

Methodologies for Fitting New Technology into Productive and Sustainable Pasture Systems

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Abstract

Conventional methods of agricultural research, largely developed in countries with long-term experience in particular crops and pastures, have limitations in the research and development of industries in regions or environments where there is no such experience. The establishment of a beef industry on acid infertile soils in the humid tropics of Queensland is an example. The establishment of ruminant industries under plantation crops is likely to be another. In the Queensland example, conventional research programs were able fairly quickly to isolate a range of pasture plants which would grow on infertile soils when mineral deficiencies were corrected. However, because there was no viable farming system in operation, researchers themselves were uncertain how the results of the experiments were likely to contribute to productivity or sustainability, let alone profitability of the farming enterprises.

A number of methodologies were used to study the integration of new or alternative technologies into farm management systems. Physical and computer-modelling activities were useful for estimating the productivity, sustainability and profitability of alternative systems. Farm survey and monitoring activities were useful for gathering information, increasing understanding and validating research. Application of the various methodologies can be cyclical. Conventional experimentation on farms establishes close contacts between researchers and farmers and in doing so enhances the quality of the information for industry appraisal. Data from the experiments are the building blocks for computer models. Knowledge gaps and sensitive areas, isolated by models, in turn lead to follow up conventional experiments which in turn lead to better computer models to aid farm decision-making.

AGRICULTURAL research is conventionally based on disciplines (e.g. soil science, plant physiology, animal reproduction) and applied to commodities (e.g. rice, rubber, sugar, beef). This has worked well where there has been a long history of a particular agricultural activity. However, problems have arisen with this conventional approach in the following situations: (a) the development of an industry in a region where there has been no long history of that industry; (b) the extension of an industry to marginal land classes or to land classes previously judged to be unsuitable; and (c) multi-enterprise farming situations.

Situations (a) and (c) apply to attempts to develop ruminant industries under plantation crops and all three situations applied to the establishment of a beef industry in the humid tropics of Queensland. This paper describes the stages and methodologies used in research for the development of pasture systems for that industry. Similar methodologies may be appropriate for the research and development of

productive and sustainable pasture systems under plantation crops.

The first step was to survey the industry and its resources. The primary aim was to isolate major problems and to consider means of improvement. Industry assessment was followed by conventional research into problems and processes. The next stage was fitting the results of the problem and process research into alternative management packages. This in turn was followed by research and development programs aimed at the selection of optimum bio-economic management systems for particular conditions. As indicated by the title, this paper focuses on the last two stages, but brief descriptions of the industry survey and the problem and process research are given.

Industry Survey

The objective was to gain an understanding of the regional environment and the physical resources used by the industry and then to consider economic aspects. Available climatic data were assembled. Soils and natural vegetation were surveyed, as were representative farm types on the range of land classes.

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Information on land suitability and soil fertility status was given high priority. Farmer experience with plant and animal production was recorded. Markets and other economic issues were discussed with farmers and subject matter specialists.

Much of the environmental and physical information came from government records and mapping agencies, as did a good deal of the economic data. Formal surveys of farmers were not particularly successful. Close contact was initially developed with a few selected farmers who were willing to supply detailed information. These activities resulted in the isolation of a few priority areas for research and the establishment of a number of on-farm experiments on the range of land classes used by the industry. This involved close contact with many farmers and provided information which was of higher quality than that derived from the formal surveys. The benefits of on-farm experiments are outlined by Miller and Lascano (in press).

In the early stages of industry establishment, those problems which should be accorded high priority were readily apparent. However, when the most obvious problems were solved and the industry progressed, a wider range of problems and opportunities for improvement was presented. The setting of priorities for research therefore became more complex and bio-economic modelling was a useful tool for managing this complexity.

Problem and Process Research

This involved the application of rigorous experimental method to carefully formulated questions. The first step was usually the formulation of a null hypothesis and the final step before interpretation was statistical analysis of data. Useful guides to methodologies used in tropical pasture research include Shaw and Bryan (1976), Mannetje (1978) and Clements and Cameron (1980).

