $4.5 – 5.5$ μm in diameter which allows it to pass through some standard filtration systems and is also immune to chemical purification of drinking waters such as chlorination (Hoonstra and Hartog, 2003). With the parasite's ability to pass through filtration mechanisms it is imperative that an assessment of risk be undertaken in areas where drinking waters are derived from runoff originating in livestock intensive areas (Grundlingh and de Wet, 2004). The current method of risk assessment for *Cryptosporidium* is 'The Scottish Model' which is a simple scoring system assessing and grading factors such as livestock numbers, soil type and climate which combine to give a final score or evaluation of risk. Although the model is easy to use and low in costs it does tend to offer only a vague and generalised assessment of risk and offers little regarding the functions and behaviour of the parasite itself.

One of the fundamental flaws in the Scottish model is that the quantitative analysis is static. The model functions on data taken at one specific time and assumes that these data will change very little over the course of a farming season and assumes that farming practices such as slurry spreading will remain uniform and adhere to stringent principles. This is never the case. Farm practices are strongly influenced by climate and location and throughout Ireland there can be significant differences in rainfall, temperature, topography and land suitability; these factors will affect the way farming is conducted. The changes in these factors are both spatial and temporal and the Scottish Model does not allow for changes over time to be accounted for. These temporal changes are: climate – rainfall, temperature, sunlight; animal housing – shorter winter housing period in the south of the country; slurry spreading – it maybe spread all at once or over the course of the season; soil – infiltration rate changes leading to excessive runoff of water and slurry; and calving – autumn and/or spring calves, housing duration and location, sale of bullocks, disposal of bedding materials.

Variations in and combinations of the temporal changes above along with various animal husbandry practices could either increase or decrease the risk of *Cryptosporidium* entering streams and rivers that serve water supplies. For example, heavy rain coupled with slurry spreading will increase the risk whereas housing calves away from slatted sheds until they are 12 weeks old and disposing of their bedding properly will reduce the risk.

Theory

In order to assess the risk of contamination of the waters in a catchment with *Cryptosporidium* oocysts it is important to gauge levels of the infective stage of this parasite over both space and time. A GIS based risk assessment model will incorporate all the relevant data and issues that contribute to *Cryptosporidium* contamination of the environment. They are as follows:

Temporal Issues

Calves
Cryptosporidium infection usually occurs in calves aged 3 – 12 weeks, and the prevalence of disease lessens as animals get older. The majority of calves in Ireland are born in the period from February to June with the male calves being usually sold within four weeks of birth. Also on some dairy farms, calving occurs in autumn to enable the production of winter milk. The weaning of calves differs from farm to farm with some farmers keeping young animals on straw bedding until they are over 12 weeks while others are kept in slatted sheds which allows their faeces to drain into the farm slurry tank.

Adult Cattle
Although the prevalence of *Cryptosporidium* infection in adult animals is considerably lower than in calves there is still a potential risk of their faeces contaminating runoff waters. The geographical location of a farm determines the time of year that the cattle are let out to pasture. With a warmer climate in the south and

southeast of Ireland, cattle herds could be grazing in March while in the colder north and west of the country grazing could start in late May.

Slurry Spreading
The spreading of slurry accumulated during the winter from housed animals can be a major cause of contamination by *Cryptosporidium* oocysts to runoff and surface waters. The timing of any slurry spreading is critical if contamination is to be avoided. Slurry is normally disposed in summer and autumn when plant uptake of slurry N is less efficient (Lalor and Schulte, this volume), thus there is a greater risk of rainfall events leading to leaching and runoff of oocysts.

Climate
As outlined above, the source of *Cryptosporidium* oocysts in runoff water and streams can change with time depending on farming practices and population of young animals. This needs to be observed in conjunction with climate conditions such as rainfall. Climate conditions in Ireland are unpredictable in the medium and long term and even short-term forecasts can be inaccurate. It is important to assess how the combination of farm practices, climate and land/soil conditions can lead to environmental contamination and the timeframe in which it can occur.

Soil
The moisture content of most soils reduces with the drier, warmer summer conditions and depending on the soil type this can occur more or less rapidly. Consequently, various soils have different responses to *Cryptosporidium* loading from slurry and/or from grazing animals. Free draining soils may allow oocysts to pass through with little filtration whereas heavily compacted soils may result in overland flow of water and oocysts. Soils may hold oocysts until they are inactivated and pose no risk. To assess soil moisture change and the soil's ability to hold oocysts requires continuous monitoring over the summer farming season.

Oocysts
Cryptosporidium oocysts are extremely resistant to environmental changes and chemical treatment. They can remain viable after exposure to temperatures ranging from $-10°C$ to $35°C$ (Fayer et al., 1998). Oocyst survival rates in the environment can be up to a year. These issues regarding oocyst survival must also be considered in any risk assessment.

Spatial Issues

Land & Animal Distribution
Within a catchment boundary it is important to identify the distribution of farms with the potential to be the source of *Cryptosporidium* and also to determine the number of livestock, especially the numbers of calves. The sum total of animals in a catchment does not indicate risk unless their age and spatial distribution is known. Once the distribution of animals is ascertained it is necessary to determine land use and its distribution i.e. grazing, silage cutting and slurry spreading and fodder crops.

Physical Features

Topography is important and needs to be factored in with land use within the catchment to assess the possible risk posed. For *Cryptosporidium* oocysts to enter a stream or river they require pathways within which to travel (the transport vector). These pathways could be either overland flow, throughflow in the soil, drainage ditches along field boundaries or through porous rock channels such as those found in limestone regions. Direct faecal contamination of surface water by animals also has to be considered. Soil types can differ within very small areas relative to the size of the catchment. It is quite common to have two or more soil types within a single field and this can affect the rate of oocyst transmission to surface water after slurry spreading or grazing. Farming practices in Ireland vary from region to region depending on the climate. The higher temperatures in the south allow a shorter winter housing period than in the colder north. In these areas animals are let out to graze earlier in the wetter spring months increasing the chances of *Cryptosporidium* oocysts entering streams and rivers. The shorter summer grazing season in the north may encourage concentrated slurry spreading in order to empty tanks as quickly as possible.

Field monitoring

After collecting information on 14 different river catchments in Ireland, it was decided that the Bellsgrove catchment on the shores of Lough Sheelin in Co. Cavan was most suitable for the study. As outlined above the principal contributors to a *Cryptosporidium* outbreak need to be monitored over space and time and this study concentrated on a single river catchment area which is 12.5 km^2 in area and the sampling was carried out from March until September 2006. A baseline sample was taken before the grazing season to determine the levels of *Cryptosporidium* contamination in the area and then on a continuous basis to monitor any changes in levels. Samples were collected from the following sources:

Adult Cattle: Baseline sampling only to determine infection rates.
Calves: Baseline and continuous sampling of calves as some are born as late as June.
Slurry: Continuous sampling from the first spread in early July.
Soil: Baseline and continuous sampling to monitor any changes in quantity and viability of oocysts in the ground.
Water: Baseline and continuous sampling for quantity and viability.
Climate: Rainfall data collected from gauge situated in catchment and other meteorological sources.
Physical features: Full survey of the catchment using maps, GIS data, local knowledge, personal observations, GPS and water level recording of all streams in the catchment.

