DO OUR EXPERTS HOLD THE KEY TO IMPROVED FARM MANAGEMENT?

PL Nuthall
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PREFACE

The development of farm management skills and techniques remains an area where there is considerable scope for improvement amongst the farming community. Various computer based tools are available to assist farm managers but the use of such tools is limited, often by the lack of the data required and the reluctance of farm managers to invest significant amounts of time in learning and maintaining the techniques available.

It is suggested that a large degree of farm management decision making is based on the less well understood factor of "experience". The output from computer based tools will therefore only be as good as the "experience" of the operator in interpreting the results.

This Discussion Paper provides a review of the ideas involved in the concept of "expert systems". The suggestion is made that "expert systems" may have more to offer to the development of farm management than the computer tools of the past. The AERU is pleased to be able to publish this material in an effort to stimulate further discussion of this issue.

Professor AC Zwart
Director
SUMMARY

Some farmers, and consultants, are better at their job than their colleagues. A branch of artificial intelligence known as 'expert systems' attempts to capture this difference (their expertise) in computer based systems and make the skills available to all producers. This paper contains a review of the developments in this area as well as a discussion on the probable place of expert systems in farm management. It is concluded that expert systems are more likely to make a contribution to practical decision making than the many sophisticated models developed over the years but which are in fact seldom used by producers.
SECTION 1
INTRODUCTION

Despite many advances in the study of agricultural economics, management science and operations research, the farm managers of the 1980's still use decision methods developed decades ago. Progress in changing farmers' practices has been poor either because educational programmes have failed, or the systems available are not practical, or do not confer advantages. In that farmers have taken up many technical advances it is unlikely that the educational programmes are completely at fault.

With the increasing availability of extensive computing power, interest in artificial intelligence (Yazdani, 1986) has increased exponentially. In particular, the branch of artificial intelligence referred to as expert, or knowledge based, systems has been given increasing attention throughout the agricultural economics and farm management research fraternity. An important question facing the whole industry is whether expert systems warrant continued research and development with the promise of providing improved decision methods to primary producers. This paper contains a discussion pertaining to this question.

The concept of an 'expert system' is simple and straightforward, the practice complex and time consuming. An expert system is a computer based representation of the procedures followed by a generally acknowledged expert in a field with well defined boundaries. Feigenbaum of Stanford University (Harmon and King, 1985) defines an expert system as "...... an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solutions. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in the field. The "heuristics" are mostly private, little discussed rules of good judgement (rules of plausible reasoning, rules of good guessing) that characterize expert level decision making in the field." It is important to note that any one expert system deals with only specific problems, the definition of which depends on the boundaries of the stored knowledge base. Early work in artificial intelligence conceived the notion of the intelligent computer that could think for itself in a wide range of areas. The reality is a machine which can mimic an expert in a defined domain limited by the knowledge and rules stored on disk.
While expert systems are only now emerging in farm management, there are an appreciable number of general texts available describing the steps and procedures used in developing expert systems. Examples are Michie (1982), Hayes-Roth et al (1983), Forsyth (1984), and Harmon and King (1985). An extensive bibliography is contained in Jackson (1986 pps 237-243). There are also many useful journal articles including Webster and Amos (1985), McKinion and Lemon (1985), O'Keefe et al (1986), and Colomb (1987).

To date, most agricultural expert systems must be described as exploratory, particularly as the systems that have been made generally available are as yet finding little use. This situation must be regarded as more of a commentary on the experience and skill used in developing the systems rather than the potential value of the concept. Examples of systems that have been developed include soybean disease diagnosis (Michalski et al, 1982), cereal disease diagnosis and treatment (Jones and Crates, 1984), grain marketing management (Uhrig et al 1985), apple orchard management (Roach et al, 1985), disease control in winter wheat (Amos, 1985), lamb fattening management (Wain, 1986), and the selection of appropriate barley varieties (Barker, 1987). Many other systems are under development around the world (see, for example, Norton, 1987; Bishop et al, 1987; and the U.S. Artificial Intelligence Newsletter Aug. 1986).

Experts, of course, have no doubt always been used in farm management. In recent times informal expert systems have been field days on outstanding farms and research stations, consultants observing the techniques and procedures used by successful farmers and subsequently transferring the knowledge to other farmers, more formal surveys used in a similar way, and also the use of farm standards (Blagburn, 1954). The "expert system" concept is an attempt to formalize these procedures at the same time as making them more flexible to enable individual farm application through computer packages.

Paper and book forms of simple expert systems have existed for decades. Examples include taxonomic tables and keys for identifying plants, troubleshooting tree-like tables for isolating problems in machinery, and so on. One example of a printed decision table which has subsequently been computerized and labelled an expert system is given by Amos (1985) (Based on work by Cook and Webster 1977, Webster 1977, and Webster and Cook 1979). The problem concerns disease control in winter wheat and the question and answer procedure designed to provide a conclusion and spray recommendation was originally published as a series of diagrams and tables by the Ministry of Agriculture, Fisheries and Food (1984). A representation of one of the diagrams is given in Figure 1.