In the example of the humid tropics of Queensland, the major problems were unreliable establishment of the recommended species and then poor persistence of those species on the large tracts of acid infertile soils. Two approaches were given priority. The first was to introduce and evaluate new pasture plants with the potential to give sustainable and profitable beef production on the soils of the region (Harding 1972). The second was to study the fertility of the soils to determine if they could be economically modified to satisfactorily sustain growth and productivity of the pasture species already in commercial use (Teitzel 1979).

Both approaches involved laboratory and plant-house studies followed by small plot field experiments and then larger field studies. The larger plots were usually grazed at some stage. Most fertility data were

obtained from soil and plant chemistry measurements and from plant yields.

The next stage of conventional pasture experimentation usually involved grazing trials. These normally consisted of a number of pastures studied over at least three fixed stocking rates. Such experiments were costly and have been criticised for giving a poor representation of actual farming systems.

Management Systems Research

The results from the above examples of conventional research into new species introduction and evaluation (Harding 1972) and soil fertility assessment (Teitzel 1979) were exciting. Some treatments were over ten times more productive than control treatments. The results of these experiments were assembled into what were considered to be appropriate technology packages for establishing productive pastures on any land class capable of being worked with wheel tractors (Teitzel and Middleton 1983). We expected that adoption of the technology would be rapid.

Unfortunately, farmers viewed the results with a great deal of scepticism. They felt that information provided by the experiments was fragmented and too specific to a rather artificial set of experimental conditions. Additionally, there was very little information on the likely level of beef production from the new pasture technology or on the longevity of the pastures. Because previous plantings of improved pastures had died out after a few years, farmers were not convinced that the pastures would be sustainable. Nonetheless, answers to both questions were required for any sensible economic appraisal.

It was clear that such new technologies could only be realistically appraised within the context of whole-farm management systems. There are now many texts on agricultural systems research (Dalton 1975, Remenyi 1985). The remainder of this paper outlines the various types of activities undertaken by our small research group to determine the productivity, sustainability and profitability of alternative pasture systems for the beef industry in the humid tropics of Queensland.

Preliminary Assembly into Management Packages (Conceptual Modelling)

This is the first step in synthesising available technical information into management packages. In the Queensland humid tropics, there are 23 land classes with different fertilizer requirements and at least three soil drainage groups. For each of these, there are several pasture species options which may be managed at different intensities with a number of

animal options. Farmers, extension officers and researchers contributed to the selection of what we considered to be the most attractive management packages for the range of purposes and land classes. These were then subjected to detailed analyses.

Preliminary Numerical Modelling

Numerical models (generally highly abstracted) of the management options were required for economic analyses. They were also a useful means of formalising the knowledge and/or perceptions of the contributors to the conceptual models. These initial models were usually fairly simple and a computer was not essential but obviously helpful because of the number of permutations involved. Using computers, many factors could be varied simultaneously and the 'what if?' questioning could be more rigorous. Although parameters for some of the options were unknown, estimates of the levels of production required for profitable operation were derived. If we considered that such levels were unlikely to be attained in practice, then that particular management option was rejected.

Physical Modelling of Management Options

The next step was to take the most attractive of the options and quantify their productivity and stability under simulated commercial conditions. Small physical models (1.6-24 ha) employing a range of management options were established on a range of land classes on farms. The approach was similar to the farmlet studies of Murtagh (1980) and Bell (1976) and the full-scale systems studies of Eadie and Maxwell (1975).

For each land class, a control management system simulated the best system in current commercial use. A comparison of the performance of this experimental control to actual commercial performance provided a test of the validity of the modelling exercise.

The first objective was to determine the stable attainable production levels for each of the management systems. This took seven years. It was not until one year after planting that any of the pastures could be safely stocked at levels attained commercially by the 'control system'. It was another year before pasture yields were sufficiently different to justify increased cattle numbers on the higher-yielding pasture systems. Cattle numbers were increased in the same way as a farmer would increase his herd. By year seven, the most productive system still had the highest pasture yields despite carrying 30% more cattle.

