AN EXPERT SYSTEM FOR MAKING FERTILIZER RECOMMENDATIONS

A thesis
in fulfillment of requirements for the degree of
Master of Applied Science

by

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ABSTRACT

Developing fertilizer recommendations based on the results of soil analysis is recognized as a standard practice in horticultural crops. The manual process requires expert knowledge and can be tedious and time consuming. This thesis reports the results of research undertaken to develop an expert system for making fertilizer recommendations. Study objectives were to explore and describe methods for the implementation of the interpretation model and the generation of fertilizer recommendations using a user interface that is highly interactive and effective as well as demonstrating the commercial feasibility of such a system. Incremental prototype development occurred both in the DOS and Windows environment, with the Windows version being more commercially acceptable and maintainable than the DOS version. The review of the prototypes by a small team of domain experts proved to be a successful method for iterating through the prototype development system life cycle. At the core of the system is a knowledge base maintained in tabular format and a linear model which resolves an optimum fertilizer recommendation solution that meets certain goals while satisfying a set of constraints. The provision of mixed initiative dialogues that support user exploration of the solution space using the results from the linear model is also reported. Pilot commercialization through a jointly funded project by the co-operating fertilizer company, Incitec and the Horticultural Research and Development Corporation was successfully undertaken and full commercialization is being funded fully by Incitec. Results from this study indicated that the system developed was commercially acceptable as a delivery platform for fertilizer recommendations.

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This work was carried out while I was employed as an Extension Officer, Horticulture Branch with the Queensland Department of Primary Industries. For the duration of the project I was stationed at Bundaberg and used the computing facilities of the Bundaberg town office. Project travel and library services were financed from Queensland Department of Primary Industries funds.

I am indebted to my primary supervisor, Professor John Smith, for his encouragement and guidance during the project. His enthusiasm and technical competence helped make this project intellectually rewarding for me. Unfortunately Professor Smith did not live to see the completion of this thesis. After the untimely death of Professor Smith, Dr. Saleh A. Wasimi became my principle supervisor and guided me in the final phases of my studies.

Advice and opinions provided by Mr. C.R. McMahon gave me valuable perspectives on the project and were greatly appreciated.

Mr. G.H. Price was the primary source of plant nutritional knowledge incorporated in the expert system and also made constructive suggestions on the expectations that could be placed on the system. Discussions with Mr. E. Coulston, Ms. Kathy Ehea and Ms. Shirley Gregor were also appreciated.

Throughout the project I received support from my wife and family.

DECLARATION

To the best of my knowledge and belief, the work presented in this thesis is original, except as acknowledged in the text. All sources used in my work have been cited, and no attempt has been made to present the contributions of other researchers as my own. The material has not been submitted, either in whole or in part, for a degree at this or any other University.

Garry Fullelove

CHAPTER 1

1. INTRODUCTION

Chemical soil analysis has been available as a tool in crop agronomy for some years. Soil samples are taken in the appropriate manner and time, then dispatched to a commercial laboratory for chemical analysis. The results indicate the level of a range of plant nutrients in the soil as well as several other soil physical factors which affect plant nutrition. While some of this information is directly useful to a grower, a complete understanding of the implications of the various results, their relative importance and their interactions require detailed knowledge of soil science and plant nutrition.

To provide a meaningful service to growers, it is necessary for the analysis results to be interpreted by plant nutritionists who prepare fertilizer recommendations based upon their interpretation.

To do this the plant nutritionist assesses the analysis data by comparing it with standards which indicate the relative levels of plant nutrients in the analysis. Further, the plant nutritionist must assess the influence of other factors such as soil pH, electrical conductivity and buffering capacity, and account for complex interactions which occur between plant nutrients and be aware of the effects of various fertilizers on these plant nutrient interactions.

The task is complex and to be done reliably requires a significant understanding of plant nutrition and soil chemistry. Despite this the standards and nutritional knowledge are well documented and the nutritionist does not have to rely on intuition. The process is a perfect candidate to be handled by a computerized advisory or expert system.

Expert systems are a branch of artificial intelligence; allowing knowledge to be applied to situations with either deep or broad reasoning requirements. With the widespread use of personal computers they provide an efficient means of commercial knowledge delivery not equaled in history. This field of computer science is relatively new and still developing. Published efforts have shown that it is possible to produce agricultural expert systems that can be used in real situations.

The objective of the study described in this paper was to investigate issues associated with the building of a commercial agricultural expert system for the development of fertilizer recommendations based on soil analysis. In particular it was intended to develop a system that allowed the user considerable flexibility in the way the knowledge was applied to the problem at hand.

Various areas of interest addressed in the study are as follows.

There are examples of very narrow domain agricultural expert systems in the literature and semi-commercial use but few fully commercial examples. The question arises as to why this is so. How hard is it to satisfy the 'knowledge / decision making' needs of agricultural decision makers? Are the constraints in knowledge description, situation description (data entry), user interface or the narrowness of the domain being too restrictive in the applied context?

Of particular interest in this study is the construction and delivery of a system broad enough to deliver knowledge on all plant nutrients commercially tested - that is the breadth of domain in this study must at least equal that of the commercial soil testing services. A system that only made recommendations on part of the soil analysis, while being useful, would not totally fulfill a clients needs. Is this objective within the reach of current expert systems technology and if not where are the constraints?

Additionally, viewing plant nutritionists undertaking the process of making fertilizer recommendation from soil analyses using the current manual method, shows that there is no one correct final outcome or for that matter, a single correct route through the exploration space of the domain. Several correct alternatives exist at several key points through the process. Can the proposed system in this study cope with such flexibility and how might the model of variable domain navigation be implemented? What controls must the system have in place to allow the user such a degree of freedom of navigation in the system but maintaining an acceptable level of precision in the final fertilizer recommendation.?

The concerns listed above suggest that two key points in the construction of the system will be efficient knowledge structures that not only model the basic crop nutrition knowledge but also model broader domain interactions, and an acceptable user interface that allows the user to navigate the domain exploration space in a controlled but flexible manner while providing non-aggressive feedback on the progress towards a fertilizer recommendation.

Finally, the manual process is computationally intensive. Many calculations are made and compromises on final outcomes are balanced off against one and other to arrive at a fertilizer recommendation that is suited to the situation. Will expert systems technology be able to implement the multitude of calculations and algorithms as efficiently as more traditional computer languages more tuned to the task? Expert system development environments appear to be adept at handling heuristic knowledge and generic domain rules but will they be capable of intensive mathematical modeling as well?

The chapters that follow contain a review of relevant research, the objectives of the research project, a description of the development of the commercial system and its underlying design and implementation, and the conclusions that can be drawn from this research. Appendix 1 is an overview of the process of making fertilizer recommendations based on soil analysis results; Appendix 2 is an extract from Incitec's "Soil Analysis Guide"; Appendix 3 is an extract from Incitec's "Fertilizer Choice Guide"; Appendix 4 is an extract from Incitec's "Fertilizer Recommendations Guide"; Appendix 5 is a collection of screen captures from a sample session in the DOS prototype; Appendix 6 is a collection of screen captures from a sample session in the Windows prototype; and Appendix 7 is a copy of the successful proposal for funding of the commercialisation of SADI to the HRDC and Incitec.

Previous publications arising from this research are Fullelove (1990); Fullelove (1991); Fullelove and Smith (1992); Fullelove and Smith (1993); Fullelove (1993) and Fullelove (1993a).

CHAPTER 2

2. *LITERATURE REVIEW - Knowledge Based Systems in Agriculture*

2.1 Summary

The essential elements of expert systems and their potential applications in agriculture, particularly in fertilizer management, are explored. Suitable candidate areas identified are pest, weed and disease identification and management, crop selection and rotation, fertilizer program selection, irrigation scheduling, machinery management and selection, and integrated crop management. Some of the major constraints in expert system development are discussed. Constraints of finding practical ways of factoring into a fertilizer decision the subjective parameters of risk, timeliness, efficiency, weather, and adaptability are difficult to resolve. Tools for building expert systems are becoming more available, especially for personal computer based systems. This will encourage agriculturists to explore expert systems for technology transfer, information dissemination and training purposes. The process of building an agricultural expert system can itself serve as a powerful analytical tool which helps workers to identify gaps in information and ways to resolve problems.

2.2 Introduction

The reality of agricultural production is of managers making decisions. Managers must decide what to do once a particular question or problem has been defined. This might involve determining what options are available and then integrating the available and relevant knowledge and information to evaluate likely outcomes of the options. The option best meeting the needs of the decision-maker is then implemented. This process of making decisions may be conducted formally or informally and with varying degrees of rigor, depending on the time available and other factors including the personal style of the decision-maker.

Computer technology is undergoing a revolution. A generation of systems that can mimic the decision-making powers of human beings, grouped under the banner of artificial intelligence (AI), offers new and exciting possibilities in many areas of science, business and management. In agriculture, computers are rapidly becoming integrated components in production systems. A great deal of computer use now concentrates on automating data collection and analysis, map drawing, irrigation control, agricultural information systems, database management and research.

From an historical view point, agricultural entomologists began using computers as early as the 1960's for spray scheduling (Watt, 1961), population modeling (Watt, 1962; Ruesink, 1976), exploring control strategies (Shoemaker, 1973; Conway et.al., 1975). More recently, in the same agricultural discipline, computers are being utilized in pest management delivery systems (Welch, 1984) and decision support systems (DSS) (Rykiel et.al., 1984) designed to enhance decision making. Although DSS have the advantage of allowing decision makers to utilize data and models to solve problems, the output of these systems still requires interpretation by the user (Coulson and Saunders, 1987). Such is the case in Fenster et.al. (1973) where a computerized soil test report (see figure 2.1) details the elemental nutrient requirements of a corn crop, but still requires the reader/grower to convert these figures into a fertilizer program.

REPORT ON SOIL TESTS
AUBURN UNIVERSITY
SOIL TESTING LABORATORY
AUBURN, ALABAMA 36830

PAGE 1

NAME FARMER BROWN
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COUNTY LEE
DISTRICT 2
DATE 12/08/71

LAB NO.	SENDER'S SAMPLE DESIGNATION	SOIL GROUP*	SOIL TEST RESULTS: pH**	SOIL TEST RESULTS: CALCIUM Ca	SOIL TEST RESULTS: PHOSPHORUS P***	SOIL TEST RESULTS: POTASSIUM K***	SOIL TEST RESULTS: MAGNESIUM Mg	CROP TO BE GROWN	RECOMMENDATIONS: LIME-STONE (TONS/ACRE)	RECOMMENDATIONS: TO SUPPLY Mg	RECOMMENDATIONS: N (POUNDS PER ACRE)	RECOMMENDATIONS: P_2O_5 (POUNDS PER ACRE)	RECOMMENDATIONS: K_2O (POUNDS PER ACRE)
9949 1	HILLSIDE	1	6.0		H 140	H 190	H	CORN	0.0		120	20	20
	RATES OF P2O5 AND K2O RECOMMENDED MAY BE DOUBLED AND APPLIED BROADCAST IN ALTERNATE YEARS. FOR CORN ON SANDY SOILS APPLY 3 LBS. ZINC (ZN) PER ACRE IN THE FERTILIZER AFTER LIMING OR WHERE PH IS ABOVE 6.0.												
9950 1	BIG BOTTOM	5	5.2		VL 40	M 80	H	FESCUE CLOVER	2.0		60	120	60
	APPLY AN ADDITIONAL 60 LBS. OF N IN EARLY SPRING IF LEGUME DOES NOT MAKE SUFFICIENT GROWTH TO SUPPLY N NEEDS OF THE GRASS.												
9951 1	GARDEN	6	5.6		H 150	M 90	H	GARDEN	1.5		120	60	120
	PER 100 FT. OF ROW APPLY 2 ½ QUARTS 8-8-8 AT PLANTING. SIDEDRESS WITH 1 ½ QUARTS 15-0-15.												
9952 1	YARD	6	6.1		M 90	M 90	H	SHRUBS	0.0		120	120	120
	PER 100 SQ. FT. APPLY 1 QUART 8-8-8 IN EARLY SPRING AND REPEAT IN EARLY SUMMER.												
9953 1	LAWN	6	5.2		EH 760	M 100	H	ZOYSIA	2.0		80	0	40
	PER 1000 SQ. FT. APPLY 6 LBS. 15-0-15 WHEN SPRING GROWTH BEGINS AND APPLY 1 LB. N (3 LBS. AMMONIUM NITRATE OR EQUIVALENT) IN MID-SUMMER. IF MORE GROWTH OR BETTER COLOR IS DESIRED, MAKE ADDITIONAL APPLICATIONS OF 1 LB. N AT 2-MONTH INTERVALS. PHOSPHORUS IS EXCESSIVE AND FERTILIZER CONTAINING THIS ELEMENT SHOULD NOT BE USED. EXCESSIVE PHOSPHORUS MAY CAUSE AN IRON DEFICIENCY. THE SYMPTOMS NORMALLY OCCUR AS A GENERAL YELLOWING OF NEW GROWTH. TO CORRECT, SPRAY WITH A SOLUBLE SOURCE OF IRON WHICH CAN BE FOUND AT GARDEN SUPPLY STORES. USE AS DIRECTED.												
	1.0 TON LIMESTONE PER ACRE IS APPROXIMATELY EQUIVALENT TO 50 LBS. PER 1000 SQ. FT.												
	THE NUMBER OF SAMPLES PROCESSED IN THIS REPORT IS 5.												

* 1. Sandy soils 2. Loams & light clays 3. Alkaline soils 4. Sandy loams of North Alabama 5. Heavy clays 6. Gardens, lawns, etc.

*** Rating & fertility index (percent sufficiency)

APPROVED

SOIL TESTING FORM B

Figure 2.1 Auburn University's computerized soil test report form.

Software systems that can mimic human reasoning in interpreting data are called expert systems and offer new frontiers to many areas of agricultural research, including formulating fertilizer recommendations.

In this review the author examines material relevant to the development of an expert system for making fertilizer recommendations based on soil analysis data. Development techniques, knowledge representation, user interface design and system dialogues in particular are explored.

2.3 Expert Systems in Agriculture

2.3.1 Overview

Agriculture is an area of great potential for applications involving knowledge based systems. Expert systems are a valuable tool to handle practical problems affecting agriculture.

Several authors expounded the virtues and uses that could be made of expert systems in agriculture (Gaultney, 1985; McKinion and Lemmon, 1985; Huggins et.al., 1986) before many examples became available. The range of uses that Gaultney (1985) foreshadowed are listed in Table 2.1. Note that soil test interpretation falls into the "interpretation" category while fertilizer program selection falls into the "multiple or combined" category.

Table 2.1 Possible application areas for expert systems in agriculture (from: Gaultney, 1985).

Problem Type	Possible Application for Expert Systems in Area
Interpretation	insect pest identification broadleaf weed identification crop nutrient deficiency identification tree identification grass identification soil test interpretation grain quality assessment crop marketing analysis
Diagnosis	crop disease identification animal disease diagnosis farm equipment troubleshooting electrical system troubleshooting crop drying system troubleshooting machinery system assessment hydraulic system troubleshooting chemical toxicity identification in plants chemical toxicity identification in animals
Synthesis	machinery selection and matching machinery scheduling grain marketing planning farmstead facilities layout crop selection (type and variety) irrigation scheduling harvest scheduling grain drying system configuration animal feed allocation design of waste management systems animal housing design pest control strategies
Multiple or Combined problem Type	herbicide selection fertilizer program selection herbicide application (rates, timing, etc.) specialty crop production automatic feeder control crop production tutorials short-term weather prediction combine performance monitoring runoff and flood prediction hydraulic system repair monitoring feed processing systems snow and wind load prediction

McKinnion and Lemmon (1985, p.31) went a step further and reported:

> "The prime targets for the development of expert systems applications in agriculture are the narrowly defined subject areas which have experts available for solving problems. All commercial crop production systems in existence today are potential candidates for expert systems. These expert systems would take the form of integrated crop management decision aids which would encompass irrigation, nutritional problems and fertilization, weed control-cultivation and herbicide application, and insect control and insecticide and/or nematicide application. Additional subject areas of potential are plant pathology, salinity management, crop breeding, animal pathology, and animal herd management."

Huggins et.al. (1986, p.21) reported:

> "The unique strength of expert systems is their ability to effectively integrate numeric, judgmental or preferential, and uncertain information in rational ways. Such power is important to provide the level of sophistication required by the biologically based, weather influenced systems which typify agriculture.
>
> The first farm applications for expert systems will be as decision support systems. Initial systems will deal with narrow domains. Examples include diagnosing plant or animal diseases and helping to develop complex marketing strategies. Future systems will enable more 'integrated' management for pests, animal production and crop production."

Both groups of opinion have been proven correct with examples of narrow-domain expert systems and broad-domain crop integration expert systems being published. Table 2.2 lists examples of narrow-domain agricultural expert systems.

Table 2.2 Examples of narrow-domain agricultural expert systems.

Product / Status	Implementation / Architecture	Area of Expertise	Reference
PEST (prototype)	Rule-based. Implemented in LPA MacProlog using the University of Edinburgh standard on a Macintosh Plus microcomputer.	Provides advice about the identification and control of insect pests of field crops in Western Australia.	Pasqual, G.M. and Mansfield, J. (1988)
GypsEX (prototype)	Simulation model as well as rule-based. Implemented in PennShell on a Macintosh microcomputer.	Provides knowledge-based decision support for two aspects of aerial application of pesticides against gypsy moth: calibration and spray timing.	Foster, M.A. et.al. (1991)
CHES (commercial)	Table driven. Implemented in LPA Prolog on a PC microcomputer.	Aids the appropriate selection of herbicides for weed control in sugar cane in Australia.	Coulston, E. et.al. (1991)
LUPEST (prototype)	Rule-based. Implemented in the Advisor-2 consultation shell on a PC microcomputer.	A pest management system for lucerne in New South Wales.	Bishop, A. et.al. (1992)
LUCVAR (prototype)	Rule-based. Implemented in the ESP Advisor shell on a PC microcomputer.	Helps determine the appropriate lucerne variety or varieties for a given situation in New South Wales.	Lodge, G.M. and Frecker, T.C. (1989)
SOYHERB (commercial)	Data base system. Implemented in Turbo Pascal 5.0 on a PC microcomputer.	Developed to assist people in determining herbicide options for soybean production.	Renner, K.A. and Black, J.R.(1991)

Table 2.2 continued...

Sprout-Doctor (Prototype)	Rule-based. Implemented in Crystal shell on a PC microcomputer	Aims to diagnose all disorders, pests, and diseases of Brussels Sprouts which occur in the U.K.	Parker, C. and Scaife, A. (1990)
CROPLOT (prototype)	Rule-based. Implemented in Rabbi shell on a PC microcomputer	A system for determining the suitability of crops to given plots in the process of plot allocation when planning the production of field crops on an individual farm.	Nevo, A. and Amir, I. (1991)
HERBASYS (prototype)	Combination rule-based and mathematical model. Implemented in Prolog and FORTRAN on a PC microcomputer.	Predicts the potential effects of residual herbicides in soil on succeeding crops.	Gottesburen, B. et.al. (1990).
GOATS (prototype)	Rule-based. Implemented in the EXSYS shell on a PC microcomputer.	Aims to diagnose the diseases in fibre and dairy goats.	Roberts, T. (1990a).
unnamed (prototype)	Object-oriented implementation of the "generalized set covering" model using the Smalltalk language. Unspecified hardware platform.	An expert system for the diagnosis of tomato disorders.	Guay, R. and Gauthier, L. (1991)

Table 2.3 lists examples of broad-domain agricultural expert systems where complete crop management rather than an individual facet of crop production is targeted.

Table 2.3 Examples of broad-domain expert systems.

Product / Status	Implementation / Architecture	Area of Expertise	Reference
COMAX (commercial)	Inference engine in LISP and crop growth model in FORTRAN. Implemented on a PC microcomputer but initially developed on a VAX 750.	Acts as an expert in cotton crop management.	Lemmon, H. (1986).
CALEX/Cotton (commercial)	Rule-based modules that interact via a "blackboard". No implementation data supplied.	Helps manage cotton crop production or predict the effect of one decision on subsequent events.	Goodell, P.B. et.al. (1990).
POMME (prototype)	Frame-based with a mathematical model of disease development. Implemented in Virginia Tech Prolog/Lisp on a VAX 11/780.	A system to help farmers manage apple orchards with specific advice on pest management, treatment of winter injuries, drought control, and general pesticide selection.	Roach, J.W. et.al. (1985).
Penn State Apple Orchard Consultant (commercial)	Frame-based. Developed with Pennshell and C programming language on Macintosh microcomputer. Sold in both Macintosh and PC formats.	Provides apple growers with the day-to-day support needed for crop production.	Travis, J.W. et.al. (1992).
unnamed (prototype)	Integrated knowledge processing system implemented in GURU on a PC microcomputer.	A management expert system that enables producers to fully assess the integrated resource requirements, management risks, and profit potential for the strategic and tactical decisions in muskmelon production.	Sullivan, G.H. et.al. (1989) Sullivan, G.H. et.al. (1992)

A third area of application not hinted at by McKinnion and Lemmon (1985) or Huggins et.al. (1986) was the use of expert systems to operate more traditional crop simulation models. In this type of application, the expert system calls as a sub-process the crop growth simulation model to test out management options for the crop in order to optimize crop inputs and yields.

Up until the mid eighties, the scientific mathematical model and the expert system had been seen as two distinct entities. This is illustrated by Davis (1986), who in contrasting symbolic reasoning based expert systems with the characteristics of process models typically drawn up by scientists notes that process models are typically expressed as a set of mathematical equations. The assumption behind the application of such a model is that a proper understanding of underlying processes allows the one model to be applied to a wide variety of occurrences of a phenomenon. He further notes that answers can be obtained rapidly from such mathematical models since computers and computer languages are designed to solve equations efficiently.

Alternatively, he suggests that expert systems must construct a "model" of the phenomenon for each case from the symbolic rules stored in the knowledge base. Consequently, answers can only be obtained for the range of phenomena described in the knowledge base. On the other hand, the knowledge contained in an expert system is easily modified as more understanding is gained, and during a consultation the system can be easily interrogated about the knowledge upon which the decision is based. The last feature is difficult to incorporate in a process model, since there is little distinction between the knowledge upon which the decision is based and the means of applying that knowledge.

Davis (1986) compared the relative advantages of each approach to decision making and this is summarized in Table 2.4

Table 2.4. Comparison between process models and inference-based expert systems. (from: Davis, 1986).

	Process model	Expert system
Mechanism	Algorithm	Inferencing
Knowledge	Process understanding	Rules
Domain	Broad	Narrow
User interaction	Low	High
Language	Procedural (FORTRAN, BASIC)	Declarative (PROLOG, LISP)
Speed	High	Low

Jones (1985) published a discussion of relationships between the "new" technology of expert systems as it might be applied to agriculture with more traditional modeling and computer simulation approaches. Jones' goals in this discussion were:

1. To further develop an overall systematic framework for interdisciplinary research, extension and technology transfer.
2. To further enhance the usability of models in a decision making framework in agriculture.
3. To systematize applications for which mathematical problems are unsuitable.

Jones (1985) described six ways that expert system concepts may help facilitate the use of models:

1. Estimate model parameters
2. Provide input for models
3. Restrict scenarios for model analysis

4. Interpret model results
5. Study the sensitivity of model parameters
6. Develop and test a knowledge base.

Lemmon (1986) reported the first integration of an expert system with a simulation model for daily use in farm management. He reported an expert system, Comax (COtton MAnagement eXpert, see table 2.3) that advises cotton growers on crop management at the farm level. It is a rule based expert system that operates the cotton simulation model, Gossym, the way a human expert would to determine three factors: irrigation schedules, nitrogen requirements, and crop maturity date.

The software components of Comax are the inference engine and Gossym. The inference engine is written in LISP, and Gossym is written in FORTRAN.

In the period from 1986 to 1992, the literature abounds with examples of narrow domain agricultural expert systems for the delivery of information and decision support to the rural community. This flurry of activity by scientists to attempt to deliver their work as an expert system to a large degree has not been followed by commercialization of these systems. In reviewing two of the commercial crop management systems, CALEX/Cotton and Penn State Apple Orchard Consultant (PSAOC) (see table 2.3) the common factor that appears to have helped in their successful adoption by growers has been the involvement of the end-user in the systems development, and some general instructional training in the use of the software. (Travis, J.W. et.al., 1992; Goodell, P.B. et.al., 1990). Hammer and White (1992, p.36) expressed this view clearly when, in a review of how computer models are used in agriculture, they stated:

> "Some researchers realized that the ability to predict production system responses could be used to provide decision-support for decision-makers other than researchers. However, the move towards real world decision-support was slow. This was related to lack of understanding of the needs of decision makers and the process of decision making by most researchers. Adding decision-support algorithms to complex computer models resulted in cumbersome products requiring centralized computer systems. They remained remote from the decision-maker.
>
> By considering the decision-making needs of the decision-maker, some recent efforts have been more successful. This has involved undertaking development activity collaboratively with decision-makers and their advisors. For many applications, simulation models did not need to be embedded in decision-support systems. The output from simulation studies could be used as a form of expert knowledge. In addition, simpler mechanistic models allowing ease of understanding and use have now been developed. The simpler models encapsulate the essence of our understanding of a production system and often predict its performance as well as more complicated models. .... ".

Recently, Carrascal and Pau (1992) undertook a survey of expert systems in agriculture and food processing.

They grouped the 110 applications covered in the survey as follows:

*	vegetable production: crops	35 %
*	vegetable production: planning	7
*	vegetable production: soil	6
*	animal production: animals	3
*	animal production: planning	7
*	animal production: feed	2
*	food processing	21
*	agricultural equipment maintenance	6
*	agricultural economics and financing	9
*	regulations	2
*	environment	2

Of the eight systems surveyed in the category "vegetable production: soil", four dealt with fertilization. The survey results for these systems are listed in Table 2.5. Carrascal and Pau (1992) noted in their survey that while most of the agricultural expert systems developed to date deal with narrow or restricted domains, they have been able to achieve useful results, either by eliciting, for the first time, heuristic knowledge about the domain in a structured way and/or delivering outputs at skill levels equal to or higher than those of the user.

It may be concluded from the range of examples in Table 2.5 that the use of expert systems as a delivery tool of agricultural knowledge in the form of decision support packages is a viable alternative to more traditional knowledge delivery systems. Moreover, the use of expert systems to front-end a mathematical model appears to have broad general support within the literature. The use of expert systems to deliver fertilizer recommendations is also considered viable judging by the prototyping of such systems overseas.

Table 2.5 Summary of expert systems dealing with fertilizer use. (from: Carrascal and Pau, 1992)

Product	Implementation/ Architecture	User / Developer	Goal	Reference
prototype	Frame-based knowledge representation, with hierarchy and attributed inheritance. Object oriented programming. Graphic package for building user interface.	-/Unisys ECAI Prointec. SP.	Provides the farmer with a complete knowledge base about the best fertilizer to use on his fields including the quantity, product type, method and schedule of applications while maintaining economical and pragmatic feasibility.	Armoni, A. et.al., (1988)
prototype	Rule-based expert system. Developed in TURBO-PASCAL on a PC microcomputer.	-/Laboratoire d'Informatique. Caen. Chambre d'Agriculture de l'Orne. F.	Soil analysis and advice on production plans.	Brutus, P. and Julien, J.L. (1988)
FSA prototype	Developed using Exper-Common Lisp on a MacIntosh microcomputer. Currently being converted to an IBM platform using C and C++.	-/(Dept. of Computer Science. - Faculty of Agriculture), University of Manitoba, Manitoba, Canada.	Provides expert recommendations enabling the farmers in Manitoba to obtain the best return on all their crop fertilizer investment.	Evans, M. et.al., (1990)
prototype	Developed using Personal Consultant Plus shell. Runs on a microcomputer.	-/(Dept. of Agricultural Engineering) University of Minnesota, St. Paul, USA	Determines the best manure application system and the ideal application rate, proposes solutions that optimize the use of nutrients and protect the environment.	Goodrich, P.R. and Kalkar, S.N. (1988)

2.3.2 Systems Review

To gain an insight into the development methodologies, user-interface, knowledge representation techniques, and system dialogues, four narrow domain agricultural expert systems are reviewed in detail.

PEST (Pasqual, G.M. and Mansfield, J. 1988) is a rule-based expert system that was developed to evaluate how knowledge engineering techniques may be used to provide insect identification and control advice to farmers and extension workers in Western Australia. The system was developed in LPA MacPROLOG (Logic Programming Associates Ltd.) using the University of Edinburgh standard on a Macintosh Plus. Construction was essentially an explorative process that was performed in incremental steps beginning with the acquisition of knowledge from the domain expert. Pasqual & Mansfield found it desirable for the knowledge engineers, (themselves), to become familiar with the domain they were working in. Knowledge acquisition was from printed text as formalized statements in a binary key format that could be easily translated into facts and rules. Interaction with experts was used to resolve questions not answered in the text and to check that the questions used in the consultation and the form of advice were correct. Shallow knowledge representation was used in PEST since its domain expertise was largely based on empirical association. Basic concepts and relations derived from the texts were easily mapped into a formal rule-based representation suggested by the Prolog language. The knowledge base consisted of 38 rules. Facts were represented in terms of attribute-value pairs where attributes are properties associated with objects, and values specify the nature of the attribute in a particular situation. The developers used a mixed strategy of forward and backward chaining in the inference mechanism. They also realized the user-interface needs to be of a high quality because of the high degree of interaction between the system and the user. The user friendly features of the PEST user-interface include the use of menus, the mouse and icons, and pop-up dialogue boxes. An explanation facility was considered premature for the system at its reported development stage. Figure 2.2 diagrammatically shows the navigation of the knowledge base during a consultation with PEST.

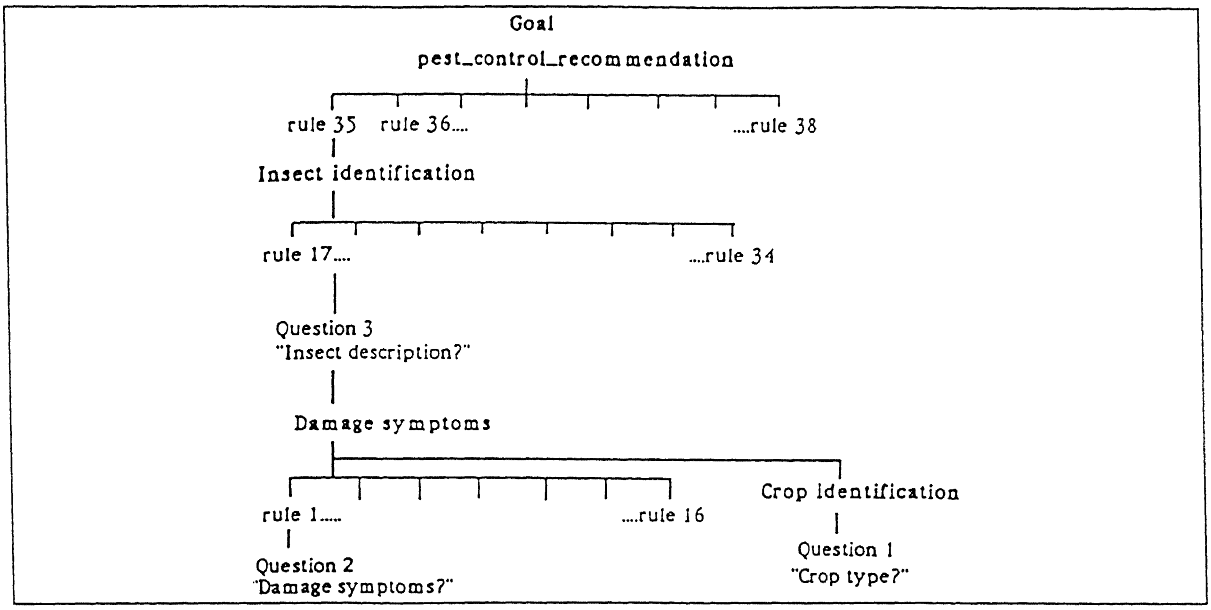

Figure 2.2 Tree diagram for PEST showing the sequence of rules used during a consultation (*from:* Pasqual, G.M. and Mansfield, J. 1988).

GOATS (Roberts, T.S., 1990a) is an expert system for diagnosis of diseases in fibre and dairy goats. The system was developed using the shell EXSYS (Exsys Inc.) on a PC, after an extensive survey of 39 system development tools. Knowledge representation was in the scheme used by EXSYS. Prototyping was used as the development methodology and was reported by the author to enable the system to prove its potential at an early stage by allowing the expert to use and appreciate the system when the rule-base was still very small. The version of the system reported contained information on 221 diseases; had 474 rules; and included 281 questions that might be asked. Roberts reported the selection of a single expert proved highly beneficial.

Multiple experts, even if in total agreement, would have created additional overheads in terms of both time and resources. The use of pre-existing text proved essential, without which the development time would have been slowed enormously.

The SUGAR BEET HERBICIDE SYSTEM (SBHS) (Edward-Jones, G. et.al. 1992), is a computer-based decision support system that provides information and assistance in giving recommendations to sugar beet advisers on appropriate herbicides, mixtures and sequences for the range of sugar beet weed problems in the United Kingdom. The system was developed in the shell, KnowledgePro (Knowledge Garden Inc.) on a PC. The shell stores information and rules with a structure and syntax very similar to its parent language, Pascal. The program was built and runs on a modular basis. The modules are initially called from the main program, and subsequently call each other as required. The entire system is menu driven with a hypertext facility that allows users to explore selected topics freely within the system without affecting the outcome of the decision. A system of rapid prototyping was used as the development methodology. The authors report that rapid prototyping motivated the experts enthusiasm for the project, demonstrated the limitations of the technology and ensured that development focused on important aspects of the domain. Knowledge acquisition was by multiple interviews with multiple experts. Conflict between the experts was resolved during workshops by a combination of discussion and consensus decision making. No time figures were presented to judge the efficiency of time use this method produced. No field testing of the system was reported. Figure 2.3 shows the conceptual program structure of SBHS.

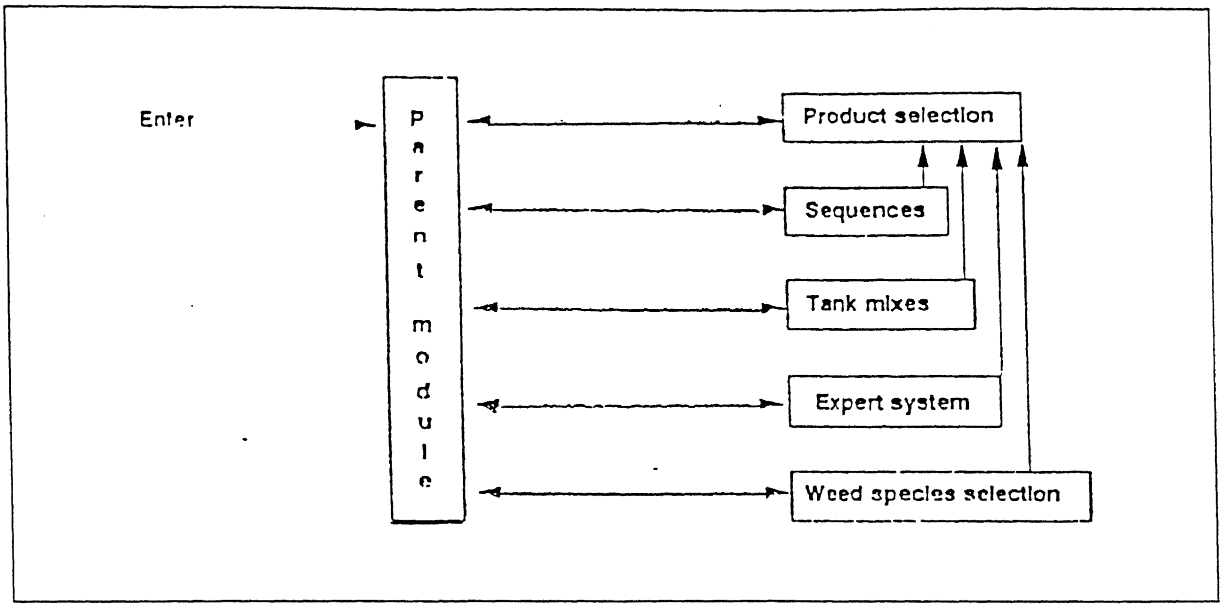

Figure 2.3 Structure of the Sugar Beet Herbicide System (*from:* Edward-Jones, G. et.al., 1992)

LUCVAR (Lodge, G.M. and Frecker, T.C., 1989) provides advice on the best lucerne varieties for a farmer to grow in New South Wales. It was designed to be used by agricultural advisers, on a PC microcomputer, when being consulted by farmers. The system contains 268 parameters which form the rule-base structure of the program and 142 individual pieces of advice in text form. Overall 560 rules are used. LUCVAR was developed using ESP Advisor (Expert Systems International). Using ESP Advisor a LUCVAR consultation takes the form of an interactive dialogue between the user and the compiled knowledge base. Questions are asked of the user who supplies yes/no answers, chooses an option from a menu screen, or enters a numerical value or text phrase. The consultation shell evaluates the value of the relevant rules and then displays only relevant advice or recommendations. Only a limited facility for a user directed navigation of the knowledge base exists. Knowledge acquisition was from a number of published sources and refined with expert opinion. The development methodology was a prototyping scheme with the authors referring to it as a series of build-test-modify cycles. They also report that upgrading to Prolog is planned to allow the use of knowledge structures not supported by the shell. Figure 2.4 shows the conceptual structure of the LUCVAR expert system.

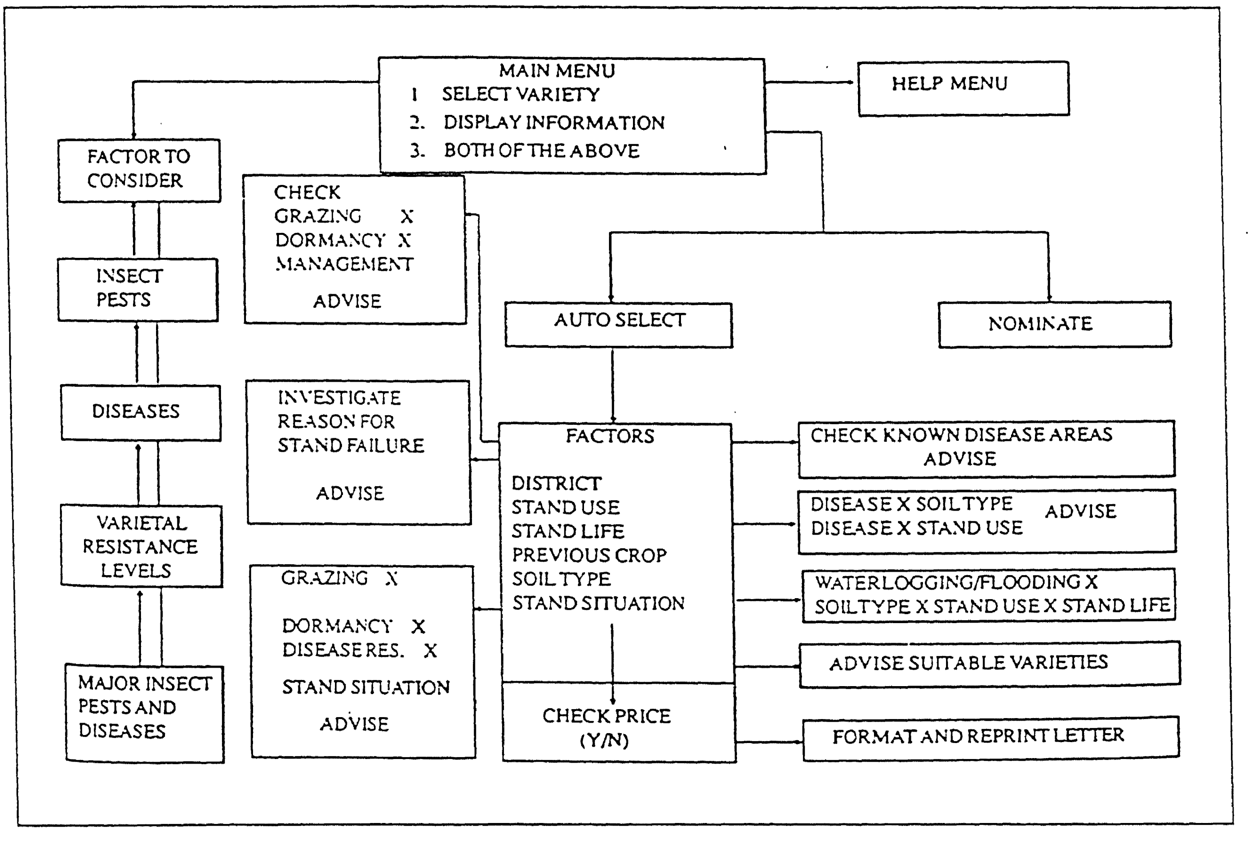

Figure 2.4 Structure of LUCVAR (*from:* Lodge, G.M. and Frecker, T.C., 1989)

2.4 System Development Methodologies

As this current study was to investigate the development of an expert system based upon linear models, it is of interest to review work on the methodology used by other authors in developing expert systems especially those that may deal with the implementation of linear models in the knowledge base.

Overviews of broad expert system development guidelines are given in Luger and Stubblefield (1989), Bielawski and Lewand (1988), Alty and Coombs (1984), Benchimol et.al. (1987) and Hayes-Roth et.al. (1983).

These texts delve into what appears to be the main subsets of expert system development cycles. These are problem description, knowledge acquisition, knowledge representation, inference engine design, user interface design/explanations and system testing/validation. These general texts deal with knowledge representation and inference engine design considerations in depth. Few if any hints as to when design principles should be applied and in what situations are given.

Wilson et.al.(1989) in reviewing the current state of the "life cycle" approach to software engineering and knowledge base system development observes that there is no consensus in industrial practice on a development method for knowledge based systems. Further he notes that there is no formalized method in use to select techniques appropriate to particular problem and knowledge types. Longwood(1990) in describing a generic expert systems development methodology used by Fujitsu also observes that "There are many expert systems being developed in Australia based on rapid form prototyping following 'intuitive' development methodologies".

Longwood(1990) brings to light the subject of rapid prototyping, a methodology recently regarded as an important phase in the systems life cycle.