The complete system is displayed on one side of a 59 x 42 cm sheet in six diagrams and six tables. The computerised
Figure 1: Example of a Section of a Paper Based Expert System

GROWTH STAGE
Stem erect-first node detectable

Was wheat or barley grown in either or both of the previous 2 years?

Yes
- Is variety eyespot disease rating 5 or less and sown before Mid-October?

Yes
- Is mildew, septoria or yellow rust obvious?

Yes
- Use eyespot fungicide Table 3

No
- Use appropriate fungicide or mixture for eyespot and mildew/septoria/yellow rust Table 3

No
- Are more than 20% of tillers affected by eyespot? Final check at growth stage first node detectable.

Yes
- Is mildew, septoria, or yellow rust obvious?

Yes
- Use appropriate fungicide for mildew/septoria/yellow rust Tables 3 and 5

No
- No treatment

No

The aim is to control severe eyespot, but control of mildew, septoria and rarely yellow rust can also be important.


Note - Tables 3 and 5 contain a list of fungicides and their attributes.
version sequentially displays the questions on the screen with a request to enter the appropriate response. This produces the next question and so on until the conclusion is reached.

This example aptly describes an expert system and the simplicity of the basic concept. However, years of experiments, knowledge and experience were used to create the paper version of the system, though computerization was relatively simple. Probably the most significant task in the development process was the extraction of the critical factors from the experts. The system relies on observation and simple choices with a notable lack of numerical analysis. This is a feature of most expert systems as it is argued experts do not operate numerically when dealing with familiar problems, though for some problems this is clearly not the case (e.g. an engineer designing a bridge).

The example described above can be classified as a planning expert system - it provides a conclusion for action. In that recognised experts operate in most endeavours, an expert system can be developed for most situations where conclusions and decisions are required. This includes the general planning area (what action to follow) as well as diagnostic problems (What is the disease? What is the plant? Why the stock feed shortage?....), predictive systems (probable wool price movements, likely share price tendencies....), and real time control systems (environmental control, production related automatic feeding control....).

There are a number of variations on these primary groupings. Two examples are design systems (woolshed configuration, landscaping....), and data collection (interrogation for survey purposes) packages. Similarly, output can take a range of forms including simple conclusions, a list of most likely answers with reasoning, through to procedures allowing the user to suggest a solution to the problem with the expert system providing a critique of the proposal. There are few limits to the conceptional structure of a system. Practicality, may, however, dictate otherwise.

Artificial intelligence (Yazdani 1986) consists of three broad areas - expert systems, robotics and natural language understanding. This discussion concerns expert systems and covers the reasons why currently available decision methods have not been particularly successful. The comments impact on the conclusions on expert systems, the theory of expert systems, important factors in developing practical systems, special problems associated with applying expert systems to farm management tasks, desirable attributes of systems most likely to succeed and, finally, a set of conclusions concerning the likely place of expert systems in farm management. The objective is not to provide commentary on the detailed method and techniques of expert
systems, but rather to provide a general discussion for the non expert on the potential significance of this emerging field.

The discussion does not cover robotic or natural language applications. However, it should be recognised that robotics is attracting an increasing interest in areas such as product harvesting and grading (see, for example, Jakeway et al (1985), Kranzler and De Voe (1985), Key (1985) and d'Esnon (1985)). Natural language understanding is a less significant development for primary production though machine recognition of the spoken word would make farm office work less tedious, and equipment control easier where both hands are required for the physical aspects of the job (e.g. handling sheep in a wool shed).

Ince (a, 1987), a computer scientist, has noted "a future demand will be for artificial intelligence staff who are capable of building expert systems ....... Already a broker is using an expert system to predict currency movements. It has already outperformed a large number of human dealers". Will the same occur in farm management?
SECTION 2
LESSONS FROM PAST DEVELOPMENTS IN FARM DECISION METHODOLOGY

Since the turn of the century researchers and practitioners alike have been developing farm management decision making methodology. The early workers evolved cost accounting (Boss, 1945; Giles, 1950), the use of surveys (Yang, 1958), farm standards and comparative analysis (Blagburn, 1954), as well as budgeting (Giles, 1964). These simple techniques predominated until after the second world war when increasing sophistication was introduced through both the further development of existing techniques (e.g. gross margins (Selly and Wallace, 1961; Giles, 1962), parametric budgeting (Candler, 1959; Byrne, 1964), statistical techniques for data comparisons and associated econometric work (Johnston 1963)) and the development of new techniques. In this latter category must come the development of production economics (Heady, 1952) and the use of production functions (Heady and Dillon, 1961), the development of investment analysis (Cocks, 1965) as well as linear programming (Waugh, 1953; Heady and Candler, 1958), systems simulation (Babb and French, 1963; Anderson, 1974), a range of other operations research techniques (e.g. inventory analysis, Candler, 1959, critical paths, Cooke-Yarborough, 1964, and OR in general, Agrawal and Heady, 1972), dynamic programming (Burt and Allison, 1963), and, finally, risk and uncertainty related decision theory (Dillon, 1958; Officer and Anderson, 1968; and Tadros and Casler, 1968).

