Using Information Technology to improve crop management

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Abstract

The greatest improvement of efficiency in northern European cropping systems, can be found in the sensible use of Information Technology, to help manage three forms of arable variability: Spatial variability, temporal variability and a third class called predictive variability.

The many crop, soil and yield maps that now exist across farms throughout Europe have quantified spatial variability. Temporal variability are the changes over time and predictive variability is where a manager must try to predict what the following year will bring and make plans to deal with it. The main factor that affects the temporal and predictive variabilities is the weather. Many existing tools and techniques help the manager to make sense of all this extra, complex data, but there is little awareness of how to incorporate weather data into the management process. As this is the largest perturbation, it should have a higher priority than it does at present.

Introduction

There is a general consistency in the methods of arable farming in the British Isles, especially regarding the production of major crops such as cereals, oil seeds, pulses and root crops. Most farmers tend to follow recommended practices regarding field operations and input levels, with relatively minor modifications to suit local conditions especially soils and climate. The conventional production system is a relatively high input: high output system, whereby mechanized field operations, hybrid varieties, and chemical additives and controls are used in combinations which, subject to the uncertainty of weather conditions, achieve reasonably consistent yield performance year to year.

Relative to other business activities, the manager of a farm contends not only with the risks of the market place, but also with the uncertainties of the production system, given its reliance on natural and biological processes. There are a large number of external, non-controllable factors, which influence the technical and economic performance of the farm system, such as prevailing weather conditions or the incidence of pests and diseases. Decisions on cropping practices are required "up-front" without full knowledge of future events and resultant outcomes. Furthermore, the response of the system to actions taken cannot be predicted for sure, and decisions made at one point in the production cycle have considerable, albeit uncertain, influences on later outcomes and decisions.

In this context farmers tend to be risk averters, adopting risk minimizing or satisfying strategies which have a reasonable chance of reliable performance across the range of possible eventualities. This is evident in practice. Farmers tend to concentrate on crops for which markets and prices are relatively stable or guaranteed. They may negotiate contracts to supply against agreed forward prices. They may also adopt methods of production such as chemical application levels, which are likely to achieve minimum acceptable, rather than maximum value-added, especially when the latter runs the risk of failure.

Conventional farming practices have evolved from a combination of experience and scientific knowledge. They are modified according to local circumstances such as soils and climate, but for the most part represent prescriptions for achieving the financial sustainability of the arable farm business. High yields and output are perceived to be the key to success. This is best achieved by relatively high variable inputs such as chemicals, which give relatively average returns per unit applied (even though in many years or in many parts of the farm, marginal returns may be low or negligible). In this respect, an element of the expenditure in the conventional package is an insurance premium, which accommodates the lack of knowledge about the future or the inherent variability of the production system. For instance, in many years the capacity of the machinery inventory or the level of pesticide application may be greater than necessary. In any one year the variation in crop condition or soil type across the farm may not warrant uniform treatment. In an uncertain business environment, however, over capacity or blanket prescriptions are often preferred to taking risks, even though, over a period of years, lower cost, risky strategies may give better average financial returns. Furthermore, the conventional package reduces the demands on farm management expertise. Risky systems are much more difficult to manage. Conventional methods economize on management skill.

Alternative farming strategies, such as low input: low output, extensification, and integrated crop management systems have been tried and indeed promoted as financially attractive options. The results from such trials show that outputs can be similar to, and inputs significantly lower, than conventional systems.

However, such analysis misses the point. For the majority of farmers, these options are not attractive for widespread adoption because they are inherently much more risky and troublesome than the conventional package. The conventional system is a surer bet.

Potential Contribution of IT to Farm Management

In the context of farm management, IT involves the use of digital information and control systems which acquire and use information to reduce risk, improve the efficiency of decision making, and assist with the implementation and evaluation of improved business management strategies.

IT improves the knowledge base and increases the ability to control the production system in order to reduce risk and uncertainty, better identify the extent of variation in the system and thereby formulate strategies which explicitly address this variation, and supports the processes to implement these strategies. In this respect IT is essentially concerned with risk management.

From a management viewpoint, IT can be classified into two broad categories:

1. Information management and decision support:
    - Methods for the collection, assembly, logging and retrieval of data
    - Methods for data analysis, interpretation and decision making
2. Implementation: monitoring and control systems

Current trends

Since the early 1980s, there has been increasing concern that agricultural practice has caused damage to 'the environment', in a range of ways. These include:

- Possible deleterious effects on the farmland ecosystem itself, which may reduce the sustainability of agricultural practice
- Reductions or changes in desirable non-farmed habitats within rural areas,
- Direct effects on human health
- Social effects, such as the non-renewable-resource costs of current agricultural practice, unpopular changes in landscape appearance, in rural employment and social structure.

