The Development of an Integrated Modelling System to Support Decisions on Organic Farms

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Abstract: An Integrated Decision Support System (IDSS) is developed which synthesises current understanding of organic farming by means of GIS, biophysical models and socio-economic models. A multiple objective framework incorporates the farming goals. The IDSS uses a multi-tiered concept of a farming system being a collection of micro-enterprises at the field level, which have individual resource endowments, objectives and activities. Farm level objectives, activities and constraints control the collective field-level micro-enterprises. Policy levers feed in at the farm level to influence overall farm planning. These effects trickle down to affect the micro-level field enterprise selection. Where historical records are lacking or require supplementation, biophysical models can be used to infer the normal expectations and variability for a crop on a particular soil with particular environmental characteristics and outside inputs. User-friendly interfaces allow for the examination of the data and the underlying models and assumptions. Part of this interface includes a GIS, which is used to organise data for input to the MP and to display output. A prototype of the IDSS framework is presented. The IDSS is being developed as a part of the Scottish Agricultural College (SAC) organic research programme.

Keywords: Integrated modelling, GIS, Socio-economics, Farming systems, Organic farming

1 INTRODUCTION

This paper describes a decision support system for organic farming. In the first section, the development of organic farming is described, together with issues in defining the sustainability of such systems. Requirements of the target user group are then outlined and, in the following section, a blueprint for a fully functioning IDSS is outlined. In the third section, a prototype of this model is described and finally conclusions are drawn about the feasibility of the modelling approach.

1.1 Organic Farming

Organic food is fast becoming the most lucrative market in the UK [Which?, 2001]. All major food retailers are increasing their range of organic products at an unprecedented rate. This growth in demand is not currently being met by domestic production and around 70% of all organic products consumed in the UK are imported. However, the number of farmers seeking organic accreditation is increasing. In the European Union, organic farming continues to grow annually at an average of 25%, with more than 93,000 farms and 2.2 million hectares either certified as organic or in the conversion process. [Lampkin and Measures, 1999]. In terms of decision support, there is a need to assist conventional farms who wish to convert to organic production, as well as the organic farms that are already operating.

Organic farming is founded on a set of principles which form the basis for the certification criteria [Soil Association, 2001]. Across the EU organic production is covered by an EU Regulation (2092/91), which lays down strict certification criteria covering the environment, socio-economics, and animal welfare. UK farmers can benefit from an Organic Farming Scheme, which is a support payment across the 5 years of conversion.

Trewavas [2001] identifies two main principles that distinguish organic farming from other agricultural systems. Inorganic mineral inputs are prohibited and synthetic herbicides and pesticides are rejected in favour of natural pesticides. He argues that agriculture based on these principles results in a more costly product mainly because of lower yields and inefficient use of land. Additionally, although organic agriculture is generally a form of sustainable agriculture it can also have negative environmental effects [Rigby and Caceres, 2001]

Nonetheless, contrary to popular belief organic farming is far from being merely the cessation of agrochemical use. It is an entirely different system of production based on a distinct set of ethical, biological, financial and social objectives. Organic agriculture demands a deep and intuitive understanding of processes in nature [Niggli, 1999]. One of the key objectives of an organic system is to internalise as much of the nutrient and energy flows such that little is lost. Resources, which are removed from the system, are maintained by understanding how biological systems replenish capital stocks. Crops are rotated to allow for nutrient build-up and to minimise the spread of disease and weeds. Many organic farms tend to be mixed, cultivating crops and keeping livestock, so that land is left as pasture as part of the rotation system.

1.2 Sustainability

There is an emerging debate about the sustainability of organic farming systems. Some have argued, for example, that organic farming and sustainable agriculture are synonymous. Others regard them as separate concepts that should not be equated [Rigby and Caceres, 2001].

The definition of sustainability has been widely discussed in the literature. Yet, definitions of sustainability have failed to satisfy either the conceptual or operational purposes of both of the environmental and socio-economic sciences through a lack of appropriate analytical frameworks [Kruseman et al., 1996]. Part of the difficulty in assessing sustainability is that appropriate scales for measurement differ both within and across the commonly identified economic and biophysical dimensions [Rigby and Caceres, 2001]. Agricultural systems are dynamic and thus are in a constant state of change whereby current events will affect their performance both financially and biologically in the future [Sharifi and Van Keulen, 1994].

The prerequisite for predicting sustainability is to select a scale at which such predictions will be made [McRoberts et al., 2000]. It has been suggested that the impact of organic farming should be assessed under seven headings - ecosystem, soil, ground and surface water, climate and air, farm input and output, animal health and welfare, and quality of food produced [Rigby and Caceres, 2001]. For the purposes of this paper, sustainability can be defined as an enterprise's ability to continue into the future [Hansen and Jones, 1996].