Despite the countless hours devoted to the development of the techniques, and the hundreds of learned papers describing enhancements and examples of the procedures, the fact remains that virtually all farm managers use nothing more sophisticated than simple budgeting in its various forms. The same comment applies for farm consultants, though researchers involved in prescriptive work do, of course, use many of the more sophisticated techniques. It must be concluded that as far as the farm manager is concerned progress has been minimal.

While prescriptive work, when carried out by an experienced researcher with an excellent knowledge of the practicalities of the problem and the methodologies available, can certainly produce useful results (e.g. optimal crop mix, optimal stock feeding and grazing programmes) giving guidelines to producers, it must be recognised it is not possible to produce plans and strategies for each unique farm and farmer each with their specific resource mix and objectives. Furthermore, as environmental, price and cost conditions change, the
research conclusions must change. Conceptually, tables of conclusions for most situations and condition sets could be produced, but their size would preclude practical use. It must also be recognized that most prescriptive research can only give general guidelines, yet the farmer is faced with making detailed decisions every day, and these can never be provided by off-farm researchers. The farmer needs decision systems accessible on the farm whenever the need arises to enhance any general guideline prescriptive research results available. If the on-farm systems produce the required analyses, it could be argued prescriptive researchers will become redundant, except as developers of on-farm packages.

Various attempts at making sophisticated decision methods available to the farmer have occurred. Most must be regarded as having been unsuccessful (e.g. linear programming performed by the Farm Management Service Laboratory in Western Australia - Schapper, 1966), though where the cost was kept to a minimum, some success was achieved (e.g. Purdue's Top Farmer Workshops using linear programming with specialist matrix generators and report writers, McCarl, 1976). Some techniques have not even, however, achieved minimal degrees of success. Commenting on dynamic programming, Barnard and Nix (1979) note (p 428) "While fascinating intellectually, dynamic programming has little significance for practical farm planning at the present time....". Similarly, Kennedy (1986) reports (p 300) "there are few reports of the commercial use of dynamic programming on a day-to-day basis". Barnard and Nix probably point to the most significant worth of the decades of methodological work, namely a better understanding of decision problems and consequently better teaching and better informed experts making improved intuitive decisions.

There are a number of reasons why sophisticated techniques are not used by managers. Primarily, their use has not demonstrably provided economic gains of any significance. The techniques have been too complex for easy use by farmers thus requiring expert help. The cost of this help has far exceeded any gains, particularly as most primary producers are relatively small businesses. Even the larger units seldom use advanced techniques on a regular basis, though there are exceptions. One notable case is the use of least cost linear programming for ration formulation. The success here is undoubtedly due to the technique matching the problem with the data requirements being easily met. Due to the complex nature of primary production, for most problems, analytical models are not a good match, with the assumptions being frequently violated. The complexity also means data requirements are high and all too frequently there is a significant lack of data. The outcome is doubtful results, particularly when it is remembered that uncertainty is a major factor in agricultural decisions. Effectively, 'experts' are required to apply the techniques and interpret the results. Their cost relative to the gains from small owner-operator businesses does not make the use
of modern systems viable. The reasons behind the profession allowing so many resources to be devoted to developing impractical procedures is another question. Perhaps a lack of accountability is a factor.

Despite the lack of advanced management procedures many primary producers continue to make acceptable returns. The nature of western economic systems ensures this outcome with the less successful managers ceasing operations in the longer run. The surviving producers rely on simple budgeting and mental figuring, trial and error and common sense, co-operative approaches with the transfer of good ideas between neighbours and others in their local networks, and the use of consultants and government advisers. A major factor, however, in the changing production systems used has been the implementation of technical research. Development of production technology, and its assessment through budgeting and common sense, has been a significantly more important factor than any advances in management technology.

Technical research is understood by the farmer, particularly as the results are frequently very visible, and implementation of most new technology requires little additional training. It is not clear, however, for how much longer significant technical advances will continue to appear. Previous decades have certainly seen major changes, but diminishing marginal returns to conventional agricultural research must be borne in mind. Whether the emerging biotechnology (Longworth, 1987) can reverse this situation has yet to be proven. Despite massive investment over many years, genetic engineering has yet to produce major changes to primary production.

Whether or not technical research can continue to impact on production methods, if managerial research can develop practical methods giving the users significant economic advantages, then clearly attention must be focused in this area. Past research has not achieved this. Can expert systems reverse this situation? Throughout the commercial world there is an increasing emphasis on management and marketing at the expense of technical and production developments. This shift is evidenced by the demand for commerce graduates. The same shift in emphasis will occur in primary production if successful farmer usable decision making techniques can be developed.