2.4.1 Problem Description / Knowledge Acquisition

One key aspect of expert systems is the high level of uncertainty involved in both the applicability of expert systems technology and the potential scale of the development resources necessary to build such a system (Longwood 1990). This is often the case because of poor problem definition, incomplete specifications for both inputs and outputs, and the lack of well founded expectations of what an expert system can provide (Weitzel and Kerschberg 1989).

A systems development methodology that can cope with such poor specifications and uncertainty needs to be used.

Prototyping has emerged as the preferred methodology for developing expert systems (Weitzel and Kerschberg 1989, Longwood 1990, Roberts 1990a, Luger and Stubblefield 1989, Lodge 1990, Wilson et.al. 1989, and Morris 1990).

Weitzel and Kerschberg (1989) present a prototyping methodology (Fig 2.5) that has four basic self explanatory steps.

Many authors have presented variations on this theme but the overall thrust of technique remains the same.

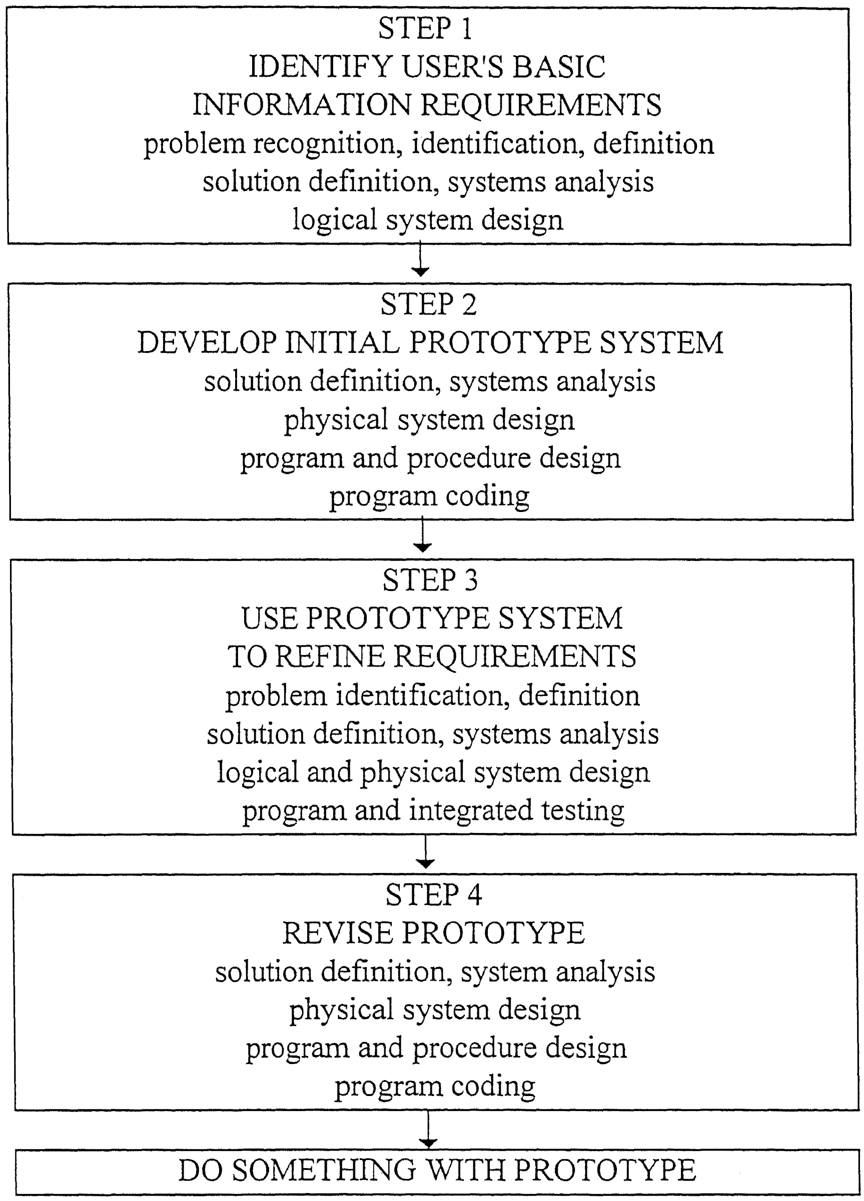

Figure 2.5 A prototyping methodology as described by Weitzel and Kerschberg (1989)

Morris(1990, p. 116) reported that prototyping had several benefits:

> "It reduces development time, eases maintenance, aids user interface design, promotes communication with users but, most important of all, it can be used as a vehicle for eliciting correct and complete specifications of requirements."

Knowledge acquisition is not a clear stage, but a crucial one, since it is involved in the problem requirement description and continues through later stages (Wilson et.al. 1989). Wilson et.al. (1989, p. 191) cites a definition of knowledge acquisition as:

> "Knowledge acquisition consists of the elicitation and interpretation of data on the functioning of expertise in some domain, in order to design, build, extend, adapt, or modify a knowledge based system. In this view, knowledge acquisition is a permanent and crucial activity throughout all stages of designing, implementing and maintaining an expert system."

Hayes-Roth et.al. (1983, p. 82) defines knowledge acquisition as:

> "..eliciting, analyzing, and interpreting the knowledge that human experts use when solving a particular problem, and then transforming this knowledge into a suitable machine representation."

These definitions support the stages of knowledge acquisition as cited by Nevo and Amir (1990, p. 54):

"1. Employ techniques to elicit knowledge from the expert.

2. Interpret this knowledge in order to infer what are the experts underlying reasoning processes.

3. Using this interpretation, construct some model (maybe a prototype) that describes the experts knowledge and performance."

There are many techniques available for knowledge acquisition including: interviews, case description, critical incident description, performance analysis, protocol analysis, twenty questions, laddered grid, card sorting and multidimensional scaling Wilson et.al. (1989).

Neale(1988) has recently reviewed this subject in detail. From this it is clear that in cases where the knowledge can be described (as in this study), interviews are the most commonly used technique for knowledge acquisition. The acquisition of knowledge in this study will be eased further by the "expert" having also published his knowledge in written form as a company technical field manual.

It would appear for this study that problem description, applicability of tools to the task and knowledge validation can be handled by the iterative development of prototype systems that can be incrementally judged at all project stages by the end-users and knowledge expert for accuracy and usability. This assumption is supported by the work of Berry and Hart (1990) who reported a trend towards a more thorough integration between design and evaluation, with an appreciation that evaluation should occur throughout the development process.

2.4.2 Knowledge Representation

Waterman(1986) observed that it was not until the late 1970's that artificial intelligence scientists realized that the problem solving power of a computer program comes from the knowledge it possess, not the algorithms or inference schemes it employs. Thus the representation of knowledge in a system became an important consideration in building expert systems.

Benchimol et.al., (1987) in discussing knowledge representation techniques describe many methods. They suggest that the aim of all of them is to improve the efficiency of inference engines during the RESTRICTION-FILTERING-SELECTION phases. The author would argue that some weight should also be given to readability and ease of maintenance in a knowledge representation. They conclude there is no way of saying whether one method is better than another as this depends to a considerable extent on the nature of the problem posed. The suggestion is made that selection of a technique "has to be based on intuition".

Waterman(1986) provides more light on the subject by suggesting that there is a standard set of knowledge representation techniques, any of which can be used alone or in conjunction with others to build expert systems. Each technique, he argues, provides the programmer with certain benefits such as efficiency, ease of understanding and ease of maintenance. Waterman(1986) observed that there are three widely used techniques in representing knowledge in expert systems - rules, semantic nets and frames. Frost(1986) reduces this to two distinct general formalizations - rules and slot and filler systems, the latter including frames, nets, conceptual dependency structures and scripts.

Rule based knowledge representations centre on the use of IF-THEN constructs. The matching of the rule's IF portions to the facts can produce inference chains through a body of knowledge/data (Waterman 1986). In problems driven by data, where branching is the norm rather than the exception, rules offer the opportunity to examine the state of the world (domain) at each step and react accordingly.

Pasqual and Mansfield(1988) in developing PEST observed that most of the current generation expert systems use shallow representation of knowledge which are often empirical associations in the form of rules. Such systems are unable to explain the basis for its reasoning beyond repeating the association. The approach chosen for building the PEST system was shallow representation of knowledge since its domain expertise was largely based on empirical association. This was best satisfied by a rule-based system.

Frost(1986) in reviewing the advantages that have been claimed for rule based knowledge representation lists the following:

a) The modular stylized structure of production rules allows such rules to be easily coded and added to the production system.

b) Encoding knowledge as a set of production rules would appear to be a natural and appropriate method for many problem domains.

c) Uncertain knowledge may be accommodated as rules.

d) Explanation facilities may be added to rule based systems.

The main disadvantage of using rules to represent knowledge cited in the literature is their inadequacy in capturing the conceptual knowledge structure or taxonomy of the domain (Johnson and Keravnou 1985, Waterman 1986, Pasqual and Mansfield 1988).

Semantic nets, frames and slot and filler representations on the other hand can all be considered together as being representations that use a network of nodes connected by relations and organized into a hierarchy (Waterman 1986). Alty and Coombs (1984) report the popularity of this method in the early 1980's arose from the processing power provided by the "is-a" link to build up hierarchies of concepts. These "is-a" links built up strong inheritance within the representations which provided an effective way of simplifying and reducing the information required to be stored at any particular node. This considerably speeded up processing of the knowledge.

Johnson and Keravnou (1985) observed that while frames and associative network schemes capture the given conceptual knowledge structure adequately, a scheme of rules does not adequately capture the given conceptual knowledge structure. As an example they show that the taxonomy of a disease is not explicitly represented through rules; it is implicitly represented by repeating the same conditions in the antecedents of rules and by including clauses that restrict competing hypotheses.

Guay and Gauthier(1991) in work on knowledge representations in a tomato disorder diagnosis system reported that rule based systems are poorly suited to problems requiring the identification of multiple simultaneous disorders. Adding frames to the basic rule based representation allowed the creation of complex semantic networks and the use of generic pattern-matching rules.

Frost(1986, p. 41) summed up the differences between the two approaches simplistically by observing:

> "that the languages of formal logic and rules in production systems allow us to represent various aspects of the universe. However they do not, in general, allow us to structure this knowledge to reflect the 'structure' of that part of the universe which is to be represented.
>
> Slot and filler representations, on the other hand, include facilities for representing structure. Slot and filler formalisms include 'frames', 'nets', 'conceptual dependency structures', and 'scripts'."

It could be inferred from the lack of its consideration in the literature, that natural language is still not considered a reasonable representation of knowledge in expert systems. Frost(1986) observes that natural languages such as English is not used for the representation of knowledge in a knowledge based system because they are not formal languages. By "formal" Frost means that a language is well defined in the sense that (a) rules exist for the construction of legal expressions and (b) rules exist such that the meaning of legally formed expressions can be derived from the meaning of the components of those expressions. Frost(1986) points out that no one has yet been able to identify all the rules which determine the structure and meaning of "legal" sentences in any natural language.

In attempting to reach some common ground between established theories and techniques used in database technology to manage large collections of data and knowledge bases, Frost(1986) suggests that knowledge which is stored in some standard canonical form would be of most utility. As the above discourse shows, there are many different ways in which a collection of knowledge can be associated to form a knowledge base. Martin(1977) in discussing data base design principles describes a technique that gives a near optimal grouping of data. The resulting minimal structure of the data is referred to as a canonical schema. Martin(1977) defines a canonical schema as "a model of data which represents the inherent structure of that data and hence is independent of individual applications of the data and also of the software or hardware mechanisms which are employed in representing and using the data". Martin(1977) defines a canonical record structure as one which is in third normal form. Third normal form is the result of applying the techniques of "normalization" (designed and advocated by E.F. Codd(referenced from Martin 1977)) to data. Normalization is a step-by-step process for replacing associations between data with associations in a two-dimensional tabular form. The table is referred to as a relation. The relation or table, is a set of tuples. If there are n-tuples (ie. the table has n columns), the relation is said to be of degree n. Relations of degree 2 are called binary, degree 3 are called ternary, and degree n are n-ary.

A relational data base is thus one constructed from this "flat" two-dimensional arrangement of data items. The author argues that this concept should equally apply to the arrangement of items of knowledge in a knowledge base. This argument is supported by Debenham(1985) and Frost(1986).

Debenham(1985) in describing a method for knowledge base design argues the need for the establishment of design and maintenance techniques for knowledge bases in which the formalism for the knowledge component embraces the expressive power of Horn clause logic at least. He further observes that such design and maintenance techniques should be capable of modeling the knowledge, of producing a good logic implementation of it, and of maintaining the knowledge effectively; that is, with a level of sophistication which compares with current information analysis, implementation and maintenance methods.

In Debenham's method for developing a logic data base, rules are represented, where possible as Horn clauses. These clauses are expressed in terms of predicates which are often relations. These relations may be thought of as containing information represented as tuples. In a sense the predicates constitute the vocabulary in terms of which the knowledge itself can be expressed. Thus, before the knowledge itself can be expressed, this vocabulary must be determined. Debenham(1985) observes that this process may be achieved by conventional information analysis. He used a version of "Binary Relationship" modeling to analyze and represent those features of the data which could not be expressed as Horn clause logic. Frost(1986) in developing the argument for the use of a relational approach to knowledge representation observes that if the relational approach is restricted to binary relations (rather than relations of any degree in third normal form), a method called the "Binary Relational" approach is obtained. In essence, the same method used by Debenham(1985).

Frost(1986, p. 24) lists various advantages derived from adopting the "Binary Relational" approach:

"a) The uniformity of the knowledge representation results in simplified storage and manipulation of knowledge.

b) Many-to-many relations can be represented with no replication of knowledge.

c) It is even easier than in the relational approach to add new knowledge to the knowledge base.

d) If tuples are labeled, it is possible to represent higher-order relationships."

The disadvantages of such an approach as listed by Frost(1986, p. 24-25) are mainly ones of implementation and are listed below:

"a) A large amount of storage space is usually required. Although knowledge is not replicated, since all representations are explicit, the knowledge base will be considerably larger than if conventional files were used.

b) Since related tuples (i.e. tuples which have a field in common) cannot always be stored in physical proximity, the retrieval of collections of related knowledge can take more effort than if conventional files were used. ....In a conventional file system, the contents of a record are generally chosen to comprise a collection of knowledge which is generally required to be retrieved at the same time."

Jansen(1987), in discussing a data dictionary approach to the software engineering of rule based expert systems, states that a knowledge dictionary developed for a system can support any relational cross product between the relations in the schema. Jansen(1987, p. 115) observes:

"This opens the way for a relational view of knowledge, where different users may see the same knowledge in a different context or perspective. ...The relational view method may be a way of hiding the implementation issues from the expert, thus expressing the knowledge closer to their understanding".

Jansen(1987, p. 115-116) concludes from his work on the SIRATAC PLUS redevelopment project that:

"...expert systems should be viewed in the same light as commercial software systems for design and implementation. When expert systems penetrate the commercial market, most expert systems development will be seen as an adjunct to conventional systems, interfaced with the conventional database systems and acting as a component in a larger information system. This integration with existing database systems implies that expert

> systems development should utilize the tools already available for database systems, in the form of modeling formalisms, data dictionaries, and eventually expert system application generators".

Thus from the literature, knowledge representation for this project, where empirical associations are used to interpret data, may be best served by a rule-based schema. Because of the minimal number of user views to be supported by the system and constraints imposed by the intended hardware platform, a standard relational rather than a binary relational record structure is indicated.

2.5 User Interface Design and Explanation Facilities

These two topics have been grouped together here for discussion as much of the literature now considers both the physical operations and visual displays involved in communicating task orientated information to the user and the more cerebral task of handling conceptual sub-goals within the task as a continuum of a single concept - the user interface.

The emphasis given to the design and implementation of the user interface has changed rapidly over the past decade. Early text books on expert systems delve deeply into the realms of knowledge representation and inference engine design and mention in passing the need of some type of usable interface with the user. For example Bielawski and Lewand (1988) in the second chapter of their book which outlines expert systems concepts, devote seven pages to describing inference engines and one page to the user interface.

Current literature reports a much heavier emphasis both on the design and implementation of the user interface. Berry and Broadbent(1987) report two studies where the coding of the expert system was dissected out into the various system components. One study reported 8% of the code was inference engine, 22% was knowledge base, and 44% was involved in user input and output. The other study claimed about 30% of effort went into the reasoning part of the system compared with about 70% on the user interface.

One of the clearest lessons learned from the early pioneering expert systems is that excellent decision making performance by itself will not bring with it user acceptance, confidence or continued use. The user interface needs to be considered from a very early stage of system development. Failure to recognize the user interface needs of expert system users has been reported as the biggest reason for the disparity between developed systems and systems in everyday use (Kidd 1985, Berry and Broadbent 1987).

Complete discussions of research results and their implications on user interface design are found in Rubin (1988) and Shneiderman (1987). Though not reviewed in depth in this study, underlying features of the user interface that affect its mechanical delivery are screen design, color and windows all of which the above mentioned authors provide functional descriptions.

Guidelines that are emerging from this research suggest that the user interface must:

a) Be consistent in form and action. This is the corner stone of the notion that users generalize about the user interface in order to navigate through it when they have no concrete knowledge of that navigation path.

Lewis(1986) while noting that learning to control a computer seemed to require constructing a mental model adequate to indicate the causal connections between user actions, system response, and user goals, he went further and proposed that four simple low-level heuristics were adequate to interpret common computer interaction patterns.

His four heuristics were: a)Identity heuristic (separate occurrences of a thing are not coincidental); b) Loose-ends heuristic (if you are showing me how to do something I am entitled to assume that everything you do contributes to the goal whose accomplishment you are demonstrating); c) Previous action heuristic (if an event follows an action immediately it is plausible that the action caused the event); d) Prerequisite relations (I need to note that the display of the word CUT by the system is a prerequisite of your being able to release the mouse button on it. This permits me to link your action in pressing EDIT to the overall goal: you pressed EDIT to get the system to display CUT so that you could signify deletion by releasing the mouse pointer on it).

Lewis(1986) suggested that designing interactions so that they fall within the scope of these four heuristics may lead to easier mastery of a system by learners.

Three years later, Lewis et.al (1989) proposed a theory relating consistency of the interface directly to the generalization process it is intended to support. The authors related causal connections obtained in using a system to generalizations about other parts of a system that led to its successful use. They devised a framework of eight heuristics (rather than the previous four) concerning the design and implementation of consistency in an interface such that actions based on generalizations will always be successful.

As a simple example of this concept, consider the use of the F1 key in most PC based systems. One has a fair chance of getting on-line help by pressing F1. Similarly by pressing ESC in a menu system one has a more than even chance of regressing back to the previous menu. In a well designed system this is always true.

Thus we can set ourselves a design goal; consistency of task commands should be such that it supports user generalization of the user interface.

b) Be tailored to the needs of the user. Berry and Broadbent (1987) report that a major factor which can affect the ease with which people use an expert system is the ability of the system to tailor its behavior to the specific need of an individual user. In a narrow domained expert system this is relatively easy since the system is expected to only perform a set of sub-tasks in order to fulfill a single major task - in this project make a fertilizer recommendation. In a broader based expert system say of plant nutrition, the user could well expect several diverse outcomes from a consultation; a fertilizer recommendation, a deficiency symptom diagnosis, or a discourse on nitrogen requirements of plants.

To tailor the system to an individuals needs, many researchers have looked at the various ways of implementing a user interface sensitive to various models of users. Berry and Broadbent (1987) report that many of the early expert systems were only designed for one type of user. They required the user to be familiar with the concepts and terms of the domain. It was originally thought that it would be easy to transform the systems so that they would be suitable for more novice users. It is now realized, however, that communicating with unknown users, unfamiliar with a domain, is a major obstacle in the construction of an expert system. Moreover, where systems are transformed so they are usable by domain novices, they often become obsolete as far as the more expert users are concerned. Hence the need for some type of adaptability on the systems behalf.

The need for an adaptive interface is questioned however where the system will be implemented in a narrow domain or with a narrow spectrum of user class.

An interesting dichotomy arises when one studies the logistics of implementing an adaptive user model for user interfacing within a system. As well as the system having a model of the user, from previous argument we can assume that the user will have a model of the system, and in some cases these will interact. The user's model of the system guides actions and helps in the interpretation of the system's behavior. If, however, the system is changing its behavior to fit the user this can lead to 'inconsistency' difficulties.

Another facet of the user interface is raised at this point. That is the area of 'mixed' dialogues. While we might not see the need for an adaptive interface in an expert system used by a narrow spectrum of users, there is argument for the user to have some facility to guide the consultation with the system rather than the consultation being totally led by the expert system. This consideration is of particular importance in this study where there are many ‘correct’ channels of navigation through the system. Kidd(1985) raised the issue that expert systems must be good consultants as well as good problem solvers. When developing an expert system, designers need to ensure that the dialogue facilities of the system match the communication needs of the users and the constraints of the task environment.

In the current project, in making a fertilizer recommendation, a user may want to provide the system with a recommendation of their own, rather than let the system optimize the available fertilizers against the requirement constraints. A facility should therefore exist whereby a) the user can volunteer a fertilizer recommendation and b) the system can expertly judge or corroborate the relevance of this recommendation within the current context.

The explanation facility of the user interface should also be capable of reflecting the various degrees of user competency. This is possibly easier to make adaptive due the consistency in the interface not varying, rather only its content. The expansiveness of the explanation facility is arguably a candidate for the user selection of the level of explanation rather than induction from a user model.

c) Be user or task orientated rather than method orientated. This principle of user interface design is discussed by Sommerville (1989) and embodies the notion that the interface should reflect and support the goals of the user rather than present the mechanics of the methodology employed. Mehlenbacher et.al. (1989) observes that the user's understanding of the task based on computer concepts could be very different from the understanding of the task based on user goal concepts. They suggest that the user interface design should accommodate the user's problem/goal representation and the knowledge base the user is bringing to the interaction. Chignell and Waterworth (1991) reinforce this concept in their study of the relationship between the physical and cognitive interface. They argue that the goal of users is to carry out tasks, and we assume by definition that the physical operations and visual responses required in satisfying the goal are handled through an interface. However, detailed physical actions will be carried out in order to achieve task oriented conceptual goals. But the users are not seeking (primarily) to select cursor positions, load files, or open and close windows per se, but through these actions they operate on the system's model of the task in such a way as to achieve their goal. Thus the need for the cognitive and the physical interface to be closely associated. Chignell and Waterworth (1991, p. 19) affirm that "This is achieved by moving beyond the display level, and beyond presentation management to sequences or structures of interaction that achieve functions in relation to user's tasks.".

There were five main styles of user interfaces found in the literature.

a) Menu selection: Users are presented with a brief list of items using familiar terminology. They can conveniently choose the most appropriate item by pointing, typing, or scrolling on the list. It is argued that this structured approach enables users to accomplish their tasks with little or no training (Rubin 1988, Shneiderman 1987). One could say that currently menu-driven interfaces are the standard for facilitating human-computer interaction. The goal in the design of any menu should be to facilitate the user's ability to make a choice quickly and accurately.

WIMP (Windows, Icons, Menus, Pointers) style interfaces can also be considered as a version of this main category though as they mature some elements of direct manipulation are being incorporated into them. Shneiderman (1987) in reviewing work on screen design notes that while 'windows' provide visually appealing possibilities and intriguing opportunities for designers, their advantages and disadvantages are still poorly understood.

Mehlenbacher et.al. (1989) reports two primary issues as most relevant to achieving this goal: the hierarchical organization of menus and the organization of items on any one menu.

The major emphasis for hierarchical organization is on the proper balance of menu breadth (the number of items one must scan on a given menu) and menu depth (the number of menus one must pass through to achieve the desired goal) because they affect search time and selection accuracy. There appears to be three variables most relevant to determining the proper balance of depth and breadth: the number of items a user must scan, the number of choices a user must make, and the system response time to those choices (Shneiderman 1987).

The emphasis for individual menu organization is on the arrangement of menu items. The issue is identifying the most effective organization of the items for the population of users. The two main options usually considered are either semantic (functional) ordering or alphabetic ordering of items in a menu list.

For full discussions of both these topics refer to Mehlenbacher et.al. (1989) and Shneiderman (1987). Although there are conflicting results about item layout within a menu, for this study the guidelines of Shneiderman (1987) will be used which recommend the use of "task semantics to organize menu structure".

b) Form fill-in: When data entry is the primary goal, form fill-in systems offer a familiar context for entry of data with only modest training. Issues affecting this style of interaction as identified by Shneiderman (1987) are the importance of screen layout parameters such as grouping related items, use of highlighting techniques, alignment (left or right justification of labels and values), consistency across screens, and multi-screen versus single screen layouts.

It is anticipated in this project that manual data entry will be facilitated for the soil analysis data. Again, the guidelines as presented in Shneiderman (1987) will be adopted.

c) Command languages: These are attractive when sufficient learning time is available and frequent use is anticipated. Other conditions reported for appropriate use of command languages are when users are knowledgeable about the task domain and computer concepts, screen space is at a premium, response time and display rates are slow, numerous actions can be combined in many ways, and macro definition is desired (Shneiderman 1987).

d) Natural language: Interaction by natural language dialogue is seen as the "ultimately desirable" style by many researchers. However, Berry and Broadbent (1987) argue that natural language is not likely to be suitable for all applications. Some applications such as this project, rely heavily on numerical or graphical data. Additionally, a natural language interface in the short to medium term future will continue to demand a certain degree of keyboard competency.

The incorporation of natural language into the interface of this project was considered beyond the scope of this project. Further, it could not be demonstrated that a natural language interface would more efficiently allow a user to accomplish the goal of making a fertilizer recommendation.

e) Direct manipulation: The central issues of this style of interaction seem to be visibility of the objects and actions of interest, rapid reversible incremental actions, and the replacement of complex command language syntax by direct manipulation of the object of interest - hence, the term direct manipulation. The interface taps the user's knowledge and analogical reasoning skills with tasks generally being accomplished by pointing and moving instead of typing.

Having reviewed the objectives and styling of the user interface, the remaining topic of its content or 'system messages' needs to be addressed.

Shneiderman (1987) reports that user experiences with computer system prompts, explanations, error messages, and warnings play a critical role in influencing acceptance of a system. Shneiderman (1987) gives seven guidelines for developing system messages and these are detailed below.

a) Be as specific and precise as possible. This guideline implies a contextual knowledge of the users situation within an application by the system and a response based on that context. Context sensitive help facilities available in some applications is an example of this.

b) Be constructive - indicate what needs to be done using a positive tone rather than condemnation. Rather than condemning users for what they have done wrong, system messages should be positive and indicate what they need to do to set things right. Writing positive messages can be easily achieved. The harder task in fulfilling this guideline is in offering advice as to what the user should have done. This requires on the systems part some estimation of what it was the user was attempting to do: a situation which may not always be possible. Approaches to this problem have been to inform the user of the possible alternatives and let the user decide. Shneiderman suggests that preventing errors from occurring should be the preferred strategy.

c) Choose user-centered phrasing. This guideline points the developer towards system messages that suggest to the user's that they are in control of the system -

the system is subservient to the user. This is contrast to system messages that portray the system as being in control of the dialogue.

d) Consider multiple levels of messages. Again the user should be allowed to control the kind of information provided by system messages and explanations. Verbose explanations at every request will be off putting to practiced users as well as being time consuming. Standard and extended on-line help facilities, summary or full explanations are examples of how this guideline can be implemented.

e) Use appropriate and consistent form. Consistency of grammatical form, terminology, abbreviations, visual format and placement of system messages and explanations all reinforce the users conceptual model of what responses can be expected from a system. This helps users to become familiar with such things as where to look for messages, prompts or explanations, when to look for them and how to respond to them.

It is interesting to note how similar the guidelines for producing good system message and explanations are to the requirements of the user interface.

2.6 Development Tool Selection

As previous sections have elucidated, the selection of a development tool greatly impacts upon the knowledge representation techniques and the inference engine design employed in a project. Further considerations of tool selection need to account for portability, maintainability, software distribution, file transfer and external connectivity, and the effectiveness of the user interface.

Some authors, for example Hayes-Roth et.al. (1983), have conducted reviews of expert system tools without making any apparent attempt to develop (or divulge) their methodology for review or evaluation in a practical format. Other authors define to various degrees their method for evaluating expert system tools.

Bielawski and Lewand (1988) provide a useful chapter on tool selection. They highlight the need for an expert systems development tool to fit five criteria they have developed to aid tool selection. These criteria were:

a) Fit the tool to the problem.

b) Effectiveness of the developer interface.

c) Effectiveness and friendliness of the user interface.

d) Integration capability with existing programs and databases.

e) Run-time licensing for delivered systems.

Carrascal and Pau (1992) observed that expert systems applications in agriculture are more complex than most of those currently in use or under development in other fields. They concluded that many currently used knowledge engineering tools (shells) are inadequate for developing agricultural expert systems because they restrict applications to narrow domains, and observed that most of the agricultural expert systems presently in use or under development are able to solve only limited problems and do not cover the wide environment of the farm.

Roberts (1990a) reports 39 different tools were evaluated before the expert system shell EXSYS was selected to develop GOATS. In a separate report (Roberts 1990b) he details the process that led to the selection of this tool. The criteria, listed below, seemed to be a more practical superset of the criteria listed by Bielawski and Lewand (1988). Roberts' (1990b) criteria were in order of importance:

a) Tool availability
b) Machine requirements
c) Rule capacity (possible size of knowledge base)
d) Cost
e) Form of knowledge representation
f) Inference mechanisms
g) User interface
h) Explanatory facilities
i) Developer interface
j) Ease of maintenance
k) Vendor support facilities

Roberts (1990b) found that by the time the fourth criteria (cost) had been applied to the original set of 39 development tools, only 9 tools remained under consideration. The remaining tools were then examined in some detail using as a focus the last seven criteria, and ranked in order of preference for the project.

Lodge (1990) set out 10 criteria by which his group judged development tools. This criteria led to the selection of the expert system shell ESP Advisor/ADVISOR 2. Five other shells were evaluated (including EXSYS) but the initial selection remained their development platform. Though slightly different from those criteria used by Roberts (1990b), Lodge's criteria were in the same vain though some difference in importance of various criteria was evident.

Outside of the agricultural arena, Bodkin and Graham (1989) reported on the desiderata used for selecting between two expert system shells used in the ARIES (Alvey Research into Insurance Expert Systems) project. (again, only shells were considered), and Gevarter (1987) compared expert system building tools.

The similarity between Robert's, Lodge's, and Bodkin and Graham's set of criteria is not surprising. The latter both listed as their first criteria the effectiveness of the user interface. Other similarities were the broad spectrum of inference mechanisms supported by a shell, the cost of the product, 'how' and 'why' facilities, separate run-time versions or compilation to protect the knowledge base, and allow interfacing to other programs. Bodkin and Graham's list included two criteria not mentioned in Lodge's or Robert's set; that of uncertainty management and debugging and testing aids such as execution tracing and rule/object browsing.

It can be inferred from the similarity in needs from these two diverse application areas that in judging expert system shells, a base set of criteria as gained from the literature and outlined above, coupled with some project dependent criteria, should be adequate to guide the selection of a shell based development tool.

Table 2.2 demonstrates that a vast array of software development tools can and have been used to develop expert systems in the agricultural arena. Few authors give any indication of why a specific tool was used over another.

Zahedi (1990) presents an attempt to introduce a formal decision analysis methodology into the arena of evaluating expert systems software products. The author identified a hierarchical structure for expert system products (Fig 2.6).

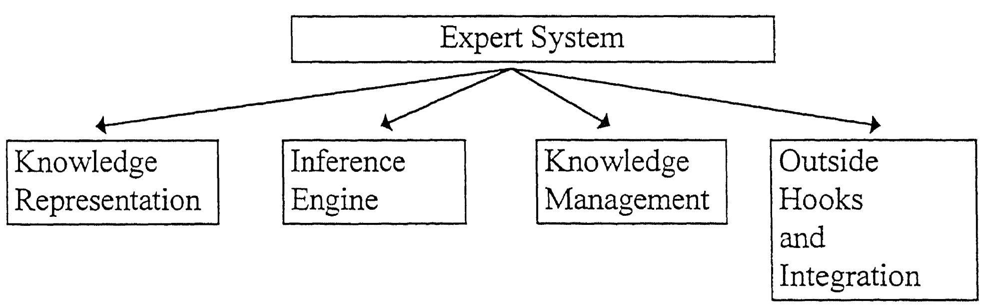

Figure 2.6 Components of an Expert System Product that can be Quantitatively Evaluated (*from:* Zahedi (1990))

The evaluation process then consisted of four steps:

a) Identification of the expert system tools' functional structure.

b) Quantification of the relative weights of the functional elements of the expert system tools.

c) Comparison of the products for the functional elements.

d) Aggregation of the product scores for each element and the relative weights of elements to arrive at a single score for each product.

This whole process depends on the development of the relative weights in the second step. The flexibility of this approach is that as development requirements change for each project, these changed requirements are reflected in differing relative weights of the product components leading to variable scores for products depending on the problem at hand.

By far the majority of systems have been developed with the use of shells. However they have their limitations. Lodge (1990) reports that when his group evolved into developing larger, more complex knowledge bases, considerable external PROLOG programming had to be undertaken to build flexible menuing and database systems. Similarly for problems that involved the linking together of several knowledge bases, programs had to be developed to handle file transfer and interfacing mechanisms. Srinivasan and Engel (1991) in reporting their "Expert System for Irrigation Management" also found limitations in the expert systems shell EXSYS used in their project. They switched development environments to another shell, but still required the use of programs written in QUICK BASIC for menuing and program integration.

Few such limitations have been reported in systems developed using 'languages' as opposed to expert system shells.

Guay and Gauthier (1991) developed a tomato disorder diagnosis system using the Smalltalk/V286 (Digitalk Inc.) environment. Extensive use of windows by this environment facilitated the development of an elegant but functional user interface. They report the implementation in an object-oriented environment as being "quite straightforward" since their model solution was based on the use of sets which corresponded closely to the notion of classes. Davis et.al. (1989) also used Smalltalk to develop the prototype of a decision support system for evaluating catchment policies. This group reported that Smalltalk was chosen as the language for the prototype partly because of the speed with which prototypes can be developed and partly because its capabilities matched some of the characteristics of the problem - again their solution model mapped neatly onto the language data structures.

The use of more standard expert system languages such as the declarative languages LISP and PROLOG to develop agricultural expert systems has been reported. Roach et.al. (1985) used PROLOG to develop the apple orchard management system POMME. Pasqual and Mansfield (1988) also used PROLOG to develop a prototype expert system for the identification and control of insect pests. Lemmon (1986) reported the use of LISP to write the inference engine of COMAX, an expert system for cotton crop management.

Of particular interest to this project was the work of Gottesburen et.al. (1990) whose team developed an expert system to offer prognoses of the persistence of herbicides and their effects on succeeding crops using PROLOG. The similarities of this work to the current project were the integration of numerical data into near linear models of crop response, the functional windowed user interface, and the optional explanation component of the system.

LISP has been widely used in the USA as an expert systems language (Walker et.al. 1987). It is designed for symbol manipulation, but is a functional rather than a relational language with various operations for logic, such as unification and search needing to be programmed in LISP as required. PROLOG on the other hand, is a programming language centered around a small set of basic mechanisms, including pattern matching, tree-based data structures and automatic backtracking (Bratko 1987). It is relational in nature and has a certain 'hybrid vigor' in that it contains declarative features from computational mathematical logic and some procedural aspects from conventional programming (Walker et.al. 1987).

Very few publications about the use of programmable spreadsheet programs such as Excel 5 for the development and delivery of expert systems were identified. Costello et.al. (1991) reports the use of Lotus 1-2-3 version 2.01 to provide a user interface for data entry into a rice crop simulation program. While execution speeds were slow due the hardware used (8088 CPU @ 8MHz) and the macro language of that version not being as developed as later spreadsheet macro languages, the authors still were able to report that the system performed well, providing interactive creation of input files prior to simulation and then displayed model predictions in tabular and graphical formats. The authors indicate that spreadsheet software was utilized because of its inherent advantages in viewing and modifying tabular data and in displaying graphics.

The literature suggests therefore that expert systems developed using shells may at some stage during their life cycle need upgrading using facilities not available in the shell. Though shells may offer developers an easier entry point to the technology of expert systems, the use of a language supported by an adequate development environment offers a more stable development, delivery and maintenance platform. Both Prolog II for a DOS environment and Excel 5 in the Windows environment meet this criteria.

2.7 Summary

Examples of narrow domain expert system prototypes abound in the literature but few if any have taken the next step of commercialisation. Further, a broad range of knowledge representations, inference engine styles, and development environments seem to have been successfully used to develop these prototypes. This plethora of approaches to expert system development offers little in the way of gauging one development methodology against another. What does come through in the literature very strongly however, is that no matter what development tools, knowledge structures and inference engines are used, an iterative prototyping development life cycle has many positive attributes in expert systems construction. How this is reconciled with project management requirements of budgetary and time scale milestones does not seem to have been fully analysed in the literature.

The literature review also indicated the importance of the user interface to the user acceptability and use of an expert system. Expert system examples in the literature show no difference in user interface design principles than that found in more conventional computer programs. It is therefore reasonable to assume that guidelines used by software engineers for the development of more conventional computer programs can be used. This is supported by the design of the user interface reported in the small number of commercialized expert systems.

Research into expert systems and their commercialisation appears to be still in an exploratory stage with few clearly defined methodologies being published and much research being qualitative as opposed to quantitative in nature.

CHAPTER 3

3. *RESEARCH OBJECTIVES AND HYPOTHESES*

Fertilizer selection is an important decision for horticultural producers. Fertilizer may represent 10-20% of the pre-harvest variable costs of a crop so judicious selection of fertilizer can have a significant impact on the farm's economic performance.

Soil analysis provides a sound basis for making fertilizer recommendations. The process involves agronomists assessing the analysis data by comparing it with published standards which indicate the level of fertilizer to be applied to optimize yield. Further, the agronomist must assess the influence of other factors such as soil pH, conductivity and buffering capacity. Account must also be taken of complex interactions which occur between plant nutrients and the effects of various fertilizers on these nutrient interactions.

The task is complex and requires some level of expertise by the agronomist in soil science and plant nutrition. Despite this, the standards and nutritional knowledge are well documented and the agronomist does not have to rely upon intuition. The vast range of fertilizers available to growers have active constituents mixed in a multitude of combinations to meet virtually every nutritional need of a crop.

A solution space therefore exists for each combination of crop and soil analysis. The fact that this solution space exists is demonstrated by the credibility given to the current manual (and time consuming) process of developing fertilizer recommendations from soil analyses.

The task therefore seems appropriate to mechanize as a computer based expert system.

Luger and Stubblefield (1989) report guidelines for determining whether a problem is appropriate for expert system solution. It would therefore be prudent to judge this project against these criteria and be guided by the outcome.

These guidelines are:

1) The need for the solution justifies the cost and effort of building an expert system.

   In this case a solution would provide a three fold benefit; a) provision of timely, accurate and consistent delivery of fertilizer recommendations to horticultural producers; b) the capture and storage of expertise in a form available for broader use and long term archiving; c) a consultative/explanatory facility to increase the user's understanding of the problem solution.

   The literature review suggests that a lack of consultative and flexible explanatory facilities may account for the failure of many expert systems to provide effective decision support in field operations.

   An objective of this project is to investigate issues associated with the provision of dialogues which support a range of user queries. The author proposes that the provision of a dialogue which allows the user to take an active role in the problem solving process (in this project the generation of fertilizer recommendations) may be both acceptable to the user and practical to implement. Implementation of this facility in the expert system will be explored and described.

2) Human expertise is not available in all situations where it is needed.

Few growers who avail themselves of the soil analysis service offered by fertilizer companies have the necessary knowledge to relate soil analysis results to crop requirements in most situations. The fertilizer company representatives, to complete the service to the growers, must therefore provide this interpretation for them. This necessitates that the representatives be trained to a competent level of familiarity with the task of making fertilizer recommendations before being allowed to make fertilizer recommendations. This level of competence is not adequate in all situations (combinations of soil analysis and crop) and frequently an expert plant nutritionist employed by the fertilizer company or the Department of Primary Industries must be called upon.

Furthermore, in the time context of this project, the fertilizer company representatives role is being redefined so that interpretations and fertilizer recommendations will not be regularly made by them. Instead, the fertilizer reseller (usually independent local distributors of rural products including fertilizers) is being asked to undertake the role of making fertilizer recommendations from soil analyses. These resellers have even less knowledge and expertise in this role and will therefore be heavily dependent on backup expertise from the fertilizer company. A computerized expert system to be used by resellers to make fertilizer recommendations is therefore seen as a viable alternative to providing human expertise backup services to the resellers.

The ultimate end-user of the commercial system is therefore seen as the fertilizer reseller's staff. But because few, if any, currently have the computer facilities or skills to test and use the proposed system they will not be targeted in this study as the end-user. Also, the aim of this study is not to produce the final commercial system but to prove the concept through development of a pilot commercial system or prototype.

Therefore, this study will use as its end-user the fertilizer company staff whose job it is currently to provide the knowledge support and training to fertilizer resellers. The small team within the fertilizer company see it as part of their training role to support adoption of the proposed system once it is proven to themselves and the fertilizer resellers have the competence and computer equipment to use the system. It is the role of this team within the fertilizer company to deliver to the fertilizer resellers, the training, commercial tools (including this system), and the technical support of their companies analytical services that back up and add value to their core business of fertilizer manufacture and distribution.

3) The problem may be solved using symbolic reasoning techniques.

In contrasting symbolic reasoning based expert systems with the characteristics of process models typically drawn up by scientists, Davis (1986) notes that process models are typically expressed as a set of mathematical equations. The assumption behind the application of such a model is that a proper understanding of underlying processes allows the one model to be applied to a wide variety of occurrences of a phenomenon. He further notes that answers can be obtained rapidly from such mathematical models since computers and computer languages are designed to solve equations efficiently.

Alternatively, he suggests that expert systems must construct a "model" of the phenomenon for each case from the symbolic rules stored in the knowledge base. Consequently, answers can only be obtained for the range of phenomena described in the knowledge base. On the other hand, the knowledge contained in an expert system is easily modified as more understanding is gained, and during a consultation the system can be easily interrogated about the knowledge upon which the decision is based. The last feature is difficult to incorporate in a process model, since there is little distinction between the knowledge upon which the decision is based and the means of applying that knowledge.