It was also important that the farms used in the sampling strategy were evenly distributed throughout the catchment and represented beef, dairy, suckler, sheep, horse and pig farming activities. Out of 22 working farms, 11 were continuously sampled which represented 50% of the agricultural land and 75% of the total adult

cattle population. Soil samples were taken from lands with different agricultural uses such as grazing, slurry spreading, silage, forestry and calf paddocks. Water samples were taken from 6 locations in the catchment where the water level recorders were located.

Final observations

It is necessary to monitor all contributors to *Cryptosporidium* contamination of the environment in order to comprehensively assess the source, distribution and transport of oocysts and to develop a risk assessment model. A simple list model does not have the capacity to determine risk over time but merely gives a probability rating the *Cryptosporidium* exists in an area and very little else. The GIS model will factor in all variables that can occur to allow for a more accurate assessment of risk.

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TOWARDS A DECISION SUPPORT SYSTEM TO IMPROVE THE DESIGN OF LIVESTOCK BUILDINGS AS A FUNCTION OF THE LOCAL ENVIRONMENT

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Abstract

Intensive methods of animal production often fail to meet adequate standards in the simultaneous control of indoor microclimate and pollutant emissions from agricultural buildings. This failure may be partially caused by the demands from the global marketplace presently reducing the differences between intensive livestock farmers' production costs and income and forcing farmers to make expert decisions on a broad spectrum of specialised issues in order to optimise animal productivity. In this study a decision support tool to aid farmers in forming educated opinions on the design of production facilities is outlined. The whole system will take input from the producer and run through the design process, from design conception to optimisation. The system also incorporates recent modelling techniques that will enhance the design process, especially when tight control over the indoor environment, ventilation rates or pollution distribution is required.

Introduction

Intensive methods of animal production have presented many challenges to environmental management over the years. The inadequate simultaneous control of indoor microclimate and pollutant emissions has caused widespread diseases in animals, and pollution of the Irish natural environment (Norton et al, 2006; Hayes et al., 2006). Microclimates within agricultural buildings contribute greatly to the health status of both farmers and animals. Farmers tend to have higher rates of asthma and respiratory symptoms than other occupational groups; the Teagasc National Farm Survey, 2004 (Teagasc, 2004) has shown that 9.9% of farmers have reported work related illnesses. As well as this, housing problems have also severely affected animal health in Ireland. For example in pig production, based on the correlation between lung lesions and food conversion ratio, it has been estimated that complicated respiratory diseases cost the Irish pig industry €3m annually (Kavanagh, 2003). With regards to environmental pollution, many Irish intensive animal production facilities have been found to have notably higher rates of ammonia emission than similar facilities in the Netherlands, Germany and UK (Hayes et al., 2006). These detrimental problems have highlighted the urgent need for new tools that can provide detailed information on the spatial and temporal distribution of climatic variables and pollutants so that the optimum design and control of livestock housing systems can be implemented.

The increasing demands of the global marketplace are presently reducing the differences between intensive livestock farmers' production costs and income. To realise the level of profits that were once taken for granted, producers must now improve management skills and enhance production strategies. Expert decisions must be made on a broad spectrum of issues dealing with animal health and welfare, and economic issues, in order to optimise animal productivity. Yet, these decisions often fall into highly specialised fields, and the ability of the farmer to determine the correct line of action when faced with challenging situations may not always be apparent. Nevertheless, running alongside the increasing pressures of market globalisation is an increased interest in developing new and effective decision support systems (DSS) which can help producers to maintain their competitiveness. One area where these systems can be fully exploited is in the design of livestock production facilities. In this context, decision support systems can highlight the design required to raise the quality of an animal's micro-climate as a function of local outdoor climate and terrain parameters; thus augmenting producer profits.

The ability to maintain optimum environmental conditions in intensive livestock production systems is dependant on the design and performance of the ventilation system. Decisions on the building design and internal layout, alongside the choice of natural or mechanical ventilation should be taken at the very early stages of the design process. Of course, as mechanical ventilation affords a directly controllable means of modifying the indoor environment, the decision in its selection can be made on purely deterministic procedures and thus optimal performance can, in many cases, be achieved. However, the heavy reliance of such systems on energy has adverse impacts on both income and the natural environment, and the pros and cons of such a system should be critically analysed before implementation. On the other hand, to create and maintain a good quality indoor environment by a naturally ventilated system, the optimal exploitation of natural forces is required. By definition these forces are heavily dependent on local weather data, surrounding terrain, indoor occupants and building topology, making accurate design difficult unless the designer has a good understanding of the physics involved.

The ability of best practice guidelines, which are used at present as supporting documents for grant aided buildings, or traditional rules of thumb, to develop production facilities with desired functionalities can often be impaired by the varying nature of the climate and the topography of the local environment, and more robust techniques are demanded. As a direct result of the above, the choice of ventilation system often falls into the hands of a salesperson, whose desire to sell a particular system supersedes their knowledge of producer requirements. Therefore the development of a DSS to aid the farmer to form educated opinions on the ventilation system is required. The objective of this paper is to define techniques that can be used to provide such a service. Also, the models that form the basis of the system will be discussed, although not in detail. The main considerations to be addressed in the system will include:

- the alignment of farm location with the most effective mode of ventilation
- the use of traditional analytical methods that will provide estimations of the required ventilation rates and ventilation configurations
- the incorporation of a modern modelling technique, computational fluid dynamics (CFD), which uses these analytical solutions as input parameters to predict a more refined ventilation system, the performance of which will be determined based on the ventilation effectiveness and the quality and heterogeneity of the indoor environment.

Overview of computational fluid dynamics, a major component of the DSS

Computational fluid dynamics (CFD), a simulation technique traditionally used by the aerospace industry, has become integral to the description of the complex airflow system behaviour within and around buildings (Gosman, 1999). CFD is presently being applied as a rapid and accurate tool for testing design concepts with every possible variation, and can substantially reduce the need for high-cost and time-consuming experiments. Internationally, several recent studies have confirmed the success of CFD in the livestock housing industry. For example, with CFD a livestock housing engineer can:

- Ensure that the essential needs of the animal are met in all parts of the building and optimise the indoor environment to increase animal performance (Norton et al., 2007).
- Combine the spatial and temporal dependant parameters that affect release of all pollutants from animals to efficiently calculate time-varying concentrations within, and emissions from, production systems (Predicala and Maghirang, 2003). This can also contribute towards reducing the virulence of airborne environmental diseases in buildings, and can enhance the current BATNEEC strategies developed by the EPA (EPA, 1996).
- Model different housing systems with alternative manure management techniques to achieve a fully integrated control of pollution (Sun et al., 2001).