An appreciable and significant number of producers are now using on-farm personal computers as decision aids. The numbers vary from country to country, but as many as 10% own computers in some countries with numbers constantly increasing. Two surveys 12 months apart indicated an annual increase of 1.3% in one country (Pryde and McCartin, 1987). Invariably these computers are used for keeping financial records, cash flow budgeting and taxation work, though there are, of course, a wide range of other packages used (Nuthall and Oliver, 1986; Pryde and McCartin, 1987).
Most of the systems are simple packages with minimal levels of analysis. They are easy to understand and use, the data required is readily accessible, they are available as and when required, provide an immediate response to a request for information and are configurable to suit individual tastes. By their very nature they are almost the exact opposite to the sophisticated decision technologies developed in recent decades. There is a clear message here.

In summary, advanced methodologies currently require more data than is readily available, cost more to implement than the apparent gains through the need for specialist implementers and the dubious nature of many of the inherent assumptions, often do not answer the day to day problems faced by producers, and are not constantly accessible. If expert systems technology is to make a contribution it must overcome these problems and be more akin to the simple methodologies that have been successful. It must also, of course, provide the correct answers.

Expert systems rely on the fact that some managers and consultants are successful relative to the others. They also rely on the concept that their skills can be captured and used by others. Variability in managerial ability certainly exists. Taylor et al (1988) provide figures on net farm income per stock unit for a sample of sheep farmers on similar land. The median was $5.88 whereas some 8% of farmers exceeded $20 and 13% were below $0/stock units. The challenge is to study the successful managers and isolate their decision rules with a view to including them in expert systems.

As noted, the rationale for an expert system is that some people make better decisions than others and these decisions are, in most cases, better than model based analytically derived conclusions. Even in areas where analytical models do not even exist, reasonable decisions are constantly being made by experts.

On the other hand, the theory behind expert systems is essentially that experts rely on knowledge and decision rules developed from years of training and experience and, when faced with a problem, it is only a matter of recalling the appropriate solution. Thus the idea of using a computer with its massive storage capacity to replicate an expert. Harmon and King (1985) note "the revolutionary ideas about expert systems are primarily new conceptual insights into how people can use computers to help solve problems".

It has taken modern thinking many years to re-invent the idea of an expert. The farm standard-comparative analysis concept (Blagburn, 1954) was a forerunner which subsequently, for theoretical reasons, dropped from favour in the professionals' eyes (Candler and Sargent, 1962), though farmers and consultants have always found the approach appealing. The contemporary view of an expert, however, is very much more sophisticated than the historical data based farm standards idea and attempts to capture the forward looking marginal analysis which is designed to suit each unique property and farmer's objective which an expert must use if he or she is, in fact, to be an expert.

While there have been many studies of the product and financial mixes, as well as production techniques and ratios, used by successful primary producers (the experts) there have not been any studies of the producers' mental models, processes and procedures used in making their decisions. Studies in other industries, however, suggest (as reported by Harmon and King (1985), Jackson (1986), as well as many other authors) that experts seldom rely on formally setting out the alternatives, calculating the costs and benefits of each and subsequently coming to a conclusion. However, faced with an unfamiliar problem within their area (domain) of expertise, use of the logic of problem solving and the first principles and theories associated with the particular task, is probably common. But having drawn a conclusion, the heuristic lessons gleaned are stored in memory for subsequent use. After many years of training and problem solving, the successful professionals become experts with a massive store of knowledge, observational skills, and decision rules which have stood the test of time and peer assessment. Thus, when
faced with a problem, it is believed a memory search is rapidly conducted to match the features of the current dilemma to produce a solution.

To create a computer replica of an expert requires, therefore, an assessment of the questions and procedures used by the expert together with a listing of all the rules used in assessing this data. Whether an expert system can replicate the skills of outstanding managers must essentially depend on whether knowledge engineers (the name given to people who develop expert systems) can successfully isolate the relevant questions, observations and rules.

An interesting side question is - "what are the features of an expert?". Perhaps decision success depends on:
(i) a good memory together with rapid recall,
(ii) an ability to notice and correctly observe the outcome of relevant events,
(iii) an inquisitiveness that results in considerable experimentation,
(iv) an approach which enables appreciating and learning from the experience of others,
(v) a reasoning ability that can evolve decision rules and interpolate from closely allied data and rules, and
(vi) a motivation to make use of these attributes.