Alty and Coombs (1984) support the view that expert systems require an alternative computer representation than traditional process models. They argue that traditional computer languages such as BASIC, COBOL and PASCAL, although capable of representing knowledge and knowledge processing procedures, are cumbersome. The representation is to closely connected with the way in which a computer operates. Alty and Coombs (1984) suggest a far better approach to representing classes and relations as required in many expert systems can be achieved through the use of predicate calculus notation. This notation when reduced to clausal form has been implemented with a single control structure as the computer language PROLOG.

Davis (1986) summarized the relative advantages of each approach to decision making in Table 2.4

The problem of making fertilizer recommendations from soil analyses can be visualized as finding solutions to many linear models using combinations of inputs bound by constraints of closeness of fit of the recommendation to the modeled requirement. In terms of the problems that can be characterized as expert tasks as set out by Hayes-Roth et.al. (1983) and Waterman (1986) this can be visualized as a two phase expert task; firstly interpretation (analysis of data to determine its meaning; forming high level conclusions from collections of raw data) and secondly design (making a specification to create objects that satisfy particular requirements; determining a configuration of system components that meets certain performance goals while satisfying a set of constraints).

For example, nutritional standards for tomatoes on sandy soils may model nitrogen requirement for a crop from a minimum of 60 kg/ha for a soil nitrate level of 40 mg/kg and above, to a maximum of 180 kg/ha for a soil nitrate level of 5 mg/kg and below. Similar standards exist for phosphorus and potassium. Using these standards an agronomist can determine from the soil analysis data the amounts of nitrogen, phosphorus and potassium that need to be applied to the soil by fertilizer to achieve an optimum yield. This is known as the interpretive phase of the solution.

Consider from the above case that a nitrogen requirement of 90 kg/ha, a phosphorus requirement of 55 kg/ha and a potassium requirement of 80 kg/ha is interpreted from the linear models.

The next phase in the solution is the fitting to these requirements of a fertilizer or a range of fertilizers that supply the required amount of nutrients; that is, designing a fertilizer recommendation. Meeting the requirements exactly is not necessary and a five percent variation either way from the requirement is acceptable in practical terms. The constraints in this phase of the solution space are therefore not crisp.

Product A may consist of 46% nitrogen only, product B may consist of 9% phosphorus only, product C may consist of 50% potassium only, product D may consist of 9% nitrogen, 5% phosphorus and 7.5% potassium and finally product E may consist of 9% nitrogen, 2% phosphorus and 8% potassium.

Several solutions may be:

1) 195 kg/ha of A plus 610 kg/ha of B plus 160 kg/ha of C

2) 1000 kg/ha of D

3) 1000 kg/ha of E plus 390 kg/ha of B

Solution 1 is a perfect fit to the requirement but involves the application of three separate products. Solution 2 is a close but not perfect fit but only involves the application of a single product. While solution 3 is a closer fit and involves the application of two products. Note that 1000 kg/ha of product E alone would not constitute an acceptable recommendation as the phosphorus recommendation is outside an acceptable deviation from the requirement.

The author proposes that an acceptable expert system can be developed using symbolic reasoning techniques to implement nutritional and heuristic knowledge that:

a) implements the interpretive model using rules

b) generates solutions from a constrained solution space using rules

c) communicates with the user in a highly interactive and effective manner.

This proposal covers two fundamental objectives. One of investigating and implementing methods of expert system development and one of investigating and implementing user interface design principles.

Methods leading to the achievement of these proposed objectives will be described.

4) The problem domain is well structured and does not require commonsense reasoning.

As stated earlier, although the task is complex, the standards and nutritional knowledge are well documented and the agronomist does not have to rely on intuition. The solution process is regularly practiced by experts giving some insight into the process of navigating through the solution space. Further, these experts also train other agronomists in the task indicating that the task is well studied and formalized, terms are well defined and the domain is clear with a specific conceptual model.

5) The problem may not be solved using traditional computing models.

The process of making fertilizer recommendations based on soil analysis has been practiced for over 50 years (Malsted and Peck, 1973). In that time few, if any, computer based fertilizer recommendation programs have appeared. This may be due to the failure of mathematical models to accurately account for the variation that naturally occurs in a complex biological system such as the soil/plant nutritional relationship. Any computer solution must be flexible enough to allow for this variability as well as additional constraints that may be overlaid on the problem by the user such as a preference for one group of fertilizers or the inclusion of some over-riding provisos such as salinity hazards. This is where the nutritionist brings to bear the wealth of defined and well understood heuristics on the problem.

The nature of expert systems in allowing the use of such heuristics to model the solution process must therefore put such computer programs at a vast advantage to more traditional data processing techniques.

6) Cooperative and articulate experts exist.

The primary expert in this case is a plant nutritionist employed by a leading fertilizer company that carries out several thousand soil analyses and interpretations each year. The expert has help developed the companies manual on soil test interpretation for making fertilizer recommendations and runs numerous training courses for the companies sales agronomists annually. It has therefore been demonstrated that the expert is willing and able to share that knowledge. Further, the company management has shown its support for the project by providing funds to assist in its pilot development and evaluation.

7) The problem is of proper size and scope.

It is important that the problem not exceed the capabilities of current technology. Although a large problem may not be amenable to expert system solution, it may be possible to break it into smaller, independent subproblems that are.

This was done successfully in the creation of XCON: initially the program was designed only to configure VAX 780 computers; later it was expanded to include the full product set of Digital (Barker and O'Connor 1989).

A similar situation presents itself in this project. One could aspire to capturing the total plant nutritional knowledge found in the literature. Such a project would be beyond the scope of this study where the objective is more one of proof of technique and methodology and the pilot commercialization of the prototype.

Therefore, one of the objectives of this project is to demonstrate the use of expert systems technology in the domain of making fertilizer recommendations based on soil analyses by developing techniques and methodologies that prove commercially acceptable in a pilot study.

It would therefore appear from the above discourse that this problem is appropriate for expert system solution.

Given this conclusion, the objectives outlined can be synthesized into project aims of:

a) explore and describe methods that implement the interpretation model using symbolic reasoning techniques.

b) explore and describe methods that can generate fertilizer recommendations from a constrained solution space using symbolic reasoning techniques.

c) explore and describe methods for the production of a user interface that is highly interactive and effective providing dialogues that allow the user to take an active role in the problem solving process. The proposed users of this pilot system were fertilizer company agronomists and once fully commercialized, the fertilizer reseller staff. The fertilizer company currently has a well documented manual process in place for making fertilizer recommendations based on soil analysis results and runs accreditation short courses to train and maintain competence of fertilizer reseller staff in the task. However, many situations arise where through either time constraints, lack of knowledge, or poor training, fertilizer company experts are called in to make recommendations or adjust erroneous recommendations. The long-term commercial aims of this system were therefore to reduce the reliance on company experts and reduce (hopefully eliminate) erroneous recommendations. The system was not intended for use by growers.

d) demonstrate the commercial feasibility of such a project by constructing a commercially acceptable prototype system.

CHAPTER 4

4. RESEARCH METHODS, TOOLS AND DEVELOPMENT HISTORY

4.1 Introduction

Having established from the literature review that the development of an expert system for making fertilizer recommendations based on soil analyses should be feasible, research was then planned to explore this hypothesis using the aims as focus points. Qualitative and quantitative data was obtained from interviews, presentations, test scenarios, and records of the development process. The data gathered was analysed in relationship to the project aims stated in the previous chapter. The development cycle of the project, the methods and tools used, and the justification for these decisions are presented in detail in this chapter.

4.2 Expert Selection

The selection of experts was straight forward. The author had in depth professional experience in making fertilizer recommendations based on soil analysis having carried out the process regularly in his employment. The author was therefore well situated in considering the balance of theoretical processes and their practical application in the domain. The fertilizer company's expert was willing to assist in the provision of expert knowledge and vetting its application. The Department of Primary Industries horticultural crops nutritional expert was willing to review both the knowledge and the dialogues used in the system.

4.3 End-User Involvement

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As described in chapter 3, the target end-user in this study was the small team of staff members within the fertilizer company whose job was currently to provide the knowledge support and training to fertilizer resellers. This small team within the fertilizer company see it as part of their training role to support adoption of the proposed system once it is proven to themselves and the fertilizer resellers have the competence and computer equipment to use the system. It is the role of this team within the fertilizer company to deliver to the fertilizer resellers, the training, commercial tools (including this system), and the technical support of their companies analytical services that back up and add value to their core business of fertilizer manufacture and distribution.

No member of this team had any broader computer skills than that of average competency in the use of parts the standard corporate software, that being Microsoft Office™ (Microsoft). This meant that no team member could specify in computer system terms before hand what they required from a computer system that automated the process of making fertilizer recommendations. A system development process was therefore required that allowed this team to review and suggest further development directions for the system on a regular basis. This requirement was well suited to the iterative prototype development methodology.

To facilitate end-user involvement, regular communication with the team members was required. To this end, one staff member was designated as "project champion" within the team and would act as the authors first point of contact to review small incremental developments, to gauge the value of various development options, and to clarify gaps or ambiguities within the knowledge base. This sort of contact would occur on average about twice per month during development work and consisted of either personal visitation, telephone, or facsimile contact. When larger development increments had been made, a meeting of all the team took place to review the work to date and give direction on future areas to explore and develop. The outcomes of these meetings were recorded as minutes and distributed to all team members. The points requiring action had the name of the team member put against it so the rest of the team were clear on who was expected to do what. Appendix 8 is a copy of one such set of minutes.

This process of continual end-user involvement gave the team a broad and detailed synopsis of the progress of the project. The process allowed them to:

- keep abreast of the progress towards project milestones
- use the current prototype version as the underlying specification for the next version
- be exposed to the power and weaknesses of the system
- use the prototype versions to test and train themselves in the systems capabilities
- come to terms with the technology
- provide detailed reviews of the system to the author

4.4 Tool Selection

A major decision was the selection of a development tool that would see the project through to, at the very least, the end of the production of the prototype system. Requirements of the development platform would be wide and varied.

Firstly it had to support incremental development. Much of the research would be on small scale test modules of code rather than a complete system. This requirement hinted at an interpreted environment where facts, objects, and rules could be altered on the run rather than having to go through tedious compilation cycles to test various options. This requirement also pointed towards good support of execution tracing/debugging. To follow the execution process in refining both the correctness and efficiency of the code, stepwise execution and tracing would be important.

Secondly, because a wide range of implementation issues such as user interface, dialogues, explanations, inference methods, knowledge representation, and report generation were going to be explored, the development environment would need to be flexible enough to allow full exploration of these issues. This requirement pointed to the use of a language based environment rather than a shell whose features maybe more fixed.

For the purpose of this project, the PROLOG-2 (trademark of Expert Systems International) implementation of the PROLOG language was chosen as the initial development tool. Reasons for this selection were:

a) Availability and past experience of other staff members in using this product.

b) The use of a language rather than a shell would lead to fewer restrictions in the software implementation.

c) PROLOG-2™ uses the Edinburgh PROLOG syntax but comes with a library that implements the DEC-10 PROLOG syntax at the same time.

d) A windowing/menu development library is also supplied with the language. This greatly eased the production of a user interface that met the design goals.

e) The package had an excellent debugging facility that implemented the PROLOG execution tracing "box model" presented by Clocksin and Mellish (1981) in their text on PROLOG programming. Readers are referred to the Prolog-2 Language Reference Manual (1986) for a detailed description of how this is implemented.

f) The package allowed the incremental development of a system by its strong support of modules and code libraries.

g) The package acts as a PROLOG interpreter allowing quick and easy exploration of design theories. Additionally, the package allowed conversion of the interpreted code to a stand alone .EXE file for final distribution.

h) Built-in predicates of PROLOG-2™ allowed the design and implementation of an event driven user interface that also supported a mouse.

i) The PROLOG-2™ package functioned effectively across a broad range of hardware configurations. Most of the initial testing was done on a IBM XT compatible with twin floppy drives. The final demonstration system was finalized on a IBM compatible '386 machine with a hard disk drive. Execution times were useable across all platforms with, though as expected the '386 hardware gave superior performance.

Krause (1990) presents a thorough review of the PROLOG-2™ development package and readers are referred to this for more details on the package.

The process of tool selection was done in 1989, at a time when the Microsoft Windows environment had not come into common use. The selection of a character based DOS programming environment was the current practice at the time.

However, at the completion of the DOS based prototype, Microsoft Windows 3.1™ was fast becoming the standard platform for personal computer software. The decision was made in consultation with the projects commercial backers to pursue the development of another prototype based on the Microsoft Windows™ environment.

Using the experience gained from the development of the DOS based prototype, several additional requirements were added to the list of selection criteria for a development environment.

Much of the user interface had evolved into tabular form fill-in style data entry and presentation dialogues as indicated in figure 4.1.

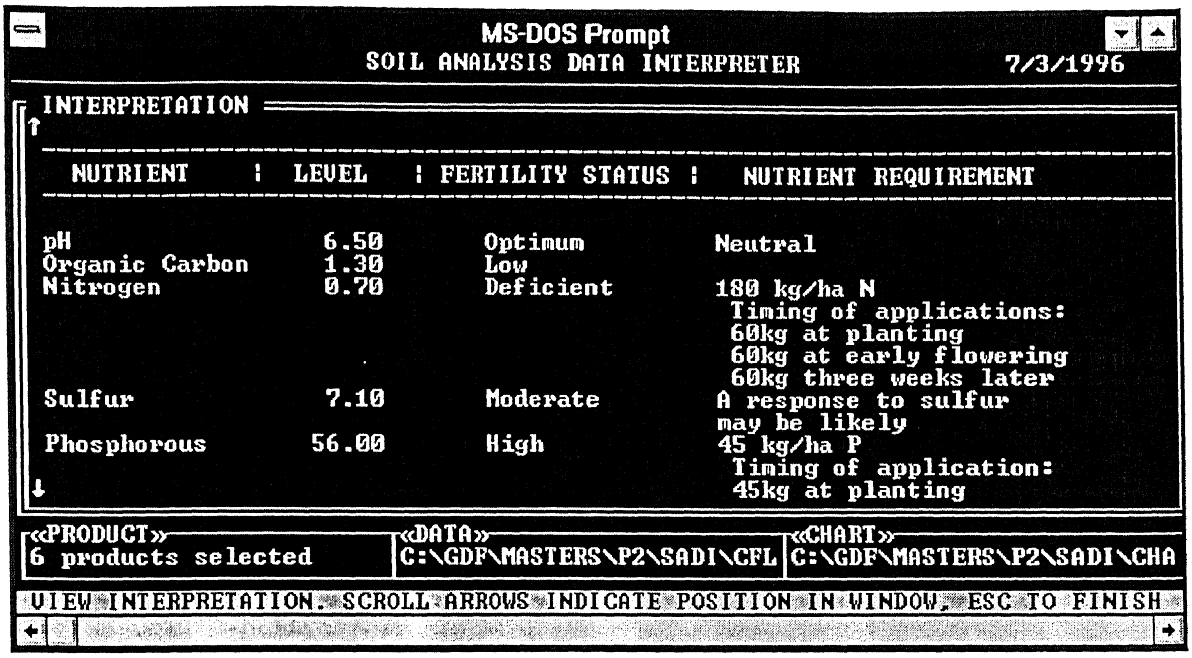


Figure 4.1 Example of tabular data entry and presentation developed in the DOS version of SADI.

There was a need to deliver the Windows based prototype in as short a time as possible indicating a very short learning curve for the product selected. User interface response times in the DOS based prototype was slowest in the part of the system that carried out intensive calculations and a system more tuned to these demands may overcome possible bottlenecks in the user interface.

After considering LPA 386-PROLOG (trademark of Logic Programming Associates Ltd., England), Excel5 (trademark of Microsoft Corporation, USA) was chosen as the development environment for the Windows based prototype.

No Windows based product would convert the user interface system designed in the DOS based prototype to a Windows user interface. A direct port was impossible - recoding from scratch was the only option.

LPA 386-PROLOG™ offered few high level Windows API functions. Considerable time would need to be spent on learning and coding the windowing system.

Excel5™ on the other hand was very 'Visual' in its user interface design. New windows and components were simply created by "dropping" them from a toolbar or menu, placing and sizing them using drag and drop mouse actions as shown in figure 4.2.

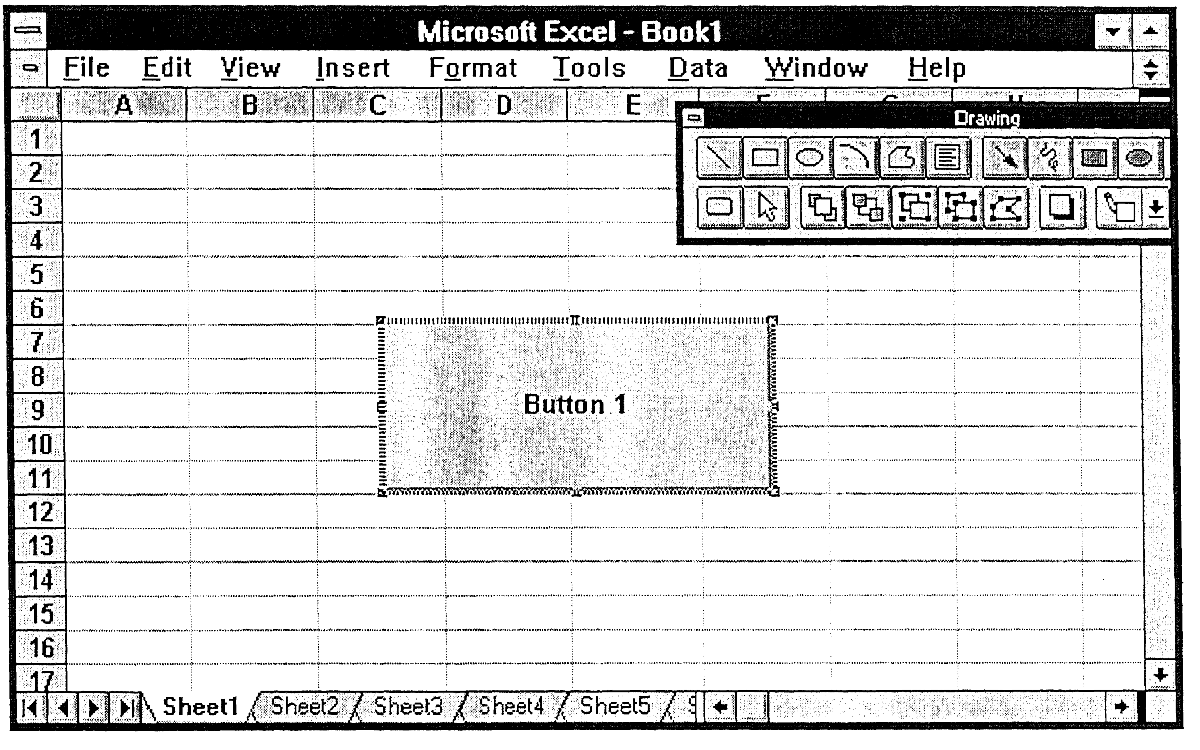


Figure 4.2 A button component in Excel5™ that has been dropped from the toolbar and is highlighted ready to be sized and placed using drag and drop mouse actions.

All user interface components such as sheets, buttons and graphics were handled in this way - simply selected from a toolbar and dragged and dropped into place on the window without any code or screen co-ordinates having to be considered.

Excel5™, being a spreadsheet environment, handled multiple calculations well with the flow and triggering of re-calculation being easily manipulated.

Other positive considerations for using Excel5™ were that it came with two programming or macro languages (Excel4™ function language or Visual Basic for Applications™), supported the design and implementation of Windows dialogues, had an excellent debugging module, a very quick learning curve, good user security through the use of passwords at the application and window level, and fully supported incremental development. Although not a compiled environment, the commercial partners in this project had selected Microsoft Office (which includes Excel5™) as their corporate software platform thus ensuring portability across all personal computers in the company.

The fact that Excel5™ was not an expert system shell as such required even closer scrutiny of its capabilities for the task at hand before making the final decision to use it as the systems development and delivery platform.

Excel5™ provided in some form many of the operationally functional components found in expert system shells. It supported the separation of the knowledge base from other system components either by allowing the knowledge bases to be stored in separate worksheets within a workbook file or allowing more than one workbook file to be opened and operated upon at one time. It supported various forms of knowledge representation through the use of lookup tables arranged either horizontally or vertically, a complete set of Boolean functions, a toolset for the definition of user-defined functions, a toolset for the definition of user-defined macros, a toolset to read ASCII data files, a toolset to interrogate external databases using

SQL constructs, OLE compliance for cross application data sharing, strong logical and looping function support, and data typing functions to test for and convert various data types automatically.

Excel5™ could also have its calculation model customized manually or programatically allowing full control over when calculation would occur, what order it would occur in, how many iterations of goal seeking or scenario testing would be run, what level of accuracy was required when goal seeking, and whether external links were to be updated. Program execution could also be easily controlled through the use of nested command macros that could be triggered by user commands from the user interface using screen components such as buttons and menu items, data input, keyboard or mouse activity, or internal system events (demons).

The above properties of Excel5™ indicated that it was a feasible option for constructing an expert system when compared to other expert system shells available for the Windows™ environment. Production rules could easily be formulated into IF-THEN constructs or look-up table structures, knowledge could be asserted or cleared either by programatically updating a knowledge structure or keeping a "blackboard" of dynamic knowledge in a worksheet, the construction of a standard Windows™ user-interface was supported, testing of "what-if" scenarios was naturally supported since this is what spreadsheets were originally designed for, and pattern matching functions are part of the programming language. While an inherent explanation facility is not present in Excel5™ this did not detract from the platforms utility in this study since an explanation facility was a very low priority in this case and the programming language of the package would allow the construction of such a facility if it were required.

4.5 Problem Dissection / Provision of User Dialogues

The task at arriving at a fertilizer recommendation based on soil analysis can be dissected into several sub-tasks. An examination of the manual process provides a good insight to what these sub-tasks may be. Also, designing the system model to be equivalent to the current manual model will help users more quickly grasp the context in which they are operating within the system.

Dialogue provision refers to the way in which the system and the user interact. A common form of dialogue in expert systems is a rigid style of consultation with an exhaustive set of yes/no or menu style questions initiated by the system. (Berry & Broadbent 1987). Both Kidd (1985) and Berry & Broadbent (1987) argue that this rigid form of system-oriented dialogue is restrictive by limiting the options the user has in directing the session. As derived in the literature review, dialogue facilities of the system need to match the communication needs of the user and the constraints of the task environment.

So what are the tasks in the process of making a fertilizer recommendation and where might the user wish to take initiatives or short-cuts? A methodology that was successfully applied for the provision of dialogues in this project is described below.

The process of making fertilizer recommendations involves five main tasks. These are:

a) Be presented with the results of soil analysis.

b) Select an interpretation chart.

c) Determine elemental requirements.

d) Select a range of fertilizer products.

e) Match fertilizer products to the elemental requirements to form a fertilizer recommendation.

This dissection then points to various system design options.

The system can be constructed of modules, each handling the sub-tasks of data entry (entering the soil analysis results into the system); chart selection (choose a knowledge base); interpretation (apply the knowledge to the data to arrive at target amounts of nutrients); select a set of fertilizer products (restrict the size of the solution space to reduce calculation load); recommendation (calculate the rate/s of product/s that best fit the solution criteria, that is the target amount of nutrients, without contravening other nutritional requirements).

Step A requires the results of the soil analysis to be entered into the system. Soil analysis data is presented as a printed report in tabular format. This suggests that a form fill-in style of data entry may be acceptable if form design can imitate that of the printed report. This step has no prerequisite step. Use of two input modes was considered in this study; manual keyboard entry and disk file access.

Manual keyboard entry was done using two screen forms that conformed to a user-interface standard as described in the user-interface section. By selecting form fill-in as the method for manual data entry, much control and therefore dialogue initiative was passed to the user. No ordering of data entry was enforced, the user could enter soil analysis data at random. All related data was displayed on the screen, keeping the user in context. Filling in all the form was not enforced thus allowing the user to back out of the task and re-enter it at will.

Alternatives to this method of manual data entry were to ask for each data item individually. While this method of dialogue control may have been easier to code (sequentially display a number of questions on the screen and wait for input to each), the utility of such a system was considered less flexible than the form fill-in method (Shneiderman 1987, p 73). Ordering of data entry is enforced if no question switching mechanism is provided. Screen layout can become cumbersome if each question is asked in a verbose fashion. Re-entry into the data entry session was from the first question cascading through to the end. This involved having to step through each answered question before arriving at the previous data entry point.

Example Prolog code from the final prototype for data entry is shown in figure 4.3. Note the use of indirection to ease maintenance and increase modularity in the menu system implementation.

```
data_menu :-
   create_stream(d_menu,readwrite,byte,window(2,50,white on black)),
   open(d_menu,readwrite),
   screen(d_menu,create(5,15,d_menu,0,0,0,all,white on
              black,2,50,hidden)),
   repeat,
   menu_heading(data_menu,Heading),
   menu_list(data_menu,Menu_list),
   menu_start_item(data_menu,Start_item),
   window(action,clear),
   req_action(data_menu),
   menu(d_menu,
        Heading,
        Menu_list,
        Selected,
        Start_item),
   update_start_item(data_menu,Selected),
   window(action,clear),
   (Selected = esc ; (call(Selected) , fail)),
   close(d_menu),
   delete_stream(d_menu), !.
```

Figure 4.3 The main piece of code that controls data entry in the Prolog DOS prototype.

Chart selection suggests a menu or list of charts that the user can choose from may be appropriate. In the manual system, all the charts are arranged numerically in a book indexed by chart number and name. Using the same indexing and naming system as the manual system would promote quick familiarity of the computer system by the user.

Chart selection has no prerequisite step. A chart contains all the knowledge for a particular crop/soil combination. Published interpretation charts are numbered, with chart 97 for example being for tomatoes and capsicum grown on sandy soils. There is very little room for flexibility in dialogue in this facet of the process. The user must simply choose an appropriate chart for the situation at hand. Standard menu selection techniques adopted for this project and described in chapter two were used to achieve a selection.

Two refinements to this step were suggested by the other experts. One was for the automatic selection of a subset of fertilizer products upon selecting a particular chart. This had a two fold effect for the user. It made the need to do step D unnecessary if the user was happy to accept the fertilizer product subset of the chart. This provided a short-cut for an experienced user. It also indicated to the user the standard fertilizers usually considered for use in that particular crop/soil combination. This gave the system a small educational/familiarization role. The system still retains flexibility for the user to take the initiative in selecting fertilizer products. External to the system, a chart may be edited to vary which fertilizer products it brings in as the defaults, if any at all. In the system, step D allows a user to remove or add fertilizer products to the subset selected. Thus the user has complete control over which fertilizer products are to be considered in the final step of making a recommendation. This refinement was incorporated into the prototype system.

The other refinement was for the system to provide an alternative method for selecting a chart. Rather than the user directly specifying which chart was required, the user could specify a crop and soil type to the system and the system would itself select the most suitable chart. This makes chart selection easier for users unfamiliar with the chart numbering used in the manual system. However it would slow the selection of a chart down since it involves two selections and an indexing back to a chart compared to the original scheme which directly loads a selected chart number. This refinement was not incorporated into any commercial pilot version of the system.

Interpretation is an intensive matching process that once started would need little if any user interaction. This suggests that the system needs to display some milestone messages to keep the user informed of the systems progress. Without these messages the user may feel isolated or wait in fear of having done something wrong.

This interpretation sub-task is where the basic nutritional interpretation occurs. This step requires that step A and step B be completed. This step involves the system applying the knowledge in the chart to the soil analysis data to arrive at the elemental requirements and associated explanations that the system then displays to the user. Where invalid data from step A has been found, a message is presented in the interpretation report making the user aware of the lack of validity of the data. The user has the flexibility to go back to step A, edit the erroneous data and proceed directly to step C again. Only when step C has been completed successfully, is the user given access to step E. This is an example of what Berry & Broadbent (1987) described as mixed initiative dialogues. That is where the system still retains some control over the direction of the consultation for reasons of safety or validity. In the context of this project, it would be careless, if not professionally negligent, to make a fertilizer recommendation based on the interpretation of erroneous data. The system must take control of the session and direct the user back to correcting the data.

Selecting a set of fertilizer products (step D) suggests a complete list of fertilizer products being presented from which multiple selections can be made. If such a sub-set were to be considered standard, the list could be presented with the sub-set selected as the default starting set-up for the list. Fertilizer companies list their products by name and nutrient content on handy product guides and a similar layout would streamline user acceptance of this step.

This step is optional if step B has already created a subset upon selection of an interpretation chart. Step D has no prerequisites.

The inclusion of this step rather than letting the system go off and consider all fertilizer products has several advantages. It lets the user direct the recommendation process (step E) towards a preconceived outcome. For example, if the client wished to use "straights" (single element fertilizer products), the user would select only this form of product in step D. This would force the process in step E to only consider these products and thus generate a recommendation in line with the users wishes. The system does not override the user and suggest alternatives outside the users wishes. Similarly, if low chloride products are required because of a salinity hazard, the user would select only this form of product in step D and step E would generate recommendations accordingly.

This step also provides an avenue for the nutrient contents of the fertilizer products to be displayed to the user. This acts as a ready reference for the user rather than having to refer to external product guides for this information.

Finally, by restricting the size of the fertilizer product subset, the optimization routines underlying parts of step E perform much faster. Additionally, the display of a subset rather than the full set gives a much tidier screen display in a non graphic (DOS) user interface.

Making a recommendation is conceptually and computationally the most complex part of the overall task. As seen from chapter three, the process involves matching elemental nutrient applications resulting from certain rates of fertilizer application to target elemental requirements. Many other factors such as availability, grower preference, number of products, and fertilizer form must be considered as well as closeness of fit to the elemental nutrient requirements. This suggests a user interface that allows the user to direct the dialogue to some degree, front-ending powerful computational algorithms that can solve several linear models on a time scale that make the real-time user interface acceptable to use. Such design criteria may be met by presenting the user with a 'live' table of results along with menus for the user to select or direct the navigation of the solution space.

This step has the prerequisites of there being a current interpretation (step C) and a selection of fertilizer products being available (step D). This step has four subprocesses; making a liming recommendation, making a basal (pre-plant) fertilizer recommendation, making a side-dressing recommendation, and writing the recommendations report.

The first and last subprocesses are closed processes, that is there is no user dialogue supported. You select either task and are presented with the end result; either a liming recommendation or a recommendations report. The two processes of making a basal and side-dressing recommendation are where the major dialogues of the system occur.

In the basal recommendations the user can select to either let the system find the fertilizer product that best fits the requirements or do the fitting manually. The user needs to know what the requirements are; what rate of fertilizer has been applied; what the difference is between the requirements and the amounts applied (this indicates the shortfall or surplus supplied by the amount of fertilizer being recommended); and some opinion advanced by the system on the consequences of accepting the fertilizer recommendation in its current state. The latter piece of dialogue introduces a consultative process into the dialogue as eluded to by Kidd (1985) as being a requirement in duplicating the human consultation process. Further, to enhance the utility of opinions advanced by the system, two forms of opinion, summarized and fully explained, can be offered to best suit two user models - the novice and experienced user.

Failure to offer two forms of opinion either make the consultation process long winded for experienced users or too shallow for novice users. The form of opinion must be user selectable since the one user may assume the two user models at different times during the one session. An experienced tomato agronomist may have to resort to full version opinions on his fertilizer recommendations for zucchini.

Once a fertilizer rate has been developed either manually or automatically by the system, the user should be allowed to experiment on this recommendation. This process of experimentation on the initial recommendation allows the user to refine the recommendation, probe the sensitivity of the rate recommended, drastically alter the recommendation, or check the recommendation against alternative recommendations that can be developed. The user must be given full initiative over the process so that the final recommendation is acceptable and understood.

Even after a best fit has been arrived at automatically, the user then has the option to manually alter this to further refine it or try alternatives. During the process of manually arriving at a best fit the system offers an automatic single element optimizing routine that takes the guess work out of fitting fertilizers to requirements.

A similar process is gone through for making side-dressing recommendations since the processes involved are essentially the same; fitting fertilizer products to requirements.

In both the basal and side-dressing recommendation sub-processes, the user can take the initiative by stating rates of products, optimizing rates of products for certain elements or selecting a new group of products to explore recommendations.

The results of this problem dissection apart from giving an indication of the sub-tasks required in the system also suggests the content of a main system menu - that being the five main sub-tasks of soil analysis data entry, chart selection, interpretation, fertilizer selection, and recommendation.

4.6 DOS Prototpye

Initial development of the DOS prototype was done on an IBM compatible 8086 machine using the Sidekick (trademark of Starfish Software) editor. This allowed the Prolog-2™ system to be running continuously while being able to jump in and out of the text editor at will, allowing for rapid prototyping of small code modules. Final refinement and commercial presentation of the prototype was done on a Toshiba 80386 laptop using the editor of XtreeGold (trademark of Executive Systems Inc.) file management program. The added speed of the Toshiba allowed a larger text editor to be used and the Prolog-2™ interpreter only started when code testing was required.

Prolog-2™ proved a satisfactory platform for the implementation of the methods developed. The implementation of the knowledge base, inference algorithms, and report generation were relatively straight forward. However, as predicted from the literature review, the largest amount of code in the system was devoted to the user interface. The user interface also proved the most difficult to implement and control. The project was developed as an event driven system and this proved easy to implement.

While Prolog-2™ came with an extensive library of predicates for a windowing and menu system, the content of these structures was based on indexed lists of text. Since much of the content of the menus and list boxes was not constant, much coding was needed to refresh and control these user interface items.

It was the excessive work required to further refine the user interface in Prolog-2™ during the beginning of the commercialization process that tipped the scales towards changing the software development platform.

4.7 Windows Prototype

The Windows prototype was begun in Excel4™ running in Microsoft Windows 3.0 on the Toshiba laptop used to finalize the DOS prototype Soon afterwards the final development was done on a 80486 based IBM compatible personal computer in Excel5™ running in Microsoft Windows 3.11. This latter machine proved to be a very acceptable development tool.

Excel5™ was a totally self-contained software development environment providing all the tools needed to develop and deliver a commercial prototype system.

Implementation of the knowledge base, inference engine and algorithms proved to be straight forward and while syntactically different, it was relatively similar in principle to the Prolog based system.

The vast improvement of this system over the DOS based system was the user interface. Much of the user interface was built by direct manipulation requiring no code to support it. Menus and dialogs were easily built and maintained. Event driven processing while also implemented in the DOS system, was fully supported in Excel5™ and used extensively. The ability to display various fonts of different color and graphics also streamlined the user interface.

Software security was also supported by Excel5™, password protection at the individual screen level as well as at the full application level. This became an important consideration in the commercialization process to protect the companies investment from other fertilizer companies.

4.8 Commercialization

The commercialization process followed in this project was one of collaborative development with the cooperating fertilizer company (Incitec), funded by a grant from the fertilizer company matched equally by the Horticultural Research and Development Corporation (HRDC), a federal government agency.

Several presentations to company representatives were made to gauge the usefulness of the DOS prototype in helping their dealers deliver fertilizer recommendations. Following positive feedback from both their technical and marketing staff, the author in consultation with the project supervisor and a fertilizer company representative, developed a project proposal that not only mapped out the planned course of action for commercialization but also included budgetary considerations to fund the process. Appendix 7 is a copy of the successful proposal.

The funding allowed the purchase of the Toshiba 386 laptop computer, software, and travel for project team members to meet at regular intervals for milestone reports and project reviews.

At the completion of the funded project and proof of the value of the full prototype system, the fertilizer company employed the services of a software consultant to expand the knowledge base to include many more charts than had been included in the prototype system. The consultant was also involved in user training, system maintenance, and system upgrading as the company's plans for the system evolved.

CHAPTER 5

5. *IMPLEMENTATION AND SYSTEM OVERVIEW*

This chapter describes how the principles formulated in the previous chapter were implemented. Examples of code, screen dumps and system statistics are presented. Design features that led to the achievement of the project aims are highlighted and reasons for their success are discussed.

5.1 System design and overview

The proposed users of the system were fertilizer company agronomists and fertilizer reseller staff. The fertilizer company currently has a well documented manual process in place for making fertilizer recommendations based on soil analysis results and runs accreditation short courses to train and maintain competence of fertilizer reseller staff in the task. However, many situations arise where through either time constraints, lack of knowledge, or poor training, fertilizer company experts are called in to make recommendations or adjust erroneous recommendations. The commercial aims of this system were therefore to reduce the reliance on company experts and reduce (hopefully eliminate) erroneous recommendations. The system was not intended for use by growers.

Within these commercial aims the system would have to run on a standard IBM compatible hardware platform, be useable by fertilizer dealer staff who are not fully computer literate, provide a fertilizer recommendation tailored to user requirements as well as the nutritional restraints indicated in the soil analysis results in real-time, and provide some facility to print a hard copy report of the recommendation.

Both prototypes and the commercial pilot system arising out of the Windows prototype met these requirements. SADI (Soil Analysis Data Interpreter) was chosen as the system name and is used in this thesis to name the system through its stages of development and commercialization.

5.2 DOS prototype

The Prolog-2™ source code of SADI consists of 2352 lines of code packaged as a 220k .exe file and three overlay files totaling 55k.

SADI is a menu/event driven system. It is made up of five sub-systems each accessed from the main menu which allows the user to:

(1) Select a soil analysis data file or type in soil analysis data

(2) Select an interpretation chart

(3) Carry out an interpretation

(4) Select a range of fertilizer products from the full product list

(5) Make a fertilizer recommendation

Figure 5.1 shows the screen design of the main menu. System messages along the lower edge of the screen keep the user informed of the current system status while some control is exercised over the user navigation of the system by restricting access to the interpretation module (bracketed menu item is not selectable) until soil analysis data is entered and a chart selected.

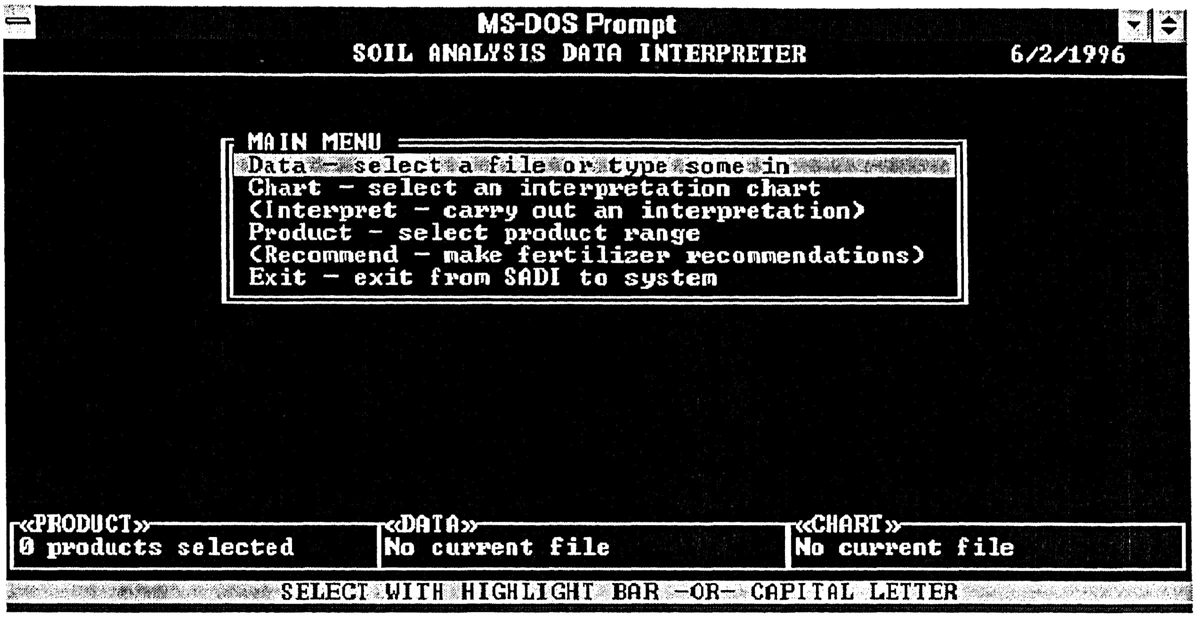


Figure 5.1 The main menu screen used in the SADI DOS prototype.

An example of code used to drive the event driven processing of the Prolog system is shown in figure 5.2. The numbers in the select_action/1 relation represent unique keyboard codes. Only the ending key (usually escape) does not fail, allowing the program to proceed out of that event capture routine back to a higher level event capture routine such as a menu.

```
assert(pos(Y,X)),        /* predicate 'pos' instantiateed */

 update_rate :-
   put_arrow,            /* initialize highlight placement */
   repeat,               /* will succeed on bracktracking */
   get_key_press(X),     /* instantiate X to keyboard code */
   select_action(X),     /* do action based on X */
   !.

put_arrow :-             /* repaints menu items to show highlight */
   pos(New,Old),         /* instantiate current values in 'pos' */
   New_pos is New + 2,   /* change highlight co-ordinates */
   Old_pos is Old + 2,
   get_prod_names(New,New_name,Old,Old_name),
   window(tile,cursor_address(Old_pos,1)),
   window(tile,text(Old_name)),
   window(tile,cursor_address(New_pos,1)),
   window(tile,attribute(white on black)),  /* unhighlight old */
   window(tile,text(New_name)),
   window(tile,attribute(black on white)),  /* highlight new */
   !.

select_action(283) :-    /* 283 = ESC, do not fail so drop thru */
   !.

select_action(20480) :-        /* 20480 = downarrow */
   number_of_products(Size),   /* count of menu items calulated */
   Size_1 is Size - 1,
   pos(X,_),
   X < Size_1,                 /* check for valid move */
   Y is X + 1,
   retractall(pos/2),
   assert(pos(Y,X)),           /* assert new selection position */
   put_arrow,                  /* repaint menu items */
   !, fail.                    /* fail and loop back to update-rate */

select_action(20480) :-        /* 20480 = downarrow */
   number_of_products(Size),   /* count of menu items calulated */
   Size_1 is Size - 1,
   pos(X,_),
   X =:= Size_1,               /* invalid when at last item */
   !, fail.                    /* fail and loop back to update-rate */

select_action(18432) :-        /* 18432 = uparrow */
   pos(X,_),
   X > 0,                      /* check for valid move */
   Y is X -1,
   retractall(pos/2),
   assert(pos(Y,X)),           /* assert new selection position */
   put_arrow,                  /* repaint menu items */
   !, fail.                    /* fail and loop back to update-rate */

get_key_press(Press) :-
   repeat,
   get_key(Press),!.           /* instantiate Press to keyboard code*/
```

Figure 5.2 Sample Prolog implementation of the event driven user interface.