1.3 User Requirements

The development of rational answers to decision making problems requires accurate information [Sharifi and Van Keulen, 1994]. The issue of what motivates people to adopt organic techniques must be carefully considered. While many adopting organic practices are doing so for ethical reasons, price premiums for organic goods cannot be ignored [Rigby and Caceres, 2001]. Farming places multiple and often conflicting demands upon natural resource use. In order to resolve these demands it is important that the decision maker has a variety of tools at his disposal [Sharifi and Van Keulen, 1994]. To develop these tools, we not only need a clear understanding of the biophysical system but also how that biophysical system links to the market [Sharifi and Van Keulen, 1994].

Key questions have been developed through focus groups with extension experts and organic farming researchers at SAC. These include:

- What is the optimal level of organic conversion support payments?
- How sustainable are organic systems in terms of accepted indicators?
- Will organic farming remain a sustainable option after conversion support has finished?
- How are organic rotations designed to best optimise the nutrient building phase?

Thus, target users are not only organic farmers themselves, but also policy-makers and those non-organic farmers considering conversion.

Farm modelling can support such decisions by providing an effective complement to research work [ten Berge et al., 2000]. This is because:

- Only a few selected farm prototypes can be tested experimentally in the field.
- Models allow better specification of the trade-off between different objectives and goals.
- Commercial farms are not suitable test sites for evaluating risky new ideas and techniques.
- External conditions may change rapidly and can have profound impacts on the feasibility of field trials.
- Experimental prototypes are developed in a particular physical environment – the models can be used to extrapolate across space and time.

There are many examples of component models covering soil nutrient flows, biophysical growth of crops, and weed-crop interactions. These models predict how the system might react in the future. However, such knowledge is not always helpful in answering the problems of rational allocation of scarce resources. To do this, resources need to be optimised across the whole planning horizon. It can be seen that optimisation techniques provide a very powerful tool for dealing with these problems across multiple time periods [Gupta et al., 2000]. With organic farming such long-term planning is paramount. For example, the application of manure in one season may have positive benefits to the crops in future seasons and it may impact on the environment. Integrated models can provide support for this dynamic planning horizon.

2 DEVELOPING AN INTEGRATED MODELLING SYSTEMS FRAMEWORK

The IDSS will synthesise current understanding by means of GIS, biophysical models and socio-economic models (Figure 1). The IDSS will be based on a multi-tiered concept of a farming system being a collection of micro-enterprises at the field level, which have individual resource endowments, objectives and activities. Farm level objectives, activities and constraints will control the collective field-level micro-enterprises. Policy levers will feed in at the farm level to influence overall farm planning.

2.1 Linking Modelling Paradigms

In this context, a way of supporting decision making on organic farms is through Mathematical Programming (MP). MP also provides quantitative analysis on how best to deploy the resources of the decision-maker, given that the system is bounded by the constraints and driven by an objective. MP is particularly appropriate for organic farming since such enterprises maximise profits whilst meeting sustainability constraints such as maximising soil fertility and/or minimising external inputs. Such an approach uses multiple, often conflicting objectives, rather than the concept of a single objective.

Where historical records are lacking or require supplementation, biophysical models of crop growth, response to inputs and yields can be used to infer the normal expectations and variability for a crop at a particular location (Figure 1). GIS has been successfully used in conjunction with MP and biophysical models to manage input data and to visualise the solutions produced. Its use at the farming system level has largely been restricted to decision support for large-scale arable farms.

At the most basic level, GIS and models can be coupled through the use of a shared database. Both the model and GIS have the ability to query the database for information, and store results in the database. This form of system usually relies on a large amount of 'user input' to generate and analyse the possible queries and model runs.