What constitutes an expert, however, is not that vital. Procedures used are of more importance as these must be replicated. In that experts frequently interact with their clients over the decision period, and this dialogue can be an important component in accepting the conclusion, it is likely a successful expert system will not only produce a correct and acceptable answer, but will also allow the user to question and interact with the package. This is part of removing the "black box" syndrome frequently reported as being a drawback in accepting the results of sophisticated analyses.
SECTION 4
FACTORS IN DEVELOPING EXPERT SYSTEMS

The key factors must be the successful elicitation of the relevant knowledge and rules from an expert, or experts, and its faithful representation within an easily used computer package. The costs of doing this are extensive and commonly require several versions before reasonable acceptance.²

To date, objective reports of the economic benefits of the large number of systems that have been developed have not appeared. This is partly due to many of the systems being in the commercial arena (e.g. the Digital Corporation's package for configuring VAX computers) and that if a system is generally regarded as being useful there is little incentive to conduct an ex post evaluation.

Considerable effort has gone into developing specialist software packages for expert system construction. These are referred to as expert system shells and generally consist of a defined framework into which the developer embeds the knowledge and rules for the particular problem. Only minimal programming skills are required to use the shells of which there are a large number on the market (see, for example, O'Keefe and Belton (1985), O'Keefe et al (1986), and Gevarter (1987) for reviews). Each shell has its own particular characteristics. For example, some allow uncertainty factors to be included, some to reason backwards from a possible conclusion and so on. Most workers, however, believe it is necessary to use more flexible languages to develop a package that best suits each particular problem (for example O'Keefe and Belton, 1985), though shells can be extremely useful for developing initial prototypes but are "usually discarded for the real project" (Hart, 1986, p 68).

² These comments are made by most writers and experts in the area.
Some systems have been developed using standard high level computer languages (e.g. FORTRAN), but specialist artificial intelligence languages are being increasingly used. The most common are PROLOG (Programming in Logic) and LISP (List Processing). These languages are designed for pattern matching activities as it is assumed humans solve problems by searching their memory for a solution to a similar problem which they have stored away.

The computer language selected must also be suitable for creating an acceptable interface as farmers clearly require an easily understood and as near to a foolproof system as possible. Part of the development process must involve assessing the way farmers approach problems and the form the output should take. Diaper (1986) discusses an interesting way to assess these factors. Two connected computers were set up in different rooms with the 'client' located at one terminal and a genuine expert at the other. The client typed in requests and the expert responded as if it was a typical problem solving interview. The computers merely acted as a communication medium. The whole dialogue was recorded on disk for later analysis and as far as the client was concerned, he/she believed they were dealing with a computer based expert system. This technique enabled the expert to first assess the current knowledge of the client and consequently modify the language and responses to suit the particular individual.

From his experiments Diaper believed a natural language interface need not have a large vocabulary given the domain of the system is made clear. Whether or not a natural language interface is ever likely to be a possibility, considerable research continues in this area (Jones, 1984).

The heart of any expert system is its set of knowledge and rules. Extracting this information is referred to as 'knowledge elicitation' (Anon, 1987) and can involve the use of a range of techniques from simple questioning of an expert through to elaborate experiments. Cammach and Yound (1984), and Cookson et al (1984) discuss types of knowledge and elicitation techniques. Ideas of protocol analysis (recording behaviour for later analysis, perhaps using videos (e.g. Wood, 1986)), computer simulated questioning and recording (Cookson et al, 1984) are all mentioned. Frequently experts find it difficult to explain their

3 For a review of a micro computer based PROLOGS see Berghel and R
procedures and methods so elaborate techniques are necessary. Furthermore the knowledge engineer may well need a detailed understanding of the problem to enable extracting the information that has become second nature to the expert. Cookson et al (1984) suggest obtaining an internal model before starting, though clearly preconceptions of the correct procedures must be prevented.

'Deep' knowledge refers to the underlying theories and internal models that experts are believed to have. One technique to expose this knowledge is to pose unfamiliar problems so that reasoning is required rather than recall from past observations. Such approaches may be necessary to divide a system into components thus allowing the unskilled to observe complex factors. An expert veterinary surgeon can cast an eye over an animal and frequently draw an immediate conclusion. To break down this process into explainable components is believed by psychologists to be possible (Wood, 1986). However, experience has shown that users of expert systems can become frustrated if the question procedure is drawn out, so it is also important to isolate the key factors used by experts in making decisions. Finesse, rather than a sledgehammer approach, is the hallmark of many experts.

While the usual procedure is to rely on experts to provide the core of an expert system, the alternative of deriving decision rules from a series of example problem/solution pairs has been proposed by a number of workers. Some shells even provide this facility given the examples are non-conflicting. A number of rule creating algorithms exist. Quinlan (1979) produced one of the first techniques which essentially tries an initial rule on the data and subsequently attempts to improve on it. A Darwinian 'survival of the fittest' approach was developed by Smith (1984), who found that after 42,000 rounds of simulated poker, the generated decision rules were beating a hand crafted poker programme in 89% of the games. In an agricultural example, Michalski and Chilansky (1980) showed that an algorithm they developed created better rules for soybean pathology decisions than a panel of experts. Despite, however, Forsyth's (1986) claim that "the age of the creative computer is about to begin", it will be some time before a machine can create better decision rules than an expert. The exception might be where well founded analytical models are used to draw conclusions, particularly as prices and costs change, which are then encapsulated in an expert system. The use of linear programming to develop least cost feed rations might be an example.