As in many other reported systems, the user-interface of SADI formed a large part of the code. In designing the interface, standardization on key-press/action response was strongly enforced and this was backed up by system messages reinforcing the system prompts. Extensive use has been made of menu boxes, inverse video highlights and keyboard function keys.

The information for SADI's knowledge bases resides in three disk files together with the knowledge generated by the third main menu selection - carry out an interpretation. The soil analysis data as typed in by the user or decoded from fertilizer company files is stored in one file. The fertilizer product information is stored in a file and loaded automatically at system start-up. This allows changes to the product range to be easily edited into the file without the need to recompile the code. It also offers some degree of security over the integrity of the information as the file cannot be directly accessed by the user from within SADI. Lastly, all the nutritional standards, linear model constraints, summary and explanatory text are stored in a file known as the interpretation chart. The information for this part of the knowledge base was gathered from the fertilizer company's published interpretation charts and their plant nutrition expert. Since this knowledge is specific to any particular crop/soil combination, a multitude of these charts may exist. This explains the need for the second option in the main menu.

Entering soil analysis data into SADI can be achieved by form fill-in or providing the name of a file that SADI can decode. Two file formats are supported; Incitec's (fertilizer company) and SADI's. The soil analysis data decoded form a file is presented in form fill-in format for editing/viewing the same as manually entered data.

Selecting an interpretation chart presents the user with a menu box where a file name representing a chart can be entered or selected from a list of files. Selecting a file "reconsults" all the predicates from the file into SADI's knowledge base. The chart when loaded also selects a small range of fertilizer products that are known to be in common use in the crop/soil situation to which it's knowledge pertains. An interesting point here is that by using Prolog-2 which supports virtual memory modules, the predicates are not physically moved into RAM from disk until they are called by the inference engine in later logic. Restrictions on knowledge base size, familiar in other development environments, have not been encountered in this prototype.

Carrying our an interpretation applies the nutritional standards in the chart to the soil analysis data to generate the intermediate knowledge - elemental requirements. The interpretation session generates an on-screen report as well as writing a report to a disk file. The interpretation process is where the bulk of the nutritional knowledge base is used. The nutritional standards are matched against the entered soil analysis data to give the interpreted elemental requirements. Knowledge base design consisted of Prolog rules about each element. Each rule is a mutually exclusive subset of the values a soil test result may take. Only the rule matching the current value fires and thus asserts its interpretation values and related text into the knowledge base to be used by the following tasks in the process of making fertilizer recommendations. Figure 5.3 shows an example of the knowledge structures used.

```
/* TOMATO91.CHT

   Tomato interpretation chart incorporating data abstraction
*/
cht([crop,"Tomatoes"]).  /* declares chart name */

initial_products([8,30,37,46,48,54]).  /* sets selected products */

interpret_list([ph,c,n,s,p,k,ca,mg,na,cl,con,cu,zn,mn,fe,b,al,mo])
.    /* list of atoms to interpret */

ph(Ph,Sph)     :- result([ph,_,_,_,_,Sph]),   number(Ph,Sph).
bph(Bph,Sbph)  :- result([bph,_,_,_,_,Sbph]), number(Bph,Sbph).
c(C,Sc)        :- result([c,_,_,_,_,Sc]),     number(C,Sc).
n(N,Sn)        :- result([n,_,_,_,_,Sn]),     number(N,Sn).

cht([n,"Nitrogen       ",Sn,"Deficient ","180 kg/ha N        ",
      " Timing of applications:",
      " 60kg at planting",
      " 60kg at early flowering",
      " 60kg three weeks later"]) :-
   n(N,Sn),              /* instaniate N result */
   0 =< N , N < 5 ,      /* if N level between 0 & 5 */
   assert(req_t(n,180)), /* assert total requirement as 180 kg/ha */
   assert(req_b(n,60,"  60")),  /* basal requirement as 60 kg/ha */
   ! .
cht([n,"Nitrogen       ",Sn,"Very Low  ","165 kg/ha N        ",
      " Timing of applications:",
      " 55kg at planting",
      " 55kg at early flowering",
      " 55kg three weeks later"]) :-
   n(N,Sn),
   5 =< N , N < 10 ,
   assert(req_t(n,165)),
   assert(req_b(n,55,"  55")),
   ! .
cht([n,"Nitrogen       ",Sn,"Low       ","130 kg/ha N        ",
      " Timing of applications:",
      " 40kg at planting",
      " 45kg at early flowering",
      " 45kg three weeks later"]) :-
   n(N,Sn),
   10 =< N , N < 15 ,
   assert(req_t(n,130)),
   assert(req_b(n,40,"  40")),
   ! .

 ....  /* if no previous rule satisfied drop thru to this message */

 cht([n,"Nitrogen       ",Sn,"          ","DATA OUT OF RANGE   "]) :-
   n(N,Sn),
   assert( danger(
 " Data out of range limits for nitrogen.      Please check data for
 validity.") ),
   !.
```

Figure 5.3 An example of knowledge base design used in the DOS prototype.

Line 7 is the default list of products asserted into the current sessions knowledge base when this particular chart is selected. The numbers are the index number of products in a list held in the products file. This structure is not as easily maintainable as other more complex structures because, if the index of a product changes in the product file, all charts must be updated to account for this. One alternative is to list the products by name in the knowledge base, then match the names to their index at run time and use the calculated indices to build the list box displayed to the user with check marks besides those default products. However the validity checking required to match product names (misspelling, case sensitivity, space sensitivity) and other "house-keeping" code was considered beyond the scope of this prototype where only a small number of charts were to be developed to prove the underlying principles.

Line 9 provides a list of elements this chart is capable of interpreting. The inference engine can call this complete list or a sub-set of it, thus providing the inference engine with some independence to the knowledge base structure. This independence of knowledge structures is again provided in the example lines 12 to 15 where the soil data is abstracted so that the rules need not change in syntax to account for any change in the way the soil data is recorded. For example the ***n(N,Sn)*** predicate is true (and thus its variables instantiated to the relevant values) when the result for ***n*** is instantiated to ***Sn*** (a string structure) and ***Sn*** is then converted to the equivalent number structure by proving the ***number/2*** predicate. Then throughout the rules for ***n*** the ***n/2*** predicate is called to provide the number *N* and the string *Sn* for the rules to operate on. If the structure of the ***result/1*** predicate changed, only a small change needs to be made to the code and not every place where the values of that soil data are required.

Lines 17 to 26 is an example of how a rule is structured that asserts and supplies knowledge to the current session. The cht/1 predicate instantiates many text values within itself as well as physically asserting a total elemental requirement (***req_t/2***) and a basal requirement (***req_b/2***) based on the criteria of the *N* value being between 0 and 5. Line 22 is where the data is supplied through the abstraction predicates and line 23 is where this data is tested for truth. Lines 50 to 55 is the catch-all predicate where if any of the previous rules have not been satisfied it supplies back to the inference engine the text to display in the interpretation report as well as asserting the ***danger/1*** predicate into the knowledge base as a trigger for further navigation restrictions on the user.

Selecting a range of fertilizer products allows the user to restrict the solution space of the linear model used by the recommendation module by reducing the number of fertilizer products to be tested for fit to the requirements. Usually, less than ten products from the full range is ample latitude. The user can toggle fertilizer product selections on or off, including those selected automatically by the chart, with a single key press.

Finally comes the recommendation task. The user is presented with a sub-menu which allows for a soil acidity management recommendation, a basal fertilizer recommendation (fertilizer applied just before planting), and a side-dressings recommendation (fertilizer applied while the crop is growing).

The process of developing fertilizer recommendations, has been discussed in detail in previous chapters and needs no further elaboration. The short example presented in previous chapters illustrates the numerous permutations that can be generated as valid solutions from a small set of available fertilizer products. The manual task of testing for fit and judging the acceptability of the fit, for the 120 fertilizer mixtures and blends available to growers in Queensland is rather tedious.

The recommendation task of SADI must therefore provide the user with:

- a method of determining a product and its rate that best meets a set of requirements (a linear model).
- a method of informing a user when a solution is within the constraints and the consequence of deviation.
- a method of taking the initiative and entering a solution to be tested by the system.
- a method for calculating rates of products to meet requirements.
- a method of reviewing the current state of a solution under development.

Methodologies to meet these goals of knowledge application were developed and implemented using Prolog by the author and are described below.

In the recommendation phase, the linear model was considered the pivot around which all other design goals would depend. The optimum fertilizer recommendation could be defined as a choice of fertilizer and application rate which provides a level of nutrients that vary the least from the interpreted nutrient requirements. A two step algorithm was used.

The first step calculates a rate for each fertilizer at which the variation from the nitrogen (N), phosphorous (P), and potassium (K) requirement (asserted by the interpretation phase as ***req_t/2*** and ***req_b/2***) is minimized. The optimizing procedure used is a least squares fit. Classical linear programming was not appropriate. The constraints are not crisp. A modest (5%) shortfall or surplus in one application is of no practical consequence.

Assume the nutrient content of a fertilizer product is Np, Pp, Kp, representing the kilograms of nitrogen, phosphorus, and potassium per kilogram of fertilizer; and the nutrient requirement of the crop is Nr, Pr, Kr, representing the kilograms per hectare required for each element. Equation (1) represents the model used,

$$Rate = \frac{\Sigma\ (x.y)}{\Sigma\ x^2} \qquad (1)$$

where x is the nutrient content of the fertilizer and y is the nutrient requirement. In the context of this project the model becomes Equation (2). This equation gives a rate of application of each product.

$$Rate = \frac{(Np.Nr\ +\ Pp.Pr\ +\ Kp.Kr)}{(Np.Np\ +\ Pp.Pp\ +\ Kp.Kp)} \qquad (2)$$

The second step selects the fertilizer with the minimum variation from the requirement. So that the variation was weighted symmetrically, a sum of the squared differences (SSD) was used to express the variation. The fertilizer product with the lowest sum of squared difference would be selected as the product to recommend.

Equation (3) shows the model used in this step,

$$ASD = \Sigma(x.rate - y)^2 \qquad (3)$$

where rate is the rate generated from equation (2). In the context of this project the model became Equation (4).

$$ASD = (Np.rate\text{-}Nr)^2 + (Pp.rate\text{-}Pr)^2 + (Kp.rate\text{-}Kr)^2 \qquad (4)$$

For each fertilizer tested for closeness of fit using Equation (2), its SSD was compared with the lowest SSD of previous fertilizers. Where the new SSD was found to be lower than the previous lowest SSD, the new SSD was taken as the lowest SSD and that particular fertilizer was taken as the current recommendation. At the end of the cycle the fertilizer product and its rate with the lowest SSD is reported as the closest fitting recommendation to the requirements.

The numerical differences were then compared with standards of fit in the knowledge base and an expert opinion generated for each element as to its validity. This opinion was expressed both in summary form (notes) and in a full explanation form. When the recommendation is outside the constraint set a warning message to this effect is displayed in the summary screen with a full discourse in the full explanation screen as to why it breaches the constraints.

Implementation of the model in Prolog proved relatively simple. Figure 5.4 presents the code. The ***ratio/3*** relation is the NPK requirements from the interpretation phase. The ***prod_b/1*** relation is the details of fertilizer products including its name (Atom) and nutrient content (Np, Pp, Kp).

```
1   optimise :-
2           (
3           ratio(N,P,K),       /* instantiate the required NPK ratio */
4           prod_b([_,Atom,_,_,_,Np,Pp,Kp,_,_,_,_,_]),
5           Factor is (Np*N + Pp*P + Kp*K)/(Np*Np + Pp*Pp + Kp*KP),
6           fit_prod(Atom,Factor),    /* calculate closeness of fit */
7           fail
8           )
9           ;
10          (
11          best_fit(Name,Mult,_),     /* with best fitting product */
12          Extra_rate is fix(Mult*100),
13          retract(prod_b([A,Name,B,C,Old_rate,E,F,G,H,I,J,K1,L])),
14          New_rate is Old_rate + Extra_rate,  /* calc rate */
15          assert(prod_b([A,Name,B,C,New_rate,E,F,G,H,I,J,K1,L])),
16          !
17          ).
18
19          fit_prod(Prod,Fact) :-
20          best_fit(_,_,Coef0),
21          ratio(N,P,K),
22          prod_b([_,Prod,_,_,_,Np,Pp,Kp,_,_,_,_,_]),
23          Coef1 is     (Np*Fact - N)*(Np*Fact - N) +
24                  (Pp*Fact - P)*(Pp*Fact - P) +
25                  (Kp*Fact - K)*(Kp*Fact - K), /* calc closeness of fit */
26          Coef1 < Coef0, /* if best one */
27          retractall(best_fit/3),
28          assert(best_fit(Prod,Fact,Coef1)),  /* assert as best */
29          !.
```

Figure 5.4 The Prolog implementation of the optimization model.

Line 5 is the implementation of equation (2) and lines 23 to 25 is the implementation of equation (4). Lines 3 to 6 will cycle on failure through all ***prod_b/1*** relations in the knowledge base. Each cycle determines a rate and then tests its closeness of fit by attempting the ***fit_prod/2*** clause which asserts the name and rate of the product with the minimum variation as the ***best_fit/3*** relation. Lines 11 to 15 then assert the best fit recommendation back into the knowledge base for the user interface and dialogue generator to use. Note how in lines 13 and 14 a product's rate need not start from zero. The user is allowed to apply a minimum rate of a product and then optimize on the residual requirements. This is an example of the flexibility built into the dialogue system to maintain user confidence.

The difference between the total nutrient requirements of the crop and those supplied by the basal recommendation becomes the side-dressing requirements. This knowledge is generated at the end of making a basal recommendation and made available to the next sub-task of making a side-dressing recommendation. The processes and models use for making side-dressing recommendations are almost identical to those employed in making the basal recommendations. Figure 5.5 shows the user interface to implement this task.

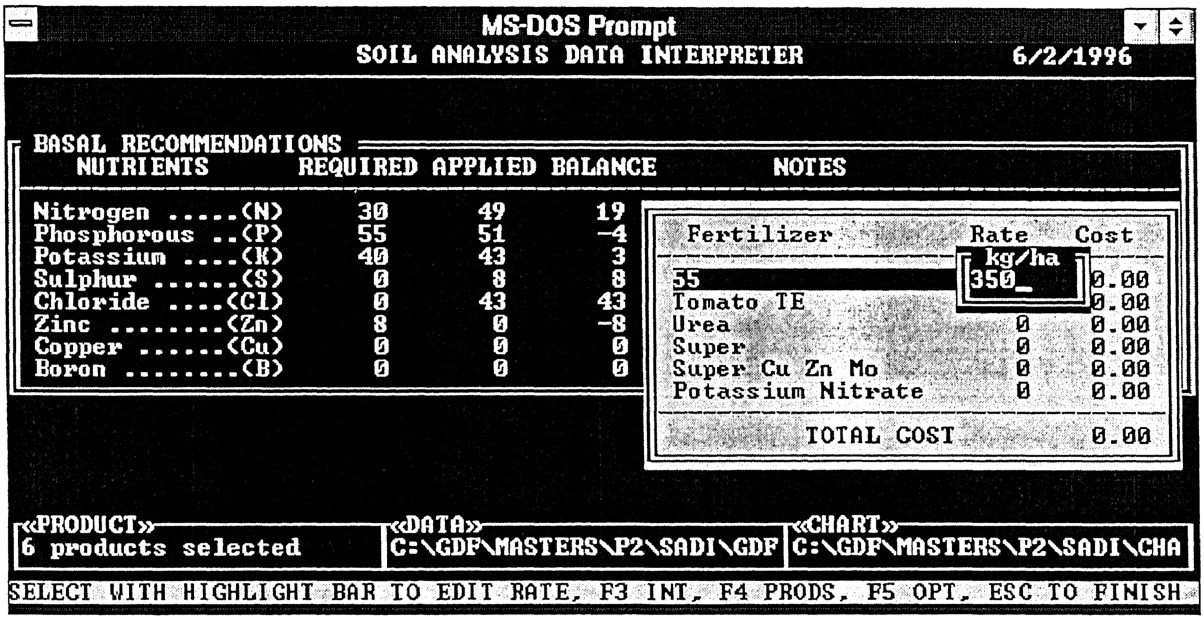
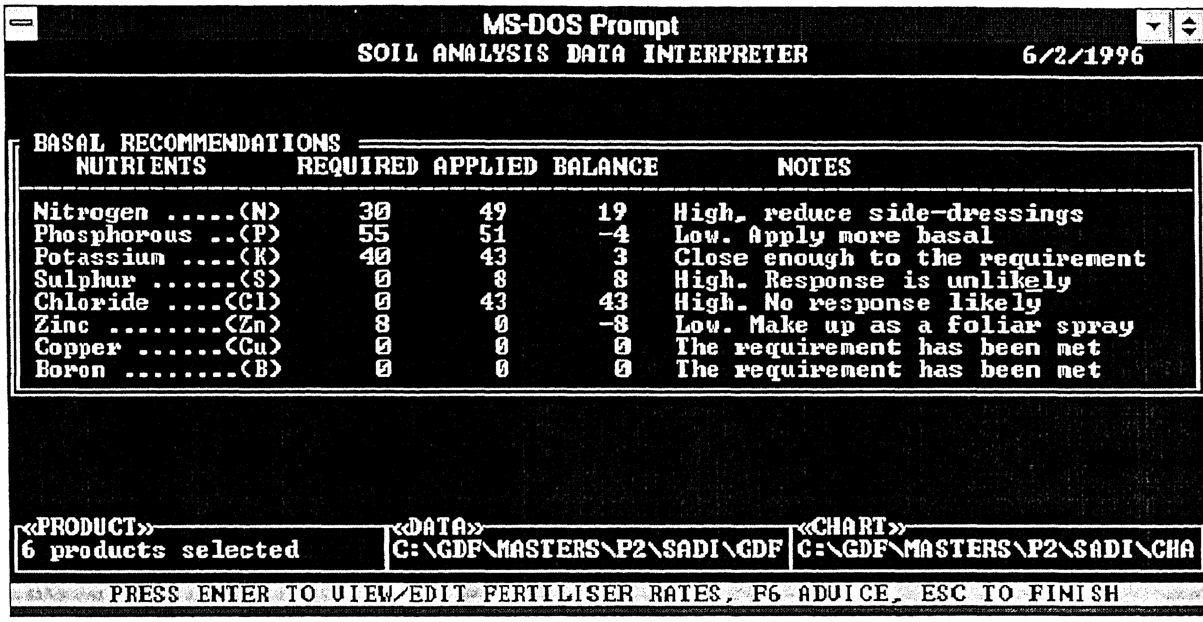


Figure 5.5 Screen design used to implement the linear model to make fertilizer recommendations.

At any point in the basal or side-dressing sub-tasks the user can call up on-screen the interpretation report, the complete product list, detailed explanatory text offering SADI's opinion of the current solution and an optimizer that determines the rate of a specified product to meet a particular elemental requirement, as the system message along the screen's lower edge indicates. Figure 5.6 shows the nutrient balance screen with expert opinions (Notes) suggesting possible user actions. Also at any point the user can return to the fourth main menu task and re-select a different range of fertilizer products to be considered in the fertilizer recommendation.


MS-DOS Prompt

SOIL ANALYSIS DATA INTERPRETER 6/2/1996

BASAL RECOMMENDATIONS

NUTRIENTS	REQUIRED	APPLIED	BALANCE	NOTES
Nitrogen .....(N)	30	49	19	High, reduce side-dressings
Phosphorous ..(P)	55	51	-4	Low. Apply more basal
Potassium ....(K)	40	43	3	Close enough to the requirement
Sulphur ......(S)	0	8	8	High. Response is unlikely
Chloride ....(Cl)	0	43	43	High. No response likely
Zinc ....(Zn)	8	0	-8	Low. Make up as a foliar spray
Copper ......(Cu)	0	0	0	The requirement has been met
Boron ....(B)	0	0	0	The requirement has been met

«PRODUCT»	«DATA»	«CHART»
6 products selected	C:\GDF\MASTERS\P2\SADI\GDF	C:\GDF\MASTERS\P2\SADI\CHA

PRESS ENTER TO VIEW/EDIT FERTILISER RATES, F6 ADVICE, ESC TO FINISH

Figure 5.6 The screen design used to display the expert opinions (notes) to the user.

The final part in the recommendations phase is to write a recommendation report when the user is satisfied with the recommendation generated. SADI, as in the interpretation phase, writes the report to screen as well as disk file. In generating the report, SADI tidies up loose ends in the recommendation by making micro-nutrient recommendations of foliar sprays for elements such as copper, zinc, and boron. The advantage of saving all reports (interpretation and recommendations) to disk is the user can incorporate them in a personalized report/letter via a work processor.

On returning to the main menu, any combination of tasks can be performed either on the current data and knowledge or by loading in new soil analysis data or interpretation chart.

The implementation of mixed initiative dialogues using event driven coding also proved a relatively easy task using Prolog. The user can select a range of from a single screen by pressing one key - the need for the user to answer a list of questions that restricted the context the user could then work in, was done away with.

The implementation of mixed dialogues using event driven code, the provision of the linear model as a tool for optimizing fertilizer rates and user messages generated from the knowledge base meets the design goals of the project. This approach appears to be appropriate in domains where the synthesis of solutions within certain constraints is required. The consultative role of the system and its exploratory tools make the user, expert or novice, more aware of the valid combinations that can be generated. Prolog proved to be a highly satisfactory platform.

A User's Guide was published for this system and is presented in the collection of publications arising from this study.

At the conclusion of the development of SADI, as 'Windows' was starting to appear, a brief attempt was made to give SADI a Windows look and feel. This sub-project was called 'Fertex' and the user interface is shown in figure 5.7.

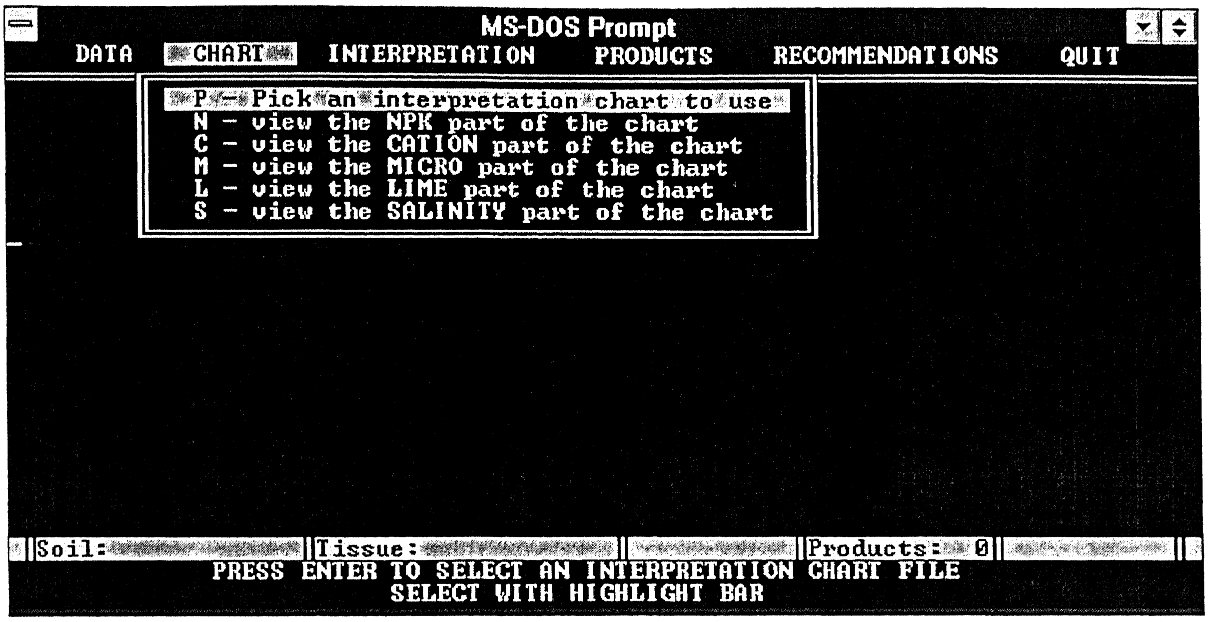


Figure 5.7 The main screen in the discontinued second DOS version of SADI named FERTEX.

The underlying inference models, knowledge bases and files would remain the same but the user interface would be re-designed to give a horizontal upper screen edge main menu with drop down sub-menus. Status bars and system messages would appear along the lower edge of the screen.

This sub-project was halted before completion with the decision to re-develop SADI in the Windows environment.

5.3 Windows Prototype

Development of this prototype began in response to user testing where a strong preference was shown for a Windows based system. The underlying operation principles of the DOS based system were in general not questioned. User testing had shown opportunities to add additional functions to the system. The aim of this part of the project was then to transfer the methods and techniques developed in the DOS prototype of SADI to a Windows environment.

In the process several user suggestions were added to the system along with underlying efficiencies the author had planned for any upgrades.

Because applications are built directly in Excel5™, lines of code do not truly reflect system statistics. The Windows prototype of SADI consists of one main workbook of 318k in size, a graphic banner of 110k in size and a small start-up script of 12k in size. The external knowledge bases are themselves Excel5™ workbooks of 63k in size. The main workbook contains eight worksheets, (seven spreadsheets and one macro sheet). Four of the spreadsheets are made visible to the user during a session thus forming part of the user interface. All other user interaction is carried out through Window's dialogue boxes or menus. The success of this project would dispel the notion that expert systems need to be developed in so called expert system shells or languages and that main stream development software is capable of delivering symbolic reasoning in certain situations for reasons detailed in Chapter Four.

Figure 5.8 shows the main menu screen of SADI. Figure 5.9 shows the use of a Windows dialogue box in the system.

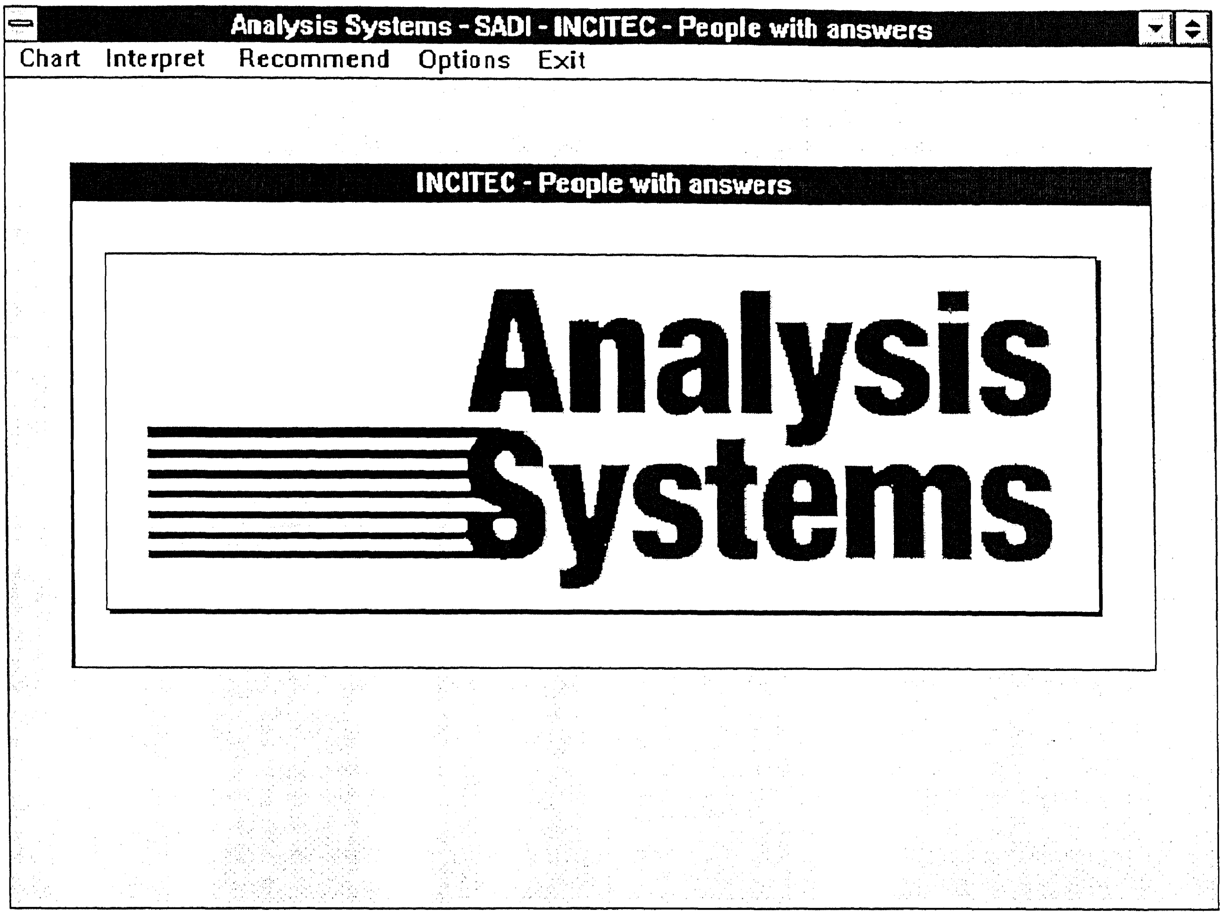


Figure 5.8 The main menu screen of the Windows prototype of SADI.

Note how the general structure of the Windows implementation has not changed. The main tasks are still in the main menu.

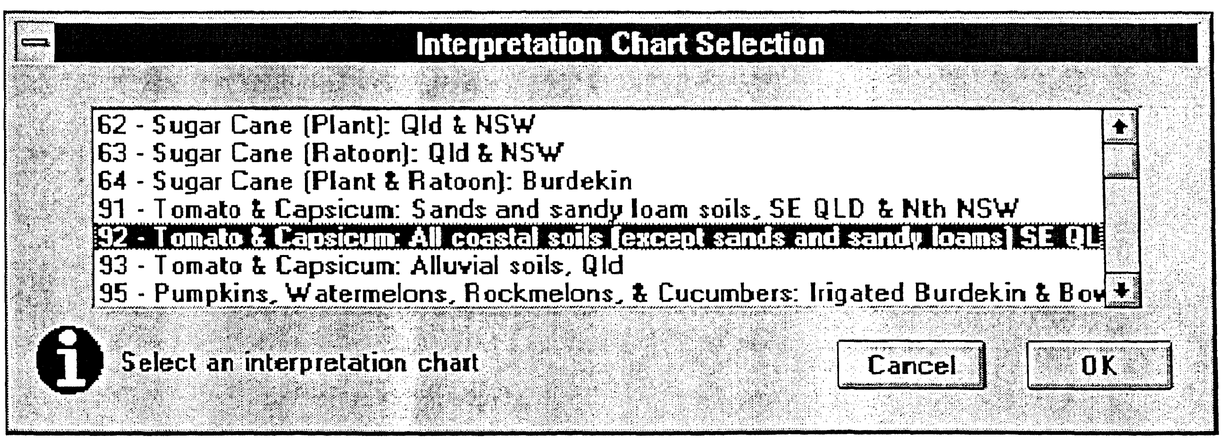


Figure 5.9 Example of a dialog box used in SADI

The only obvious change has been that of data entry. Instead of entering data onto a data form and then copying this across onto the interpretation report after an interpretation task is requested, this prototype allows the user to enter the data directly onto the report. Upon each entry the system immediately carries out an interpretation of that nutrient thus presenting the user with immediate feedback on the data. Response time for this is virtually immediate. Figure 5.10 shows the user interface of this section.

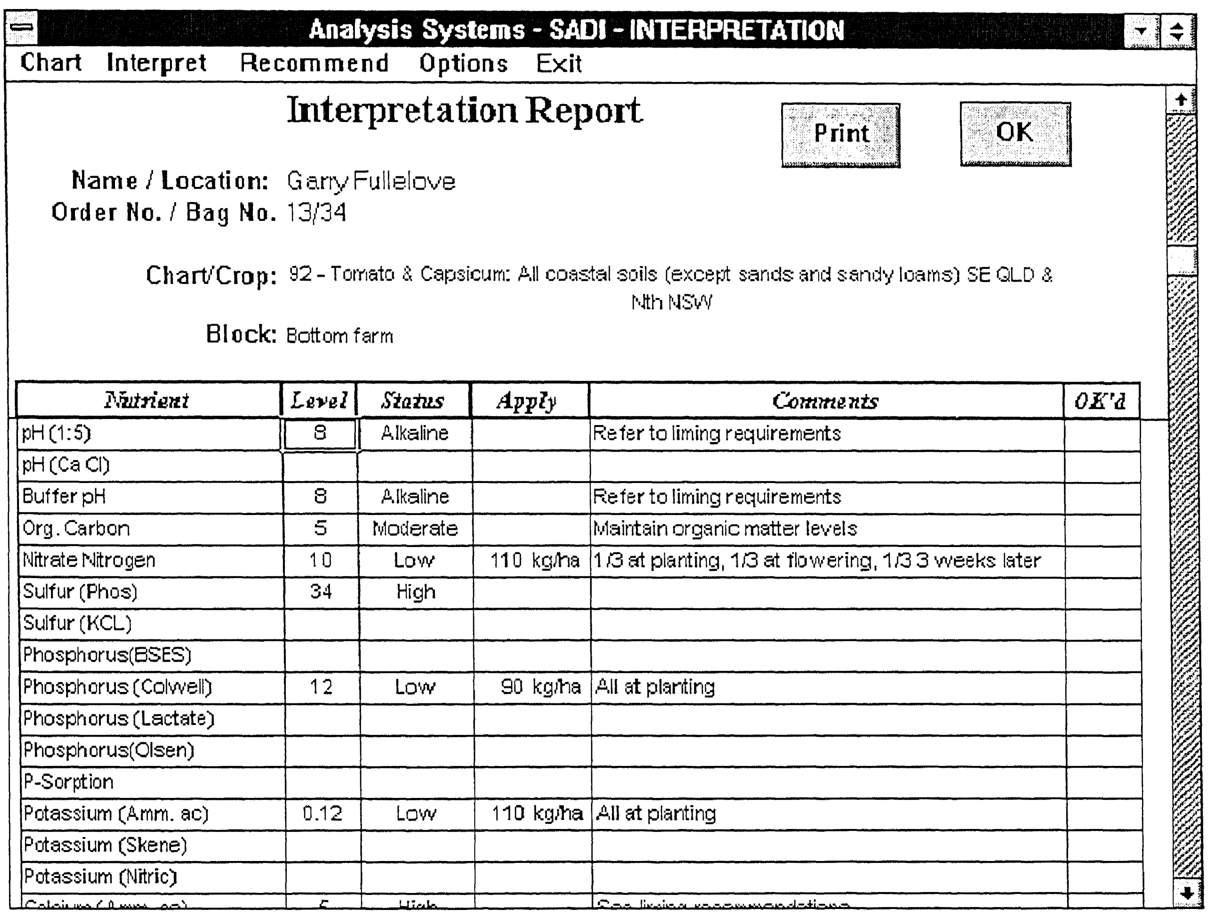

Analysis Systems - SADI - INTERPRETATION

Chart Interpret Recommend Options Exit

Interpretation Report

Print OK

Name / Location: Garry Fullelove
Order No. / Bag No. 13/34

Chart/Crop: 92 - Tomato & Capsicum: All coastal soils (except sands and sandy loams) SE QLD & Nth NSW

Block: Bottom farm

Nutrient	Level	Status	Apply	Comments	OK'd
pH (1:5)	8	Alkaline		Refer to liming requirements	
pH (Ca Cl)					
Buffer pH	8	Alkaline		Refer to liming requirements	
Org. Carbon	5	Moderate		Maintain organic matter levels	
Nitrate Nitrogen	10	Low	110 kg/ha	1/3 at planting, 1/3 at flowering, 1/3 3 weeks later	
Sulfur (Phos)	34	High			
Sulfur (KCL)					
Phosphorus(BSES)					
Phosphorus (Colwell)	12	Low	90 kg/ha	All at planting	
Phosphorus (Lactate)					
Phosphorus(Olsen)					
P-Sorption					
Potassium (Amm. ac)	0.12	Low	110 kg/ha	All at planting	
Potassium (Skene)					
Potassium (Nitric)					

Figure 5.10 Implementation of data entry and interpretation tasks in SADI.

The columns to the right of the data entry are editable by the user allowing system generated text to be modified by the user should they feel additional or alternative comments need to be made. Before the recommendation tasks can be undertaken, the user must OK the interpretation so that they accept responsibility of the systems results. This is made easy by simply double-clicking in the cell in the OK column or once in the cell pressing the space bar (the largest keyboard target).

The event driven code that responds to data entry and carries out an interpretation is shown in figure 5.11. Line 6 captures the space key and handles the OK column entry. Line 7 captures the DEL key and handles undoing an interpretation. Line 8 captures the data entry event and calls the interpretation task.

```
1       int_edit
2       =update_menu(3)
3       =ACTIVATE("[sadi5.xls]REPORT-I")
4       =FORMULA.GOTO(SADI5.XLS!report_i_home,TRUE)
5       =FORMULA.GOTO(report_i_enter_screen,TRUE)
6       =ON.KEY(" ","int_check_box_toggle")
7       =ON.KEY("{DEL}","int_clear")
8       =ON.ENTRY(,int_do)
9       =UNHIDE("sadi5.xls")
10      =WINDOW.TITLE("INTERPRETATION")
11      =PROTECT.DOCUMENT(TRUE,TRUE)
12      =CALCULATION(3)
13      =ENTER.DATA(2)
14      =RETURN()
```

Figure 5.11 Macro code that captures data entry and invokes the interpretation task

Windows removes the task of application developers to code in printer support due to the print management function within Windows itself. For this reason, the reports in SADI can be printed out from the application rather than an ASCII file as in the DOS prototype.

Knowledge base design was similar in principle to the Prolog rules but implemented as a "look-up table" in the Excel5™ function language. Figure 5.12 shows the structure of the look-up table for Nitrogen (N).

Microsoft Excel - C9201.XLS

File Edit View Insert Format Tools Data Window Help

	A	B	C	D	E	F	G	H	I	J	K	L
27	Comments	Increase	Increase	Increase	Maintain c	Maintain c	Validate level					
28												
29		c_e										
30	Level		5	10	15	20	30	40	200			
31	Status	Low	Low	Low	Moderate	Moderate	Moderate	High	Out of range			
32	Req	180	140	110	90	60	40	30				
33	Units	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha				
34	Comments	1/3 at pla	1/3 at pla	1/3 at pla	1/3 at pla	1/2 at pla	Apply at l	All at plar	Validate level			
35	pre											
36	pl	34	34	34	34	50	100	100				
37	td1	33	33	33	33	50						
38	td2	33	33	33	33							
39	td3											
40	td4											
41	td5											
42	td6											
43	td7											
44	td8											
45												
46		c_f										
47	Level		10	20	150							
48	Status	Low	Moderate	High	Out of range							
49	Req											
50	Units											
51	Comments	Use sulfu	No response likely		Validate level							
52												
53		c_g										

chart / Lime / Weightings /

Figure 5.12 Example of the lookup table used in Excel5™ for the structure of the knowledge base

Row 30 is the levels of nitrogen that the table can relate elemental requirements to. As in the Prolog version the last value is a catch all that indicates that the value is out of range. The lookup table function finds a column in the table (A30 to K44) with the largest value in the *level* row (row 30) that is less than the lookup_value; in this case the value entered by the user as a soil analysis. All data in the column found is then returned by the function. In this context all the knowledge related to a certain level of soil analysis is stored in the relevant column and accessed when the level indicates that column fits the criteria. In this way text and numeric values are passed to the system based on the soil analysis results just as text and numeric values were instantiated and asserted by the Prolog rules when they were fired.

In relation to figure 5.12; if the value of nitrogen entered by the user is 6.8, the look-up table selects the second column of the table (column C) as being the appropriate level and thus returns ***status*** text as "Low"; ***requirements*** as 140; the ***units*** of that value as "kg/ha"; ***comments*** beginning with the text "1/3 at pla..."; 0% applied ***pre-plant***; 34% applied at ***planting***; 33% applied at ***top-dressing-1***; 33% applied at ***top-dressing2***; and 0% for the remaining ***top-dressings***.

An argument for this structure over the Prolog rules is that the tabular layout of the knowledge is far easier to comprehend and therefore maintain than the verbose rule layout. An argument against the tabular layout is the table look-up function can only consider one factor (in this case the soil analysis data level) as its indexing criteria. If, in the future the nitrogen interpretation needed to consider another variable as well as the soil level, the table model would need to be greatly modified. Rules on the other hand could simply have another rule inserted to operate in conjunction with the initial rule without a great deal of modification.

As in the DOS system, user navigation through the system is controlled or managed for integrity, by enabling or disabling the menu options as system milestones are passed. In the DOS system menu items were disabled and brackets appeared around the disabled option. In

Windows, menu options are grayed out when disabled and passed milestones can be checked with a tick mark beside them. Figure 5.13 shows an example of this.