Predicting the effects of changes in management which are likely to arise from the adoption of a 'high information' strategy is only possible in very general terms, although some attempts at quantification of new strategies have been made in the USA [Pimentel et al 1993]. Most of the research to date has concentrated on quantifying the effects of historic changes in practice, which, until at least the mid 1980s, usually involved increasing use of fertilizers, biologically active inputs, and capital. It would not be appropriate simply to assume that the results of a reduction in inputs would be the exact reverse of the effects of increasing inputs. There are now limited data from experiments which deliberately look at such reductions [Greig Smith et al 1993, Game Conservancy 1992, 1993, Jordan 1993, Ogilvy 1993, LEAF, 1993] but these are insufficient to provide quantitative estimates of effects on a wide scale. Data from organic farming systems are more widely available [Lampkin, 1992], but represent an extreme form of management that is unlikely to be reflected in majority practice. Similarly, data from the initial years of set aside [Clarke, 1992] may not provide a reliable basis for estimating the effects of selective reductions in use of inputs within active husbandry systems.

A basic comparison will be made between 'conventional' and a 'high information' strategy, which assumes that much more detailed management information is available, so that 'what-if' investigations can be made readily. Within such a system, the final decisions made will vary, depending on the values of the decision maker [Fishbein and Ajzen, 1975, Hochman et al 1994], but the opportunity will exist to take into account environmental as well as economic management variables. The weighting put on environmental variables will depend on the decision maker, and may well range from zero to relatively high rankings, [Carr & Tait 1991, Jordan, 1993, LEAF, 1993], so the actual implementation arising from a 'high information' strategy will also vary. However, it is assumed that in general, the total use of biologically active inputs will be reduced in the 'high information' strategy.

In the arable and grassland context, traditional managers have tried to treat fields uniformly. All the field operations have been managed to produce an even distribution, even though it is known that the conditions may vary across the field. High or low yielding areas may have been identified but only on the small traditional farms was there the capability to treat selectively. On the bigger farms the technology for varying the treatments has not been available.

In recent years the problem has become worse as arable fields have increased in size due to economies of scale that were gained from the mechanization sector. Mechanization is no longer the limiting factor to efficient production but has now become the arable inputs such as seed, fertilizer, sprays, etc. From initial studies in Europe and the USA it has been found that there are significant potential benefits from selective treatment, in both the economic and environmental senses.

If the spatial variability of the land and crops are investigated, then the potential savings become apparent. The higher the variability, the higher the potential savings.

The future situation

The long term trend facing farming in Northern Europe is that of a continuing deterioration in the terms of trade whereby the prices of agricultural outputs fall relative to those of inputs. The response by farmers in the past has been a mixture of intensification and amalgamation, protecting incomes by yield improvement through high use of variable inputs such as fertilizer, and economizing on fixed inputs such as labour and machinery by enlarging the scale of operation. Given the financial pressures on farmers, improved farm business management, supported by IT, becomes a more critical factor in ensuring financial survival.

More recently, farmers have found it beneficial to target their output to the changing needs of the food market, especially regarding quality and supply assurance. The liberalization of agricultural production and marketing will hasten this process. These changes will further encourage the use of IT as part of a sophisticated production and marketing system.

Pressures to protect incomes is likely to encourage the use of IT as a means of achieving more economic use of inputs as well as enabling production and marketing activities which increase the "added-value" at farm level. The use of IT, particularly for business management, is likely to become an integral part of commercial farming systems and a pre-requisite for successful management. To this extent, IT will encourage its own diffusion amongst farmers. Those who do not use it will be disadvantaged.

In addition to economic pressure, there are likely to be greater constraints on land use and farming practice in order to meet environmental criteria. These constraints are emerging in the form of policy initiatives such as the Nitrogen and Environmental Sensitive Area Schemes and the EU Nitrification Directive. For the most part, these schemes are voluntary with incentives to participate. It is likely that they may become compulsory, with, and in some cases without, compensation for income lost.

In such circumstances, conventional management practices no longer apply. The environmental constraints may be imposed in terms of the use of inputs and practices such as nitrogen use, or on limits on environmental impacts such as leachate in ground or surface water. In either case, farmers will have to record and report that they are meeting the set criteria. IT has a role to play for monitoring and confirming compliance.