Expert systems are seldom ever finalised. Improvements constantly suggest themselves. Also new knowledge becomes available and existing rules change due to changing market and production conditions.
whether a system is sufficiently developed to become a practical proposition is an evaluation, or validation, problem. Validation must involve assessing the output against the conclusions of independent experts. Their assessment must also be available to allow potential users to assess whether to 'employ the expert'. It is interesting to speculate on how a human expert is chosen. When selecting, for example, a dentist, most rely on the university to have given an 'acceptable' stamp together with word of mouth recommendations from friends and acquaintances. Personal experience then takes over. In the case of computer experts, the panel of judging experts is the university's equivalent.

Considerable effort has gone into developing validation systems for medical expert systems (Chandrascheran, 1983; Gaschnig et al, 1983). Detailed case records of presenting problems, treatment and outcome are often available and consequently allow diagnostic-treatment systems to be statistically tested. In agriculture, records for management decisions are most unlikely to be available, thus the need for using a panel of experts working on a number of example cases. A variation on this process is to have two panels. Each problem is given a solution by either the panel or the expert system. The second panel is then asked to assess the conclusions which are presented in random order to prevent any bias against, or for, computer solutions.

Even in agriculture there will be cases, however, where objective testing is possible. Systems designed to diagnose plant or animal disease could be assessed against the results of chemical and culturing tests. Similarly, in some management decisions objectivity will also be possible. An example might be a product marketing problem where records will eventually enable a decision on whether the strategy adopted gave maximum returns.
SECTION 5
PROBLEMS IN APPLYING EXPERT SYSTEMS TO FARM MANAGEMENT

Uniqueness, complexity and uncertainty are key words in primary production. Each farm is essentially unique in terms of its resource set quality and structure, and needs its own solutions. Given the predominance of owner operator properties, objective functions and abilities similarly tend to be unique and important in the decision process. Part of this uniqueness is the attitude to risk and uncertainty.

Primary production involves a complex array of biology, weather, markets and man, with output being dependent on a large array of both controllable and uncontrollable variables. Together with the uniqueness attribute, this complexity means a large amount of information is required for good decisions. For success in farm management, expert systems need to adequately cope with all these problems, though simple diagnostic systems are perhaps in a different situation. A package to make, for example, internal parasite drenching recommendations can be quite general.

In that an expert farm consultant allows for farm uniqueness and individual objectives, it should conceptually be possible to include these factors, though this increases the length of the questioning procedure. To date there has been a complete lack of any reference in the expert system literature to different objectives, partly because it is probably believed the objective is unambiguous. In medical expert systems it is assumed the objective is to obtain a correct diagnosis and the subsequent curing of the malady whereas, in some cases, the risks and costs associated with treatments could conceivably suggest that patient, as well as community, objectives might be a relevant component of the problem.

Primary production management does not abound with objectively measurable variables. This is in contrast to many industrial processes which can often be controlled from consoles displaying all manner of data. The farm manager is constantly making complex observations of plant and animal, soil, weather and market conditions using all the faculties an observer has available. The problem of recording these observations in a relatively simple form will be a major challenge to expert system developers. Often a consultant personally observes these factors when advising a producer, and also questions the producer relying on many unstated interpretations to draw a conclusion. It is interesting to note that some 60-70% of communication is believed to be non-verbal (Pease, 1985). The problem is to discover the key factors observed and the rules used to categorise them.
and draw conclusions. As noted earlier, some psychologists (Wood, 1986) believe it is possible to isolate the key factors obtained from complex observations by people who are regarded as expert judges. In agriculture, however, extensive experiments and trials will be necessary before the same conclusion can be drawn.

The 'decisions under uncertainty' problem is not unique to agriculture. However, the many formal decision processes developed (Bayesian and probabilistic approaches, game theory, certainty equivalents...) are seldom used by the managers. Yet, expert producers do, in fact, make reasonable decisions under uncertainty, so expert system researchers have attempted to formalise some of the informal methods used. In that people often talk about 'greater chance', 'less likely' and similar subjective classifications, some of the work involves inexact reasoning (Ganascia and Kodratoff, 1985) though much of it concerns variations on probability approaches. One well known medical system (MYCIN) relies on using a measure of belief, and a measure of disbelief, associated with all the evidence collected to give a confidence factor (given by the measure of belief minus the measure of disbelief) on the recommendation or hypothesis (Jackson, 1986, pps 229-236). Various other models have been developed (see, for example, White, 1984; Mamdani, Efstathiou and Pang, 1985; Gamaerman and Creeney, 1986; and Liu and Gammerman, 1986 for descriptions and reviews) as well as systems using standard Bayesian logic (Naylor, 1984), though the latter is not an attempt to mimic an expert but to introduce conventional decision theory logic. One of the problems of this approach is the heavy demand on data and the difficulty of maintaining a decision maker's interest through a tedious questioning process to obtain all the subjective probability estimates. Furthermore, the answers can easily become inconsistent.