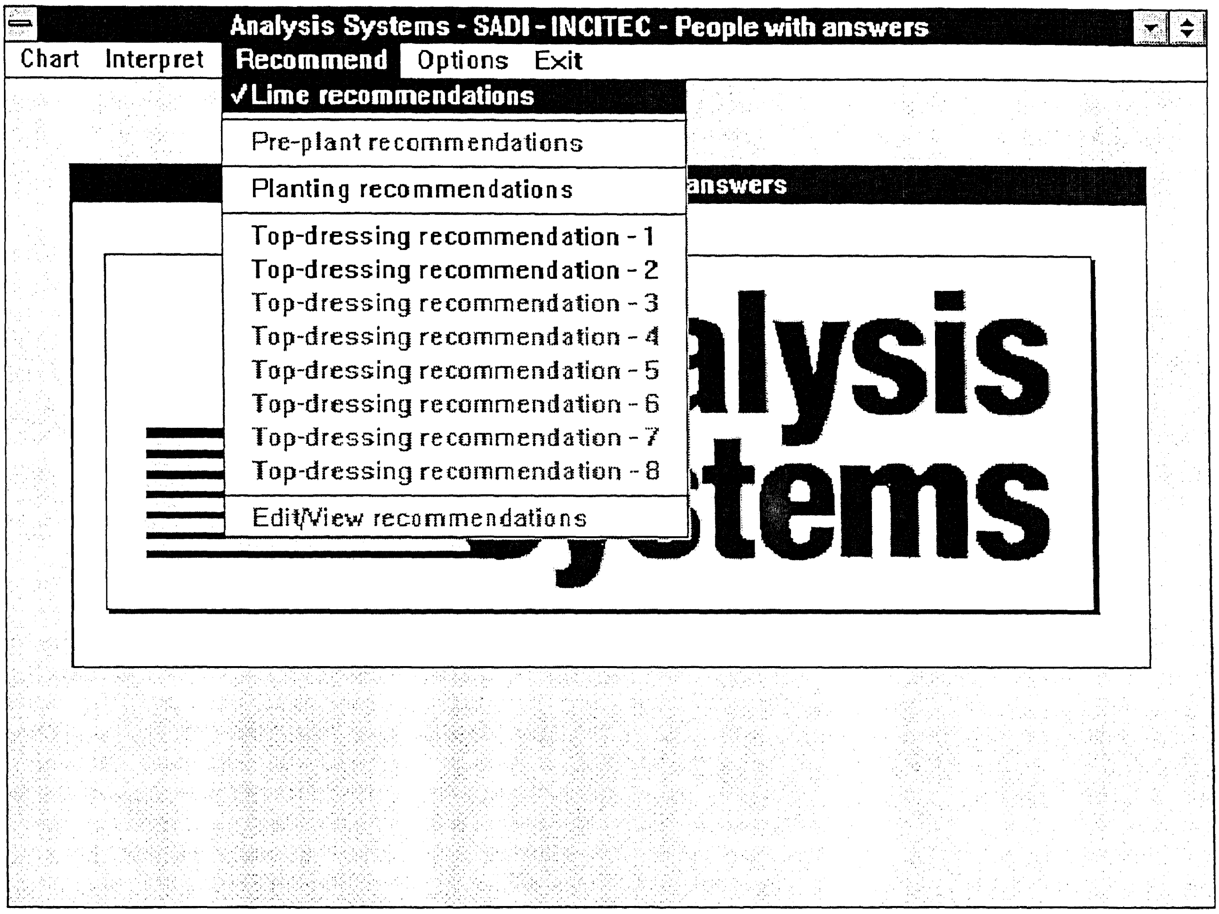


Figure 5.13 An example of menu cues managing the navigation of the system by the user.

The linear model used in the recommendation module of the DOS system is implemented in a very similar fashion in the Windows system. The algorithms are the same, only the language syntax has changed.

However the user interface and options available to the user to explore the solution space are greatly expanded in the Windows prototype. Because of the vastly improved calculation power of the software and hardware platform, the solution space did not need to be reduced by selecting a sub-set of the fertilizer products to consider, the whole product range is now available to the user to produce a solution from. Additionally, extra optimization tools are presented to the user through 'buttons' so more varied exploration can be undertaken. Though not shown in this publication color is used extensively to convey system status and editable areas of the screen. For example, recommendations that do not supply enough of a particular nutrient generate a negative 'balance' figure. This negative number is displayed in a red colored font. The color will change depending on the systems opinion of the 'nutrient balance'. Figure 5.14 shows the screen design of this part of the system.

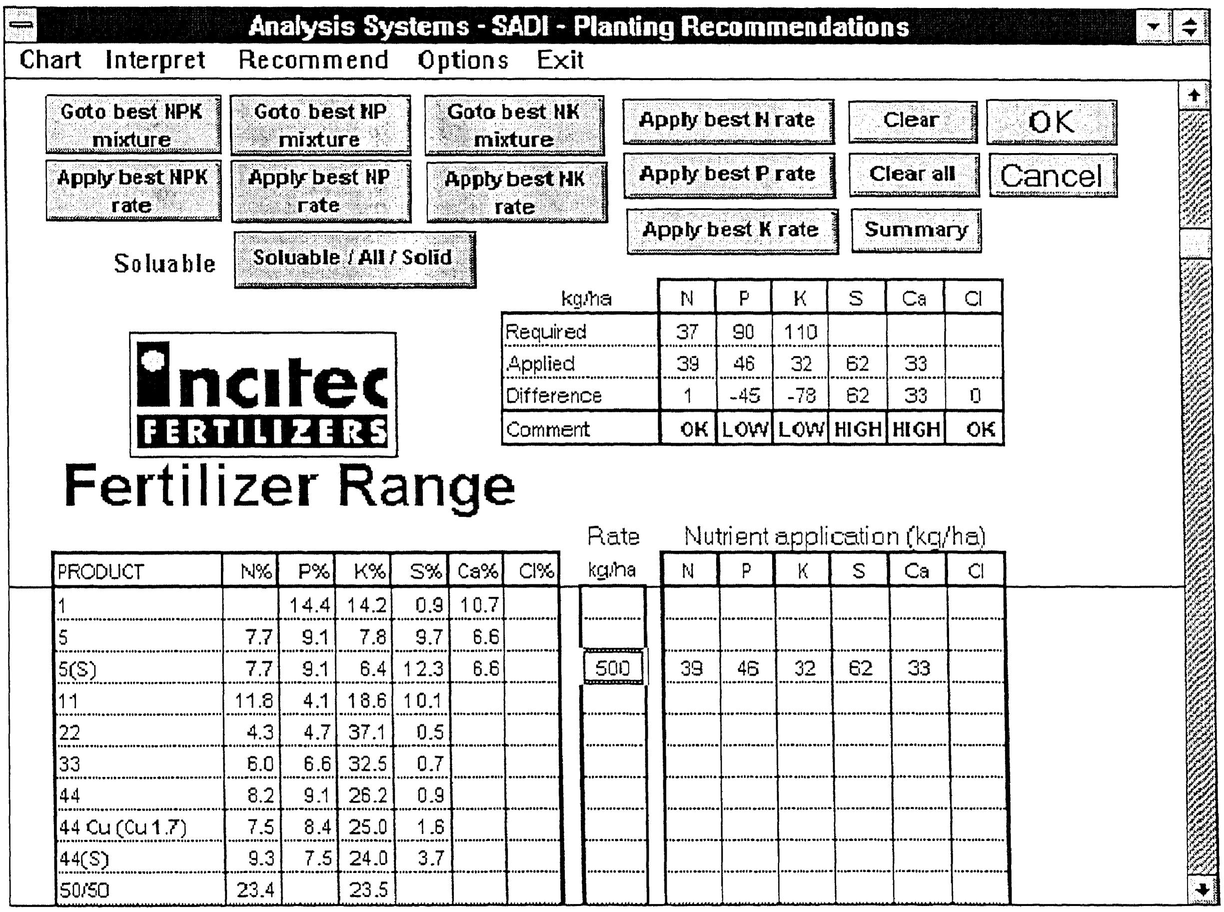
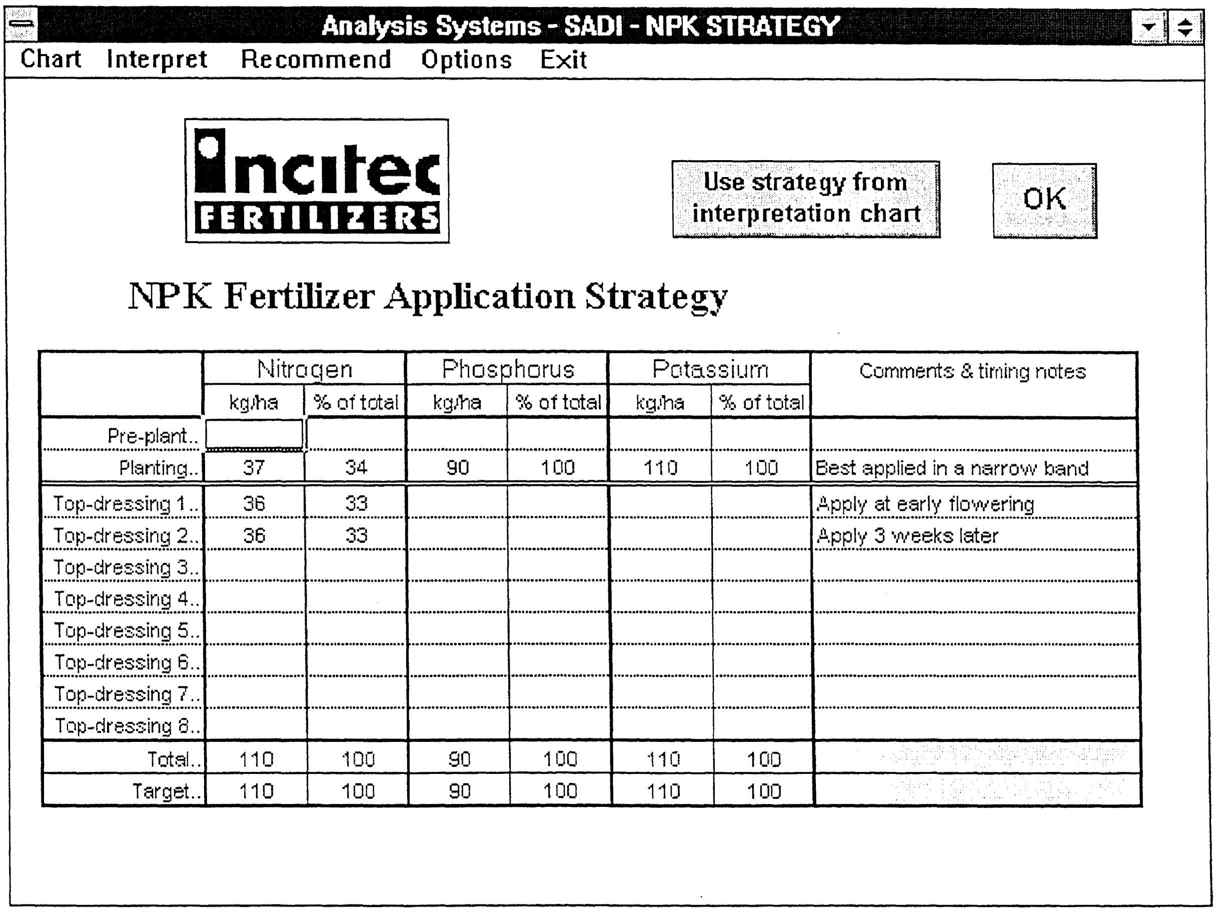


Figure 5.14 The recommendation screen of the Windows prototype

Further flexibility was built into the Windows prototype by allowing the user and/or the system to define the balance of nutrients that were to be applied at various stages during the crop cycle. The DOS prototype simply enforced a basic model of having the interpretation process assert the systems knowledge on the timing of nutrient application without allowing any user intervention. The user could over ride this in the recommendation phase but was not presented with any method to specify exactly the new timing. Figure 5.15 shows the user interface that implements this part of the Windows system.



	Nitrogen		Phosphorus		Potassium		Comments & timing notes
	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total	
Pre-plant..							
Planting..	37	34	90	100	110	100	Best applied in a narrow band
Top-dressing 1..	36	33					Apply at early flowering
Top-dressing 2..	36	33					Apply 3 weeks later
Top-dressing 3..							
Top-dressing 4..							
Top-dressing 5..							
Top-dressing 6..							
Top-dressing 7..							
Top-dressing 8..							
Total..	110	100	90	100	110	100	
Target..	110	100	90	100	110	100	

Figure 5.15 User interface implementing the fertilizer strategy in the Windows prototype

Again color is used to cue the user on the closeness of the total to the target. Also upon user request in prototype testing, (see Appendix 8, item 7) the ability to either enter a kg/ha amount or a relative percentage was developed. During testing it was found that the fertilizer company representatives were quite often converting the percentage splits into absolute kg/ha amounts to validate them. The ability to enter either the relative percentage or absolute kg/ha rate and get immediate feedback of that entry on the alternative units of measure greatly removed the need for human calculation and thus errors.

This part of the system was implemented using event driven code that responded accordingly depending on which cell an entry was made. This also allowed a top down integrity model to be implemented where-by the user had to define the fertilizer strategy in a chronological order. This prevented the loss of integrity where the user may have entered data in the pre-plant, planting and top-dressing 1 rows and then entered an amount in the top-dressing three row leaving a blank top-dressing two amount. A zero entry in the top-dressing two amount would be a valid entry before progressing onto top-dressing three, but a blank entry in top-dressing two would not allow an entry in top-dressing three.

To further help the user, a button that automatically set the table to the figures the system calculated as being relevant was provided. An initial alternative to this was for the system figures to be loaded into the table upon entry into the screen. This had several drawbacks; it erased any previous user data that was being revisited for editing; and it necessitated the user leaving the screen and re-entering it simply to reload the system's calculated amounts. By providing a button to load the system's calculations, the user took control of when this event occurred. However the system maintained an integrity check in that the targets had to be met before the dialogue could be successfully completed (see Appendix 8, item 7). Figure 5.16 shows the system dialogue displayed when the integrity test failed upon exiting the screen.

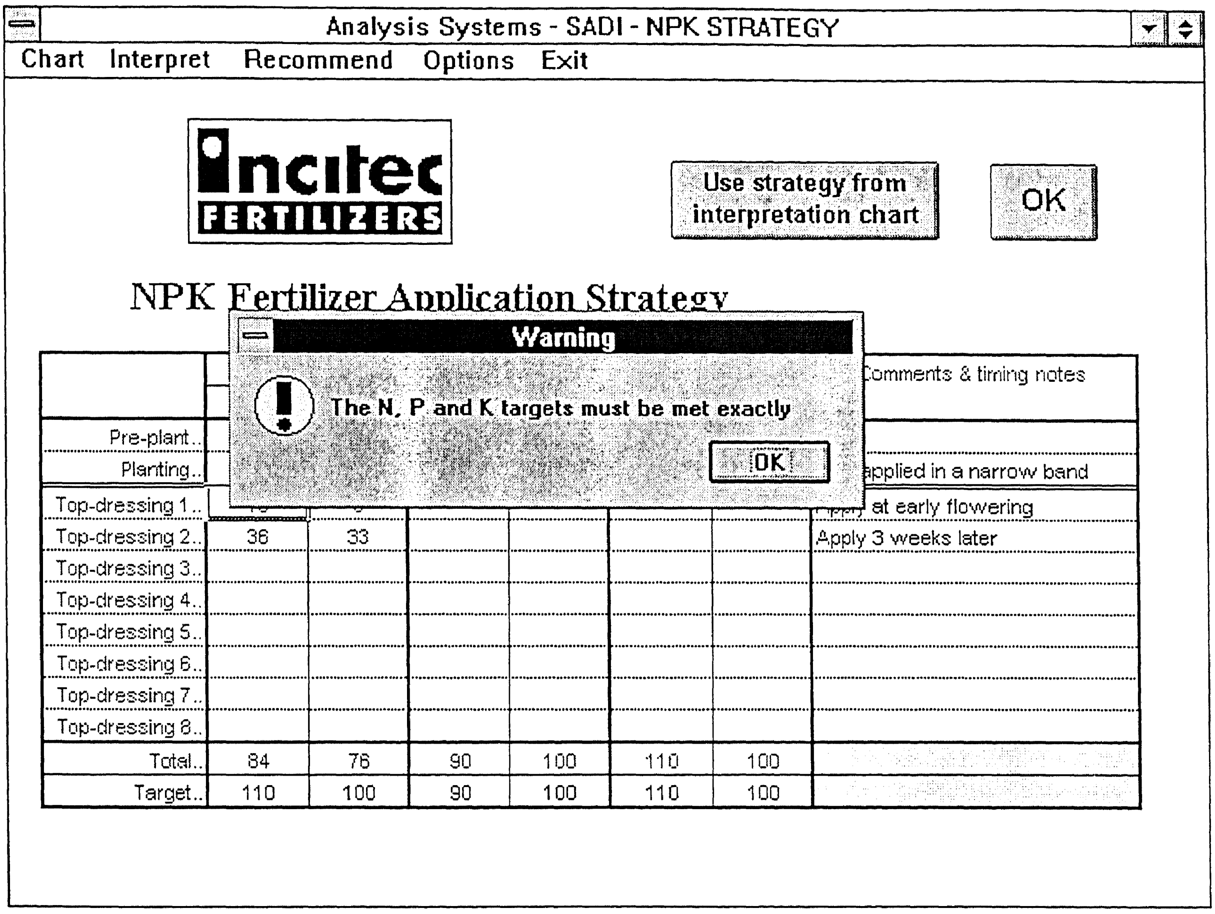


Figure 5.16 System dialog displayed when integrity test failed

In general, the Windows prototype fulfilled many more user expectations and allowed far more flexibility in upgrading than the DOS prototype. This was in part due to the direct manipulation of the user interface design being far quicker to edit than hard code in the DOS prototype, and also due to the development environment language where much higher level data constructs were supplied.

The prototyping cycle of development and user testing proved to be very acceptable to the end-users as their testing also provided them with hands-on milestone reports as it were. They could physically see and use the achievements made on the system since last they saw it instead of trying to imagine the system as explained in some milestone report.

One drawback the author found in using this development methodology was that when the users tested the system they often dreamed up additional items they wanted added to the system. This made it hard to put an exact time scale on system development and eventually led to a blow out in the Windows prototype development cycle. Though this was not critical, since it was at the users direction, a more commercially orientated project would have to make allowances for this 'exploration of added possibilities' users seem to go through when presented with prototypes.

Several authors hinted at such twists when using a prototyping development methodology. Morris (1990, p.116) in portraying prototyping as part of the system's life cycle reported, amongst other things, "... that prototyping aids user interface design, promotes communications with users but, most important of all, it can be used as a vehicle for eliciting correct and complete specifications of requirements."

Wilson et.al. (1989, p.190) in reviewing life cycles in software and knowledge engineering, reported that "... the traditional life cycle model used in software engineering has provided some benefits to knowledge based systems development, although it has been shown not to apply to all styles of product development; particularly where program requirements are initially ill-specified." Such was the case in this study, where the beginning and end points were known, but as it turned out, the process of navigating from beginning to end was only specified at a macro level and many micro level specifications were developed and implemented during the prototype iterations.

Weitzel and Kerschberg (1989, p.483) noted "... that users often cannot determine if formal specifications satisfy their requirements. For the user, the best way to do this is using the system. Prototyping facilitates this." As was also the case in this study, Weitzel and Kerschberg (1989) reported that the prototype could either be kept as the production system or used as the design specification for a standard implementation of the production system.

Chapter 6

6. RESULTS AND DISCUSSION

From a very early stage in this project, the pilot commercialization of the prototype became one of the main goals upon which all work was to be judged. System performance acceptable to the commercial sponsors was the criteria used to refine the prototype during the many iterations of the 'Prototyping' development cycle (described in Chapter 2).

This chapter discusses the results of the work described in the previous chapter with regard to the project objectives arising from the hypothesis put forward.

6.1 Evaluation Procedures

The process of iterative prototype review by the end-user team was used in this study as the evaluation process. Since the end-users of the system developed in this project were the staff team from the fertilizer company, their subjective review of each major prototype iteration starting at the beginning of the project and continuing to the end of the pilot commercial system was seen as an effective evaluation and end-user communication process. Additionally, by having the staff team consisting of both domain experts and the manager of the Analytical Services section, a cross section of views could be generated on both a correctness and completeness basis as well as a usability basis.

No formal evaluation criteria were developed by which to judge the prototypes. This was a deliberate decision as no team member had any firm idea as to what a system should look like and they were happy to subjectively test the prototypes as they were developed using their domain knowledge and training background to gauge the systems effectiveness in meeting the demands placed upon it. Feedback to the author occurred either immediately at a team meeting or informally during the next development cycle. Two way communication was always supported and often lengthy discussions between the author team members took place exploring various alternatives in system design and function. On some major issues, the author could present the team with several prototype options as possible solutions, and after review the team would recommend the direction the next prototyping cycle should follow.

Only once did the review team deem it necessary to refer to the ultimate end-user of the proposed commercial system, the fertilizer resellers, to come to a decision for the prototype system. This was the decision of which operating system platform to develop the system for - the choice being to say with a DOS platform used by the original prototype or upgrade to a Microsoft Windows ™ (Microsoft) platform. The feedback confirmed the teams own opinion and the decision was taken by the team to upgrade the prototype at that stage to a Microsoft Windows™ (Microsoft) platform.

Examples of the major design directions influenced by the iterative reviews of the prototype by the team are:

- use form fill-in for data entry rather than ordered prompts
- automatic re-calculation of nutrient requirements in the interpretation phase rather than at the users commend

- automatic selection of a subset of fertilizer products upon selection of a particular chart
- the provision of dialogues that allowed either a kg/ha amount or a percentage of the total requirement to be specified when defining the NPK strategy.
- the provision of more tools to explore the solution space in the recommendation phase
- the provision of a filtering system on the type of products considered in the recommendation phase
- the ability to print out system reports only when several cross-checks had been undertaken within the system by the user.

The cycle of iterative prototype development and testing proved to be very acceptable to the end-users of this pilot system as their testing provided them with not only a hands-on milestone report but also with a way of expanding their own ideas on what such a system was capable of doing. One drawback the author found in using this development methodology was that when the users tested the system they often dreamed up additional items they wanted added to the system. This made it hard to put an exact time scale on system development and eventually led to a blow out in the Windows prototype development cycle. Though this was not critical, since it was at the end-users direction, a more commercially orientated project would have to make allowances for this 'exploration of added possibilities' users seem to go through when presented with prototypes.

Though the action of not having any published evaluation criteria for the prototype system may go against the views of some authors found in the literature (Berry and Hart, 1990), the notion was held by the fertilizer company team that this was explorative work to test the technology for developing and delivering fertilizer recommendations and they would judge it by their own intuitive and professional competency as to whether the system was meeting the goals they clarified over time.

6.2 Interpretation Model

The requirement of this project task was to derive elemental nutrient requirements and supporting textual explanations and directives from soil analysis data. The model used was a non-functional implementation of a crops sigmoidal response curve to increasing nutrient availability in the soil (Johnson 1991). This curve is not linear and an exact input / response relationship is not required in this instance. Therefore the construction of sampling windows along the response curves and representation of the input / response relation as discrete levels or steps was acceptable.

This was in line with the fertilizer companies own published manuals on the subject as shown in figure 6.1.

Incitec Analysis Systems

Interpretation
Chart No: 91
Effective April 1996

TOMATO AND CAPSICUM
Sands and Sandy Loam Soils
S.E. Queensland and Northern New South Wales

SOIL

GENERALLY NO ACTION REQUIRED

Sampling Depth: 0-15 cm.

pH (1:5 water)	Value	4	5	6	7	8	9			
	Rating	VERY STRONGLY ACIDIC	STRONGLY ACIDIC	ACIDIC	NEUTRAL	ALKALINE	STRONGLY ALKALINE			
				OPTIMUM						
ORGANIC CARBON	% w/v C	0.5	0	3.0	5.0					
	Rating	VERY LOW	LOW	MEDIUM	HIGH					
NITRATE NITROGEN	mg/kg N	5	10	15	20	25	30	40	50	60+
	Fertilizer N kg/ha	180	165	130	100	80	60 MINIMUM			

Figure 6.1 An extract from the published interpretation charts used by Incitec showing the non-linear representation of a crops fertilizer response curve.

Incitec supported the representation of this part of the knowledge base in a non-linear form. Ease of visualization of and maintenance of the values was high on their priority list for knowledge representation in this phase. Ease of coding the published knowledge into the system was enhanced by the system having a similar style of knowledge representation. The expert could also validate the knowledge base by viewing it directly as well as testing its application through running the prototype.

Implementation as either rules or tables proved successful. Tabular representation with the added ease of layout and understanding was the preferred method. Excel 5 also gave the added advantage of being able to have large amounts of text in a cell without necessarily making all the text visible - thus allowing an even better layout to enhance visualization. In the fertilizer companies published manuals this text was always left to the user to supply and generally not presented in their tabular layout.

This non-function based knowledge representation proved acceptable to the expert and commercialization consultant.

A requirement by Incitec for the user to accept responsibility of the interpretation results before being able to print them out was met in the Windows prototype by implementing a 'check column' in the interpretation report as described in Chapter 5. To allow users who have poor keyboard skills to not get bogged down in 'OK -ing' many rows of interpretation results, two short-cuts were implemented to assist completion of the task. The most accessible key on the keyboard (space bar) was chosen as a hot-key to insert the check mark (in this case 'OK') into the column or a simple double mouse click in the check cell achieved the same thing. The typing in the check cell of 'OK' was kept as the base method to check/validate the results.

A user message highlighting the need for result checking/validation was displayed on the screen if an attempt was made to print the interpretation report before checking/validation had been accomplished. Graying out of the 'Print' button would have been the preferred method of informing the user of this requirement, however this function was not available in the macro function language used for the prototype. This is a change the commercialization consultant may implement using the VBA language also supplied with Excel 5.

The immediate feedback provided by the Windows prototype doing the interpretation as the soil analysis data was entered was an improvement the Incitec review team viewed favorably. In the

DOS prototype, the user entered the soil analysis data, exited out of that module and then ran the interpretation module to create an interpretation report to see the results of the interpretation. This proved to be usable but improvable when the interpretation report showed invalid data had been entered and the user had to exit the interpretation module, run the soil analysis data module and edit the errant data, exit this module and run the interpretation module (re-interprets *all* data) again to see the results of the interpretation.

In the Windows prototype, the immediate feedback of the interpretation result by the data entry triggered interpretation of that particular element proved to be far more acceptable to the review team.

Apart from providing this immediate feedback it also supported another use of the system that the DOS prototype provided but did not truly support in acceptable user response time. The ability of the user to enter fictitious soil analysis data and immediately view the interpretation results enabled the user to explore the solution space of this part of the knowledge base for what ever purpose they intended. This flexibility in use of the system enhanced the utility of the system for the review team. This shows that while both prototypes could apply the same knowledge and arrive at the same results - the method of delivering that ability to the user changed the utility of the underlying knowledge and inference engine.

The ability of the user to alter either by changing or adding to the interpretation report was seen as a necessary ability by the review team. This was to allow the user to express knowledge they brought to the consultation session not present in the knowledge base. Such knowledge was an awareness of local conditions such as weather, grower management skills, and yield goals that would have taken many question/answer iterations to determine from the user if the knowledge base was to be aware of them. Because not all of this extra knowledge was required at each consultation of the system, it would have been a burden for the user to enter this knowledge, knowing that it would have no benefit to the outcome. To overcome this problem, the system would have had to be given some knowledge as to when it needed this extra knowledge - a never ending cycle that could only be resolved by making assumptions that were not valid for every consultation in any case. It was seen as far more desirable to have the system present the results of its knowledge application to the situation at hand and allow the user to judge the need for and then directly apply, any extra knowledge required for, what that user considers, is a full and complete answer.

This highlights several areas in the way expert systems can be used that was considered during this study and relates to ways a set of user models are incorporated into the system and ways the system outputs are malleable by the user. Many systems give the user a feeling of being hemmed in - that is of being forced to navigate the knowledge base in a fixed way by a very fixed method and then have the results delivered in a fixed manner. The author suggests that these systems have low user utility, not only because of their narrowness of knowledge but also because of their narrowness in its application and delivery. By providing the user with a broader range of knowledge application methods and an ability to customize the resulting output, the author feels that the utility of that same knowledge is greatly enhanced. Commercial acceptance of these principles in this project would suggest that such a claim is well founded.

The system critical values that the user knowledge could impact upon were the rates and timing of nutrient application. The rates could be edited directly in the interpretation report and editing of the timing of nutrient applications was allowed for in the Nitrogen (N), Phosphorus (P), and Potassium (K) strategy options.

The NPK strategy was initially implemented as a table filled with the system default settings generated from the interpretation process. The user could then edit these figures quoted as kilograms per hectare if there was a need for change. During prototyping, it became evident that some users think about and express this knowledge in kilograms per hectare and others think about and express the timing of nutrients as a percentage of the total requirement. The final version supported both user views in tabular form where a percentage or a rate per hectare could be entered and the alternative figure was calculated automatically and displayed in a column alongside the edited value. If the user wanted to return to the system defaults a button was on the dialog to enable this.

Thus in one simple form, multiple ways for the user to interact with the system and underlying knowledge base were presented, substantially increasing the utility of the system without any addition to the knowledge base.

It has been shown through the acceptability of the system to the review team that the interpretation model can be implemented using symbolic reasoning techniques.

6.2 Fertilizer recommendations

The requirement of this project task was to arrive at a combination of fertilizer products and rates that met, within pre-defined constants, the elemental nutrient requirements determined in the interpretation phase. The model used was not a linear programming solution but a two step minimization of a sum of squares differences as described in Chapter 5. The same algorithm was used in both the DOS and Windows prototype. However its application to the problem was different in each prototype. In the DOS prototype the algorithm was used to calculate the rate of a product from the user-defined sub-set of products based upon its closeness of fit to the Nitrogen (N), Phosphorus (P), and Potassium (K) requirements. While this was very useful, the review team saw the need for additional filtering and/or refinement in the way the algorithm was applied to the problem. Such scenarios as determining the rate of a product which best fits only the Nitrogen and Potassium requirements, reducing the solution space to only soluble fertilizer products, and finding a product and its rate which best fits only the nitrogen requirement were additional tasks thought likely to be useful to exploring the solution space.

The DOS prototype was capable of this but in an indirect fashion. Because it worked entirely on a sub-set of fertilizer products, the filtering or refinement was done by altering the composition of the product sub-set. For instance, if the best soluble product was required the user exited the recommendation module, entered the product selection module and choose only soluble products before re-entering the recommendation module and triggering the best-fit algorithm.

This was overcome in the Windows prototype by presenting the user with a group of buttons that triggered a range of alternative refinements to the general algorithm as shown in figure 5.14. Note how the task of selecting a product and determining its rate is separated as well where as in the DOS prototype this was all one process. The separation allows the user to find what the system calculates as the best NPK fitting product but then calculate a rate that optimizes any combination of nutrients.

Again the principle of giving the user varied ways of navigating the solution space was the commercially preferred method of delivering this knowledge.

Of salience in this module, as in the interpretation module, is the immediate feedback given by the system to the user of any actions taken. The nutrient balance sheet presented on the right of the screen (the nutrient analysis of each product is presented on the left of the screen) and the recommendation balances presented in the top right of the screen in figure 5.14 update immediately after a rate of a product is entered either by the system or manually by the user. Use of colored response text acts as an extra visual trigger to the user of system message status.

As in the interpretation module, editing of the recommendation report to the users acceptance was required by the review team. The reasons for this were the same as given for the same requirement of the interpretation report.

It has been shown through the commercial acceptability of the system that valid fertilizer recommendations can be developed and delivered to users of the system using symbolic reasoning techniques.

6.3 User Interface

It was a design goal of this project to explore and describe methods for the production of a user interface that is highly interactive and effective. To this end a menu based, event driven interface was developed and tested in the DOS prototype. The Windows environment is by default an event driven graphic user interface comprising windows, menus, dialog boxes and graphic event triggers directed by either keyboard or mouse entries. The Windows prototype extended the scope of the user interface study by researching the construction and delivery of solution space exploration tools.

In the DOS prototype, the menu system came as a library of window and menu predicates with the Prolog-2 package. This library enabled the creation of windowed screen areas. These areas could be overlapping, bordered, colored, arranged in display priority and hidden. A menu in this system was a special case of a windowed screen area.

The provision of an interface using menus then became a task of passing arguments to these library predicates that determined the size, layout and contents of the menu and what should be done upon a selection within the menu. This made the process of building indirection into the system for maintenance purposes relatively straightforward. It was possible therefore to implement menus whose contents were unknown at the time of running the system and were dynamically created depending on data in the system. An example of this is in the product selection menu and the product rate menu of the recommendations module. Such dynamic user interface components were well accepted by the review team and considered essential in developing a context sensitive user interface. This concept differs from that discussed in chapter two where an adaptive user interface was explored. In that argument the user interface changed its basic behavior in response to a perceived user model. In this example only the content of the user interface not its underlying design changes in response to system events.

Indirection was seen as an important programming concept to overcome the need to constantly edit logic code during development. Indirection supplies pointers to data from within a body of code rather than needing the data to be placed in the code. This concept of removing data from the code and replacing it with pointers to the data was used heavily in the menu and message modules of the DOS prototype. An example of the use of indirection is in the message module where the predicate is called with the name of the message to be displayed instantiated. The contents of that message may alter during refinement of the prototype but the editing of the message contents takes place in the message file not in the system code.

The delivery of the system in the Microsoft Windows environment was more acceptable to users than a semi graphic platform used in the DOS version. The direct building nature of the user interface in Excel 5 rather than coding as in the DOS prototype, greatly enhanced the iterative prototyping methodology used in system development.

The principles of giving the user varied methods of applying the knowledge and navigating the solution space coupled with immediate feedback of the result of this domain navigation were proven commercially acceptable in this project. System utility and user acceptance were enhanced when these principles were enacted in the system and gave further foundation to the notion put forward by Waterman(1986) that the problem solving power of a computer program comes from the knowledge it possess, not the algorithms or inference schemes it employs. The results of this study also support the notion expounded by both Kidd (1985) and Berry & Broadbent (1987) that rigid forms of system-oriented dialogue are restrictive by limiting the options the user has in directing the session. This suggests that solution space exploration tools, as distinct from algorithms and inference schemes, further enhance the problem solving power of a knowledge based computer program.

6.4 Commercialization

The process of contracting a software consultant already being used by Incitec to implement office software customization proved successful. The consultant was very familiar with customizing the Microsoft Office suite of software, of which Excel 5 was an integral part, into other parts of Incitec's business. This experience of the software platform, an already established professional relationship with Incitec, and a constant daily contact with the review team has seen the commercialization process proceed to the point where most of the interpretation charts have been entered in to the knowledge base and system release to fertilizer resellers is planned for mid 1996.

Chapter 7

7. CONCLUSIONS

The aim of this study was to develop an expert system that makes fertilizer recommendations based on soil analysis data with the purpose of investigating issues associated with symbolic reasoning techniques to implement the interpretation and recommendation models, user-interface design, and the commercialization of the prototype.

Findings indicate that it is possible to develop a prototype expert system for the stated purpose as well as up-scaling this prototype into a commercially acceptable production system. In this study, development was accomplished by a small team using iterative prototyping. While from the literature, there is no consensus in industrial practice on a development method for knowledge based systems, the use of methods and guidelines for more conventional software design and development, especially the user-interface design, modular code design, and normalized relational data structures, proved successful.

Iterative prototype cycles did produce the benefits found reported in the literature. Specifically these were ease of maintenance, aids user-interface design, promotes communication with users, and provided a vehicle for eliciting correct and complete specifications of requirements.

Questions raised in the introduction as to the likelihood of success in this project, specifically in the areas of commercialization, domain size, user-interface design to facilitate flexibility of solution space navigation, and the combination of intensive calculations and symbolic reasoning techniques, have largely been answered.

Much effort was expended on developing a synergy between the symbolic reasoning required of the system and the intensive calculations required to support the task at hand. The result is a system composed of a maintainable knowledge base due to its simple tabular layout, a task orientated graphical user-interface that supports mixed initiative dialogues, and an extremely efficient inference and computational engine that provides feedback within acceptable time limits for a real-time system. Some of this success stems from the software platform used to deliver the system. Excel 5 being a powerful, Windows based spreadsheet environment is itself optimized to intensive computational work. This feature in conjunction with its underlying programming languages and direct build user interface components provided the capacity to deliver symbolic reasoning capabilities to the task at hand. The speed and ease of which user suggestions could be incorporated and tested into the system enhanced the prototyping development methodology used in the study.

Examples with the computational complexity and support of multiple navigation routes through the solution space were not found in the literature suggesting that this system had gone beyond the limits of other published agricultural expert systems. Furthermore, the use of spreadsheet based development environments was rarely mentioned in the literature. The success of this project would dispel the notion that expert systems need to be developed in so called expert system shells or languages and that main stream development software is capable of delivering symbolic reasoning in certain situations.

In designing the user-interface, concepts from traditional software engineering were integrated into the system with the principle that user-interface should be user or task centered (Sommerville 1989) being adopted. Various researchers discussed the concept of user modeling within a system for purposes of user-interface refinement where the system responses vary according to a model of the user. No such user modeling was incorporated within the prototypes developed in this study. The author's view is that providing an arsenal of tools by which the solution space can be navigated in many combinations and permutations, accommodates not only multiple user models but different goals that any particular user may bring to the system on different occasions. This approach offers the user more flexibility, a chance to explore the solution space without being directed immediately to an end result, and the ability to take control of the session as opposed to rigid 'question - answer - result' style dialogues. The user acceptability of the system developed in this study would suggest that this view is valid.

The development of an acceptable prototype, that covered the entire domain of Incitec's soil testing service provided an ideal starting point for the commercialization process. Proof of the technology, continual user review, and delivery of a usable prototype system indicated that commercialization should succeed and has been initiated with the hiring of a software consultant to expand the knowledge base of the system and explore software security issues as much proprietary knowledge and competitive advantage exists within the system. The work presented here supports the notion that the final prototype can be used as either the production system specification or as the production system itself. The small amount of literature describing the commercialization process of expert systems suggests that user involvement from an early stage in system development is a major factor in the successful adoption of the system. This study supports that suggestion and the author notes that by using an iterative prototyping development methodology where users test the various versions, user involvement is hard to avoid.

The findings of this study indicate further areas where research may be warranted. The knowledge base for the system relied upon the value of one variable to index and retrieve the knowledge that pertained to the situation at hand. It would be of interest to investigate methods where multiple variables were used to interrogate the knowledge base and what inference mechanisms proved efficient for such interrogation. Considerations of variable weightings (that is how important one variable's value is compared to another's), system integrity with missing data (that is how does the system respond if only three out of four variables have been given a value), and default starting values would need to be addressed.

The provision of higher level expert opinions by the system as compared to the current single word 'status' messages could be investigated. In the DOS prototype, very little use was made of the expanded explanation facility, thus leading to its demise in the Windows prototype. Do users require an explanation style facility in the system and if so how best can it be implemented? Are system messages warning users of the approach of solution space constraints or boundaries sufficient or are more educational 'How' and 'Why' messages required?

Comparative studies with different methods of presenting the vast array of numerical data generated in the system would yield information on how the system may be able to cater for numerically challenged users. In particular, the use of graphics to represent numerical proportions within the system and mouse activated gauges verses keyboard data entry would be worthy of investigation.

With regard to the use of an expert system to commercially deliver fertilizer recommendations, the value of this current study lies in its attempt to show, through the system development and commercialization, that computationally intensive tasks and symbolic reasoning can be combined within a standard software platform. The lack of published findings in this arena should not prohibit the investigation of the issues in providing such a combination in an expert system. The commercial interest in this project would suggest that aims of the project have been in most parts successfully addressed and that further investigations of the areas described above is warranted.

GLOSSARY

Algorithm An effective procedure for solving a particular mathematical problem in a finite number of steps.

Artificial Intelligence The subfield of computer science tat is concerned with symbolic reasoning and problem solving.

ASCII American Standard Code for Information Interchange. This is a table that assigns integers from 0 to 127 to characters and certain other non-printing outputs.

Assertion The database or fact part of the knowledge base. It includes rules that are known to be true or false and any other associated information.

Atom A named symbolic entity in the PROLOG language.

Backtracking A technique used in tree searches. The process of working backward from a failed objective or an incorrect result to examine unexplored alternatives.

Backward Chaining A search techniques used in production ("if-then" rule) systems that begins with the action clause of a rule and works backwards through a chain of rules in an attempt to find a verifiable set of condition clauses.

Blackboard A globally accessible database used in expert systems for recording intermediate, partial results of problem solving.

Database The organizing of data into tables and/or files of related units that are then viewed as a single storage concept.

Decision Support System Computer based information system that combines models and data in an attempt to solve non-structured problems with extensive user involvement.

Declarative Language A style of computer language used to specify only the desired results rather than the detailed steps of how to arrive at them.

Demon A procedure that is automatically activated if a specific predefined state is recognized.

Development Life-Cycle The processes involved in designing, constructing and testing a computer system. Parts of the life-cycle can include iterative developments of a prototype.

Dialog System The hardware and software that provide the user interface for DSS. It also includes the ease-of-use, accessibility and human-machine interface.

Domain An area of knowledge or expertise

Domain Expert A person with expertise in the domain in which the expert system is being developed

Expert System A computer system that applies reasoning methodologies on knowledge in a specific domain in order to render advice or recommendations much like a human expert.

Explanation Facility The component of an expert system that can explain the system's reasoning and justify its conclusions.

Firing a Rule Obtaining information on either the IF or THEN part of a rule which makes this rule an assertion.

Frames A knowledge representation scheme that associates one or more features with an object in terms of various slots and particular slot values.

Goal -seeking The capability of asking the computer what values certain variables must have in order to attain a desired goal.

Heuristics The informal, judgmental knowledge of an application area that constitutes the rules of good judgment in the domain and the problem solving process.

Icon A visual, graphic representation of an object, word, or concept.

IF-THEN A conditional rule in which certain action is taken only if some condition is satisfied.

Inference The process of drawing a conclusion from given evidence.

Inference Engine That part of an expert system that actually performs the reasoning function.

Instantiation The process of assigning a specific value to a variable object.

Interface The portion of a computer system that the user interacts with.

Iterative Process A systematic process for system development where multiple versions of a prototype are refined towards the final production system.

Knowledge Understanding, awareness, or familiarity acquired through education or experience.

Knowledge Acquisition The extraction and formulation of knowledge derived from various sources including domain experts.

Knowledge Base A collection of facts, rules, and procedures organized into schema.

Knowledge Engineer An artificial intelligence specialist responsible for the technical side of developing expert systems.

Knowledge Representation A formalism for representing in the computer facts and rules about a domain.

Linear Programming A mathematical model for optimal solution of constrained resource allocation type problems.

Matching The process of pattern recognition.

Natural Language A language spoken by humans on a daily basis such as English.

Normalization Process of reducing a data base structure down to a set of non-redundant field and table specifications.

Optimization Identification of the best possible solution.

Pattern Recognition The technique of matching an external pattern to one stored within a computer's memory and often used in inference engines.

Predicate Calculus A logical system for reasoning used in artificial intelligence programs to indicate relationships among data items. The basis for the computer language PROLOG.

Procedural Language A style of computer language used to specify the detailed steps that should be followed in arriving at a result.

Production Rules A knowledge representation method in which knowledge is formalized into rules containing an IF part and a THEN part.

PROLOG A high level computer language designed around the concepts of predicate calculus.

Prototyping A strategy in system development in which a scaled down system or portion of a system is constructed in a short time, tested ,evaluated and improved in several iterations.

Relational Database A database whose records are organized into tables that can be processed by either relational algebra or relational calculus.