From the above it is clear that CFD should be used in the livestock housing industry as a design tool to optimise housing systems by ensuring the essential environmental needs of the animal and farmer are met in all parts of a building and to reduce pollution emissions. CFD can model all environmental parameters that influence airborne pollutant release from animals to determine spatial and temporal concentrations within, and emissions from, a production system, so that pollution control strategies can be developed with great effectiveness. Furthermore, the successful use of CFD in recent animal housing simulations has highlighted its superiority in the design of naturally ventilated animal houses (Norton et al., 2007). Figure 1 illustrates the powerful flow visualisation that is proffered by CFD. Thus, the authors believe that the employment of this technique would be almost essential in a DSS, especially when tight control over the micro-climate is sought.
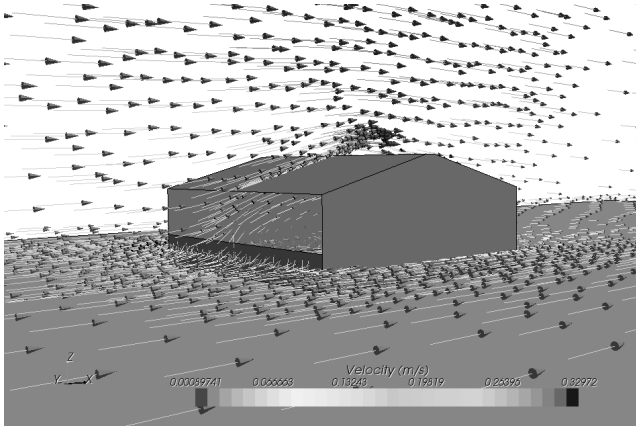
Figure 1. CFD simulation of wind flow through a naturally ventilated animal house.

Outline of the decision support system

The proposed DSS, called VENTMAN, will be based on a number of models to efficiently evaluate the ventilation choices and ultimately determine the design of the most effective ventilation system. Information will be passed among the first three components, progressing from the conceptual design stage to the optimisation stage.

The final component of the DSS will use evolutionary algorithms, a by-product of artificial intelligence, to optimise the proposed ventilation system. These correspond well to the reasoning procedures and evaluation used in the design process (Malkawi et al., 2005). As a consequence, optimization modelling techniques such as computational fluid dynamics (CFD) can be exploited. As optimization is a stage during the design process that defines a rigorous means for iteratively searching the best decisions, given a set of requirements and conditions under which these requirements must be realised, the synergetic coupling of CFD with evolutionary algorithms will greatly enhance the performance of VENTMAN.

VENTMAN consists of four main components whose functions are the following: (1) to determine the ventilation rate requirements of a species as a function of their micro-climatic needs, (2) evaluation of the ability of the local climate to provide these ventilation rates; leading to a decision between the choice of mechanical ventilation or natural ventilation, (3) prediction of opening placement for the natural ventilation system, or prediction of the type of mechanical ventilation system (+ve, –ve or neutral pressure systems) suitable for the local weather conditions, (4) optimisation of these design proposals using CFD techniques.

Ventilation rate requirement
The minimum ventilation rates requirement per head of animal under no-wind conditions will be calculated using time-dependant energy and mass balance equations, so that minimum ventilation conditions for all all-year-round can be determined. These models will provide an approximation of the suitable ventilation

rates required to maintain adequate indoor temperature, remove excess humidity, and remove excess dust and other pollutants. The heat and mass transfer rates used will be determined from parameters provided by the farmer.

Evaluation of the local climate

This component of the system will use a simplified modelling technique proposed by Facastoro and Perin (2002), which determines the suitability of a building configuration to natural ventilation in a specific locality. This tool combines a number of models that, when given a few important and readily known building parameters and information about the local outdoor climate, enable the designer to determine the most suitable ventilation system. This tool takes advantage of two non-dimensional coefficients, ξ and ζ, which allow the frequencies of effective pressure over a building (needed to maintain minimum ventilation) to be determined, based on building topography and surrounding terrain, from wind frequency data. The ultimate outcome from this component of the system is a recommendation whether mechanical or natural ventilation should employed on the farm.

Determining ventilation configuration

(a) Natural ventilation

If natural ventilation is the mode chosen from the above evaluation then openings will be sized and positioned according to the well validated models of Foster and Downs (1990), which will be coupled with the first component of the system. These computations will form good quality initialisation for the final refinement stage of the DSS.

(b) Mechanical ventilation

The knowledge base for this component will be constructed from knowledge acquired from two major sources: human experts and that obtained from previously modelled systems. The main factors to be used in this assessment are classified as: thermal comfort, humidity and pollutant removal. Quantitative models specific to the type of mechanical ventilation could be used, but these may provide insufficient information to move forward in the design process.

Refinement of ventilation techniques

For each design choice, a CFD analysis is automatically performed to evaluate the ventilation effectiveness and thermal environment of the building. This process runs iteratively until the best designs are found. The thermal requirements of the housed animal will act as driving criteria for these optimisation simulations. The criteria will include draught ratio, animal standard operating temperatures, animal critical temperatures, local mean age of air (i.e. local ventilation rates). Figure 2 shows the data flow for the DSS, and highlights the importance of the optimisation phase.
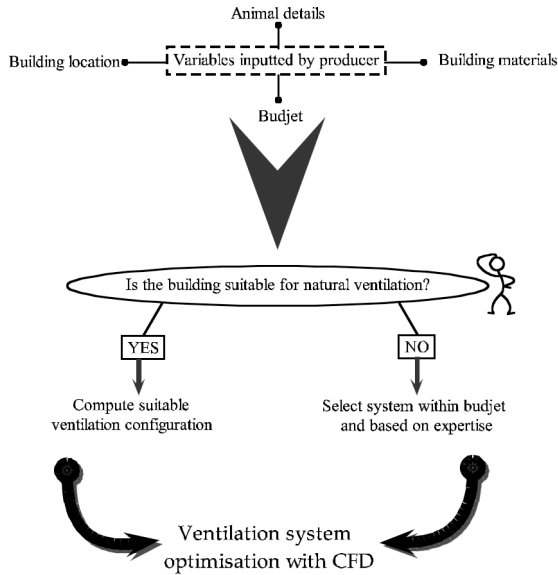
Figure 2. Data flow in VENTMAN

Conclusions

An outline of a decision support system to help farmers in the selection of ventilation systems for agricultural buildings has been presented. The system incorporates recent modelling techniques that will enhance the design process, especially when tight control over the indoor environment, ventilation rates or pollution distribution is required. The system takes into account the local terrain parameters to assess whether a sufficient pressure drop, to maintain minimum ventilation rates, can be developed over the building during all weather conditions.

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KEY DATES WITHIN REPS 3

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The Rural Environmental Protection Scheme (REPS) was initiated in Ireland in 1994 as the Irish government's response to the EU Agri-environmental Regulation (90/20788/EEC). It was designed to reward farmers for carrying out their farming activities in an environmentally friendly manner. Since its establishment over €1.8 billion has been paid to farmers under REPS.

In order for a farmer to join the REPS s/he must undertake twelve compulsory measures. Along with this they must complete two or more optional measures out of a choice of eighteen. Coupled with this there is a choice of six supplementary measures available to the farmer.

Therefore, in a typical REPS plan, a farmer must undertake a suite of measures out of a possible thirty six. Many of these measures have specific dates e.g. dates for mowing, grazing, planting. This large number of dates, which must be adhered to in order to receive REPS payments, can lead to confusion amongst the farming community and hence possible penalties for non-compliance. Figure 1 presents a Key Date Calendar for use as a decision support tool for REPS.