At least one group (O'Keefe et al, 1986), however, believes including uncertainty has little effect on the conclusions. This is possibly due to the exclusion of any specific allowance for an objective function. Another factor might be that an inherent allowance for uncertainty occurred through other questions included.

Whatever the situation, it is exciting that new views of decision making under uncertainty are emerging which may provide further insights into the problem, with the chance of practical procedures being developed.
SECTION 6

DESIRABLE ATTRIBUTES OF EXPERT SYSTEMS

A good expert system should not only produce conclusions similar to those of excellent producers, but it should also follow the procedures used by expert consultants, if not improve on them. This means using techniques like adjusting the questioning to suit each individual farmer, evaluating 'what if' questions, providing rationales, estimating the effect of parameter variations and so on.

A good consultant varies his or her techniques to suit the individual farmer so that the terminology used is adjusted, the depth of questioning varies and the extent of inspections are modified to suit. Similarly, the form of the discussion and recommendations needs to be tailored to the individual so while detailed budgets and written comments might be appropriate in one case, abbreviated summaries desirable in another. Effectively, an expert system is required to appraise the producer through developing a model of the user\(^4\) and act as an interface to the main expert system. Such an approach can potentially remove user frustrations so often a problem with inflexible packages.

Effectively, an intelligent front end is required (Bundy, 1984). This also involves minimizing the input required, recognizing when the domain encompassed by the expert system does not encompass the presented problem ("I'm out of my depth, I need to call for assistance"), allowing for any special restrictions requested by the producer (overdraft must not exceed \(y\)) (Kidd, 1985, found this aspect to be important), allowing the user to volunteer information that is believed to be important at any stage of the process (but very difficult to achieve) and, finally, producing a log of questions and answers for later review and 'discussion'. An ideal system would also allow 'visual questioning'. It is technically possible to connect video disk systems to computers so that high quality screen images of, say, a diseased plant can be shown as required. At

\(^4\) A group (L. Ford et al) at the University of Exeter, Exeter, are experimenting with 'user' expert systems.

\(^5\) Logica plc, Cambridge, have developed, in conjunction with Exeter University, KBET (Knowledge Based Engineering Training).
A consultant working with a farmer involves a two-way interactive process. Questions such as 'why is that factor important' constantly occur. Similarly, the consultant probes to elicit information and may well adjust conclusions as the process evolves. Many expert system shells allow the elementary inclusion of 'why, what and how' questions, but few have an emphasis on adjusting the result following further 'discussion' though there is no technical reason why this should not be included.

Part of the interactive process may involve the use of qualitative simulation. Hunter (1986) believes experts use mental qualitatively based models to assess causes and effects. It may be important to include such models in expert systems to allow the exploration of possible solutions and their consequences. Frequently, it is argued, the lack of detailed data means qualitative reasoning occurs using models developed over many years of experience. This is a similar argument to the use of fuzzy terms in handling uncertainty.

Sensitivity analysis is also an important part of the interactive process. Traditionally, sensitivity analysis has been a part of achieving confidence in a conclusion and no doubt is inherently carried out by experts. Some expert system shells (e.g. VPExpert) provide the opportunity to change the answer to any question and subsequently re-work the problem. Ideally, the ability to initially indicate a range of replies and have the system re-assess the conclusion for each combination should be included. This is part of the learning process. Equally, part of this process is the ability to add new knowledge and rules to an expert system, particularly where an individual farm warrants special features. A problem here is ensuring consistency as with a rule set consisting of hundreds of entries, some of which may be infrequently used, it has been found difficult to ensure complete conformity unless a clear model and framework is used (Cunningham, 1985).

Finally, if providing the best answers possible means integrating an optimization model, then this should be included. The example of least cost feed formulation using linear programming is a case in point. It is doubtful whether an expert could perform better than such a model, particularly where there are many ingredients, and so an expert system involving, say, pig management should include a linear programming model as a component. As new practical optimization techniques, or indeed any numerical techniques, are developed they should logically supersede any expert systems if they outperform them. In the longer run a whole series of mixed models can be envisaged. There are already moves in this direction (Jones, 1985; Hearn, 1987).

6 Produced by Paperback software
SECTION 7
CONCLUSIONS

The fact that some producers and consultants are experts relative to others means the concept of an expert system has a contribution to make assuming they can be developed with the attributes described. Advances in computer methodology means this will eventually occur. Their introduction, however, will take many years as by far the majority of farmers have yet to learn the basics of using computers. The introduction of micro-computers for simple financial recording has taken some six or seven years to be taken up by 5-10% of producers. It will take at least a generation change before computer numbers reach the 80 to 90% uptake level.