Rule A formal way of specifying a recommendation, directive, or strategy, expressed as IF premise THEN conclusion.

Scenario A statement of assumptions and configurations concerning the operating environment of a particular system at a particular time.

Schema A data structure for knowledge representation such as rules or frames.

Sensitivity Analysis A study of the effect of a change in one or more input variables on a proposed solution.

Shell A kind of expert system development tool usually consisting of at least two components: a rule manager and an inference engine with explanation facilities and report generators as bundled extras.

Spreadsheet (Computer) Computer technology that is similar to columns-and-rows worksheets used by accountants but with far greater computational power and flexibility.

Symbolic Processing Use of symbols, rather than numbers, combined with heuristics, in order to process information and solve problems.

System Development Life Cycle The processes involved in designing, constructing and testing a computer system. Parts of the life-cycle can include iterative developments of a prototype.

"What If" Analysis The capability of "asking" the computer what the effect will be of changing some of the input data.

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APPENDIX ONE

This appendix gives a broad overview of the process of making a fertilizer recommendation for a crop based on the results of soil testing. The overview puts this study in perspective and highlights the intellectual environment in which the results of this study will be used.

Soil testing as a means of managing the fertilizer inputs into a cropping enterprise is practiced in nearly all parts of the world with some degree of success. In a broad sense, soil testing is any chemical or physical measurement that is made on a soil. But through common usage the term "soil testing" has been given both a more restricted and a much broader meaning. The term is restricted in the sense that it has come to mean rapid chemical analyses to assess the available nutrient status of the soil, and broadened to include interpretations, evaluations and fertilizer recommendations based on results of chemical analyses and on several other considerations.

There are some 16 elements known to be essential for crop growth. Three of these elements - nitrogen, phosphorus and potassium - are widely deficient in the soil. Soil pH also is a common limitation to plant growth. Secondary and micronutrient deficiencies are found in some soils, with sulfur, zinc, and boron being the most common, but these are usually restricted to special soil areas. Soil testing therefore, predominantly involves nitrogen, phosphorus, potassium and pH with secondary and micronutrient analyses varying widely on a regional basis.

The soil testing process starts with the collection of a soil sample, or samples from a field. The analytical results are expected to be representative for the entire field. The first basic principle of the soil testing process is that a field can be sampled in such a way that chemical analyses of collected samples will accurately reflect the field's true nutrient status.

Once the soil sample has been collected and prepared its level of available nutrients must be determined. By available nutrient one usually means the chemical form or forms of an essential plant nutrient in the soil whose variation in amount is reflected in variations in plant growth and yield. It is a basic principle of soil testing that simple rapid chemical analytical procedures can be designed to accurately measure, or be a measure of, the level of available soil nutrients. Many chemical methods have been suggested, and are being used, for the measurement of essential available plant nutrients. Actually the chemical method used is important only to the extent that it must accurately measure the available form or forms of the particular soil nutrient. A sample report of analytical results used in this study from a commercial laboratory is shown in figure A1.1.

It is these soil test values, highlighted by a black border on the right hand side of the report that are the input data for the system developed in this study. The additional data of crop, soil type and sometimes geographic location are implicitly entered when an interpretation table (also know as an interpretation chart or simply a chart) is selected. Other secondary factors such as field slope, weather patterns and climate are much harder to quantify and as in the manual process are left as value judgments by the user as to whether any slight adjustment need be made to the calculated results. Given the inherent variability and risk in any agricultural enterprise, these judgments are very subjective and will vary between individuals even for the same situation.

Analytical results obtained from chemical analyses of soils must be interpreted meaningfully and is the first major computational module in this study following data entry of the analytical results. This is usually accomplished through some type of a previously determined correlation between soil test results and known field crop responses. Therefore, sound correlation studies must precede intelligent interpretations of soil test values. A basic principle of soil testing is that a soil test value can, under most circumstances, be treated and related as an independent variable to the percent yield and response obtained for a specific crop. These correlation's have been developed and published by the co-operating fertilizer company, Incitec, and an example of one of their interpretation tables is shown in figure A1.2. As can be seen from this figure, the interpretation table exists of a front page of scales for determining required nutrient rates and a back page of fertilizer timing and placement information, both pages being for that specific crop / soil combination.

This step, in the current manual process of providing a fertilizer recommendation by the fertilizer company is for its agronomists to compare the soil test values for each element with values on the interpretation table to arrive at a elemental nutrient requirement that in the general situation will optimize crop yield against the cost of fertilizer input.

For example, in figure A1.3, a phosphorus soil test value of 43 mg/kg P would correlate to an elemental phosphorus requirement of 30 kg/ha P. As discussed above, the direct relationship between soil test value and crop nutrient requirement is modeled in these tables. In addition to this rate, the second page indicates that that the recommended phosphorus rates are for band application at planting. Where soil levels exceed 50mg/kg, phosphorus may be broadcast, but at rates 20% greater than recommendations.

The final step in the manual process is to then meet the elemental nutrient requirements generated in the interpretation stage by calculating what rate of a particular fertilizer or practical combination of fertilizers best supply those elemental nutrient requirements. Given a list of available fertilizer products, (see figure A1.3) this process becomes one of mathematical optimization with non-distinct (fuzzy) boundaries (refer to page 9.81 section 9.6 of Appendix 2 and page 10.14 section 4 of Appendix 3).

In the manual process this is usually done by eye using the ratios of nitrogen, phosphorus, and potassium in a product versus the crop requirement. Once several close fitting fertilizer products have been identified, more detailed calculations are performed to determine which may best supply the nutrient requirements. Several different fertilizer programs may be arrived at, each quite valid, with the final choice up to the end user. In most horticultural situations, fertilizer cost is a secondary issue, with yield optimization through an accurate and practical fertilizer program being the most common goal. If several fertilizer programs can be calculated for a given scenario, several considerations such as product availability, application machinery, irrigation method, personal favor, as well as cost must be taken into account before choosing a program.

In this study, an environment was developed that enabled the user to quickly explore and generate various scenarios of fertilizer products and rates, that guided the user towards an optimal solution. The system however left the final choice of which scenario to accept up to the user as it was beyond the goals of this project to attempt to model and incorporate into the optimization process the myriad of external pressures and preferences a user is influenced by in accepting a fertilizer recommendation.

Figure A1.1. Sample "Soil Analysis Reports" detailing the soil test values determined for that sample and corresponding "Soil Interpretation and Recommendations Reports" (following).

SOIL ANALYSIS REPORT

Incitec Ltd
Australian Company Number 010 767 263
Paringa Road, Gibson Island, Murarrie
P.O. Box 140, Morningside, Qld 4170
Tel: (07) 867 9300

Analysis Systems
From Incitec People with answers.

CCS C2

Phone	:	Fax	
Nearest Town	Brookstead	Postcode 4352	
Distance to Town	17.0	Direction to Town E	
Australian Map Grid Ref	. .	Average Annual Rainfall	mm

SOIL SAMPLE AND SITE INFORMATION:

Sampling depth(cm)	0-10	Surface	Months of Fallow	1
Sampling depth(cm)	-	Deep	Age of cultivation	55 yrs
			Drainage	
Paddock area		ha	Stubble/Trash	
Soil type			Tillage	
Slope			Irrigation	
Soil profile depth	m			

Reasons for sampling 1. Determine fertilizer needs
2. Monitoring soil fertility

PRODUCTION INFORMATION:

			yrs mths
Main species to be fertilized Wheat		Age established	-
Variety		Root stock(Hort)	
Previous best yield		Plant population	ha
Yield last year		Canopy radius(Hort)	m
Vigour of growth		Grain protein	
Row/tree spacing(Hort)	m X m	Legume content	
Row spacing(Grain/Cotton)		Stock type	
Interrow treatment		Stock number	
Stage in Crop Cycle(Sugar Cane)			

Method of fertilizer placement:
1. Banded with seed 2. 3.

FERTILIZER HISTORY:	Fertilizers	Application Rate	Units	Date Applied Year Month
Most Recent Crop				
Sorghum	MAP [Starterfos]	50.0	kg/ha.	9109

Previous Crop

Previous Crop

:

Other Relevant Comments

Results of Analysis

PADDOCK NAME	NCH
ORDER NUMBER	5435
PRODUCT	Hort and Full Range Soil
SAMPLE BAG NUMBER SURFACE	1889
CORRESPONDING DEEP SOIL BAG No	
DATE OF SAMPLING	10/03/92
DATE RECEIVED	12/03/92
DATE OF REPORT	

Soil colour (Munsell)	Black
Soil texture	Clay
pH(1:5 Water)	8.5
Organic Carbon %C	1.3
Nitrate Nitrogen mg/kg	5.0
Sulfur mg/kg	4
Phosphorus(BSES) mg/kg	200+
Phosphorus(Colwell) mg/kg	39
Potassium meq/100g	1.40
Calcium meq/100g	33.79
Magnesium meq/100g	27.42
Sodium meq/100g	2.40
Chloride mg/kg	35
Copper mg/kg	1.1
Zinc mg/kg	2.1

Calculations

Cation Exch. Capacity meq/100g	65.02
Calcium/Magnesium Ratio	1.23
Sodium% of cations(ESP)	3.69
Elec. Conductivity (s.e.) dS/m	0.8

Methods, Calculations outlined overpage.

FOR INTERPRETATION OF THESE RESULTS,
PLEASE CONTACT YOUR DEALER:
BACCOUNT
GIBSON ISLAND LAB

OR YOUR INCITEC AREA MANAGER

Registered Signatory

Samples are analysed as received

Report # 24896

Form No. 804 (Rev 1)

Analysis Systems
From Incitec People with answers

Soil Interpretation and Recommendations

Client CCS C2 Location Brookstead Date 10-3-92

Depth: 0-10 / 10-60
Colour: Black
Texture Clay

Order No. 5435 Sample No. 1849 | Order No. Sample No.
Paddock Name NCH | Paddock Name
Crop Wheat | Crop

Nutrient/Test	Soil Analysis	Comments	Nutrient Requirement	Soil Analysis	Comments	Nutrient Requirement
pH	8.5/8.9	St. Alk.				
Liming Estimate (Buffer pH)						
Organic Carbon	1.3	Low •	Min till			
Nitrate Nitrogen	5/0.8	Low •	55-65 kg N			
Sulfate Sulfur	4/F	L/M •	Worth a try			
Phosphorus BSES, Bicarb, Bray	200 BS 39 Bd	Good	5kg/ha			
Potassium	1.4	H				
Calcium 1:2	33.79	H				
Magnesium	27.42	H				
Aluminium/Aluminium Sat'n %	—					
Sodium/Sodium %	2.40 3.69%	M L OK				
Chloride	35/105	L / OK				
Electrical conductivity	.8/1.0	OK				
Copper	1.1	OK				
Zinc	2.1	OK				
Manganese						
Iron						
Boron						
Cation exchange capacity	65.02	High				

SUGGESTED FERTILIZER & SOIL PROGRAMME:

2) 20-30 kg MAP with seed.

1) 120 kg/ha Urea pre-plant - drilled in & covered.

3) Discuss Low OM - High Mg

Dealer Representative ______ Area Manager ______

SOIL ANALYSIS REPORT

Incitec Ltd
Australian Company Number 010 767 263
Paringa Road, Gibson Island, Murarrie
P.O. Box 140, Morningside, Qld 4170
Tel: (07) 867 9300

Analysis Systems
From Incitec People with answers.

NORTH C2

Phone
Fax
Nearest Town Ayr
Postcode 4807
Distance to Town
Direction to Town
Australian Map Grid Ref
Average Annual Rainfall mm

SOIL SAMPLE AND SITE INFORMATION:

Sampling depth(cm)	0-25	Surface	Months of Fallow	1
Sampling depth(cm)	-	Deep	Age of cultivation	yrs
			Drainage	Good
Paddock area	4.0 ha		Stubble/Trash	
Soil type	Silty Loam		Tillage	Conventional
Slope	Slight		Irrigation	Flood
Soil profile depth	1.0 m			

Reasons for sampling
1. Determine fertilizer needs
2. Aiming for top yields

PRODUCTION INFORMATION:

Main species to be fertilized	Sugarcane	Age established	- yrs mths
Variety	Q117	Root stock(Hort)	
Previous best yield		Plant population	ha
Yield last year		Canopy radius(Hort)	m
Vigour of growth	Fair	Grain protein	
Row/tree spacing(Hort)	m X m	Legume content	
Row spacing(Grain/Cotton)		Stock type	
Fallow treatment		Stock number	

Stage in Crop Cycle(Sugar Cane) Ploughed-out replant
Method of fertilizer placement:
1. Banded away from seed 2. 3.

FERTILIZER HISTORY:

	Fertilizers	Application Rate	Units	Date Applied Year Month
Most Recent Crop	Grocan 300	700.0	kg/ha.	9009
Previous Crop				
Previous Crop				

Other Relevant Comments

Results of Analysis

PADDOCK NAME	Block One
ORDER NUMBER	017651
PRODUCT	Sugar Cane
SAMPLE BAG NUMBER SURFACE	4189
CORRESPONDING DEEP SOIL BAG No	
DATE OF SAMPLING	10/11/91
DATE RECEIVED	18/11/91
DATE OF REPORT	03/08/92

Soil colour (Munsell)	Brown
Soil texture	Clay Loam
pH(1:5 Water)	7.0
Buffer pH	6.6
Sulfur mg/kg	61
Phosphorus(BSES) mg/kg	135
Potassium meq/100g	0.36
Calcium meq/100g	12.22
Magnesium meq/100g	5.27
Aluminium meq./100g	0.01
Sodium meq/100g	1.58
Electrical Conductivity dS/m	0.42
Potassium(Nitric Acid)meq/100g	5.8

Calculations

Cation Exch. Capacity meq/100g	19.44
Calcium/Magnesium Ratio	2.32
Aluminium Saturation %	0.1
Sodium% of cations(ESP)	8.13

Methods, Calculations outlined overpage.

FOR INTERPRETATION OF THESE RESULTS,
PLEASE CONTACT YOUR DEALER:
BACCOUNT
GIBSON ISLAND LAB

OR YOUR INCITEC AREA MANAGER

Registered Signatory
Samples are analysed as received
Report # 10612

Form No 804 (Rev 1)

Analysis Systems

From Incitec People with answers

Soil Interpretation and Recommendations

Client NORTH C2 Location AYR Date

Order No. 017651 Sample No. 4189 | Order No. Sample No.

Paddock Name BLOCK ONE | Paddock Name

Crop SUGAR CANE P/OUT REPLANT ≡ RATOON | Crop

BROWN CLAY LOAM

Nutrient/Test	Soil Analysis	Comments	Nutrient Requirement	Soil Analysis	Comments	Nutrient Requirement
pH	7.0	OPT				
Liming Estimate (Buffer pH)						
Organic Carbon						
Nitrate Nitrogen			200			
Sulfate Sulfur	61	HIGH				
Phosphorus BSES, ~~Bicarb~~, ~~Bray~~	135	HIGH	–			
Potassium	0.36/5.8	MEDIUM	–			
Calcium	12.22	HIGH				
Magnesium	5.27	HIGH				
Aluminium/Aluminium Sat'n %						
Sodium/Sodium %	1.58 (8.13%)	HIGH	GYPSUM 5t/ha			
Chloride						
Electrical conductivity EC_{se} = 3.7	0.42	MARGINAL				
Copper						
Zinc						
Manganese						
Iron						
Boron						
Cation exchange capacity	19.44	GOOD				

SUGGESTED FERTILIZER & SOIL PROGRAMME: As soon as possible apply GYPSUM at 5 t/ha and incorporate so it has time to work before planting in autumn. If dissolvenator is available apply Gypsum at 1.25 t/ha, annually.

Preplant Urea at 125 kg/ha

Sidedress Urea at 315 kg/ha, before ~~(ratoon)~~ crop is out-of-hand.

– if possible bury this along the side of the row.

Dealer Representative ____________ Area Manager ____________

Note: Interpretations and recommendations given here are a guide only, and depend upon proper and representative samples being analysed, additionally environmental and managerial factors influence production, therefore Incitec Ltd does not accept any liability whatsoever arising out of these interpretations and recommendations for any damage loss or injury of any nature and the user takes these interpretations and recommendations on these terms. This recommendation is made in good faith, based on the best technical information available.

Form No 390 (Rev 5

Figure A1.2. The "interpretation table" for beans to be grown on alluvial soils in Queensland as published by Incitec (following).

Incitec laboratories - Gibson Island

SOIL ANALYSIS SERVICE

INTERPRETATION CHART No 88

BEANS - Alluvial Soils

QUEENSLAND

pH (1:5 water)	Value	4	5	6	7	8	9
	Rating	VERY STRONGLY ACIDIC	STRONGLY ACIDIC	ACIDIC	NEUTRAL	ALKALINE	STRONGLY ALKALINE
		LIME SOIL TO pH 6.0		OPTIMUM			

ORGANIC CARBON	% w/v C	1.0	2.0	3.0	4.0	5.0
	Rating	VERY LOW	LOW	MEDIUM		HIGH

NITRATE NITROGEN	mg/kg N	5	10	15	20	25	30	40	50	60
	Fertilizer N kg/ha	180	150		120		100 MINIMUM			

SULFATE SULFUR (Phos-extr)	mg/kg S	10	20	30	40	50	60	70	80	90
	Rating	LOW	MODERATE	HIGH						

PHOSPHORUS (bicarb-Colwell)	mg/kg P	10	20	30	40	50	60	70	80	90
	Fertilizer P kg/ha	100-80	65	50	40	30	20	12	7	Generally no action required

POTASSIUM (Amm. acetate)	meq/100 g K	0.12	0.25	0.37	0.5	0.6	0.75	1.0	1.25	1.5
	Fertilizer K kg/ha	100	70	55	35	20	Generally no action required			

CALCIUM (Amm. acetate)	meq/100 g Ca	0.5	1.0	1.5	3.0	4.0	5.0	10	15	20	25	30
	Action	PREPLANT LIME 1.5 t/ha OR GYPSUM 1-2 t/ha			SOME CALCIUM MAY BE REQUIRED		Generally no action required					

MAGNESIUM (Amm. acetate)	meq/100 g Mg	0.8	1.6	3.0	4.5	6.0	8.0	16	24	30	36
	Action	DOLOMITE 3 t/ha OR $MgSO_4$ 250 kg/ha OR GRANOMAG 200-100 kg ha	DOLOMITE 1.5 t/ha OR $MgSO_4$ 125 kg/ha OR GRANOMAG 100 kg/ha	Generally no action required							

ALUMINIUM (1M KCl)	Al saturation %	5	10	20	30	40	50	60	80
	Rating	Generally no action required	SENSITIVE						

SODIUM (Amm. acetate)	meq/100 g Na	1.0	2.0	3.0	4.0	5.0	10	15
	Rating	LOW	MEDIUM	HIGH				
	ESP%	5	10	15				
	Rating/Action	LOW	MEDIUM - APPLY GYPSUM AT 2.5-4.0 t/ha	HIGH				

CHLORIDE	mg/kg Cl	100	200	300	400	500	600	700	800	900
	Rating and Action	SATISFACTORY	EXPECT HARMFUL EFFECTS, PARTICULARLY WHERE WATER QUALITY IS MARGINAL TO POOR, AND UNDER HARSH GROWING CONDITIONS - CONSULT AGRONOMIST							

ELECTRICAL CONDUCTIVITY (Sat'd Extract Equivalent)	dS/m	0.1	0.5	1.0	2.0	4.0	6.0	8.0	10	20	30
	Rating and Action	SATISFACTORY	90%	50% OF MAXIMUM YIELD - CONSULT AGRONOMIST							

COPPER (DTPA)	mg/kg Cu	0.1	0.2	0.3	10	20
	Action	SPRAY $CuSO_4$ 50g/100L WATER - at 1 WEEK	Generally no action required	COPPER ACCUMULATION LIKELY TO BE HARMFUL	COPPER MAY BE TOXIC. LIME SOIL TO pH 6.0	

ZINC (DTPA)	mg/kg Zn	0.5	1	2	3	10	15	20
	Action	SOIL APPLY ZINC	SPRAY Zn SULFATE HEPTAHYDRATE SEE NOTES	Generally no action required	ZINC ACCUMULATION MAY BE HARMFUL			

MANGANESE (DTPA)	mg/kg Mn	2	4	30	50	55	60
	Action	SPRAY Mn SULFATE 100g/100L WATER - at ONE WEEK	Generally no action required	Mn MAY BE TOXIC - LIME SOIL TO pH 6.0 MODIFY FERTILIZER PLACEMENT			

IRON (DTPA)	mg/kg Fe	1	2	4	6	8	10	20	30	40	50
	Action	TEST STRIP Fe CHELATE 100g/100 L WATER - at ONE WEEK	Generally no action required								

BORON ($CaCl_2$)	mg/kg B	0.05	0.1	0.2	0.5	1.0	2.0	3.0	4.0	5.0
	Rating	LOW	MEDIUM	HIGH						

SAMPLING DEPTH 0 - 15 cm

▩ GENERALLY NO ACTION REQUIRED

Incitec Ltd P.O. 140, Morningside, Qld. 4170

CHART 88 — BEANS - ALLUVIAL SOILS - QUEENSLAND.

The recommendations from this chart give best results where weeds, insect pests and diseases are controlled and ample water is available throughout the life of the crop.

NITROGEN - Recommended rates meet total crop requirement.

Apply half at planting, away from the seed, and the balance at the early flowering stage.

In all situations the MINIMUM TOTAL DRESSING is 100-120 kg N/ha. Beans tend to do better with some ammonium nitrogen, as well as some nitrate nitrogen.

At Bowen, beans grown as seed crops have higher N requirements.

PHOSPHORUS - Recommended rates are for band application at planting. Where soil levels exceed 50 mg/kg, phosphorous may be broadcast, but at rates 20% greater than recommendations.

SODIUM - Where soil crusting occurs and/or germination is markedly reduced, and Na% of cations is >5%, GYPSUM at 2.5 t/ha should be recommended. If Na% of cations is >10%, soil is very likely to be responsive to GYPSUM at 4.0 t/ha.

Application of Gypsum to soils with Na% >5% and low to moderate conductivity will improve soil structure.

On medium conductivity (1:5) soils (0.2 - 0.4 dS/m) with Na%>5%, the addition of high rates (up to 7.5 t/ha) of Gypsum will improve seedling survival during periods of natural rainfall. This beneficial effect will be short-lived (<2 yrs) where poor quality irrigation water high in Mg, Na and/or Cl is used.

On high conductivity (1:5) soils (>0.4 dS/m) application of Gypsum may be detrimental to seedling establishment as a direct result of increasing conductivity. Do not apply Gypsum even if Na% >5. Leach with good quality irrigation water to reduce conductivity. Gypsum may be applied to these soils once conductivity is below 0.3 dS/m.

CHLORIDE AND CONDUCTIVITY - Where chloride and conductivity levels are borderline and potassium is required, Sulfate of Potash should be recommended. The threshold for ECse is 1.0 dS/m, above which a yield decrease may be expected.

MICRONUTRIENTS - Absorption of nutrient improves by addition of 4.5 kg Urea to 1000 L of spray solution. Apply in 450 L of water total volume/ha. If nutrient is deficient, 3 - 4 spray applications may be needed. Foliar sprays should be applied at 2 week intervals for 6 – 8 weeks.

Zinc: Soil applications of zinc sulfate monohydrate at 20 - 30 kg/ha can be applied well before planting. Zinc sulfate heptahydrate may be sprayed onto the soil at 40 kg/ha, or sprayed onto the foliage at 1 kg/450 L of water/ha in the early stages of growth.

Avoid foliar sprays on very hot days or during the middle of the day.

Where zinc deficiency is suspected, irrespective of the soil analysis value, zinc sprays should be applied.

If conditions are very wet, weekly sprays may be required.

Boron: If boron deficiency is suspected, use plant tissue analysis, or apply Solubor at 1 kg/450 L/ha of spray solution to the foliage. For more severe deficiencies, apply Solubor to the soil through a boom spray at a rate of 2.5 kg/ha with 1000 L of water. Sprays containing boron are not compatible with sulfates of Zn, Cu, or Mn.

RESAMPLING - Follow the practice of resampling before planting each crop, for at least 3 years.

Use in conjunction with Plant Tissue Analysis.

Figure A1.3. The fertilizer product guide detailing Incitec's fertilizer product range (following).

PRODUCT	NITROGEN N%	PHOSPHORUS P%	POTASSIUM K%	SULFUR S%	CALCIUM Ca%
SUGAR PLANTING					
22	4.3	4.7	37.1	0.5	
33	6.0	6.6	32.5	0.7	
44	8.2	9.1	26.2	0.9	
44 Cu (Cu 1.5)	7.5	8.4	25.0	1.6	
44(S)	9.3	7.5	24.0	3.7	
66	11.3	12.5	17.7	1.3	
66 Cu (Cu 1.5)	11.1	12.3	15.2	2.0	
SUGAR RATOONING					
110	20.2	5.0	19.4	0.5	
120	25.0	5.0	14.1	0.5	
135	32.2		14.0		
50/50	23.4		23.5		
140	24.5	2.5	18.6	0.3	
140(S)	22.7	2.0	17.2	3.7	
150	24.8	3.5	16.7	0.4	
150(S)	24.0	2.9	15.2	3.1	
32-2-10	32.0	2.0	10.0	0.2	
Nitra-K	28.2		18.4		
Nitra-K (S)	26.1		15.7	4.2	
NSW Ratooner	35.4	1.7	7.8	0.2	
SPECIALTY PRODUCTS					
Supergrow Controlled Release	19.3	3.0	8.2	2.9	
Fused Potassium Silicate			16.5		
IBDU (Fine & Coarse)	31.0				
Woodace (Mg 2.0)	12.0	2.6	5.0		

TRACE ELEMENTS	
Liquifert Micro Fe 12.7% Fe	Chelated Iron for use in iron deficient soil or crops.
Borax 11.3% B	Use as a soil treatment for low boron situations.
Magnum 54% Mg	Use as a soil treatment to overcome magnesium deficiency.
Liquifert Mag 9.6% Mg, 12.4% S	To correct magnesium deficiency via the soil or directly to crop.
Liquifert Tracer 31% Mn, 19% S	To correct manganese deficiency via the soil or directly to the crop.
Molybdenum Trioxide 60% Mo	To correct molybdenum deficiency via soil or directly on seed.
Liquifert Moly 39% Mo	To correct molybdenum deficiency via soil or directly on seed.
Solubor 20.5% B	Use as a foliar spray in boron deficient situations.
Liquifert Tuff 19.7% Fe, 11.5% S	Use as a soil or foliar treatment to correct iron deficiency.
Liquifert Zinc 22.7% Zn, 11% S	Use as a soil or foliar treatment to correct zinc deficiency.
Zinc Sulfate Monohydrate 35% Zn, 17.2% S	To correct zinc deficiency via soil applications.
Liquifert Micro Zn 14.0% Zn	To correct Zinc deficiency in horticultural and agricultural crops by soil or foliar application.

PLEASE NOTE: Not all products are registered for use in both Queensland and New South Wales. Refer to your local Incitec Dealer regarding availability.

Exclusion Clause

Before using fertilizer seek appropriate agronomic advice. Fertilizer may burn and/or damage crops. Because climatic and soil conditions, application methods, irrigation and agricultural practices are beyond the control of Incitec Ltd and cannot be foreseen, Incitec Ltd accepts no responsibility whatsoever for any commercial damage, loss or other result following the use of this product whether used in accordance with directions or not, subject to any overriding statutory provision and provided that such liability under those provisions shall be limited to the replacement of the goods as supplied or the rendering again of the services that are provided. The buyer accepts and uses this product subject to these conditions.

Warning - Fertilizers can be corrosive to metals. Avoid contact with eyes and sensitive skin as some irritation may occur. Wash hands after use.

Incitec FERTILIZERS

Certainty. In an uncertain world.

Product Range

Liquifert

PURE SOLUBLE QUALITY

GRANULOCK

BIG N

Incitec Analysis Systems

BRISBANE

Effective date

April 1995

PRODUCT	NITROGEN N%	PHOSPHOROUS P%	POTASSIUM K%	SULFUR S%	CALCIUM Ca%
HORTICULTURE BLENDS					
5	7.7	9.1	7.8	9.7	6.6
*5(s)	7.7	9.1	6.4	12.3	6.6
11	11.8	4.1	18.6	10.1	
55	13.2	14.7	12.3	1.5	
*55(S)	12.5	13.9	11.7	6.1	
*77(S)	13.0	2.2	13.3	18.7	
*77(S) Cu Zn (Cu 0.9, Zn 0.85) For broadcast application for avocados, custard apples and macadamias once per year.	12.2	1.9	12.5	18.5	
88	14.8	4.3	11.3	13.4	
Cucurbit Special	5.3	10.0	11.7	5.0	9.0
Greengrove TE (Zn 0.8, B 0.5) For broadcast application for avocados, custard apples and macadamias once per year.	13.2	3.3	12.3	12.9	
*Tomato TE (Zn 0.8) For tomatoes	7.0	10.6	10.0	8.5	6.7
Banana Mix	10.4	0.6	22.0	12.3	
Banana Big K	13.9	2.9	29.4	0.3	
Q7(K)	10.7	2.0	22.1	10.8	
Q5	5.1	5.7	4.9	13.0	12.5
*Fertica (Mg 0.7, B 0.2, Zn 0.4, Cu 0.3) For horticultural crops. Do not apply in direct contact with seed or planting material. Do not band - apply in row crops at high rates. Do not apply to boron sensitive crops.	11.7	6.5	12.9	13.2	
Primegrow	10.3	3.1	6.4	16.0	6.9

PRODUCT	NITROGEN N%	PHOSPHOROUS P%	POTASSIUM K%	SULFUR S%	CALCIUM Ca%
LIQUIFERT (Soluble Fertilizers)					
Liquifert N	46.0				
Liquifert Lo-Bi	46.0				
Liquifert Pinnacle	34.0				
Liquifert P	12.0	26.0			
Liquifert K			51.0		
Liquifert K Nitrate	13.0		38.3		
Liquifert K Spray			41.5	16.5	
*Liquifert Balance	20.0	8.2	16.0		
Calcium Nitrate	15.0				18.0
Liquifert Nitracal	14.5				19.5
*Liquifert Diamond	24.1	3.8	18.0		
*Liquifert Emerald	9.3	18.5	12.0		
*Liquifert Jade	4.8	5.1	31.9	9.7	
*Liquifert Opal	23.6	4.5	18.0		
*Liquifert Pearl	9.5		1.5		14.5
Liquifert Ruby	27.1		20.0		
*Liquifert Topaz	12.8	3.8	31.5		
*Contain Trace Elements					
GRAIN & COTTON BLENDS					
1		14.4	14.2	0.9	10.7
600(S)	17.5	4.9		18.6	
700	31.6	8.2		0.9	
Nisul	34.4			9.9	
Pop-up	7.4	16.1	12.3	1.7	
Phosul	11.8	17.1		6.5	
GRANULOCK					
Granulock ST-Z	9.4	20.5		2.2	
Granulock 2Z (Zn 2.0)	43.0				
Granulock 4Z (Zn 4.0)	41.8				

PRODUCT	NITROGEN N%	PHOSPHOROUS P%	POTASSIUM K%	SULFUR S%	CALCIUM Ca%
ALL CROPS					
Nitrogen					
Prilled Urea	46.0				
Nitram®	34.0				
Nitrate of soda	16.0				
Nitrogen & Sulfur					
Gran-am®	20.2			24.0	
Nitrogen & Phosphorus					
Starterfos Not suitable for use as a stock supplement	10.0	21.9		2.3	
DAP Not suitable for use as a stock supplement	18.0	20.0		2.0	
Phosphorus					
Trifos Not suitable for use as a stock supplement		20.7		1.3	15.0
Potassium					
Muriate of Potash			50.0		
Prilled Potassium Nitrate	13.0		38.3		
Sulfate of Potash			41.0	16.5	
Sulfur				99.5	
Phosphogypsum Bulk only				14.5	18.5
PASTURE					
Single Supers					
Super Not suitable for use as a stock supplement		8.8		11.0	20.0
Super Mo 0.02 (Mo 0.02)		8.8		11.0	20.0
Higher Phosphorous					
Pasture King	5.9	14.2		7.9	10.3
Pasture Starter	6.5	13.6		8.6	9.8
Longlife		11.9		12.7	18.2
Rock Phosphates					
RPR		12.4		1.4	30.4
RPR Supreme		8.5		10.2	20.9
Pasture Blends					
Greenton K	32.2		10.5	2.9	

APPENDIX TWO

Incitec's "Soil Analysis Guide" detailing the steps to be used in undertaking the interpretation phase of developing a fertilizer recommendation from pages 7.7 to 7.18 of the guide (following).

1. PURPOSE:

The reasons why soil samples are analysed for an assessment of important fertility factors are:-

(i) to help diagnose reasons for poor growth in one area compared to another ie. trouble-shooting;

(ii) to monitor soil fertility on a regular basis to check for changes in pH, nutrient content, salinity status and potential toxicities;

(iii) to help fine-tune fertilizer programs to economic optima (where such information is available);

(iv) to assess general soil fertility status and its suitability for growing different crops;

(v) to complement plant tissue and water analyses;

The end result, and perhaps prime objective, is to arrive at a fertilizer product, rate, time and placement recommendation best suited to each situation.

2. FIELD SAMPLING:

The key element in soil sampling is to take a representative sample ie one that represents the area of interest or concern, and which relates to the sampling procedure used in the research which supports the interpretation chart. Other important factors which help determine how to take the sample properly are:-

the type of pasture or crop;

whether a crop is growing or to be grown;

the soil type and its variability;

the depth of soil and sub-surface characteristics;

the depth to which sample for calibration refers;

slope, aspect, erosion potential;

soil surface condition, including stubble, trash and tilth.

2.1 PITFALLS:

There are several situations under which sampling is not advisable, unless the reason for sampling includes the need for an assessment, under such conditions. Some of these are:-

during extremes of climate e.g. drought, flood, water logging;
within three months after a lime application;

within two months after a fertilizer application;
close to fence lines, boundaries or trees other than those involved;
obvious atypical area eg. eroded areas, near streams, in odd poor patches (unless trouble shooting), near watering points in grazing paddocks.etc.

2.2 SAMPLING DEPTHS:

The recommended sampling depths are:-

Pastures - New South Wales	to 7.5 cm
Pastures - Queensland	to 10 cm
Horticultural crops	to 15 cm
Most field crops	to 10 cm
Cereals - for deep nitrate	to 60 cm or 90 cm or to the depth of wetting front.
Sugar cane	to 25 cm or to the depth of plough layer.
Cotton - Queensland	to 15 cm and 15-60 cm
Cotton - New South Wales	to 30 cm

2.3 HOW MANY CORES?

As the sample being collected represents a very small part of the root zone of the crop or species, it is necessary to take a number of sub-samples of the volume of soil concerned. In practical terms, this means adequately covering the area of the soil type, collecting 25 or more cores, with the sampling tube. For deep samples, where the sub-soil is usually less variable, fewer cores are required; 8-10 are sufficient.

The sampling pattern can be in a zig zag, circle or on a grid system, taking into account the principles mentioned above. The pattern used should be uniform from one site to another.

2.4 WHEN TO SAMPLE?

For the sample and the results of its analysis to be useful, ensure enough time is allowed to have the sample analysed, results returned and interpreted and for delivery of the fertilizer products required. This will take from 1-4 weeks.

2.5 HYGIENE:

Cleanliness and hygiene are most important. Because of the small sample size, any contaminant containing the elements tested can adversely affect the results. Therefore, all equipment used for sampling should be kept clean. Use a clean plastic bucket or bag to collect cores, ensure sampling tubes are cleaned before sampling a new paddock or soil type and if the cores are broken up by hand, ensure the hands are clean. Keep away from galvanised iron (wire or sheds) and avoid excessive handling as wet, sweaty hands (salt) may increase sodium, potassium and chloride levels in the soil sample.

2.6 HOMOGENEOUS SAMPLE:

After collection make sure the cores are mixed into an homogeneous sample. Any obvious organic matter, (roots, stems or leaves) and stones should be removed from the sample. Twenty-five cores of surface soil usually weighs 1.5-2.0 kg, so mixing cores and sub-sampling in the field may be necessary. If the sample is too large to send to the laboratory, mix the sample well and take a sufficiently representative sub-sample. The laboratory needs 400-500 g of soil. Fill the bag up to the indicated level and seal securely.

One accepted method of sub-sampling after mixing is the quartering or three quartering technique. Spread the soil out on a clean plastic sheet or bag (not a fertilizer bag), lift corners from side to side so the sample is thrown back and forth to mix well, then divide the pile into four and remove one quarter from the sheet. Then mix the remainder as before, divide into quarters and remove one quarter, then mix the remaining soil etc. until a sample of the appropriate size remains. Place this sample in the numbered plastic bag.

2.7 FIELD INFORMATION/ORDER FORMS:

One Field Information/Order (FI/O) form should be filled in for each sample. However, if much of the information is the same for more than one sample, there is a facility to have the information lifted from the first form to subsequent forms by recording the order number of the first form on the subsequent forms.

The information requested on this form is essential for the most reliable interpretation of the results. The first page is to allow the product to be charged to the correct account as well as giving a lead as to why and when the sample was taken, and the farm location (as distinct from the client's postal address). The second page is the dealer copy of page 1.

The third page asks for the site history details, fertilizer history and the intended crop or use of the paddock. Provide as much appropriate information as possible. Don't forget to write the sample bag number on the Field Information/Order form to ensure a quick return of results. Insert the folded FI/O form in the pocket at the back of the soil sample bag.

3. SAMPLE HANDLING AND TRANSPORT:

Once a sample is collected, the main objective is to despatch it to the laboratory as quickly as possible, so it reaches the laboratory in a condition as close as possible to that when it was collected.

Soil samples are best kept in plastic bags, but because most samples contain moisture, microbial activity will continue while suitable temperatures prevail. Therefore, it is recommended that bagged soil samples be transferred to an esky or cool box, containing cooler bricks or dry ice, as soon after sampling as possible. Samples can be transferred to a refrigerator or freezer for storage overnight or until ready to despatch.

This procedure is especially necessary where nitrate-nitrogen and sulfate-sulfur tests are required.

Samples should never be left in their bags in the sun or in the back of a ute or hot car or other similar places for extended periods. The chances of biologically induced changes to the chemical properties of the soil are reduced if this advice is heeded.

An alternative to cooling is to air dry the soil, so moisture is removed sufficiently to prevent microbial activity. The sample can be spread out on a clean plastic sheet or bag in direct sunlight, away from any likely contamination. In cool climates in winter, this may not be possible or necessary.

A special arrangement has been negotiated with Australian Air Express to ensure that most samples reach the laboratories either overnight or on the following day.

When ready to despatch, place the samples with their Field Information/Order forms into the Australian Air Express postpak. Fill in the consignment note and hand over the counter at the nearest convenient Post Office.

Send samples on the day or morning after their collection. Don't delay postage by collecting samples over a number of days, to send as a batch. If this is done, ensure the samples are treated properly (dried and/or refrigerated). Don't post samples late on a Friday. Bear in mind that the postal service and laboratories do not work over the weekend, and the samples will be better off refrigerated over the weekend and posted early on Monday.

4. LABORATORY ANALYSIS:

On arrival at the laboratory, each sample is given a unique identification number, assessed for colour and texture, then placed in a forced-air drying oven at 40°C. After samples are dried, they are removed from the oven. The sample preparation process consists of crushing (at Port Kembla only), mechanical or manual removal of stones and organic matter, mixing and then fine grinding the sample, so that it is fine enough to pass a 2mm sieve.

The samples are stored at room temperature, 21-25°C, in numbered polystyrene, capped cups. Sample residues are retained for 2 months (minimum) to allow any repeat analyses which may be requested from the field.

Samples are compiled into batches for analysis. Every tenth sample in a batch is a "standard" sample, the analysis of which is known, so the accuracy of the extraction and/or the measurement of the nutrient can be checked.

Laboratory methods and hygiene are kept at a high standard to avoid contamination and maintain accuracy and reproducibility. All the analytical methods are well-known and documented and have been chosen for usefulness, safety and robustness.

4.1 TESTS CONDUCTED AT BOTH LABORATORIES

* 1:5 soil:water - for pH, electrical conductivity, nitrate-nitrogen and chloride.
* Buffer pH test.
* Sulfuric acid digest - for organic carbon, as a percentage of dry soil.
* Calcium phosphate - for sulfate-sulfur, as mg/kg.
* Sodium bicarbonate (Colwell) - for phosphorus, as mg/kg.
* DTPA and other chemicals - for copper, zinc, manganese and iron, as mg/kg.

4.2 TESTS CONDUCTED AT GIBSON ISLAND ONLY

At the Gibson Island laboratory, the following tests are also conducted:-

* Dilute sulfuric acid (BSES) - for phosphorus, as mg/kg for sugar cane and some other situations.
* Ammonium acetate - for potassium, calcium, magnesium and sodium, as meq/100 g.
* Potassium chloride - for aluminium, as meq/100 g.
* Calcium chloride - mannitol - for boron, as mg/kg.
* Nitric acid (BSES) - for potassium.
* Hydrochloric acid (BSES) - for zinc.

4.3 TESTS CONDUCTED AT PORT KEMBLA ONLY

At the Port Kembla laboratory, the following tests are also conducted:-

* 1:5 soil:calcium chloride - for pH.
* Ammonium fluoride (Bray 1) - for phosphorus, as mg/kg.
* Barium chloride - for potassium, calcium, magnesium, sodium and aluminium, as meq/100 g.
* Hot water - for boron, as mg/kg.
* 1M KCl at 40°C - for available sulfur as mg/kg.

For details of tests performed for each crop situation, refer to the product brochures.

4.4 REPORT FORM:

The report form includes a copy of the field information provided by the farmer and the results of the analyses.

Calculations for liming estimates, exchangeable sodium % of cations (ESP), aluminium saturation and effective cation exchange capacity (CEC) are reported beneath the results to assist with the interpretation of results.

4.5 TURN-AROUND TIMES

Both laboratories have turn-around time goals of five (5) working days from receipt of sample. Most results are despatched within 4-6 days of receipt.