M9A - Green cover must be maintained up to January 15th light grazing is permitted
Measure A – Supplementary feeding of livestock (in the High Burren) is permitted for nine weeks from January 15th
M1 – FYM can be stored on land between January 16th and October 31st

No burning or cutting of growing vegetation e.g. hedgerows March 1st to August 31st
Supp. M5 – Cover crop must be maintained up to March 1st
Supp. M1 – No grazing of corncrake habitats after March 15th

Measure A – supplementary feeding of livestock must cease after April 12th

Measure A – Grazing prohibited in areas identified as winterage (High Burren) May 1st to September 30th
Supp. M 5 – Seed must be spring sown before May 31st
M1 – Apply chemical phosphorus to peat soils by May 31st

Supp. M 2 – Orchards may be mown, or grazed with sheep from June 1st onwards
M 2a – Traditional hay meadow may be cut from June 15th onwards
Measure A – Summer grazing of winterage (High Burren) permitted for a total of one week in June or July

M 2b – Species rich grassland may be topped – July 15th onwards
M 9b – Set-aside must be mown – July 15th to August 30th
M 9C – Field margins may be mown – July 15th to September 30th

Supp. M 1 – Mowing permitted (if no corncrake spotted by BWI) – August 1st onwards
Mowing permitted if corncrake spotted August 10th onwards
M 4a – Newly created habitat may be topped – August 8th onwards
Measure A – all slurry must be spread –August 31st (Burren foothills)

Supp. M 1 – Margins may be cut – September 1st onwards
M 9b – Set-aside may be grazed – September 1st to January 14th
M1 – Chemical N applications must cease by September 1st on established grassland

M 4b – Broadleaved trees should be planted – October to April
M2 – Silage effluent, slurry and dungstead applications must not take place between October 1st and January 15th

Supp. M 2 – Traditional Irish Orchards must be planted – November to March
M1 – FYM must not be spread between November 1st and January 31st
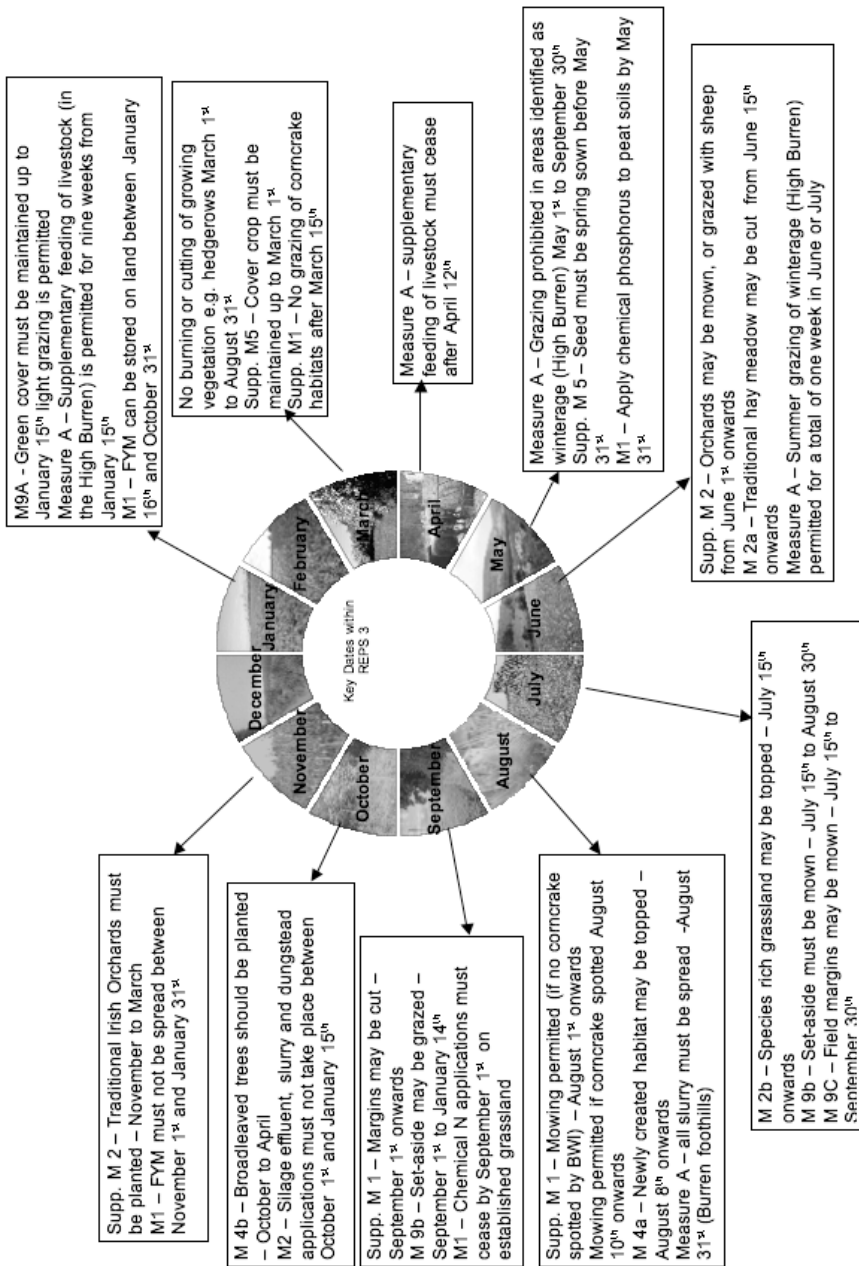
Key Dates within REPS 3

Figure 1. A Key Date Calendar for use as a decision support tool by REPS farmers.

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TOWARDS A DECISION SUPPORT SYSTEM FOR SUSTAINABLE GRAZING MANAGEMENT REGIMES – THE EFFECT OF URINE APPLICATION TIMING AND SOIL TYPE ON N LOSS TO THE ENVIRONMENT

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Abstract

Nitrogen (N) losses from grazed grassland systems to ground and surface waters have been recognised as a major environmental concern for a number of years. In grazed systems, N leaching mostly occurs from urine depositions and is influenced by soil type and grazing regime (stocking rates and timing of grazing). This emphasises the need to develop a decision support tool for optimal grazing management that guarantees reduced nitrate losses in accordance with current legislation. The effect of three soil drainage classes (poorly, medium and well-drained) that represent varying degrees of N loss risk and five timings of urine application (April, July, September, October, November, plus one unamended control and fertiliser-only treatment) were investigated in a lysimeter experiment. Nitrogen losses from the system in gaseous form, by leaching and through pasture uptake were quantified by determining total mineral N content in the drainage water, nitrous oxide emissions and the nutrient content of the herbage. As expected, urine application resulted in increased N loads in the leachate compared to the control treatments and soil type had a significant effect on N leaching with the well-drained soil being prone to higher losses. Total cumulative N content in the drainage water as well as N concentration at any one sampling date were considerably higher when urine was applied in autumn (September, October, November) (e.g. 100-400 kg N ha^{-1} yr^{-1} for the autumn treatments compared to 2.5-20 kg N ha^{-1} yr^{-1} for the control treatments) highlighting the risk of increased N leaching from autumn grazed pastures. The results obtained in this study can be used to construct a model to more accurately predict the impact of a range of grazing management regimes on N loss to the environment by leaching or in gaseous form for varying soil classes in Ireland, and to suggest more sustainable grazing management strategies.