Constraints on farming for environmental purposes initially are likely to come in technological packages, similar in concept to the blanket prescriptions of the conventional approach. Environmentally sensitive low input - low output systems are unlikely to sustain a viable farm sector without significant levels of income support. However, IT could help to formulate and implement locally relevant farming strategies, which, through better-targeted input use, achieve financially viable farming systems, which simultaneously comply with environmental quality criteria. In its most sophisticated form, IT would involve instrumentation and control for spatially variable field operations. Thus, IT by reducing the business risk inherent in environmentally sensitive farming systems, and providing the means of protecting environmental quality without compromising financial performance, could provide the key for sustainable agriculture in European arable farming.

Information technology and management

Managers are increasingly using information technology to help them improve their decision making capabilities, particularly when trying to manage the inherent variability found within the crop environment.

One example is called Precision Farming, which is a systems approach to managing crops and land selectively, according to their needs. It utilizes expertise from many disciplines and integrates the latest information technology tools and techniques to enable farm managers to get a better understanding and control of their fields. Management is the essential factor to achieve a stated outcome for the farm. Managers should identify their own strategies and practices that allow them to deal effectively with the variability found on their farm.

Three types of variability have been identified. The first type is spatial variability, which can be seen as changes across the field. An example would be where one side of the field yields higher than the other side. Temporal variability is identified when parameters change over time. This can be seen when a crop starts by growing well but results in a poor yield.

Predictive variability, is the difference between what the manager predicted would happen and what actually happened. The classical example of predictive variability is where the manager predicts that a certain yield will be achieved if a certain amount of fertilizer is applied, but the crop does not achieve it because the weather changes. Each type of variability must be measured, assessed and possibly influenced, according to how significant it is.

Measuring variability

The first stage in the process is to measure important factors that indicate or affect the efficiency of the growing crop. The two main approaches are to create yield maps through instrumenting the harvesting system or assessing soil parameters by sampling. Both techniques give information about different parts of the cropping system. Yield maps are historic and cannot be used while the crop is growing, but record the actual yield during harvest. Soil sampling can be expensive but many soil parameters such as texture and horizon depths do not change over time, so are a good investment. Measuring soil nutrient status must be treated with care as repeatability, let alone accuracy, is difficult to achieve. Sampling strategies based on a simple grid tend to be expensive and better-targeted sampling techniques are being developed [Thomas et.al. 1999]. Asset surveys can also be carried out to record physical features, such as field and crop boundaries, high trees that may cause shading, compaction in gateways, etc. Other high-density measurement techniques are rapidly becoming more important such as Remote Sensing and ADP (Aerial Digital Photography) or non-contact sensing (e.g. Electro-magnetic induction). ADP can give real-time information of the crop canopy and allow management to be modified while the crop is growing.

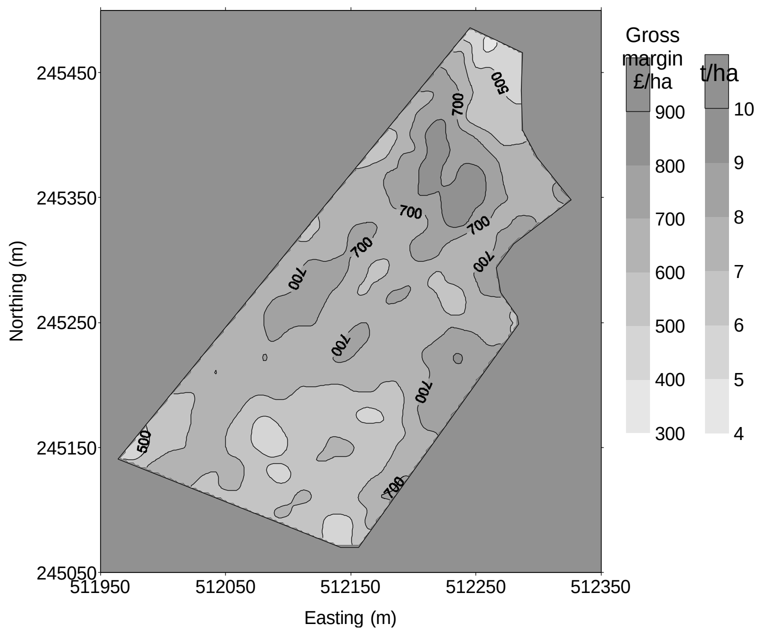

Fig. 1. Gross margin map with yield scale

Assessing the significance of variability

The spatial variability must be assessed for significance to the manager. Normally this is done by looking at the spread of the data or seeing if the extreme values lie outside acceptable thresholds, such as indices for soil nutrients. One technique is to reclassify yield data into 'gross margin' maps [Blackmore 2000]. See Fig. 1. This technique deducts the variable costs from the income, which varies spatially with the yield, resulting in a gross margin map that shows which areas generated more income than others did. Some gross margin maps have shown areas that actually loose money. Given enough detail, a similar map based on inputs could be produced to show environmental impact such as nitrogen fertilizers in a nitrate sensitive area. The temporal effect of weather and prices are shown in Fig. 2.