5. INTERPRETATION OF RESULTS:

5.1 OBJECTIVE

The objective of the interpretation process is to provide the farmer/client with the most appropriate course of action for his situation, taking into account:-

(i) the field information, including previous yields, and/or yield goals, previous fertilizer history and the reasons for sampling;

(ii) the analytical results from the laboratory;

(iii) local knowledge and experience of how the crop or plant performs in the district, as influenced by soil types and climatic conditions; and

(iv) specific knowledge of the client's management practices, constraints and goals.

5.2 THE INTERPRETATION PROCESS

Prior to conducting the interpretation, it is advisable to review the operations preceding the receipt of results.

FIELD SITUATION:

Is it a specific soil or crop problem? How many sites are involved?
Is the client monitoring pH or fertility changes over time?
Is the client fine-tuning a fertilizer program?

DECISION:

- Decide answers to above.
- Are soil, plant tissue or water tests required?
    - Refer to sampling instructions for answer to "how to sample?"
    - How many sites are to be sampled?
    - What depth of soil/plant part? refer instructions.
    - How many cores/plants, trees or leaves?
    - What sampling pattern, where to take samples?
    - When is preferred time, growth stage, age, - month, day of week, time of day?

ACTION: - Collect samples (store if necessary in cool place).
- Fill in FI/O form(s).
- Send to appropriate laboratory by Australia Post Express Courier.

AT LAB: - Analyses conducted as requested.
- Results reported to client, dealer and Area Manager.

6. KEY TO INTERPRETATION OF SOIL ANALYSIS RESULTS :

6.1 PROCESS

The most convenient steps to progress through the assessment and interpretation of soil analysis results are :

READ the Field Information section of the report form.

CHECK information on date sampled, crop location, soil type, reasons for sampling, past fertilizer use, to obtain a grasp of what crop/soil situation is being assessed.

RECORD the relevant information at the top of the Interpretation and Recommendation form.

FIND the correct Interpretation Chart in the Manual by referring to the index (section 3.2). If no chart available, see 6.3 below.

REFER to any other information likely to be relevant e.g. crop nutrition guides, local knowledge check lists, other soil analysis results from the same area, any associated plant tissue analysis results.

COMPLETE the Soil Status column, indicating beside each value a rating, or recommended use, from the chart.

USE the key below to assess each value and determine courses of action.

RECORD appropriate comments on the Interpretation & Recommendations form.

6.2 THE KEY TO SOIL ANALYSIS INTERPRETATIONS WITH A CHART

Start with Question 1 (pH) and proceed through Question 17 (Boron). Generally a YES answer results in progression directly to the next element.

QUESTION 1 :

pH

1.1 Is the pH value in the OPTIMUM range?

YES- No action needed if Ca, Mg, Al and Na values are in shaded (satisfactory) portions of chart. Check pH within 3 years if liming program in operation.

However :

If Ca is low - consider use of gypsum (See 7.4-7.7).
If Mg is low - consider magnesium use (See 8.3-8.6).
If Al saturation % is high - consider use of lime (See 9.1).
If Mn is high - consider use of lime (See 15.5).
If Na% of cations is high (>7.5%) and/or Mg >25% in clay soils, consider gypsum use (See 10.2).
If Cl is high - drainage may be necessary (See 11.2).
If EC is high - corrective action required (see 12.2).
Refer to calculation of CEC and relate to texture (refer to manual notes pages 2.57 and 2.58).

After considering these points, return to Question 2.

NO - Go to 1.2.

1.2 Is the pH value BELOW the optimum range?

YES- Corrective action likely to be needed, depending on other soil characteristics. Check buffer pH and liming estimate calculation. Compare with interpretation chart estimates for quantity needed to reach OPTIMUM pH range. Consider all factors listed in 1.1.

For crops sensitive to Mo deficiency (legumes, lettuce, crucifers, etc.), Mo may be needed, with or without pH adjustment.

NO - Go to 1.3.

1.3 Is the pH value ABOVE the optimum range?

YES- Corrective action may be warranted, especially where Na, Mg, Cl and EC are high. If lime has been applied recently, do not reapply until further test.

Ignore buffer pH value and liming estimate.
If Na% of cations is high, consider use of Gypsum (see 10.2).
If Mg% of cations is high (>25%) consider use of gypsum (see 10.2).
If Cl and EC are high - drainage and leaching of salts may be necessary before gypsum is beneficial (see 11.2 and 12.2).
Micronutrients (Cu, Zn, Fe, Mn) availability may be reduced at high pH values (> 8.0).

QUESTION 2 :

ORGANIC CARBON

2.1 Is the organic carbon % value MEDIUM or HIGH?

YES- No action generally required.

NO - If VERY LOW or LOW, suggest ways to avoid further decline and/ or to build organic matter level with green manure crops, stubble retention, trash blanketing, pastures in rotation, incorporation of mill mud, farm manures, composts, etc.

QUESTION 3 :

NITRATE - NITROGEN (N)

3.1 Is a DEEP or PROFILE sample result available?

YES- Calculate weighted mean (see back of chart) and note required N rate; adjust for stubble, moisture and grain protein level as indicated (for cereals).

NO - Go to 3.2.

3.2 Is a RATE of N use specified?

YES- Adopt recommended rate, allowing for timing of application where specified. Adjust for stubble, moisture and grain protein levels as indicated.

NO - Consider N use as indicated on back of chart. Where higher rate of use is not specified, maintain the rate at current levels for high N-using crops. If relevant, refer to BSES recommendations for sugar cane N rate.

QUESTION 4 :

SULFATE - SULFUR (S)

4.1 Is the Sulfur value in the MODERATE or MEDIUM range?

YES- No action usually required; maintain existing rates of S application.

NO - Go to 4.2.

4.2 Is the value in the HIGH range?

YES- No additional S is required; consider use of products containing lower S content.

NO - Go to 4.3.

4.3 Is a rate of S use specified, or a test strip recommended, where the value is LOW?

YES- Determine suitable product to apply and rate to be used for trial purposes, if recommended to do so.

NO - If LOW or VERY LOW, apply S in fertilizer or test strip. If gypsum is being recommended, additional S is unlikely to be required as well. Check back of the chart for any further information.

QUESTION 5 :

PHOSPHORUS (P)

5.1 Does the P value fall in the SHADED (high) portion of the chart?

YES- Additional P probably not required. Check notes on back, particularly if soil has high P fixing capacity and for crops which have a minimum basal P rate.

NO - Go to 5.2.

5.2 Is a TEST STRIP recommended?

YES- Determine suitable product and rate of usage. Check notes for broadcast or band application.

NO - Go to 5.3.

5.3 Is a RATE of P usage specified?

YES- Apply minimum rate if stated. Note situations where rate is to be split between planting and sidedressings. Adjust for high P fixing soils, VAM and fallow length. Check whether banded or broadcast application required.

NO - Refer to back of chart for any further information on P use.'

QUESTION 6 :

POTASSIUM (K)

6.1 Does the K value fall in the SHADED (high) portion of the chart?

YES- Additional K probably not required. Check notes on back for situations where maintenance rate needed for high K use or high value crop.

NO - Go to 6.2.

6.2 Is a TEST STRIP recommended?

YES- Determine suitable product and rate of usage. Check notes for broadcast or band application and placement relative to seed.

NO - Go to 6.3.

6.3 Is a RATE of K usage specified?

YES- Apply minimum rate if stated. Check whether for broadcast or band application and for placement relative to seed. Check whether rate is to be split between planting and side dressings. Extra K may be needed if Na or Mg dominates cation exchange complex.

QUESTION 7 :

CALCIUM (Ca)

7.1 Does the Ca value fall in the SHADED (adequate - high) portion of the chart?

YES- Calcium deficiency rarely occurs. Check notes on back for where situations requiring attention do occur.

NO - Go to 7.2.

7.2 Is Ca or lime noted as likely to be required or BENEFICIAL?

YES- Consult notes on back re strawberries, beans, peas, asparagus, vegetables.

NO - Go to 7.3.

7.3 Are LIME RESPONSES VARIABLE at this test level?

YES- Consult agronomist, as advised, for pastures advice.

NO - Go to 7.4.

7.4 Is a particular situation for GYPSUM use specified?

YES- Apply gypsum to cotton soils or to peanuts at recommended rates. See notes on back.

NO - Go to 7.5.

7.5 Is a particular situation for LIME use specified?

YES- Apply lime as required for soybeans where low pH and high manganese occur.

NO - Go to 7.6.

7.6 Is a TEST STRIP of lime or gypsum recommended?

YES- Apply at recommended rates after checking need for magnesium. See notes.

NO - Go to 7.7.

7.7 Is LIME or GYPSUM recommended?

YES- Apply at recommended rates. Check for need for magnesium and effect of pH as indicated on back of chart. Check that recommended rate does not cause pH to rise above optimum range.

NO - In some situations, a foliar spray containing calcium might be a short-term remedy. If calcium is critical for yield and quality, and a deficiency is still likely to occur even where soil test levels appear adequate, or soil treatments have been applied - apply foliar sprays of calcium (eg for blossom end rot in tomatoes, bitter pit in apples).

QUESTION 8 :

MAGNESIUM (Mg)

8.1 Does the Mg value fall in the SHADED (adequate - high) portion of the chart?

YES- Magnesium deficiency rarely occurs. Check notes on back, for where situations requiring attention do occur. Check Mg% of cations - if >25%, also check Na% of cations (ESP), soil structure, crusting, etc, with a view to determining a gypsum need, refer to 1.3 and 10.2.

NO - Go to 8.2.

8.2 Is dolomite noted as likely to be BENEFICIAL?

YES- Check notes re use of dolomite and Mg sprays on strawberries.

NO - Go to 8.3.

8.3 Are magnesium RESPONSES VARIABLE at this test level?

YES- Consult agronomist, as advised, for pastures advice.

8.4 Is a TEST STRIP of dolomite, Granomag or Magnesium Sulfate recommended?

YES- Apply at recommended rates after checking which product is preferred. See notes on back for specific situations.

NO - Go to 8.5.

8.5 Is a magnesium sulfate FOLIAR SPRAY recommended?

YES- Apply sprays as recommended for beetroots, carrots, tomatoes and potatoes.

NO - Go to 8.6.

8.6 Is the USE of magnesium sulfate, magnesium oxide, Granomag or dolomite recommended?

YES- Apply preferred product to soil as indicated, prior to or at planting. See notes on back for specific situations related to pH, Mn and alternative use of foliar sprays.

QUESTION 9 :

ALUMINIUM (Al)

Refer to Aluminium saturation calculation as shown on bottom of soil analysis report.

9.1 Does the Al saturation % value fall in the SHADED (low) portion of the chart?

YES- No action required.

NO - Al tolerance of many crops is indicated on the charts, in the range highly sensitive, sensitive, moderately (or marginally) tolerant, tolerant or highly tolerant. Consult Soil Intepretation Manual Qld (2.36) or NSW (2.41) for further information on amount of liming material needed to reduce Al to various levels. Species and cultivar differences occur in tolerance to high Al levels. Refer also to pH section of this key.

QUESTION 10 :

SODIUM (Na)

10.1 Does the Na value fall in the LOW range?

YES- No action required.

NO - Go to 10.2.

10.2 Is the Na value in the MODERATE to HIGH range?

YES- Refer to calculations of exchangable sodium percentage at bottom of report :

a) If Low (< 5%), no action required.

b) If Medium (5 - 15%), apply gypsum at recommended rate, depending on whether the value is above or below 10%.

c) If High (> 15%), refer to Information Bulletin on Soil Salinity for method of soil treatment.

(d) Check Mg% of cations - if Mg >25% and ESP >5% check soil structure, surface crusting and cloddiness with a view to recommending gypsum to ameliorate these conditions.

QUESTION 11 :

CHLORIDE (Cl)

11.1 Does the Cl value fall in the SATISFACTORY range?

YES- No action required. Check deep profile sample result if available, for confirmation.

NO - Go to 11.2.

11.2 Is the Cl value LIKELY TO LIMIT GROWTH?

YES- Check profile levels where available.
Consider sulfate form of potash if K needed.
Check water quality and drainage if crop to be irrigated.
Check tissue levels in pasture plants.
Check whether fertilizer containing Muriate of Potash was recently applied.

NO - Go to 11.3.

11.3 Is the Cl value HIGH or VERY HIGH?

YES- Consult agronomist as indicated. Refer to Soil Manual Qld (2.40) or NSW (2.46) for further information and Water Analysis Interpretation Manual for list of tolerant and susceptible plants. Check drainage, and if necessary advise improvement needed before payable responses to fertilizer may be expected.

QUESTION 12 :

ELECTRICAL CONDUCTIVITY (EC)

Refer to Calculation of EC se.

12.1 Is the rating SATISFACTORY?

YES- No action required. Check deep profile sample results if available, for confirmation.

NO - Go to 12.2.

12.2 Is the rating above the level indicating a yield depression of 50 or 75% of maximum yield?

YES- Check deep profile sample results. If available, for confirmation consult agronomist. Refer to Soil Manual Qld (2.40) or NSW (2.47) for information on use of gypsum and irrigation water.

NO - Between 50 and 90% of maximum yield is indicated at this rating. Yields are likely to be improved by early corrective action, especially gypsum and leaching of soluble salts, and use of less saline irrigation water. Refer also to pH section of this key.

QUESTION 13 :

COPPER (Cu)

13.1 Does the Cu value fall in the SHADED (satisfactory) portion of the chart?

YES- No action usually required, unless levels are marginal (towards deficiency or toxicity), and local experience suggests remedial action may be necessary.

NO - Go to 13.2.

13.2 Is TEST STRIP recommended as a spray or soil application?

YES- Apply required product to the soil or growing crop as recommended.

NO - Go to 13.3.

13.3 Is a COPPER APPLICATION recommended, as a Cu fungicide, routine spray or early growth stage spray?

YES- Apply as directed. Do no exceed strength of foliar spray or number of sprays.

NO - Go to 13.4.

13.4 Is a SOIL APPLICATION recommended?

YES- Apply as directed.

NO - Go to 13.5.

13.5 Does the value fall in the range where copper accumulation may be HARMFUL or TOXIC or where a Cu toxicity may be expected?

YES- Do not apply copper to soil. Apply lime to reduce Cu availability, as directed. Until lime has taken effect on pH, use an alternative to Cu fungicide for application to foliage. Avoid use of copper sprays whenever possible.

QUESTION 14 :

ZINC (Zn)

14.1 Does the Zn value fall in the SHADED (adequate - satisfactory) portion of the chart?

YES- No action usually required, unless levels are marginal (towards deficiency or toxicity), and local experience suggests remedial action may be necessary.

NO - Go to 14.2

14.2 Is a TEST STRIP recommended as a spray or soil application?

YES- Apply required product to the soil or growing crop as recommended. Do no exceed spray strength or number of sprays to be applied to foliage.

NO - Go to 14.3.

14.3 Is a SOIL APPLICATION recommended?

YES- Apply as directed. Note that some Crop King fertilizer blends containing zinc are available.

NO - Go to 14.4.

14.4 Is a SPRAY APPLICATION to seedlings or plants recommended, either as a routine spray or specifically where zinc value is low?

YES- Apply as directed. Do not exceed spray strength.

NO - Go to 14.5.

14.5 Does the value fall in the range where zinc accumulation may be HARMFUL?

YES- Do not apply zinc to crops or soil.

NO - Go to 14.6.

14.6 Does the value fall in the range where zinc may be TOXIC?

YES- Apply lime as directed to increase pH value and reduce zinc availability. Symptoms of zinc toxicity not yet reported, but high Zn could reduce uptake of Cu, Mn or Fe.

QUESTION 15 :

MANGANESE (Mn)

15.1 Does the Mn value fall in the SHADED (adequate - satisfactory) portion of the chart?

YES- No action usually required.

NO - Go to 15.2.

15.2 Is a TEST STRIP recommended as a spray or soil application?

YES- Apply to soil or crop as directed. See notes.

NO - Go to 15.3.

15.3 Is a SOIL APPLICATION recommended?

YES- Apply as directed.

NO - Go to 15.4.

15.4 Is a SPRAY APPLICATION recommended?

YES- Apply at rates and times specified. Routine fungicide sprays containing Mn may assist to reduce deficiency.

NO - Go to 15.5.

15.5 Does the value fall in the range where Mn may be TOXIC or HARMFUL?

YES- Apply lime to increase pH as recommended to reduce Mn availability. Modify fertilizer placement as directed under Calcium, Magnesium, pH, Manganese heading on the back of the chart.

NO - Disregard Mn test for sugar cane soils. For pineapples, see notes under Micronutrients on the back of the chart.

QUESTION 16 :

IRON (Fe)

16.1 Does the Fe value fall in the SHADED (adequate - satisfactory) portion of the chart?

YES- No action required. Iron deficiency is rare in acid soils.

NO - Go to 16.2.

16.2 Is a TEST STRIP of iron chelate or iron sulfate recommended?

YES- Apply to foliage as directed. Do not exceed spray strength.

NO - Go to 16.3.

16.3 Is a SPRAY APPLICATION of iron chelate or iron sulfate recommended?

YES- Apply as directed, at correct strength, rate and timing.

NO - Disregard Fe test for sugar cane soils. If value is above 100 mg/kg, may be high P-fixing soil. See notes on phosphorus.

QUESTION 17 :

BORON (B)

17.1 Does the B value fall in the MEDIUM range of the chart?

YES- No action required. See notes.

NO - Go to 17.2.

17.2 Does the B value fall in the HIGH range?

YES- Do not use wood shavings or sawdust containing boron. Check with leaf analysis for B-sensitive crops. Obtain advice on ways to reduce level in soil.

NO - Go to 17.3.

17.3 Does the B value fall in the LOW range?

YES - Apply B product as directed, either to soil or as foliar spray. Some Crop King mixtures containing B are available. Check with plant tissue analysis.

6.3 THE KEY TO SOIL ANALYSIS INTERPRETATIONS WITHOUT A CHART

REFER to any relevant information from QDPI or NSW Agriculture booklets, Agfacts, Agnotes, crop production notes or manuals.

If no publication is available, refer to information for a related crop, including any interpretation chart for this crop.

QUESTION 1:

Is an optimum pH range quoted (refer to Figure 1.3 {p 2.4} of Manual also), and if so, is the pH value within this range?

YES - No action required.

NO - Determine whether amendments might be needed by reference to the pH requirements of similar crops on similar soils. Check Ca, Mg, Na, Al saturation, Mn. See also Questions 1.2 and 1.3 of key section 6.2.

Refer to Soil Manual notes Qld p 2.57 and 2.58 or NSW p 2.67 and 2.68 for comments on fertilizer use and liming relative to texture class.

QUESTION 2:

Are Ca and Mg lower than adequate for this crop or for other crops in the same group?

YES - Lime or dolomite may be necessary.

NO - Maintain current program, unless very high, when applications may be reduced.

CALCULATE the clients' nutrient (NPKS) application rates and compare these to the recommended rates for this crop or related crop in the district.

QUESTION 3:

Is usage similar, but soil test values low or high?

YES - Increase or reduce rate of application as indicated by the soil test.

QUESTION 4:

Is usage LOWER than recommended AND soil test value LOW?

YES - Increase nutrient application rate.

QUESTION 5:

Is usage LOWER than recommended AND soil test value HIGH?

YES - Maintain current rates or reduce and recheck by monitoring soil fertility. Use plant tissue monitoring if interpretation data are available.

QUESTION 6:

Is usage HIGHER than recommended AND soil test value LOW?

YES - Maintain rates, monitor soil fertility status. Use plant tissue monitoring if appropriate.

QUESTION 7:

Is usage HIGHER than recommended AND soil test value HIGH?

YES - Reduce rates appropriately.

QUESTION 8:

Are any of the MICRONUTRIENT values LOW, as indicated by soil test values for similar crops?

YES - Apply products and rates as suggested, either to the soil or to the crop or apply as a test strip.

7. PRODUCT RECOMMENDATIONS:

The above process provides recommendations for the use of specific rates of nutrients and products to correct nutrient deficiencies, prevent imbalances or remedy soil conditions detrimental to plant growth.

Details as to product choice, timing of application, placement and particular points to consider are outlined on the back of the chart where appropriate. Refer to the manual section on Fertilizer Recommendations and to the Fertilizer Choice Guide for further details.

Local knowledge and experience may result in modification of the recommendations. This applies particularly to situations where certain soil types and conditions have an influence on fertilizer and ameliorant usage. Heed the warnings on fertilizer bags and in crop nutrition guides relating to the possible effects of local soil, climatic and other conditions on crop responses to fertilizer application.

8. REVIEW OF THE PROGRAM

Consider the total program. Does it look sensible, i.e. reasonably typical for the crop, soil type and district? If not, seek further advice to verify. In discussions with the client, ensure the recommendations being made can be followed, including attending to the cost of any products, their application and other management aspects essential to the success of the program. Modify as appropriate to allow for the resources of the client. Where a program over a longer period of implementation is required, e.g. in counteracting salinity or a soil structure problem, plan priorities for action in the best order possible to achieve the highest productivity over the course of the program.

9. BENEFITS

i) Soil analysis by Analysis Systems provides the most appropriate assessment of soil fertility and other soil properties for crop production.

ii) Interpretation procedures are standardised, using information from credible published sources, local resources and demonstrations and practical experience.

iii) Product recommendations based on scientific knowledge and local experiences are made, taking into account the client's requirements and managerial skills.

iv) The recommended program is tailored to the resources and capabilities of the client, including any changes to current farming practices.

v) The dealer is provided with opportunities to influence local farming practices, promote a preferred range of products and to provide quality service to clients.

vi) The use of Analysis Systems for soil analysis provides dealers with additional opportunities for continuing sales in soil fertility monitoring programs and for the use of plant tissue and water analysis.

10. PRACTICAL EXERCISES

Exercises to practise interpreting soil analysis results will involve the use of case studies.

Points to cover in recs

1) Choice of prods
2) Rates of Aplic
3) Aplic method
4) Frequency of Aplic
5) Timing of Aplic → CRAFT

APPENDIX THREE

Extracts from Incitec's "Fertilizer Choice Guide" detailing some considerations to be used in developing fertilizer programs (following).

Analysis Systems

Accreditation Course

FERTILIZER CHOICE GUIDE

1.17 HOW CAN FERTILIZER RATES BE CALCULATED FROM NUTRIENT RATES?

$$\text{Required fertilizer rate} = \frac{\text{Required Nutrient rate} \times 100}{\text{Fertilizer Analysis (\%)}}$$

e.g. to apply 75 kg/ha of nitrogen as urea (46%N), the fertilizer rate will be:

$$\frac{75 \times 100}{46} = 163 \text{ kg/ha}$$

The recommended rate to apply should be rounded, eg to 150 or 175 kg/ha.

1.18 HOW CAN NUTRIENT RATES BE CALCULATED FROM FERTILIZER RATES?

$$\text{Nutrient rate} = \frac{\text{Fertilizer Rate} \times \text{Analysis (\%)}}{100}$$

9.5 WHY ARE BLENDED FERTILIZERS USED?

Blended fertilizers are used in place of straights because of the convenience they provide, in avoiding the need for separate applications of single nutrient or straight fertilizers.

Blends are not only convenient for the grower, but they can give Incitec dealers a competitive advantage in the market place. Not all fertilizer suppliers will have access to blending facilities, or the same range of blend ingredients.

9.6 WHAT SHOULD BE RECOMMENDED IF A FERTILIZER IS NOT AVAILABLE WITH THE DESIRED PROPORTIONS OF NUTRIENTS?

If there is no product available which exactly meets the grower's requirements, remember that:-

(a) The grower may not want the inconvenience of making up the rate with a straight(s).

(b) Soil and plant analysis interpretations and the recommended rates of nutrient derived from them are not absolutely required.

(c) The difference in yield or performance of the crop may not be significantly different if a slightly lower or higher rate is used.

"Near enough is good enough" is usually a satisfactory compromise. If it comes down to a choice between over-supplying one nutrient and under-supplying another, it will normally be best to err on the high side in high value horticultural crops, unless there is a risk of excessive application affecting yield or quality. This can apply to nitrogen where excess N may depress yield (fruit set) by stimulating vegetative growth, or produce over-sized soft fruit.

The relative cost of the nutrients has to be considered, phosphorus costing more per kg than nitrogen or potassium. However, the relative response from a kilogram of each nutrient is the deciding factor.

As a rule, get the phosphorus right in the planting mix. An excess or deficiency of N or K in the planting mix can usually be allowed for in the choice, rate, and timing of pre-plant or sidedress fertilizer, if this is the practice.

9.7 SHOULD PRESCRIPTION BLENDS BE PROMOTED?

Incitec can provide prescription blends (custom or special mixtures) on request. The extent to which dealers will want to utilize this facility will depend on the individual. Some will elect not to promote them at all.

APPENDIX FOUR

Incitec's "Fertilizer Recommendations Guide" detailing the considerations to be used when making a fertilizer recommendation based on a soil test (following).

4. FERTILIZER RECOMMENDATIONS:

Fertilizer recommendations need to be specific, covering the key points as detailed in the cue-word CRAFT.

C hoice of product(s).

R ates of application.

A pplication method and placement.

F requency of application.

T iming of application.

When making a product recommendation for nitrogen, phosphorus, or potassium, round off the rate to the nearest 5, 10 or 25 kg/ha or give a range. To recommend to the nearest kg implies that very precise recommendations can be derived from soil and plant analyses, whereas differences in soils, seasons and management make it impossible to predict exactly how much fertilizer is required. Application equipment cannot be calibrated to this accuracy and the flow rate of the fertilizer can vary with the product, batch and the weather, even throughout the day.

More precise recommendations are usually required for the micronutrients or trace elements which are applied at lower rates.

5. EXAMPLES OF FERTILIZER PROGRAMS:

There are no firm rules to be followed in determining a fertilizer program. In arriving at a recommendation, the keys outlined in section 3 illustrate the thought processes which help make this task easier.

Four (4) examples are shown herein (NPK only), to illustrate how recommendations for nutrients can be converted to a product recommendation.

The analyses of fertilizers referred to in this section are detailed in the appendix.

EXAMPLE 1

Crop: Wheat
District: Moree

Nutrient Requirements: N 50 kg/ha
P 10 kg/ha

Should these Nutrients be Applied in a Single Application?

No, unless provision is available to apply the nitrogen separately from the phosphorus and place it away from the seed (i.e. a separate fertilizer box and delivery hoses). Otherwise, two fertilizer applications will be necessary. This rate of nitrogen is excessive in direct contact with the seed.

When and How can the Phosphorus be Applied?

Phosphorus is best applied at planting with the seed either as Crop King DAP, Starterfos or Trifos; or Greenleaf Super.

Farmers will probably opt for the convenience and economy of a fully granulated high analysis product.. At Moree this will most likely be Starterfos (10% N, 21.9% P) due to its good physical quality and agronomic suitability on neutral and alkaline soil types. Greenleaf Super is not suited to application through equipment such as air-seeders.

Required Rate of Starterfos: (to apply 10 kg/ha of P)

$$\frac{10 \text{ kg/ha}}{0.219}$$

= 46 kg/ha (round off to 45 kg/ha, or closest calibration available on equipment)

Nitrogen Applied in Starterfos: 0.10 x 45 = 5 kg

Nitrogen to be Applied Separately: 50 - 5 kg N = 45 kg N

When Should the Extra Nitrogen be Applied?

At Moree, pre-plant. Responses to topdressed nitrogen are less certain as rainfall in the spring (to carry the fertilizer into the soil and the root zone) is unreliable.

How Can the Nitrogen be Applied?

As Crop King Big N, Urea, Greenleaf Nitram or Crop King Gran-am. The two most economical sources of N are Big N and Urea. If solid and applied pre-plant, the fertilizer should be incorporated in the soil, rather than left on the surface.

In this example, assuming the grower does not have access to, or the necessary equipment to apply Big N, Urea is used.

EXAMPLE 2

Crop: Potatoes
District: Dorrigo

Nutrient Requirements:	N	160 kg/ha (maximum of 80 at planting)
	P	75 kg/ha (minimum rate on krasnozem)
	K	70 kg/ha

Nutrient Requirements at Planting:	N	up to 80 kg/ha
	P	75 or more kg/ha
	K	70 kg/ha

Planting Fertilizer:

A product is required with approximately equal levels of N, P and K.

Ex Newcastle Crop King G5 (5.0-5.9-4.2) and Grower 11 (9.4-14.2-9.3) have the closest NPK ratios.

Ex Brisbane, Crop King Q5 (5.1-5.7-4.9), 5 (7.7-9.1-7.8) and 55 (13.2-14.7-12.3) are available.

The lower analysis products, G5 and Q5, both of which contain dried single superphosphate as the phosphorus source, are normally preferred on these red volcanic soils.

At Dorrigo, product is most commonly drawn from Newcastle.

Crop King G5 is therefore chosen in this example.

Crop King G5 Application Rate:

Crop KingG5 to apply required rate of P $\frac{75 \text{ kg/ha (minimum)}}{0.059}$
= 1271 kg/ha (min)

Crop King G5 to apply required rate of K $\frac{70 \text{ kg/ha}}{0.042}$
= 1667 kg/ha

Crop King G5, if applied at 1667kg/ha, will supply 83kg/ha of N (0.05x1667), slightly more than the recommendation to apply up to 80kg/ha, but this small excess is not a worry.

The balance of the nitrogen not applied at planting can be sidedressed.

Required Rate of Crop King G5: 1270 - 1670 kg/ha
Choose an intermediate rate of 1500 kg/ha

At 1500 kg/ha, Crop King G5 supplies 88 kg/ha of P and 63 kg/ha of K.

This supplies 17% more phosphorus than the minimum indicated as necessary by soil analysis and local experience but on this soil type, this may be advantageous. Potatoes are a high value crop and the extra investment could be easily recouped.

The potassium requirement of 70 kg/ha is not quite met (shortfall is 7 kg/ha or 10%), but the grower is unlikely to want to sidedress or apply additional potassium to meet this deficit.

N applied in Crop King G5 at 1 500 kg/ha = 0.05 x 1500 kg/ha = 75 kg/ha

Note: Up to 80 kg/ha of N can be recommended for application at planting, so this is safe.

Balance of N to be Topdressed: 160 - 75
= 85 kg/ha

How Can the extra Nitrogen be Applied?

As Crop King Urea or Greenleaf Nitram. Urea will usually be preferred on account of its lower unit nitrogen cost.

Urea rate: $\frac{85 \text{ kg/ha}}{0.46}$
= 185 kg/ha (round off to 200 kg/ha)

Recommendation:

Plant with Crop King G5 at a minimum rate of 1500 kg/ha.
(Up to 1600 kg/ha, supplying 80 kg/ha of nitrogen at planting, can be considered)

Sidedress with Crop King Urea at 200 kg/ha within 3 weeks of emergence.

EXAMPLE 3

Crop: Tomatoes
District: Bundaberg (sandy soil)

Nutrient Requirement:	N	165 kg/ha (total)
		1/3 at planting (55 kg/ha) (min of 40 kg/ha)
		1/3 at early flowering
		1/3 three weeks later
	P	55 kg/ha at planting
	K	90 kg/ha
		1/2 at planting, (min of 40 kg/ha)
		1/2 at early flowering

Calculations:

(i) Planting 40-55 N, 55 P, 40-45 K

Product Choice: Of the high analysis blends available, Crop King 55 (13.2-14.7-12.3) has the most suitable NPK analysis and would normally be used. Crop King 5 and Q5 have similar proportions of N:P:K and could also be considered, and may be preferred by some growers.

Application Rate of Crop King 55:

As some N and K are to be sidedressed, Crop King 55 should be applied at a rate which supplies the recommended rate of P.

Crop King 55 needed to supply required rate of P

$$\frac{55 \text{ kg/ha}}{0.147}$$

= 374 kg/ha (round off to 375 kg/ha)

N and K supplied at this rate	N	0.132 x 375 = 50 kg/ha
	K	0.123 x 375 = 46 kg/ha

(ii) First Sidedressing

At the first sidedressing, the balance of the K and half the remaining N should be applied.

N $\frac{165 - 50}{2}$ = 58 kg/ha

K 90-46 = 44 kg/ha

Required N:K ratio = 58 : 44 = 1.3 : 1 (approx)

Product Choice	Crop King 140 (24.5-2.5-18.6) or Crop King Nitra-K (28.2-0-18.4)	
	N:P:K ratios of these products are	
	Crop King 120	1.3 : 0.13 : 1
	Crop King Nitra-K	1.4 : 0 : 1

As there is no necessity to sidedress additional P, Crop King Nitra-K is chosen.

As there is no need to apply additional K in later sidedressings, and a third application of N is to be recommended, the rate of Crop King Nitra-K is determined by the potassium requirement.

Crop King Nitra-K to supply required rate of K

$$\frac{44 \text{ kg/ha}}{0.184}$$
= 239kg/ha (round off to 200-250 kg/ha)

N applied in Crop King Nitra-K at

225 kg/ha (midway between 200-250)
= 0.282 x 225
= 63 kg/ha

(iii) Final Sidedressing

Nitrogen requirement is 165 kg/ha, less that applied at planting and in the first sidedressing.

N required 165 - 50 - 63 kg/ha
= 52 kg/ha

Product Choice Crop King Urea (46% N) or Greenleaf Nitram (34% N)

Urea chosen in this example, as it costs less per kg of N, and is to be watered in after application.

Urea rate $$\frac{52 \text{ kg/ha}}{0.46}$$
= 113 kg/ha (round off to 100-125 kg/ha)

Recommendation:

Plant with Crop King 55 at 375 kg/ha.

At early flowering, apply Crop King Nitra-K at 200-250 kg/ha.

Three weeks later apply Crop King Urea at 100-125 kg/ha.

EXAMPLE 4

Crop: Ratoon Sugar Cane
District: Mackay

Nutrient Requirement: N 200-250 kg/ha
P 20 kg/ha
K 100 kg/ha

Fertilizer Programs: Farmer has requested two programs, one for a NPK mixture plus Urea; the other for a single application Urea blend.

Calculations:

(i) NPK Mixture plus Urea

As N is to be applied as urea in addition to the NPK mixture, a product is required which supplies some N, and the required amounts of P and K.

Desired P:K ratio 20:100
1:5

Product Choice:

Crop King Mixture and Analysis	P:K ratio.
Grocane 44 (8.2-9.1-26.2)	1:3
Grocane 33 (6.0-6.6-32.5)	1:5
Grocane 22 (4.3-4.7-37.1)	1:8

Grocane 33 has a P:K ratio meeting requirements.

To apply required rate of P $\frac{20}{0.066}$
= 303 kg/ha

To apply required rate of K $\frac{100}{0.325}$
= 307 kg/ha

N applied in Grocane 33 at 310 kg/ha 0.06 x 310
= 19 kg/ha

Balance of N to be applied as Urea (200-19) to (250-19)
180 to 230 kg/ha

Required rate of Urea $\frac{180}{0.46}$ to $\frac{230}{0.46}$ kg/ha
= 390-500 kg/ha

Final Recommendation: **Crop King Grocane 33 at 300-325 kg/ha**
Crop King Urea at 400-500 kg/ha

(ii) Urea Blend:

Desired N:P:K Ratio 10:1:5 to 12:1:5

Crop KingProduct Choice (N:P:K Ratios) as derived from product analyses:-

120	5:1:3
Grocane 140	10:1:7
Grocane 160	10:1:6
Grocane 300	11:1:5

Preferred Product: Grocane 300 (of products available, most closely approximates desired N:P:K ratio).

Analysis of Grocane 300: 29.1:2.7:13.2

To apply required N: $\frac{200}{0.291}$ to $\frac{250}{0.291}$
= 690 to 860 kg/ha

To apply required P: $\frac{20}{0.027}$
= 740 kg/ha

To apply required K: $\frac{100}{0.132}$
= 760 kg/ha

Final Recommendation: **Crop King Grocane 300 at 750-800 kg/ha**
Apply 850 kg/ha if grower wants to use higher N rate.

Note: Where additional S is required, Crop King Grocane 33 (S) plus urea, or Grocane 300 (S) can be used, the rates being adjusted to allow for the overall lower P and K content.

Analysis Systems

Accreditation Course

FERTILIZER RECOMMENDATIONS

APPENDIX

FERTILIZER ANALYSES

PRODUCT	ANALYSIS (%)			
	N	P	K	S
Greenleaf Super	0	8.8	0	11.0
Crop King Trifos	0	20.7	0	1.3
Crop King Starterfos	10.0	21.9	0	2.3
Crop King DAP	18.0	20.0	0	2.0
Crop King Gran-am	20.2			24
Greenleaf Nitram	34			
Crop King Urea	46			
Crop King Big N	82			
Crop King Q5	5.1	5.7	4.9	13.0
Crop King G5	5.0	5.9	4.2	12.3
Crop King 5	7.7	9.1	7.8	9.7
Crop King Grower 11	9.4	14.2	9.3	5.0
Crop King 55	13.2	14.7	12.3	1.5
Crop King 22	4.3	4.7	37.1	0.5
Crop King 33	6.0	6.6	32.5	0.7
Crop King 33(S)	9.3	5.9	24.5	5.3
Crop King 44	8.2	9.1	26.2	0.9
Crop King 120	25.0	5.0	14.1	0.5
Crop King 140	24.5	2.5	18.6	0.3
Crop King Grocane 140	24.5	2.5	18.6	0.3
Crop King Grocane 160	26.9	2.6	15.9	0.3
Crop King Grocane 300	29.1	2.7	13.2	0.3
Crop King Grocane 300 (S)	28.3	2.0	12.0	3.0
Crop King Nitra-K	28.2	0	18.4	0

APPENDIX FIVE

This appendix shows screen captures from a sample session with the DOS prototype.

Data used in this session is real data from a soil test done for P.& A. & D. Vincenzotti of Bundaberg in July 1988 wishing to develop a fertilizer program for tomatoes to be grown on a loamy sand soil.

Clients name:	P.&A.&D. Vincenzotti
Location:	Bundaberg
Laboratory date:	880715
Laboratory number:	012
Paddock name:	Elliot River
Soil texture:	Loamy sand
pH (1:5 water):	6.50
Buffer pH:	6.10
Conductivity:	0.02
Organic carbon %w/v	1.30
Nitrate nitrogen mg/kg	0.70
Sulfur (Phos extrac.) $\mu g/cm^3$	7.10
Phosphorus BSES mg/kg	130.00
Phosphorus Bicarb mg/kg	56.00
Potassium meq/100g	0.22
Calcium meq/100g	2.72
Magnesium meq/100g	0.15
Sodium meq/100g	0.04
Chloride mg/kg	5.00
Copper mg/kg	1.80
Zinc mg/kg	0.50
Manganese mg/kg	1.00
Iron mg/kg	81.00
Boron mg/kg	0.05
Aluminium mg/kg	0.00
Molybdenum mg/kg	0.00

Use chart number 91 which is for “Tomatoes and Capsicums - Sands and Sandy Loam Soils”.

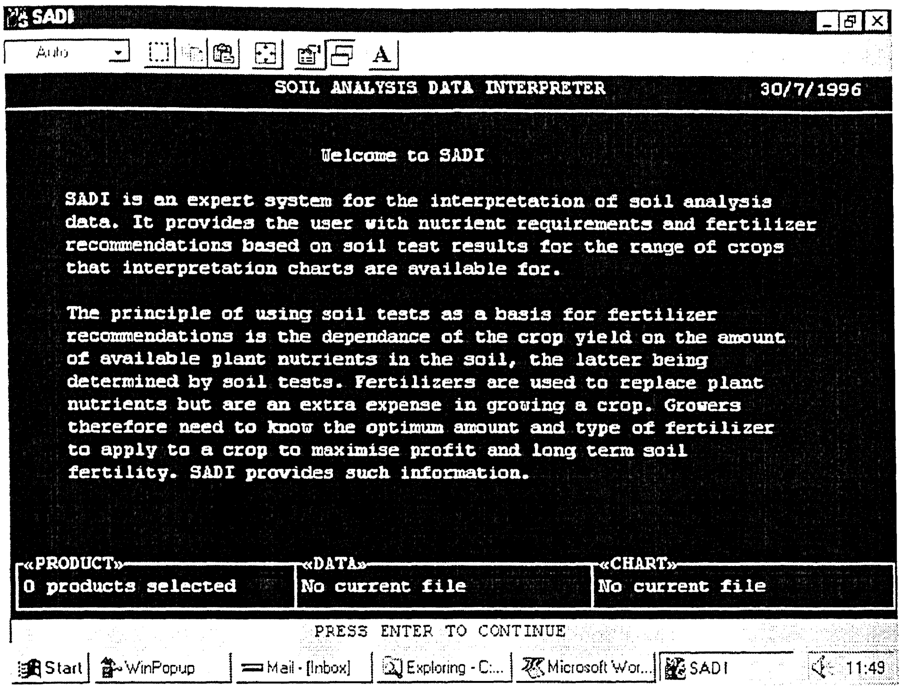


Figure A5.1 First of three introductory screens when SADI is first started.

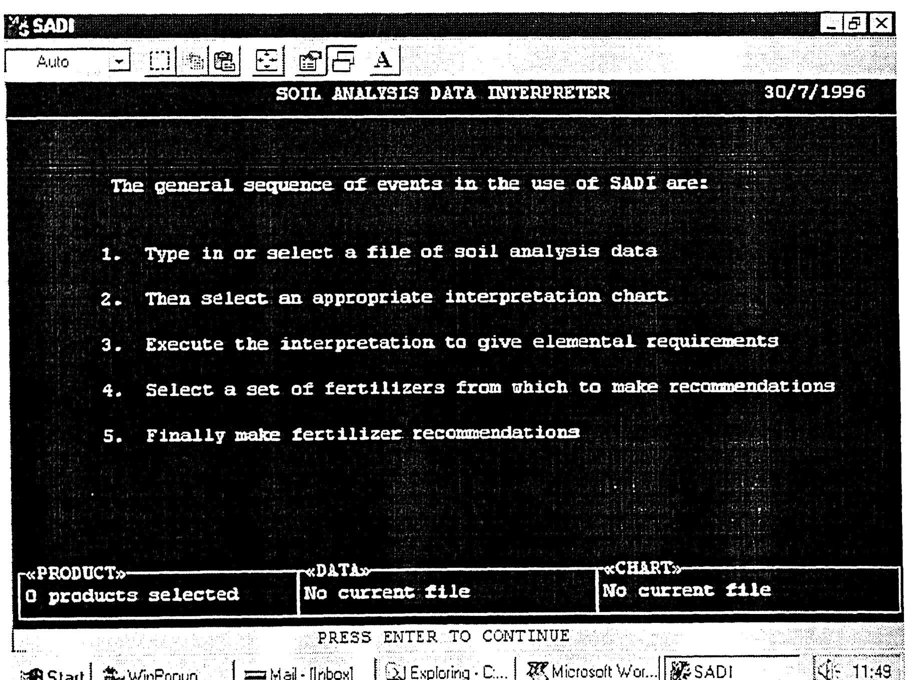


Figure A5.2 Second of three introductory screens when SADI is first started.