To confirm that even higher production levels were not sustainable, we gradually increased stock numbers

beyond those established by the first stage of experimentation. These stock increases resulted in a steady reduction in animal growth rates and a fairly rapid weed invasion of systems with the lowest pasture yields. After two years of deliberately heavy grazing, cattle were losing weight in all systems and weed invasion was severe. This was regarded as the 'crash point' of the experiment.

The final phase of the study was the 'regeneration phase'. After reaching their crash points, the pasture systems were destocked and weeds were slashed. Three months later, stock were again introduced and numbers gradually increased. Two years after the 'crash point', the desirable pasture species had recovered to dominate weeds and stocking rates were again at the 'stable attainable' levels. Replanting was not required in any of the pasture systems under study.

The production parameters established during the five-year 'stable attainable' phase were thus regarded as good estimates of the sustainable operating levels of the management options on a 'year in, year out' basis.

Numerical Modelling of Biological Processes

Computer modelling procedures involving rate processes and stochastic elements have been regarded as important tools for studying complex and dynamic biological processes (de Wit and Goudriaan 1974, Dalton 1975, Dent and Blackie, 1979). Simulation models (McKeon et al. 1985) have attempted to link all the processes involved in climate-soil-plant-animal production systems. They may be regarded as alternatives to the physical modelling procedures described above. Large computer capacity and well developed computing skills are required. Dynamic simulation models have been useful for giving researchers an increased understanding of the systems under study. However, there are not many examples where they have been used for farm management decision-making.

Bio-economic Modelling

This can be a logical extension of the above simulations of biological processes. In practice this requires considerable computing skills and results in very large and complex models. However, a distinction between 'scientific' and 'practical' models is made by Neeteson and Van Veen (1988), and scientific models are becoming more refined whereas practical models are becoming increasingly simplified.

A wide range of computer modelling procedures is now available. However, because of the large data sets required for a realistic numerical description of the biological, physical and economic aspects of whole-farm production systems, the choice is probably

limited to either dynamic simulation or linear programming.

Simulation has the advantage of allowing a realistic description of the dynamic biological processes. However, as mentioned earlier, whole-farm simulation models have been complex and cumbersome to operate. Additionally they have limited analytical capacity and there has been a tendency for operators to become bogged down in endless trial-and-error simulation runs.

Because standard linear programming (LP) algorithms are deterministic and linear, there is a tendency to regard them as not very appropriate means of representing biological systems. However, with the now ready availability of very powerful LP packages, it is possible to construct LP models which approximate non-linear and non-deterministic situations. In a study by Teitzel et al. (1986), each model solution was deterministic, but a sequential series of experimental manipulations of the model provided a series of moving optima, an approach which is clearly non-deterministic. Additionally, individual model solutions provide sensitivity analyses of variables under management control. Similarly, although the relationship between data points in an LP matrix is by definition linear, the practical representation of non-linear biological relationships is not insurmountable. For instance, in the above study, monthly cattle bodyweight changes and monthly carrying capacities of the land/pasture units were represented by a series of lines of different slopes which, when connected on an annual basis, can represent the known non-linear relationships with time. Such models are powerful tools for experimenting with selected systems to optimise the integration of components and to identify the most important knowledge gaps and weaknesses.

Management Decision Support Models

The large bio-economic models described above fit into this category. However, because of their size, they generally require a main-frame computer.

Practical alternatives are provided by a number of management decision support packages now available on personal computers. Spreadsheets, database management systems and graphics packages have been very useful for highly abstracted comparisons of alternative management systems. Simple spreadsheet models have been particularly useful in highlighting the differences between options to farmers, bankers and other non-scientific groups. Packages used here are also useful for the preliminary numerical models mentioned earlier.

A more recent development has been the use of expert systems concepts. Jones (1989) describes five groups of expert systems. First, he describes heuristic

expert systems which are designed to mimic the knowledge of a tried and true expert. Secondly, real-time expert controls that use an expert's knowledge to build decision tables for use with feedback sensor data to regulate control systems are described. Thirdly, model-based expert systems that link simulation models and expert systems to facilitate the use of proven models and/or interpretation of results, fourthly, expert databases that facilitate the search for the most relevant information and, finally, problem-specific shells are developed to enhance the application of expert systems concepts to agricultural problems.