The current cost of computers and software means the economic gains do not have to be greater than $4-5000 per annum to ensure a worthwhile contribution to profit. While some workers in agricultural computing believe there is only a limited number of producers that can effectively use computer based financial packages, good expert systems are, in fact, likely to have a greater uptake as they should be easier to use. However, in the longer run, all producers will be forced by the commercial world to constantly use computers for basic business activities such as banking, ordering, messaging and marketing, so access to management packages will not be difficult. When this occurs expert systems will have a much wider use.

The limited number of agricultural expert systems currently available does not provide guidance to the systems most likely to be successful, nor whether all the intelligent components of experts can be simulated. It is easy to argue, however, that problems requiring a large base of information that need complex rules and calculations to solve, are consequently very demanding, that do not require massive data entry (either due to automatic data collection or summarisation down to key elements), and where the producer believes he, or she, has a deficiency of knowledge, are likely to be the successful ones. One example might be tax management. Tax laws can be complex and involve many pages of regulations with at least a reasonable amount of calculations required. Where a producer keeps computer based financial records the data can be transferred to the tax expert system thus requiring a minimum of additional data entry.

At the other extreme, simple diagnostic and management systems will find at least initial use by people facing decision problems in these areas. Examples are crop spraying problems, pricing decisions for stock buying, sources and methods of organising working capital, and fertilizer recommendations, to name a few. After constant use the concepts may be acquired by the users so that the expert system provides a learning experience and the user acquires some of the skills embodied in the package. However, particularly where use is not constant, reverting to the formal system will provide re-inforcement of the decision rules.

Most producers will find use for a range of packages, both expert systems and traditional data recording and analysis packages. A crucial factor in the acceptance and use of the management aids will be their careful integration. There will be nothing more counterproductive than the producer, or his/her assistants, having to switch between packages supplied by different organisations requiring the re-keying of data and a familiarity with a range of formats. Achieving this integration will require leadership from public bodies and farmers alike.

It might be reasoned that simple problems are better presented in table and book form. This will certainly be the case where a manager is unfamiliar with computers and where decision rules are unlikely to change. With time, however, it is probable computer based systems will be easier to use in that colour graphics and well designed structures will remove even the need to read the instructions at the bottom of tables, making them easier to use. Updating as new information becomes available will certainly be easier.

In assessing the potential contribution of expert systems it is useful to consider the functions of management. An excellent manager will have good:

(a) negotiating skills
(b) personnel management abilities
(c) technical skills and knowledge
(d) problem solving and diagnostic capabilities
(e) product and production method selection abilities
(f) observational and anticipatory skills
(g) operational and mechanical abilities
(h) market assessment skills
(i) organisational capabilities and, finally
(j) communication skills.

Traditional farm management and decision theory do not consider many of these components of good management, yet abilities in the negotiating arena might, for example, save
$5000 on a new header. At least in the training area, if not in direct decision making situations, expert systems can play a much wider role in some of these areas than traditional economic models through providing a framework for a manager to explore possible strategies. When faced with negotiating an arrangement, for example, a package reflecting the procedures used by a skilled negotiator could be used to practise possible approaches. Similar systems could assist with personnel management, organisation problems and possibly communication difficulties.

In some respects, acknowledging the concept of an expert system is an acceptance that objective analytical models cannot be developed in many areas. This is certainly true, but where an expert outperforms the best models available, and the procedures used can be repeated in a computer program, it would be irrational to dismiss the approach as lacking an underpinning theory and consequently should not be pursued. The sensible approach is to accept mixed procedures and as, and when, practical optimizing analytical approaches are developed, these should be integrated with expert systems.

As expert systems do become available, the question of legal liability will arise. Micro-computer software currently available presents data in various forms rather than directly suggesting decisions. Workers in the United States are acutely aware of this potential problem and whether standard disclaimers are sufficient to protect against potential claims of lost profit due to negligence remains to be seen. The profession must clearly give careful thought to the problem and make every effort to avoid the problem as otherwise a potentially very useful approach may be lost.

The potential benefits of expert systems warrant extensive research and development over the next few years. Crucial factors must be whether methods can be developed which partially mechanise the observational skills of experts and capture some of the interactive features of consultant-client interviews. Planning systems which allow for these factors, together with individual farmer objectives and farm attributes, may well require computers with memory and data processing capabilities in excess of those currently available. Such systems may need the neural computers that are reputedly (Ince, 1987) being developed.

8 W. van Beek, Purdue University, West Lafayette, has raised this question, pers. com.
Production advances will eventually mean these machines are economically justifiable for the farm office.

The concept of a computer based 'expert-system' is certainly a new approach to problem solving. It has the potential to have as profound an influence on effective farm management as the 'whole-farm' philosophy has had over many years. While a cursory investigation of the concept often provides a conclusion that an expert system is a shallow approach to a complex problem, further study shows that mimicking an expert is a complex and challenging task.
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