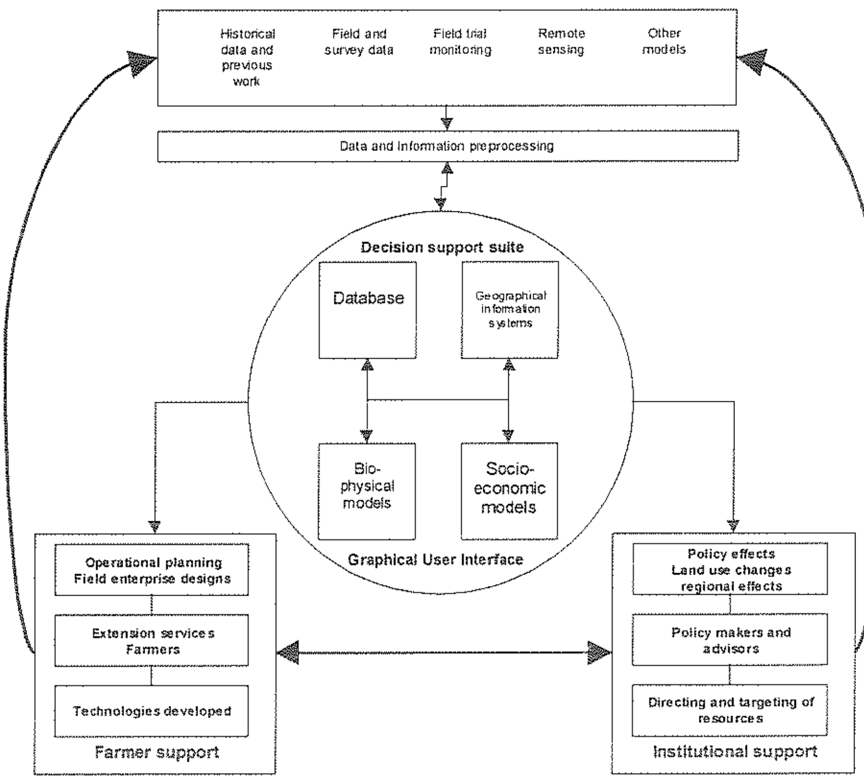

Figure 1. Framework for integrated decision support and monitoring systems (in part based on Fedra, 1996).

The GIS is used to manage all of the geo-referenced information relating to the farm and to visualise the output from the models. Previous attempts to use MP software with GIS have generally involved so-called "loose coupling" [Stoorvogel, 1995]. In a "loosely coupled" configuration, GIS software is interfaced with other packages simply by exchanging data using a common file format. The common file format is used to move data between the GIS and the MP software, but no attempt is made to present the user with a single, unified menu system that gives access to both GIS and MP functions.

Recent development of technologies has simplified the process of linking GIS to other software packages. It is now possible to use "deep coupling" approaches [Fedra, 1996], in which all functions can be accessed from a single integrated menu system. This form of user-interface allows for the examination of the data, underlying models and assumptions, and allows the more feasible pre-planning of environmental and human impacts (Figure 1).

3 PROTOTYPE MODEL

3.1 Description of Case Study Farm

The case study farm is a mixed lowland arable unit producing cereals, roots and vegetables, beef and sheep. This farm is one of several research sites currently being studied by SAC through their Organic Farming Centre. The farm comprises an area of just less than 60 hectares of which two thirds is arable land with one third being permanent pasture. From an analysis of soil data, it appears that permanent grazing is situated in an area of poorly drained alluvial soils near to the river, which forms the southern boundary. Annual rainfall at the farm is on average 730mm. Conversion to organic began in 1989 with full organic status being achieved in 1992. The farm follows a six-year rotation with three years of grass ley, one cereal, one roots and vegetable and one undersown cereal. Nutrient cycling is internalised on-farm through the finishing of suckled calves (approximately 50 per year) and a flock of 200 ewe hoggets reared for sale as gimmers[1].

3.2 Data

Input data for the model is derived from three sources: a GIS database, farm management records, and farm management handbooks [Lampkin and Measures, 1999; Chadwick, 1998] and other organic farming literature. Data held within the GIS included information on soil types and the areas of individual fields. Detailed 1:2,500 scale Land-Line digital map layers were obtained from the national mapping agency, the Ordnance Survey. This data set includes surface drainage, roads, buildings, and field boundaries as well as many other cartographic features. As no spatially referenced soils information was held on the farm, soils data were derived from a 1:50,000-scale map, part of a series covering most arable areas of Scotland [Soil Survey of Scotland, 1984]. Farm management data included a historical record of field level inputs and outputs for the years from 1989 to present.

3.3 Construction of Linear Programming (LP) Model

LP is the most basic of the MP techniques described previously. The LP model has been constructed to analyse the enterprise mix of the case study farm within the context of the whole farm system and prevailing constraints. The model has a profit maximising objective set within the constraints of the need for a crop rotation, which is modelled on the rotation used in the farm data. Livestock enterprises are incorporated, capturing the necessity of livestock in the recycling of nutrients. There are two types of activities in the model: those that take place at farm level (e.g. the hiring of labour) and those that take place at sub-farm level (e.g. cultivation). For the purposes of the prototype, sub-farm units consist of 3 blocks of fields, each having similar soil characteristics and historical land use records. Thus, it is the sub-farm level activities that use data from the GIS as inputs. Input data for farm-level activities are derived from sources such as farm management records and farm handbook figures for prices of agricultural produce.

Constraints comprise standard physical constraints of land and labour needs of each activity. Land constraints include restrictions on the stocking densities of livestock on the farm. Labour constraints have been relaxed by allowing the hiring of additional labour to the farmer's own working time. Yields have been estimated within the LP based on the historical, field-level management records. Resources are passed from supply activity to sale or demand activities. At present the model represents a single year and rotation is handled by restricting the proportion of land given over to any one crop. However, future developments would include the extension to multiple year models to capture more fully the need for crop rotations.