A detailed treatise of agricultural decision analysis is given by Anderson, Dillon and Hardaker (1977).

Demonstration Farms

While the computer modelling activities mentioned previously provide additional information and increase our understanding, there are credibility problems. Even the physical modelling experiments were regarded by farmers as somewhat unreal. There were doubts about the validity of extrapolating from the small model to a large farm. Additionally, there was a perception that model farmlets were over-managed and that labour and machinery inputs were unrealistic on a large scale. Conversely, scientists believed that production estimates from the physical models were overly constrained by carefully defined experimental procedures required for objective comparisons of the different systems.

To resolve this conflict, the most favoured pasture management systems were established on a whole-farm scale under the watchful eyes of management committees which included farmers. All inputs (man hours, machinery hours, fertilizer, seed, cattle, etc.) and outputs (cattle sales) were carefully recorded and costed.

These demonstration units provided some of the most carefully measured input data (particularly on labour and machinery) for the bio-economic and decision support models discussed earlier. Such data from commercial farms were generally just 'best estimates'. On the other hand, output from the demonstrations provided useful standards for validating the computer models.

These demonstrations created a good deal of farmer interest and were an important influence on the adoption of new technology.

Monitoring of Commercial Developments

Our physical modelling activities and demonstration farms could only be established on a few sites representing a very limited number of land classes. However, commercially, the technology could be

applied to all land classes and sometimes in ways not envisaged by researchers. We therefore began careful monitoring of selected farmers to provide increased understanding and to facilitate early discovery of emergent problems. We established transects on selected land classes and pasture types and initiated stock movement recording programs.

This monitoring has provided us with early warning of possible flaws in the new technology and has facilitated rapid investigation of the causes. Our most frequent problems were with farmers overestimating their area of improved pastures (resulting in overstocking) and with inaccurate application of fertilizers (resulting in weed invasion of the under-fertilised sections).

Conclusions

Conventional procedures used in agricultural research (largely developed in temperate countries with a long history of agricultural research) have limitations when applied to the development of industries in new regions or environments where there is no long-term experience with that industry. The establishment of a beef industry on infertile soils in the humid tropics of Queensland is an example. The establishment of ruminant industries under plantation crops is likely to be another.

In the Queensland example, because there was no viable farming system in operation, farmers wishing to develop a beef enterprise needed guidance on the synthesis of available research information into practical farming systems. Conventional research programs were able fairly quickly to identify a range of pasture plants which would grow on the infertile soils when mineral deficiencies were corrected. However, the researchers themselves were initially uncertain as to how the results of the experiments were likely to contribute to improvements in productivity and sustainability, let alone profitability.

A whole-farm approach was particularly important in this situation. A number of methodologies were used to study the integration of new or alternative technologies into farm management systems. Physical and computer modelling activities were useful for determining the productivity, sustainability and profitability of alternative systems. Farm survey and monitoring activities were useful for gathering information, increasing understanding and validating research.

Application of the various methodologies was critical. Conventional experimentation on farms led to the establishment of close contacts between researchers and farmers and this enhanced the quality of the information for industry appraisal. Data from the experiments were the building blocks of computer models. Knowledge gaps and sensitive areas, isolated

by the models, in turn led to follow up conventional experiments which in turn led to better computer models.

These procedures have been used reasonably successfully in the beef industry in the humid tropics of Queensland. Here, there are commercial examples of grass-legume pastures which have been continuously stocked at 2.5 beef cattle/ha producing around 450 kg liveweight gain/ha/year. After more than 20 years producing at these levels, the pastures are still in excellent condition. More recently, the farming systems studies have indicated that (due to increased beef prices) more costly N-fertilised grass pastures are more productive and more profitable. These systems have maintained stocking rates of 5 steers/ha and produced around 900 kg liveweight gain/ha/year for more than ten years.

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