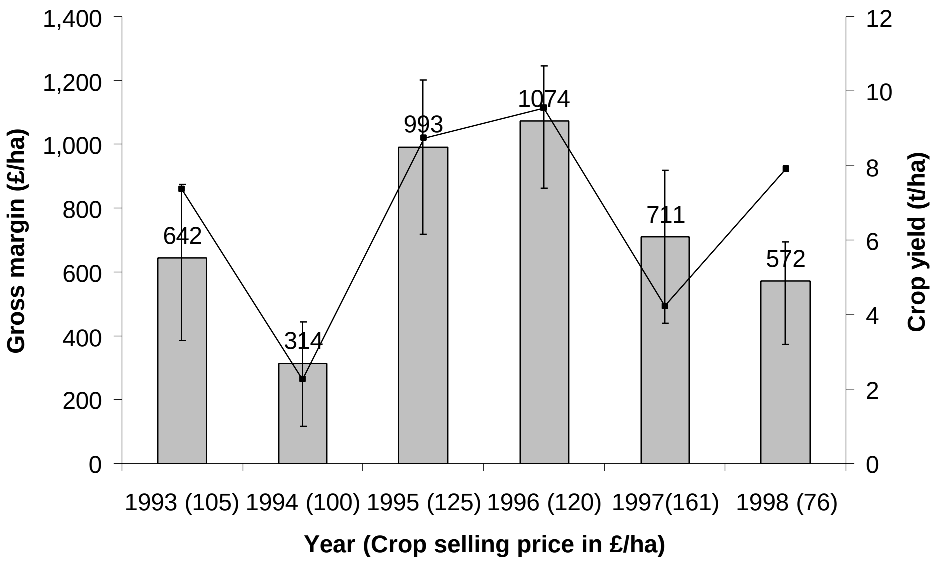

Figure 2. Gross margins and the in-field variability between 1993 and 1998

The bars in Fig. 2 show the change in average gross margin over 6 years. Superimposed are the whiskers denoting maximum and minimum gross margins experienced in that year. The line denotes the average yield for that year and the selling price is included in brackets. Note that in 1994 and 1997 the crop was oil seed rape and the wheat prices slumped in 1998.

Management of inputs

Most traditional systems over-apply inputs such as seed, spray and fertilizer to reduce the risk of crop failure. With better assessment techniques, the inputs can be reduced or redistributed to optimal levels and the risk of failure can be managed. This will result in making the system more efficient.

Regardless of the country and crop, management of an agricultural system is complex. To improve the efficiency, computer based Management Information Systems (MIS) must be sophisticated enough to deal with this complexity and the manager's strategies and practices [Blackmore 1996]. The management input and computing support is the same in each country and each crop. Some crops may well have special considerations that should be taken into account when designing the MIS, such as planning the harvesting logistics when supplying crop to a processing factory.

The size of the management unit in the treatment map depends on the ability to measure and manage it. Although a DGPS may be accurate to within one metre, a combine header may be ten meters wide, and the spreader width may be 24 meters. The management unit will be limited by the spreader width. A draft methodology for dealing with in-field variability has been proposed [Blackmore and Larschied 1997].

The ultimate goal is a full understanding of the whole process and rational decisions being made following the management philosophy. This will never happen, as there are too many unknowns in a very complex process, the weather being the most obvious. Nevertheless IT can still automate many of the repetitive tasks and help to provide accurate information at the right time. Levels of automation are bound to rise, as are the use of computers and controllers. The trend is towards a better understanding and a smaller unit of treatment. Information sources will be on-farm as well as off-farm. Examples of on-farm sources are; yield mapping, weather station, quantities held in storage bins, weigh bridge, etc. Examples of off farm sources are; market prices, pest prediction models, expert advice, etc. Both of these sources could be integrated into a system that allows the manager easy and timely access precisely when the decision must be made.

Conclusions

The main thrust of IT into agriculture in the 1990s has come through the management of spatial variability. Many maps have been produced that have quantified this effect, but only a few management guidelines of how to deal with it are currently available. As time progresses better understanding of temporal variability is becoming apparent. A seasonal change in the weather is the main factor that gives rise to temporal variability, which leads to gross predictive errors. Some method of classifying the current year to better manage weather trends is needed.

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