Introduction

Excess nutrients from agricultural activities increasingly create problems for the environment and society. These include accumulation of toxic compounds in the soil (e.g. N-nitroso-compounds), eutrophication of surface waters, contamination of groundwater due to runoff and leaching of nutrients such as nitrate, which can hold acute biological and ecotoxicological dangers (e.g. formation of carcinogenic nitrosamines in humans) and contribution to ozone depletion through emission of nitrogenous gases (e.g. nitrous oxide) (Crutzen 1981). Nitrogen loss from agricultural land by leaching or in gaseous form is hence a major concern worldwide. Recently

introduced national and European water quality legislation has increased the pressure on farmers towards more sustainable management of nutrient inputs and animals.

The main sources of N in grazed grasslands are mineral fertilisers, organic matter amendments, N fixation and animal excretions. A large proportion of the N lost from grazed grassland systems originates in urine patches, which contain high concentrations of N (Jarvis and Pain 1990). The quantity and form of N lost from grassland systems is therefore mainly a result of grazing intensity (Cuttle *et al.* 1992), which affects the spatial distribution of urine patches. Other factors affecting N loss include soil type, fertiliser rate and biological activity, e.g. mineralisation rate. Soil structure and texture affect hydrological properties and thus the leaching behaviour of soils (Decau *et al.* 2003). In addition, N cycling processes are influenced by biological activity, which varies significantly across soils due to differences in soil structure and texture and throughout the year as a result of changes in temperature and soil moisture. Consequently, the amount of N lost from urine patches will differ depending on the N load deposited, the time of year urine is applied and the soil type.

In this paper, we present measurements of nutrient loss from grazed grasslands that can be used to develop a decision support system for more environmentally sustainable grazing management regimes. A lysimeter experiment was designed to assess the potential risk of N loss under different soil types and different grazing management regimes. Urine was applied to soils from three drainage classes (well, medium and poorly drained) at different times of year (spring, summer, autumn) and leachate was analysed for total mineral N content.

Materials and Methods

In 2003, 21 intact monolith lysimeters (0.8 m diameter by 1 m deep) were collected from each of three sites in Ireland, and installed in the field lysimeter facility at Johnstown Castle, Wexford according to the protocol established (Cameron *et al.* 1992). The chosen soil types represented a range of drainage classes and included a poorly drained gley (Rathangan Series), a moderately drained brown earth (Elton Series) and a well drained brown podzol (Clonakilty Series).

Each soil was subjected to seven treatments including five different timings of urine application, plus an untreated control and a fertiliser-only treatment. Each urine treated lysimeter received 310 kg N ha^{-1} in the form of urine except for the October treatment (620 kg N ha^{-1}). In addition, all lysimeters (with the exception of the untreated control) received mineral fertilisation (291 kg N ha^{-1}) as urea (app. 20%) and calcium ammonium nitrate. Treatments were applied in a randomised complete block design with three replicates per treatment (see Table 1, an example of the 2005 treatment structure). Herbage was harvested regularly corresponding to a 28-day rotation of livestock and analysed for dry matter yields and N content.

From September 2004 on, leachate was collected from the lysimeters after significant rainfall events. After establishing total leachate volume, a subsample was analysed for total mineral N (= nitrate (NO_3^-) + ammonium (NH_4^+) + nitrite (NO_2)) as well as

phosphorus and a range of cations and anions. Throughout the experiment, gas samples were taken from the lysimeters in intervals after urine application and nitrous oxide concentration in the samples was determined by gas chromatography.

Table 1. Treatment structure for lysimeter experiment in 2005.

	Treatment ID	Timing of urine application	Amount of N applied (kg ha^{-1})
1	Control	n/a	--
2	Fert only	n/a	291 (as fertiliser)
3	Urine Apr	25 April 2005	291 (as fertiliser) + 310 (as urine)
4	Urine Jul	18 July 2005	291 (as fertiliser) + 310 (as urine)
5	Urine Sep	12 September 2005	291 (as fertiliser) + 310 (as urine)
6	Urine Oct	12 October 2005	291 (as fertiliser) + 620 (as urine)
7	Urine Nov	10 November 2005	291 (as fertiliser) + 310 (as urine)

The experiment is ongoing in 2006 with treatments 1, 2, 5 and 7 (see Table 1) being maintained, while treatments 3, 4 and 6 were adjusted to address new research questions. Once the data set is complete, it will be used to construct a model to help upscale the results to farm-level (Dennis *et al*., this volume) and estimate the impact of a range of grazing situations on various soil types in Ireland. The results presented here are for the 2005 leaching season only and include data collected between May 2005 and June 2006.

Results and Discussion

N loss by leaching
Total cumulative N load (kg ha^{-1}) differed amongst treatments as a result of soil type (Table 2). Mean drainage and N loss were highest from the well-drained soil Clonakilty, followed by the medium well-drained Elton. While the ranges observed were not dissimilar for the three soils, the high variability in drainage and nutrient concentration and the relatively large standard errors observed in some cases (Figure 1) are likely a result of variations in soil structure and texture (Toor *et al*., 2005; Stark *et al*., 2006).

Table 2. Mean cumulative drainage (mm) and total mineral N (kg ha^{-1}) leached between May 2005 and June 2006. n=24 for Clonakilty (well-drained), n=23 for Rathangan (poorly-drained) and Elton (moderately drained). sem = standard error of mean.

	Drainage (mm)		Total mineral N (kg ha^{-1})	
	Mean (sem)	Range	Mean (sem)	Range
Clonakilty	671 (23.3)	423-971	153 (32.9)	1.58-512
Elton	577 (29.6)	229-827	85.3 (24.2)	0.03-448
Rathangan	434 (23.5)	225-724	47.1 (11.9)	1.35-205

Total cumulative N load (kg ha^{-1}) varied with soil type as well as timing of the urine application (Figure 1). These observations are in accordance with the general assumption that not only larger drainage volumes but also higher nutrient loads would be expected from well-drained soils (Clonakilty).
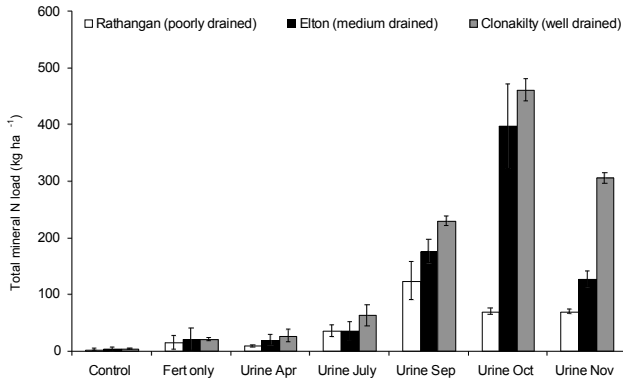
Figure 1. Mean cumulative mineral N load (kg ha^{-1}) lost from lysimeters subjected to 7 different treatments between May 2005 and June 2006. For each treatment, values are average per lysimeter and year. Bars are standard errors of means. n=3.