[1] A female sheep typically 14-27 months old

3.4 Linking of LP Model to GIS

The GIS fulfils two roles: firstly, it is used to manage and integrate all of the geo-referenced information relating to the farm; and secondly, it is used to visualise the output from the LP model. In this study, the MapInfo GIS system is controlled from within MS-Excel, embedded within a Visual Basic for Applications program. The field identifier codes for the FIS map layer are used to link LP output to boundaries stored in MapInfo and output can be transferred between Excel and MapInfo via data-tables.

3.5 Results

LP results are prescriptive rather than predictive, since they indicate the optimal mix of activities given a set of constraints and an objective. Thus, the activity mix predicted by an LP model does not necessarily accord with the actual activity mix adopted on a given farm. Tables 1 shows LP model output with and without variable quality arable land. In the first case, the farm was simply divided into permanent pasture and arable land; in the second case, permanent pasture was retained and arable land was further divided into high and low yielding areas. In both cases, overall profitability per hectare is similar to that for a representative organic farm (624-632 £/ha compared to 753 £/ha for a representative farm). Introducing variable quality arable land into the model therefore had little impact on overall farm profitability. Both model scenarios suggested that the optimal stocking of sheep is somewhat greater than current levels on the farm and the optimal number of cattle lower. When variable quality arable land was introduced based on historical yield variation between fields, the model suggested that better land should be planted with vegetables initially.

4 DISCUSSION

This simple case study indicates three potential areas of difficulty in constructing a GIS-LP decision support tool for organic farming: technical feasibility, data availability, and current scientific understanding of organic techniques.

4.1 Technical Feasibility

These preliminary results suggest that the provision of low-cost LP-GIS software to organic farmers and their advisors is feasible. Many UK farmers already have home computers to assist in farm management and the proposed system architecture could be incorporated into the popular MS-Office suite of software, thereby making software costs relatively cheap.

4.2 Geo-spatial and Other Data

The advantage of an IDSS over a more conventional whole-farm LP model lies in its ability to handle variability across space. However, absence of detailed soils data is an important geo-spatial data constraint. Field boundaries are available for all farms in Scotland through the Field Information System. These data can be combined with Land-Line data depicting drainage, boundaries, building, roads, and other infrastructure, thereby improving cartographic display. The geo-spatial data used by the model would need to be pre-processed. This would mean importing necessary map layers, identifying homogenous blocks of fields, and standardising the structure of attribute data. Other non-spatial data important for modelling decision-making is becoming increasingly easy to obtain. Aside from farm records, key parameters such as farm-gate prices for crops and livestock products are now published more regularly.

4.3 Current Scientific Understanding of System Linkages in Organic Farming

The main benefit of a GIS-LP model is through improved handling of crop-soil interactions, but this feasibility study suggests that many aspects of crop-soil interactions on organic farms are poorly understood at present.

Table 1: Farm-level LP model output compared to actual case study farm records

Farm Information	Actual farm data	Without variable quality arable land (2 land classes)	With variable quality arable land (3 land classes)
Farm Size (ha)	57	57	57
Margin (£/farm ha)	753[1]	632	624.2
Sheep (head/farm ha)	3.51	5.23	5.19
Cattle (head/farm ha)	0.79	0.10	0.10
Hired labour (hours/ farm ha)	Not known (labour not accounted for)	20.3	19.77

([1]Margins are for a representative organic farm as described in Lampkins and Measures, 1999)

Shafari and Van Keulen [1994] were able to model the impact of climate and soil on yields within their GIS-LP for conventional farm enterprises and carry out some limited validation of predicted yields. However, in an organic farming context, far fewer studies of soil-yield relationships are available.

5 CONCLUSIONS

Many enhancements would need to be made to the prototype model presented here before it could be deployed as a decision support tool. In this scoping model, historical farm records were used to estimate yields. This restricted the crops that were modelled to those already cultivated on the case study farm. Such yield records would not be available on a conventional farm wishing to convert to organic production and even on existing organic farms, historical records would only be available for some crops.

In a fully functional model, a temporal dimension would also need to be introduced into the LP to represent all 6 years in the rotation cycle. Much could also be gained by explicitly modelling soil nutrients. In addition, the modelling of farmyard manure and lime application could be undertaken at field level, rather than farm level as in the present model.

A collection of constraints to test sustainability should be introduced. These will be based on the accepted set of sustainability indicators and measurable at the field level. For each indicator, aspiration levels can be set which drive the farm towards "sustainability". Additionally, once explicitly represented, trade-offs between the various criteria can be carried out within a systematic framework.

As well as sustainability criteria, constraints, which explicitly represent the EU Regulation criteria for organic farming, can be introduced and if properly constructed, a temporal modelling system will be able to map conversion from conventional to organic.

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