N loss through drainage was low from the control (3-4 kg ha^{-1}) and fertiliser-only treatments (15-20 kg ha^{-1}) on all three soils and there were no significant differences as a result of soil type. Urine application in April and July resulted in only marginally higher N leaching compared to the fertiliser only treatment. It is, however, evident that the application of urine in autumn (i.e. September, October and November, respectively) significantly increased N leaching with N loads ranging from 200 to 460 kg ha^{-1} compared to 36 to 63 kg ha^{-1} for the July treatments. N loss was particularly high in October from the medium and well-drained soils, while for Rathangan (poorly drained) the highest N loads were measured in September. This is most likely due to the lag in water movement through the soil column resulting from soil structure and texture as well as denitrification activity. Denitrification is expected to be higher under anaerobic conditions, which are more common in poorly-drained compared to well drained soils.

Assessing the mean total mineral N concentration lost from the Rathangan-lysimeters (poorly drained) for each treatment separately showed that N concentration in the leachate decreased after an initial increase (breakthrough) when urine was applied in April, July or September (Figure 2). In contrast, the October and November treated soils still showed elevated concentrations at the end of the 2005 leaching season in June 2006. This indicates that more mineral N leaching can be expected from these treatments in autumn 2006.

The experiment was designed to simulate different grazing management regimes by investigating the effect of urine patch distribution (i.e. urine vs. no-urine treatments) and timing (i.e. application of urine at different times of year) on N leaching on the three soil types. Differences in N loss as a result of soil type and urine timing indicate that in order to reduce N loss from grazed grassland systems a tailored grazing management regime is needed taking into account grazing intensity and duration and environmental factors, such as rainfall and soil type, especially at higher risk times such as autumn.
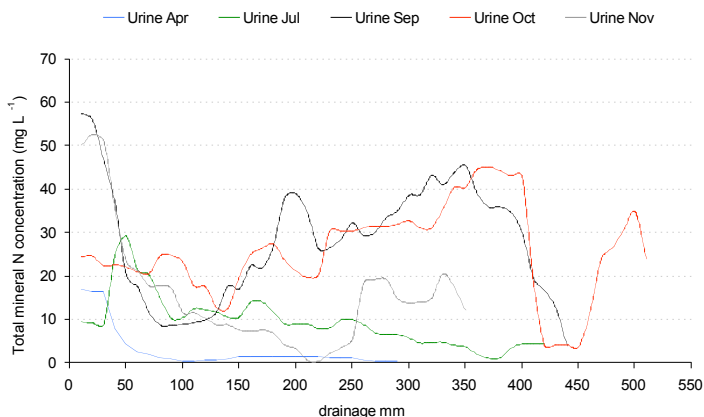
Figure 2. Mean concentration (mg L^{-1}) of total mineral N in leachate collected from urine-treated lysimeters under poorly-drained Rathangan soil between May 2005 and June 2006. n=3 for all except Urine Nov and Urine Oct: n=2 (One replicate excluded from the analysis due to large variability in drainage volume).

Gaseous emissions

With respect to gaseous emissions from the lysimeters, the results confirmed the expectation that soil type, mineral fertilisation and urine application would have significant effects on nitrous oxide losses. Higher emissions were measured from the poorly drained soil (Rathangan) and from the urine treated lysimeters compared to the lighter soils and the control treatments, respectively (data not shown).

Conclusions

The experiment presented was designed to assess N loss to the environment as leachate or in gaseous form under varying conditions (farming systems, soil types, weather). It, thus forms a foundation to determine the potential environmental impact of different grazing management regimes. Once completed, the results from the experiment will be used to construct a model that estimates N loss to the environment from a variety of conditions. Taking into account the spatial distribution of urine patches in the field will enable us to extrapolate to farm level and predict the effect of grazing management on N loss for a wide range of soil types and grazing situations in Ireland. A model will form the basis for a decision support tool that facilitates the development of more sustainable grazing management strategies.

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IMPLEMENTATION IN IRELAND OF THE CANADIAN FOREST FIRE WEATHER INDEX SYSTEM (FWI)

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Abstract

The importance of meteorological elements in the occurrence and spread of forest fires has been the subject of much research. A fire risk model developed in Ireland has been used operationally by Met Éireann for many years. This model has limitations in that the fire risk is calculated using current weather conditions and takes no account of past weather. Alternative models were investigated and the Canadian Forest Fire Weather Index System (FWI) was chosen as a suitable replacement. The Model was run using historical datasets, with the results stored in the Met Eireann database and used to develop a daily severity rating, (DSR). Since July 2006 the model has been run operationally using current weather observations. A forecast FWI for five days ahead is also produced each day using weather forecast data from computer models. The model still need to be verified before it can be used with full confidence for Irish conditions

Introduction

At present about 10% or 700,000 ha of the total land area of Ireland is afforested. The current strategic plan for forestry sets an afforestation target of 20,000 ha per annum to the year 2030. Ireland's forest fire season normally extends from February to October with a pronounced peak from March to May. On average 450 ha of forest are destroyed by fire each year, (ITGA, 2006). As approximately 1% of the land area of Ireland will be afforested every three years, assessing the risk of forest fires will become increasingly important.

The weather parameters which have most influence on fire risk are precipitation and humidity, with wind playing an important role in the spread of fires. The size of the annual fire loss depends on fire weather, ignition risk and fire control. Many countries have developed models relating fire danger to weather conditions. The Fire Probability model previously in use in Met Éireann was developed in the mid 1980s (Duffy, 1985). It calculated fire probability based on current weather observations and the past 32 hours rainfall total, however, it did not take into account weather conditions on previous days and weeks. It is accepted that fires are most frequent during dry spells and that past weather conditions are important in determining the fire risk. Following a review of available fire models, the Canadian Forest Fire Weather Index System (FWI) was chosen as a suitable replacement.

The Canadian Forest Fire Weather Index (FWI), and Daily Severity Rating (DSR) System (Van Wagner, 1987) was first developed in 1970 after several years work by a number of fire researchers in the Canadian Fire Service and has been continually

updated. The Canadian system is used in many countries around the world. A 2003 study by the United Kingdom Meteorological Office, compared four different Fire Indices and came to the following conclusion (UKMO, 2003 p 34)

"…the Canadian DSR index is therefore recommended as the most appropriate fire severity index for the types of weather conditions and vegetation common to England and Wales. Its strengths are that:
- it is good at picking out periods of greatest risk in hot, dry summers, wet summers and springtime;
- it has a strong basis of scientific evidence underpinning its development;
- it is more sensitive than other indices as it has a greater value range, highlighting both specific peaks and gradual increases in risk;
- it is able to identify fire risk from a range of different weather scenarios;
- it can be used to assess risk for different vegetation types;
- it is used successfully outside Canada."

The Canadian Forest Fire Weather Index and Daily Severity Rating Systems were implemented in Met Éireann using the original equations developed in Canada for standard fuel types.

Structure of the Canadian Fire Weather Index System
The FWI is based on the moisture content of three classes of forest fuel each at a different level in the ground, plus the effect of wind on fire behaviour. The system consists of six components, three of these are fuel moisture codes which follow daily changes in the moisture content of three classes of forest fire fuel, each with different drying rates: the Fine Fuels Moisture Code (FFMC), the Duff Moisture Code (DMC) and the Drought Code (DC). The other three are fire behaviour indices representing rate of spread, fuel weight consumed and fire intensity: the Initial Spread Index (ISI), the Build-up Index (BUI), and the Fire Weather Index (FWI) which represents fire intensity as energy output rate per unit length of fire front. It is then used to determine the Daily Severity Rating (DSR) of the fire danger (Figure 1).
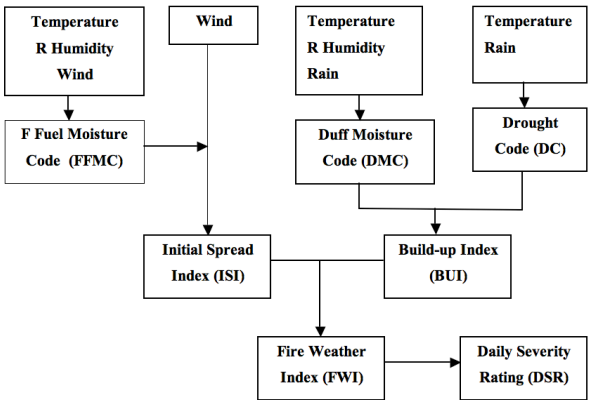

Figure 1. Block diagram of the Fire Weather Index System

The FWI model requires 12:00 UTC readings of temperature, humidity, wind speed and a 24hr 12:00-12:00 UTC rainfall total as input parameters. (UTC: Universal Time Co-ordinated, the international time standard, formerly known as GMT)

Fuel moisture codes

For each of the three fuels in the FWI system an index was developed with two phases, one for wetting by rain and one for drying. These indices, called fuel moisture codes (Table 1), are bookkeeping systems that add moisture after rain and subtract some for each day of drying. These are arranged with values rising as moisture content decreases. The three moisture codes and their corresponding fuels are:

Fine Fuels Moisture Code (FFMC). This represents the moisture content of litter and other cured fuels in a forest stand, in a layer weighing 0.25 kg m^{-2} when dry. It has a nominal depth of 1-2 cm and time lag of 2 to 3 days. (Time lag is the time taken to lose 0.66 of moisture at a temperature of 21 $^{\circ}$C and relative humidity of 45%). The potential FFMC scale length is 101, and the maximum moisture content is 250%.

Duff Moisture Code (DMC). This represents the moisture content of loosely compacted, decomposing organic matter weighing 5 kg m^{-2} when dry. It has a nominal depth of 7 cm, moisture changes more slowly with a drying time lag of 12 days. DMC rises logarithmically with decreasing actual moisture content.

Drought Code (DC). This represents a deep layer of compact organic matter weighing 25 kg m^{-2} when dry. It has a nominal depth of 18cm and a drying time lag of 52 days. Drought Code is estimated by an exponential function of the moisture content.

Each of the three fuel moisture codes has a different wetting and drying phase, the wetting is calculated from the actual rainfall, and the drying is calculated from an estimated actual evapotranspiration, for these readings of rainfall, temperature and humidity are required. Each fuel is considered to dry exponentially, so that its instantaneous drying rate is proportional to its current free moisture content. The drying phase of the surface FFMC layer is also wind dependent. On a given day wetting is assumed to occur before the drying begins.

Table 1. Summary of properties of the three moisture codes (where t is temperature, rh is relative humidity, w is wind, r is rain and mo the month)

Code	Timelag days	Water Capacity mm	Required weather parameters	Nominal Fuel Depth cm	Nominal fuel load kg/m^2
FFMC	2-3	0.6	t, rh, w, r	1.2	0.25
DMC	12	15	t, rh, r, mo	7	5
DC	52	100	t, r ,mo	18	25

Fire behaviour Indices

The three moisture codes plus wind are linked in pairs to form two intermediate indices that are in turn combined to yield the final index, the FWI. These are:

Initial Spread Index (ISI). This is a combination of wind and the FFMC that represents rate of spread alone without the influence of variable quantities of fuel. The name refers not so much to the behaviour of a fire during its early stages, but rather to the basic rate at which the fire will spread when the fine fuel is dry.

Build-up Index (BUI). This is a combination of the DMC and the DC that represents the total fuel available to the spreading fire; weighted to give the main effect from the DMC.

Fire Weather Index (FWI). This is a combination of the ISI and the BUI that represents the intensity of the spreading fire as energy output rate per unit length of the fire front.

The FWI doubles for every increase of 19 km h^{-1} in wind speed, because of the influence on the ISI. The FWI scale is open at the top, which is in keeping with its concept as a function of frontal fire intensity, and not as a percentage or fraction of some imagined worst possible state. As a result, no matter how high the FWI might rise, it can rise still higher if the fire weather becomes more severe.

Daily Severity Rating
An additional component of the FWI system is the Daily Severity Rating (DSR). Severity ratings were conceived to provide a measure of control difficulty in terms of the fire danger index. The DSR is computed directly from the FWI with the effect of weighting the FWI as it rises, in a manner deemed to reflect control difficulty in more direct proportion. The DSR averaged for a whole fire season is termed the Seasonal Severity Rating (SSR), which can be used as an objective measure of fire weather from season to season, or fire climate from region to region.

Danger Classes
It is customary in fire danger rating to quote a danger class, derived from the FWI, ranging from low to extreme as well as or in place of an index number, especially for the general public. This allows for the FWI system to be used to fit a regionalised pattern of fire weather as classes can be defined to suit local conditions.

Danger class rating had to be adapted for Irish conditions. The following method is suggested by the Canadian Fire Service for developing a rational class breakdown (Van Wagner, 1970, p 29). First, compile a historical database of Indices, FWI and DSR. Second, decide how many extreme days should be allowed each season on average, and set the lower limit of the Extreme class. Third, arrange the other classes on a geometric progression in terms of the FWI.

Application of the Canadian FWI

Model runs 1971-2005
The model was run (using source code for the FWI provided free of charge by the Canadian Fire Weather Service) from 1st January 1971 to 31st December 2005 using

quality controlled input data from 14 Met Éireann synoptic weather stations. The six indices, FWI and DSR were calculated for each day and written to a database. Standard default values of FFMC, DMC and DC were used as the initial conditions on the first day of the model run, subsequently the previous day's value of the FFMC, DMC and DC are used as initial conditions. Having created a 35 year database of indices, FWI, and DSR it was possible to develop a Danger Class Rating (Table 2). A five level Danger Class Rating, very low, low, medium, high and extreme was adopted. Following the methodology suggested by the Canadian developers 2% of days in each season were allocated to the extreme class. This revealed that the threshold value of FWI for extreme Fire Danger Rating was different in summer than winter. The FWI value of 18 was calculated as the threshold for extreme values in the summer fire season, 8th May to 21st September. The FWI value of 10 was calculated as the threshold for extreme values in late autumn, winter and early spring. For the 'shoulder' months 1st April to 7th May, and 22nd September to 1st November, the bands are calculated by linear interpolation of the DSR scales. The thresholds for the different ratings are calculated from the FWI values on a geometric progression.

Table 2. Danger Class Ratings for Summer season 8th May to 21st September and corresponding Fire Weather Index (FWI) and Daily Severity Rating (DSR) ranges. These Danger Class Ratings correspond to different FWI and DSR ranges for the rest of the year (cf. text).

Danger Class	Lower FWI	DSR range
5 Extreme	18.0	>4.5
4 Very High	9.6	1.5 to 4.5
3 Moderate	4.7	0.4 to1.5
2 Low	1.6	0.06 to 0.4
1 Very Low	0	0 to 0.06

Use of indices at Met Éireann (FWI, DSR, and Danger Class Rating)

Daily Operational Model Run using current data
For operational calculations input parameter values are extracted directly from the observations from the Met Éireann synoptic weather stations before these data have been quality controlled. The six indices, DSR, and Danger Class are calculated each day at approx 12:50 UTC, as soon as the observations are available, and the outputs are written to the database (Table 3). In addition, a html file is created with a table showing the calculated Danger Classes for the past five days. This is automatically emailed to interested parties at approx 13:05 UTC. At the end of each month the model is rerun for the past three months using quality controlled data and the results written to the database, overwriting any results obtained with non-quality controlled data.

Forecast Model runs
The model is also run each day using forecast data from Numerical Weather Prediction (NWP) model of the European Centre for Medium Range Weather Forecasts (ECMWF). These data are available at a 25 km resolution, and the input parameters are interpolated to the synoptic weather station locations. The model is run

for five days ahead at approx 12:55 UTC each day using current values of FFMC, DMC and DC as initial conditions. The outputs are written to the database. In addition, a html file is created with a table showing the calculated Danger Classes for the next five days. This is automatically emailed to interested parties at approx 13:05 UTC.

Table 3. Sample model output for selected stations (station is the synoptic weather station number , class 1 is very low; 2 low; 3 moderate; 4 high; 5 extreme)

date	station	ffmc	dmc	dc	bui	isi	fwi	dsr	class
30-Jun-06	953	57.4	6.6	137.3	11.8	0.7	0.5	0.01	1
30-Jun-06	962	69.1	25.8	220.5	39.9	1.3	3.1	0.2	2
30-Jun-06	969	50.3	19.2	205.2	31.2	0.4	0.4	0.01	1
30-Jun-06	980	56.7	4.4	139.1	8.2	0.8	0.4	0.01	1
30-Jun-06	976	73.1	10.7	184.1	18.6	5.6	8.5	1.19	3
30-Jun-06	974	79.4	20.9	193.7	32.9	2.2	5	0.46	3

Significance of using a combination of indices
As the FWI combines so many effects, the same index value can be reached by many different weather combinations and histories. Therefore, it is difficult for one figure to represent the fire danger, and hence the other components of the FWI system are needed for full interpretation of the fire weather. The system can be pictured as a pyramid with the FWI at the top, and successively more components at each lower level:

First level: The FWI, DSR or Danger class alone, with all effects combined as well as possible in a single output.
Second Level: The ISI and BUI quoted separately, providing direct information on both spread and fuel consumption.
Third Level. The FFMC, DMC, DC, and wind speed, all quoted separately, indicating the respective influences of surface dryness and wind on potential spread rate, and of medium and long term dryness on potential fuel consumption.

Discussion and Conclusions

The Canadian Forest Fire Weather Index System (FWI) has been successfully implemented in Met Éireann. However, due to the difficulty in obtaining detailed quality data on occurrence and location of forest fires in Ireland, it has not been possible to perform any detailed verification on the model outputs and assessment of the utility of the system for forest managers. Even though the FWI is an improvement on the previously used model by Met Éireann it still has limitations. The only variables within the system are weather parameters, and it does not take into account the seasonal variation in fuel types or amounts, or differences in local geography and topology. These factors may contribute to the actual fire danger at any given location.

References

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Appendix 1. Questions asked of participants during the Workshop

Questions asked about the user:

1. How would you describe your main professional activity?
Farmer   Farm advisor   Researcher   Other

2. Are you using a computer for your professional activities?
Frequently   Rarely   Never

3. If you have a computer: what is the operating system you are using?
Windows   MacOS   Other   Don't know

4. Are you using the internet?   Yes   No
    If yes, do you have Broadband access?   Yes   No

5. Are you using a mobile phone?   Yes   No
    If yes, do you use text messaging?   Yes   No

6. I had heard about Decision Support Systems, *before* I heard about   Yes   No
this workshop
7. This workshop made me curious about Decision Support Systems: Yes   No

The questions asked about each decision support system:

1. How much help did you need to be able to use the system?
a) no help   b) some help – just short introduction   c) sustained help during the whole session, but would be able to use this system on my own now d) would not be able to use this system on my own

2. The system looked attractive and made me curious about its contents
(5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree)

3. The decision support system contained valuable information
(5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree)

4. It was easy to find the answer to the question set at the workshop
(5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree)

5. It was easy to understand what information the system was using to give advice
(5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree)

6. It was easy to find out how accurate the model prediction was.
(5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree)

7. Any comments about the system?

Questions asked about the future use of decision support systems:

1. In what area of your farming operations do you need more expert advice?
Tick all that apply

Crop systems	Grazing systems	Accounting	Marketing
Slurry spreading	Pest management	Disease management	Forestry
Drainage	Fire management	Nutrient management	Erosion
Natural diversity management		Agricultural policy and legislation	

2. Would you consider using decision support systems to help with your farming operations?
Circle one:
   a) Yes
   b) Yes, depending on the ease of use
   c) I would be curious to learn about systems, but am unlikely to use them
      on day-to-day basis
   d) I have no interest in computers, but would consider using decision support if it were
      delivered over the phone
   e) No

3. How reliable do you think decision support systems are?
   a) Very reliable – will always follow advice
   b) Somewhat reliable – will mostly follow advice
   c) I think my experience of farming is better e than any
      decision support system, but would still use them for information
   d) I think they are unreliable: I would not use them

4. To what level of detail would you like to know how the decision support system works?
   a) Great detail: I want to see a diagram of the model and all the equations in it
   b) Some detail: I want to know the basic processes incorporated in the model
   c) General information: I just want to know when the model is applicable and the level of
      confidence of the predictions.
   d) I don't care what is behind the model, I just want to know an answer.

Any comments? (*use back of page if necessary*)

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Scientific knowledge in combination with data collected on a national scale, such as weather and land-use data, can assist farmers in making decisions to attain sustainable production. Increasingly it will become feasible to deliver this information in real-time and with location specificity to farmers and advisors using Information and Communications Technology (ICT). Decision support systems (DSS) are currently being developed to avail of modern ICT. AGMET organized this workshop to allow Irish DSS developers to learn from progress in other countries, and for potential users to experience the breadth of possibilities of DSS in agriculture. The workshop was interactive to encourage communication between participants. This volume contains papers from invited speakers, from the Irish agrometeorological research community and a summary of the workshop findings.