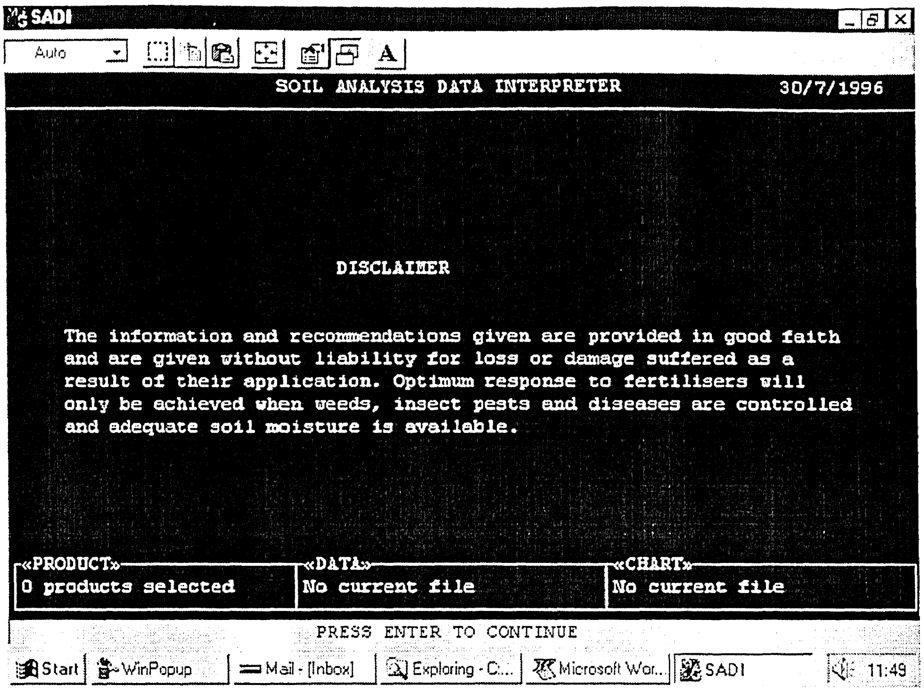


Figure A5.3 Third of three introductory screens when SADI is first started.

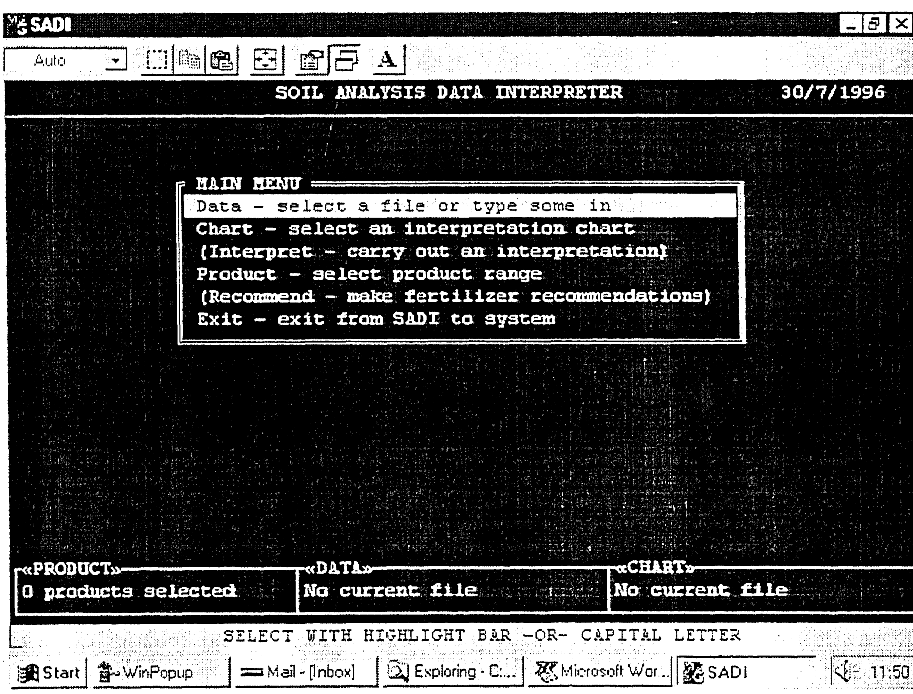


Figure A5.4 The SADI main menu. Note how the "Interpret" and "Recommend" options are unavailable since no products, data, or chart have been selected as soon near bottom of screen.

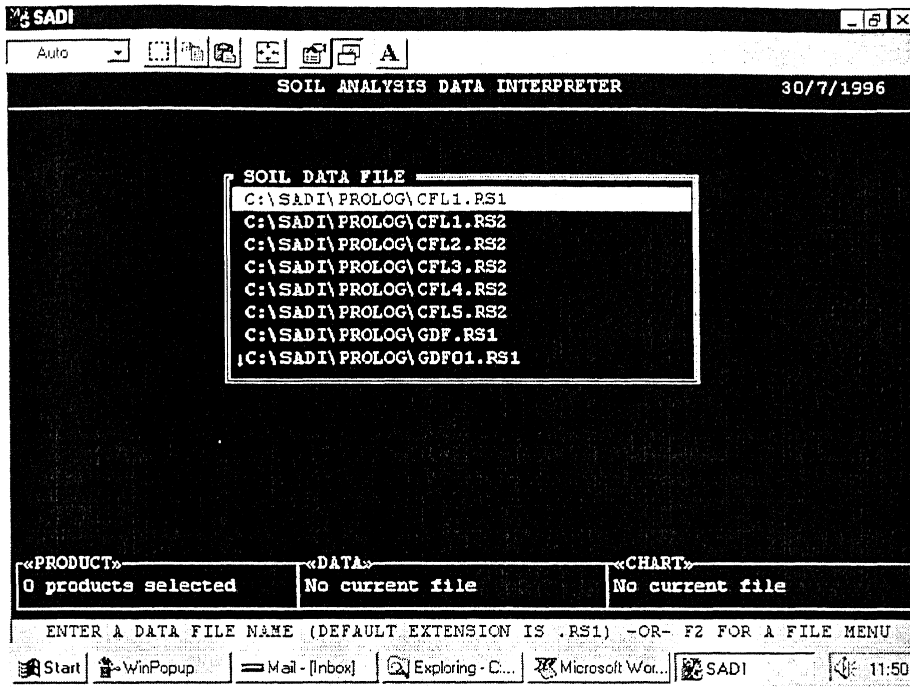


Figure A5.5 Menu list of data files available to use or a new file could have been created.

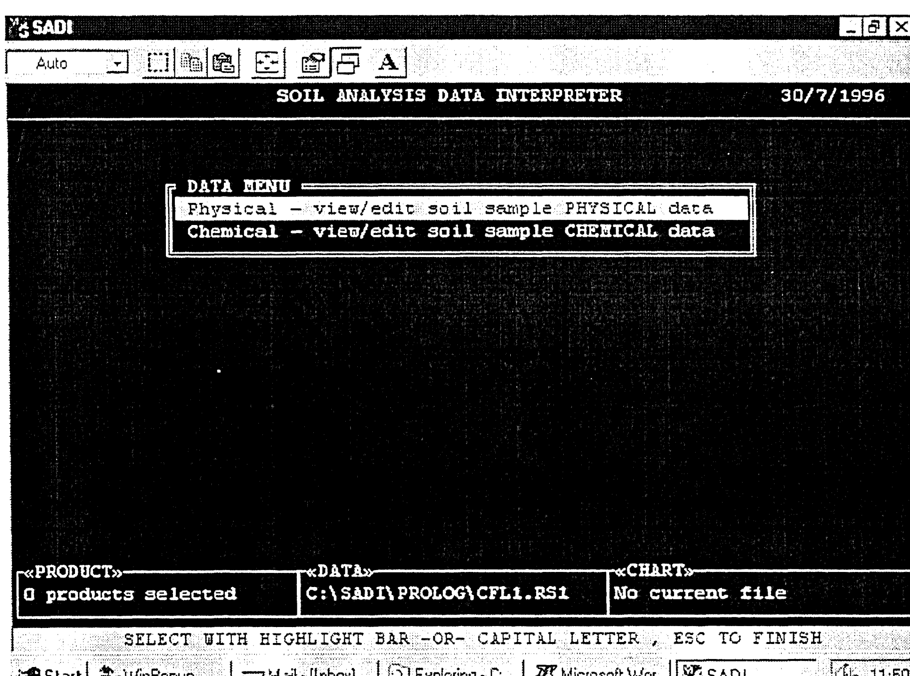


Figure A5.6 Having selected a data file as shown in lower screen, user now given option to view/edit the data.

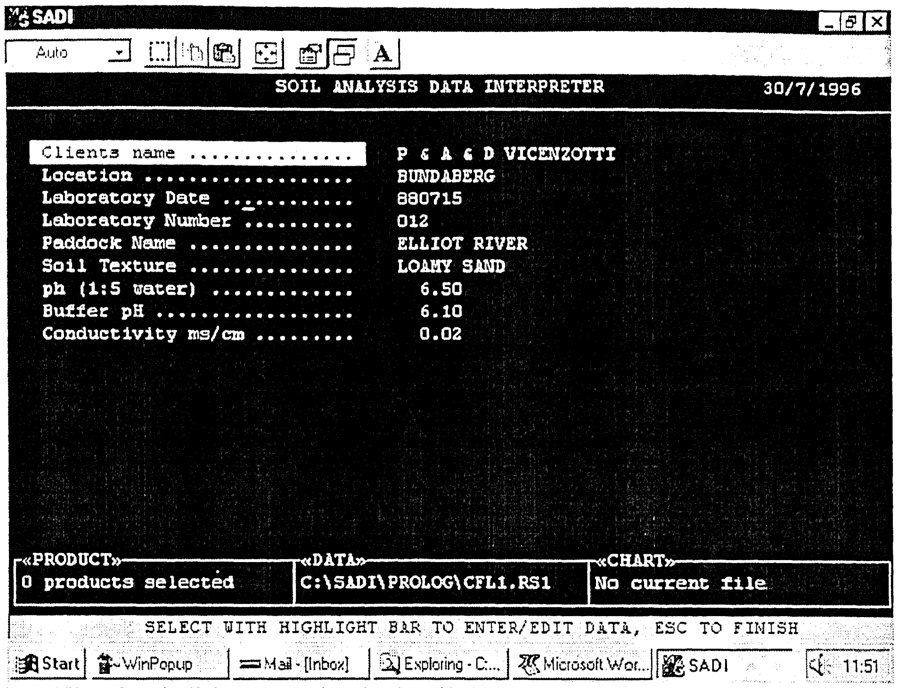


Figure A5.7 Viewing/editing the physical soil data

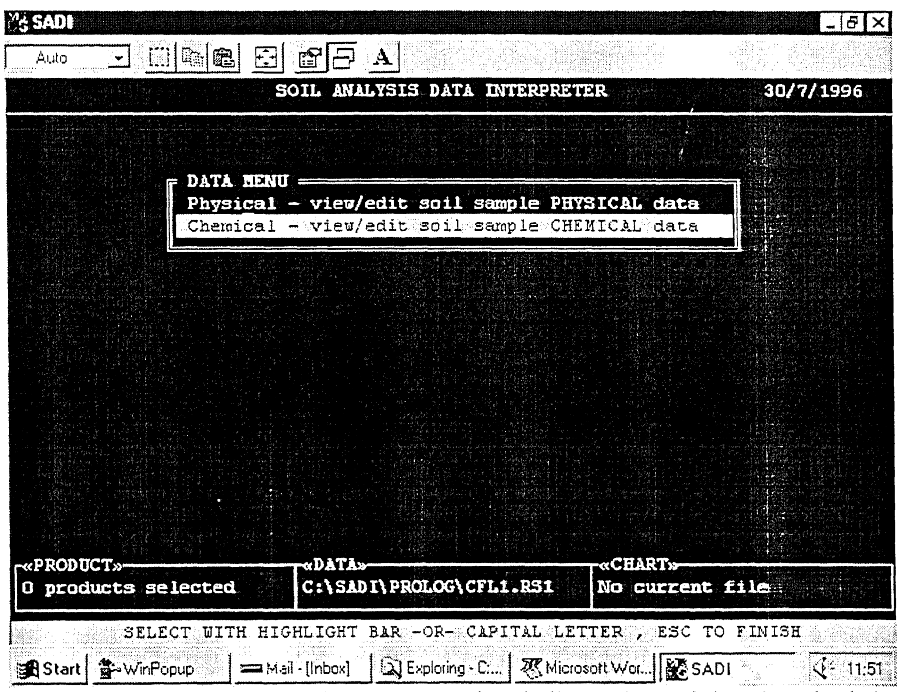


Figure A5.8 Escape takes the user back to the view/edit option of the chemical data.

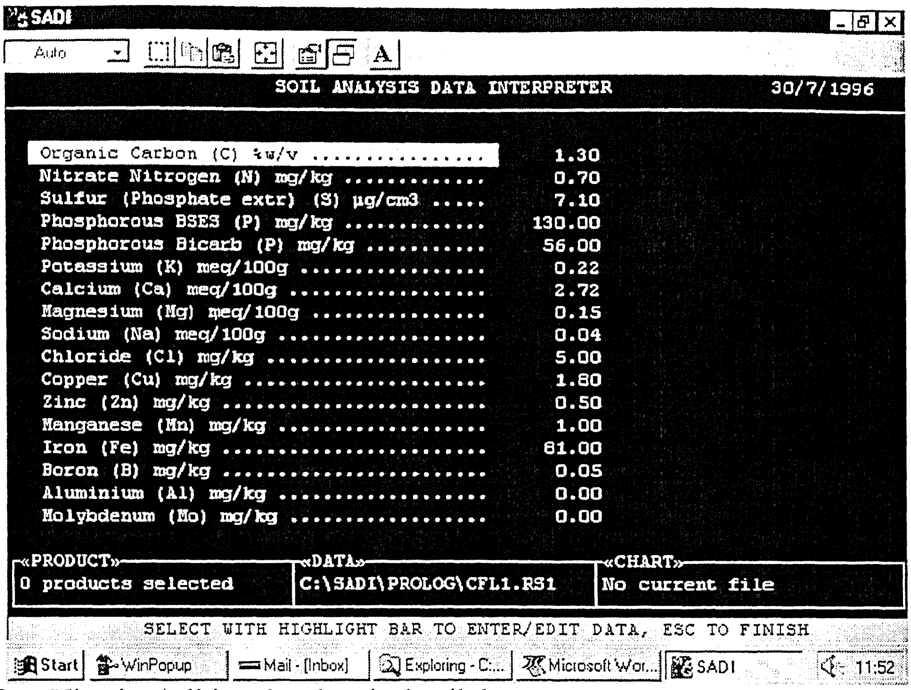


Figure A5.9 Viewing/editing the chemical soil data.

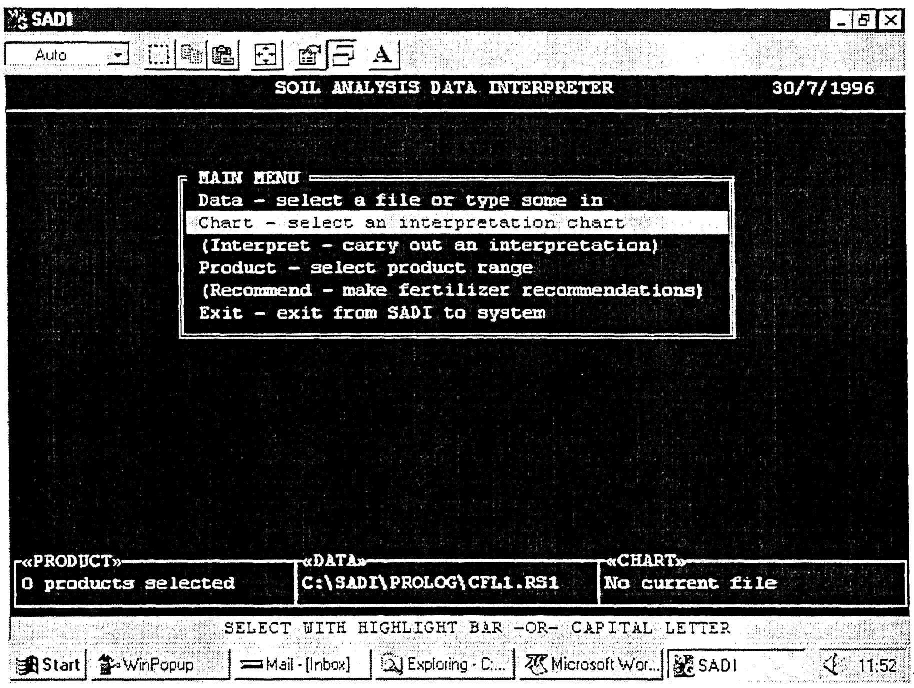


Figure A5.10 Escape takes the user back to the main menu to select an "Interpretation Chart".

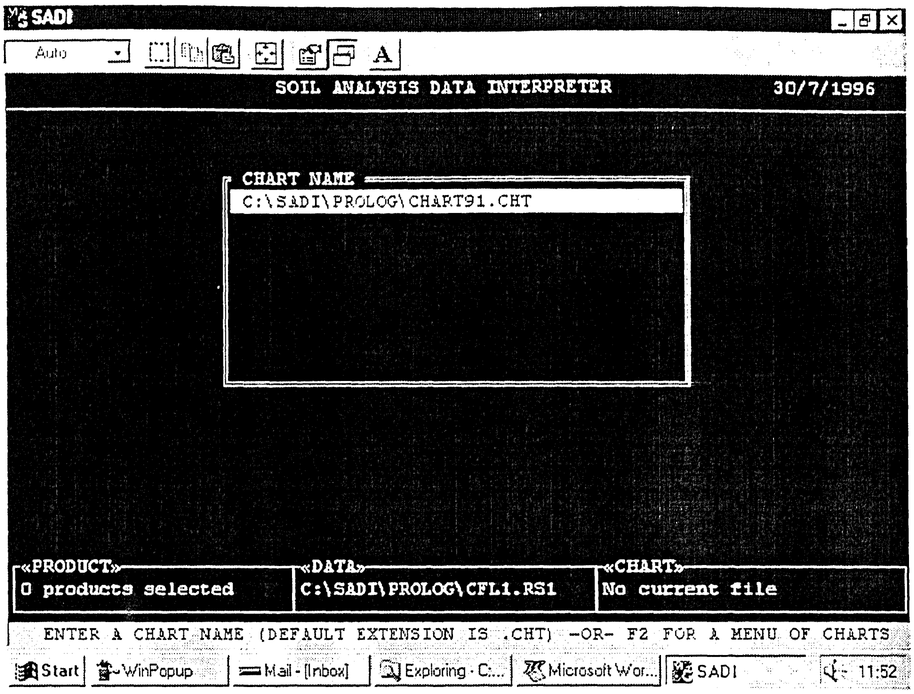


Figure A5.11 As with the soil data files, a menu list of available charts is provided for the user to choose from.

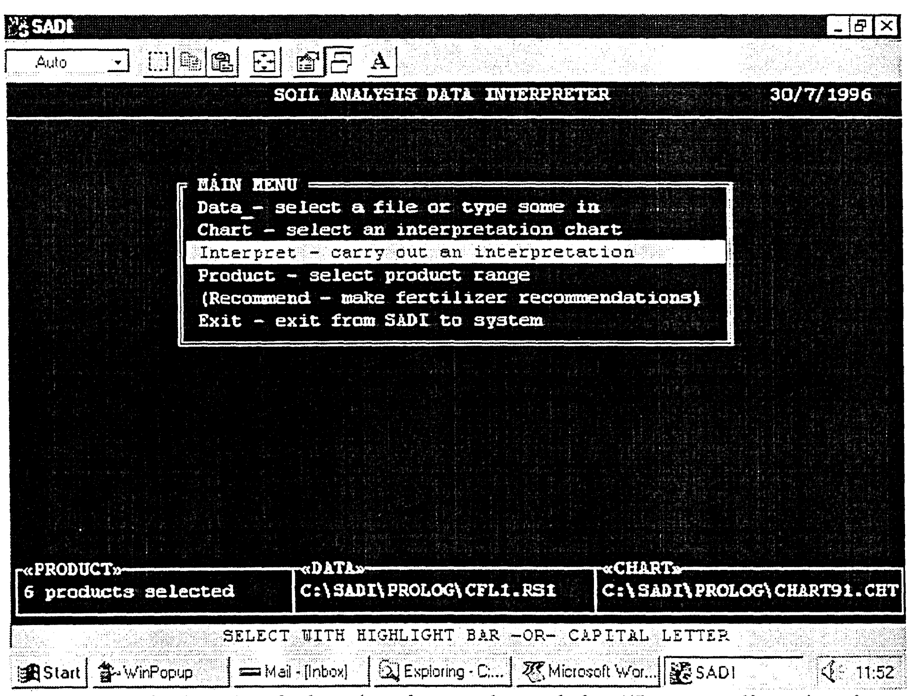


Figure A5.12 With soil data loaded and a chart selected the "Interpret" option is now available to be undertaken as the next step in the process.

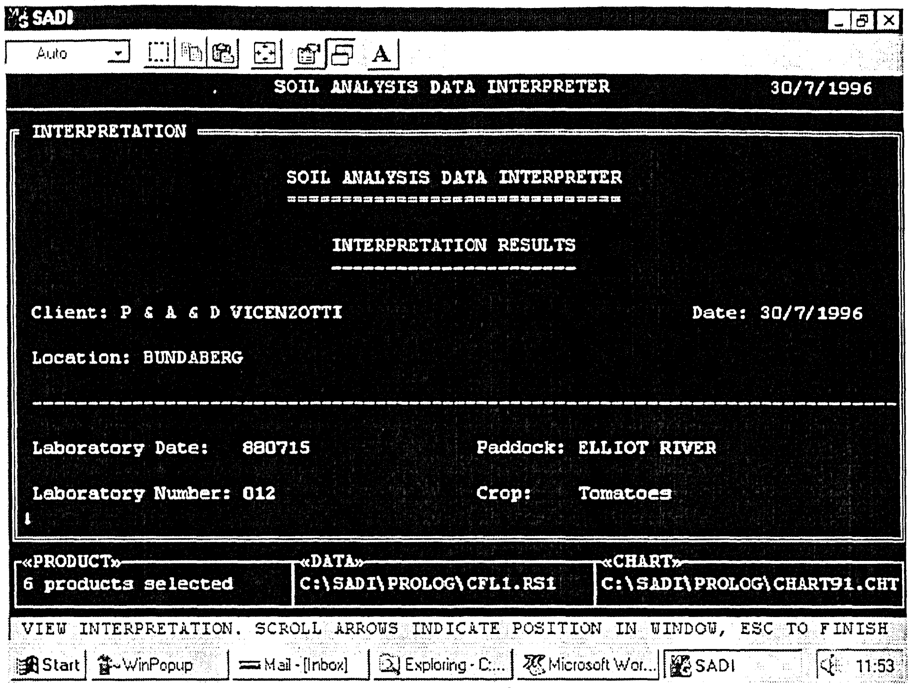


Figure A5.13 The first screen (top of report) of the interpretation report. Note how the interpretation process also automatically selected 6 fertilizer products.

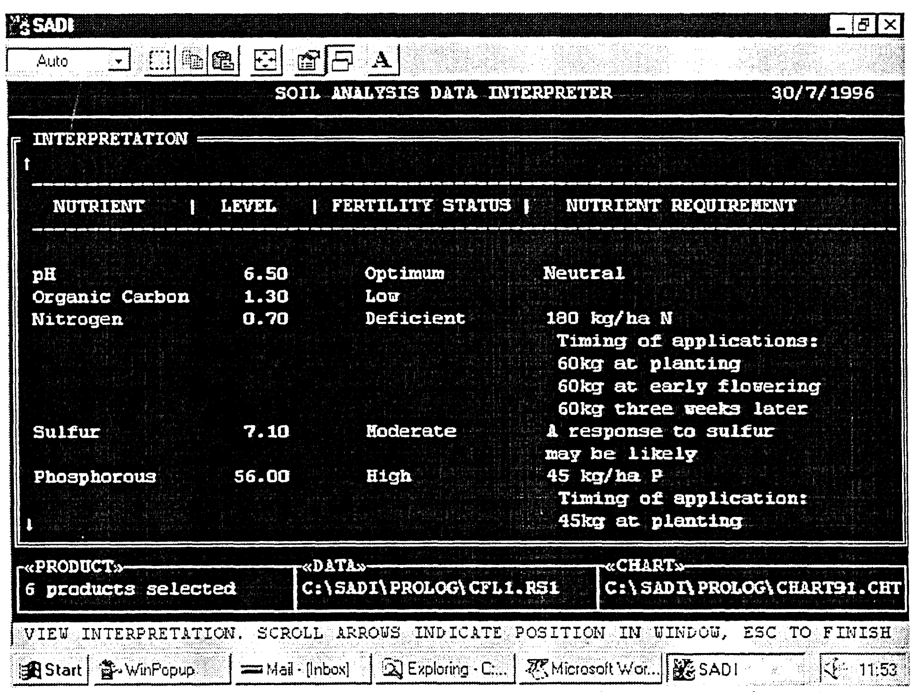


Figure A5.14 The body of the interpretation report showing the nutrient, its soil test level, a comment on that level (status) and the interpreted elemental requirement with timing of application information.

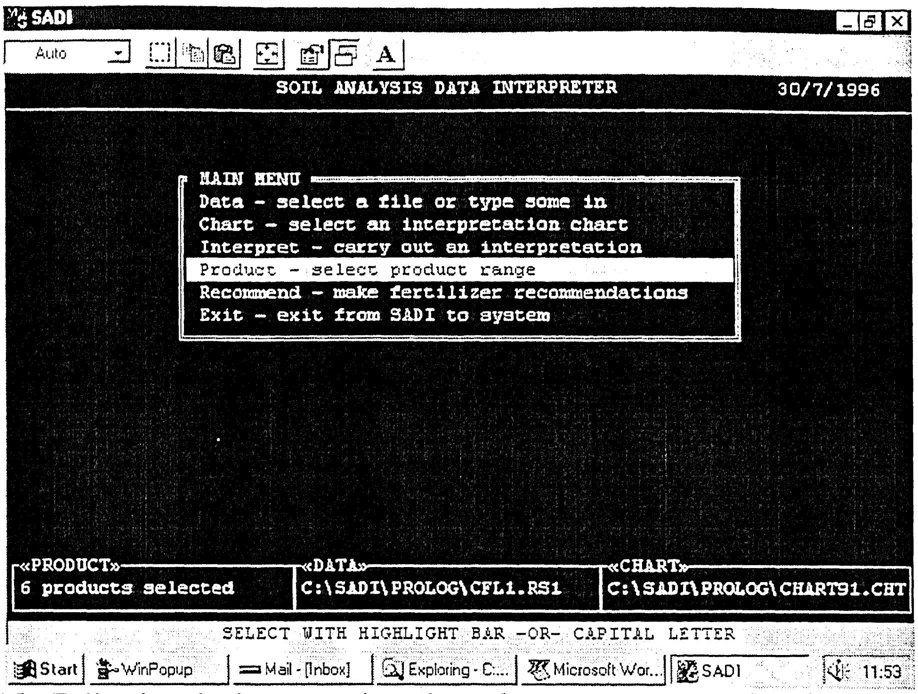


Figure A5.15 Following the interpretation phase the user can now select / unselect a range of fertilizer products. Because 6 have been selected already the "Recommend" task is now available on the main menu.

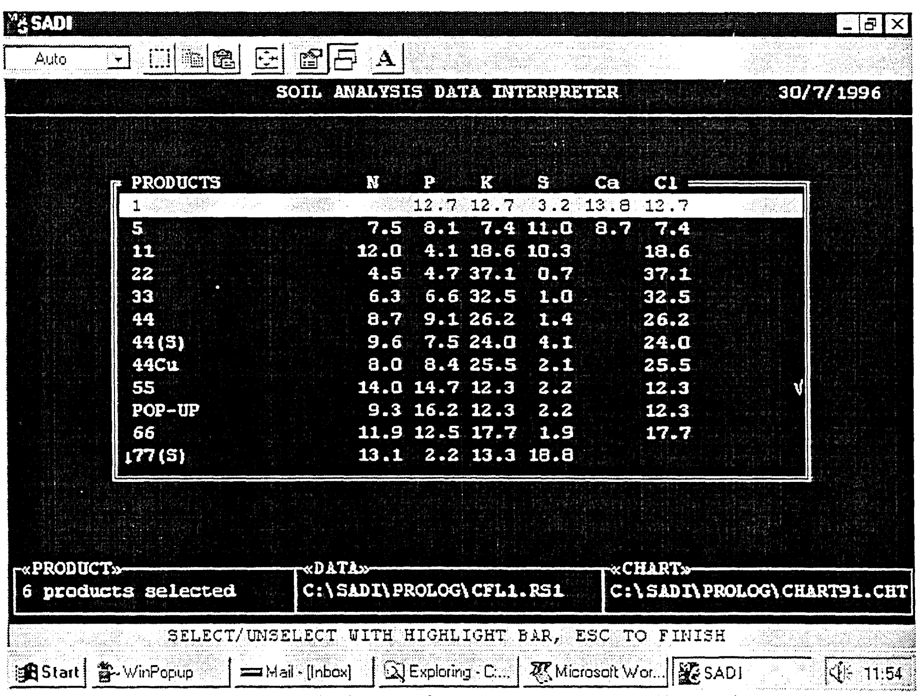


Figure A5.16 Product names and their nutrient contents are listed in a drop down menu for users to select from. Selected products are indicated by a tick on the right margin of the menu box, for example "55".

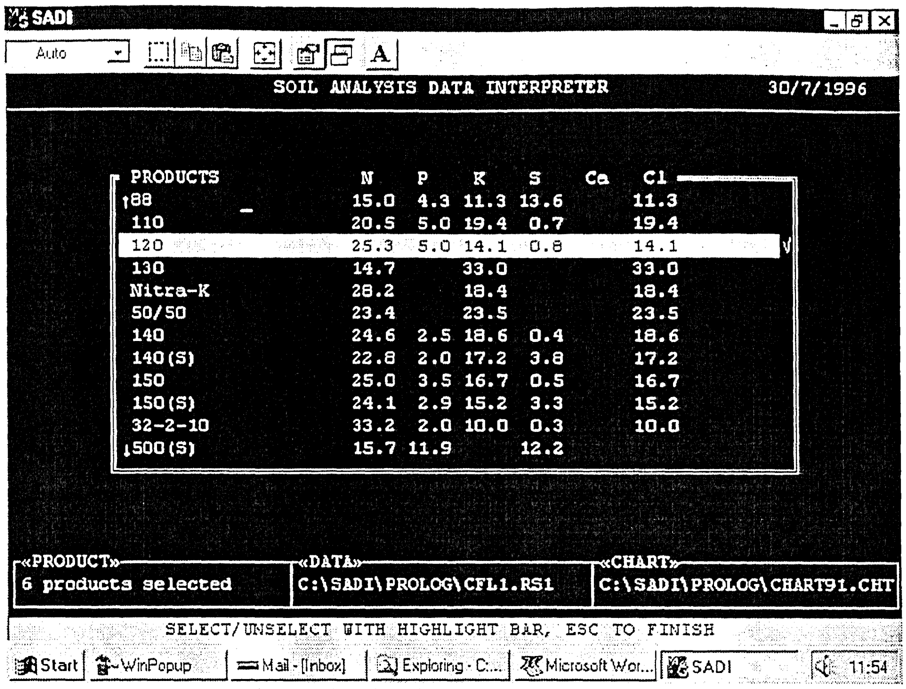


Figure A5.17 To select a product, the keyboard arrow keys move the highlight bar to the product and pressing the enter key ticks it as being selected.

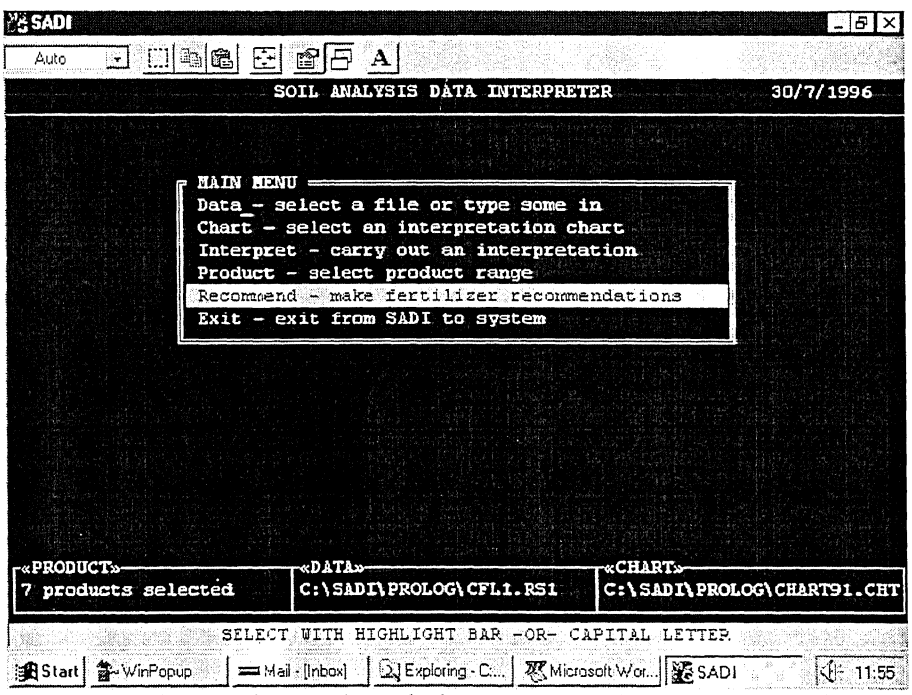


Figure A5.18 Now with 7 products selected, the recommendation phase can be undertaken.

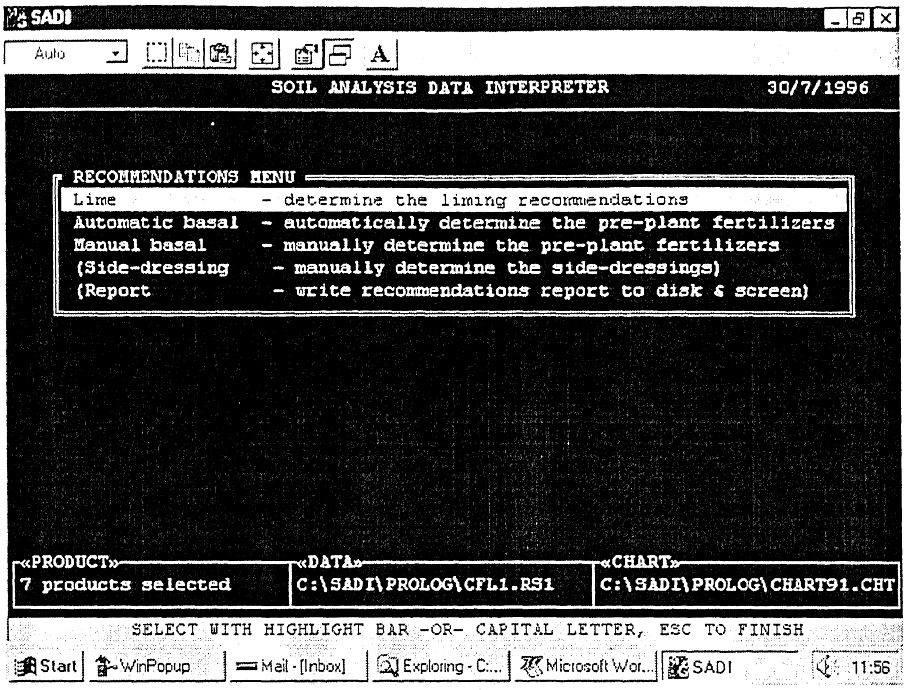


Figure A5.19 The recommendation menu with the "side-dressing" option unavailable since a basal recommendation has not yet been made.

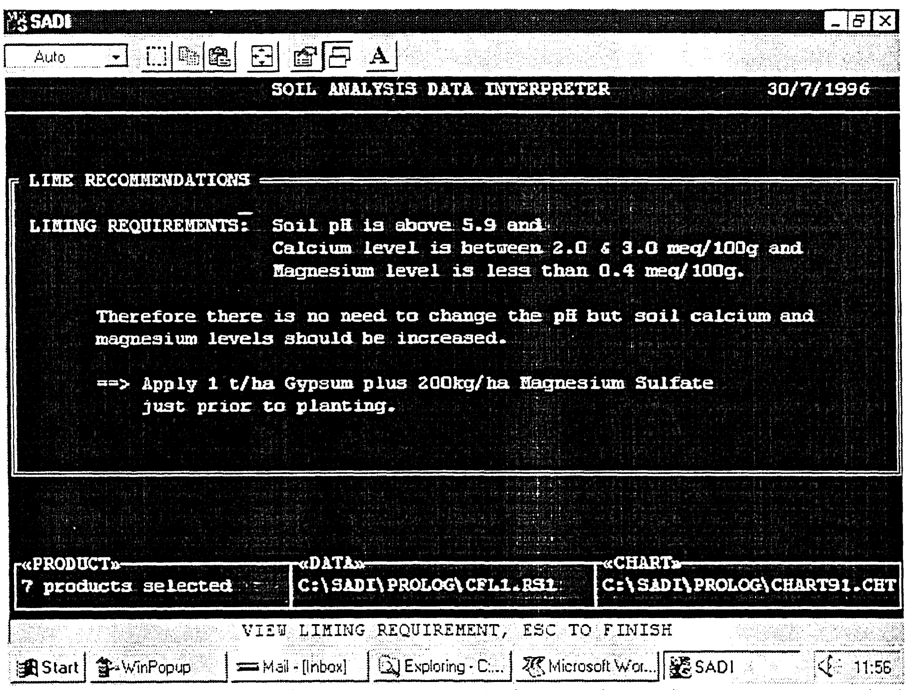


Figure A5.20 The results of the first recommendation task, a lime recommendation showing the basis of the recommendation and the recommendation itself.

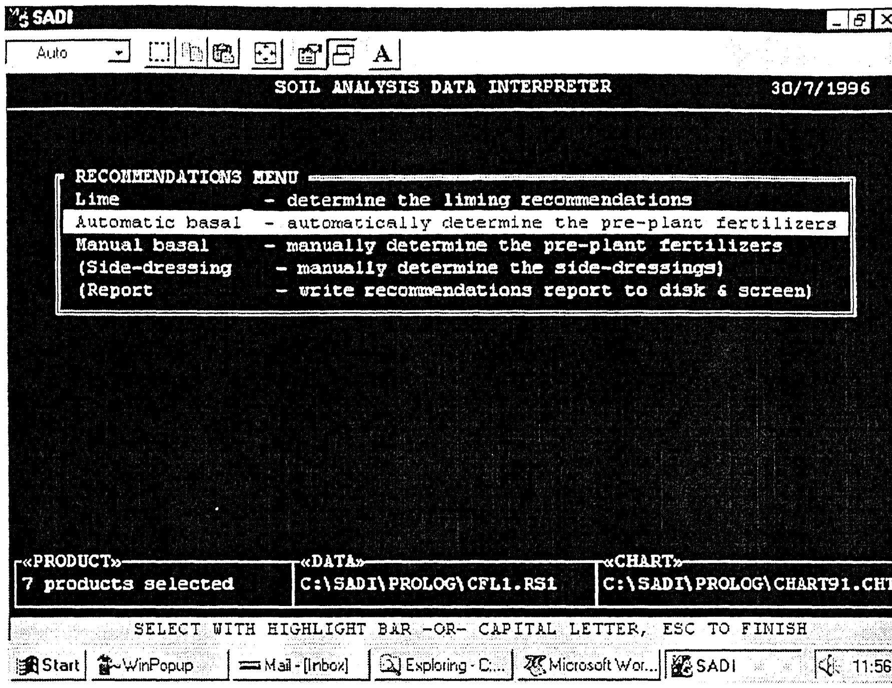


Figure A5.21 Selecting the "automatic basal" option will generate a best fit recommendation using one product from the range selected using the underlying linear model to optimize the recommendation.

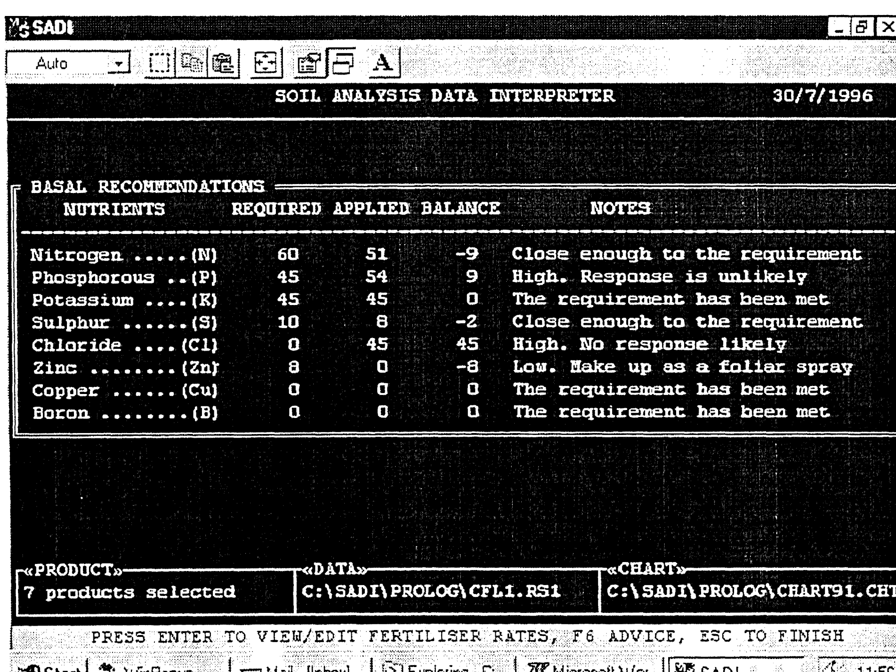


Figure A5.22 The nutrient balance sheet as a result of generating a basal recommendation automatically. The notes column is a summary of more in depth advice found by pressing F6.

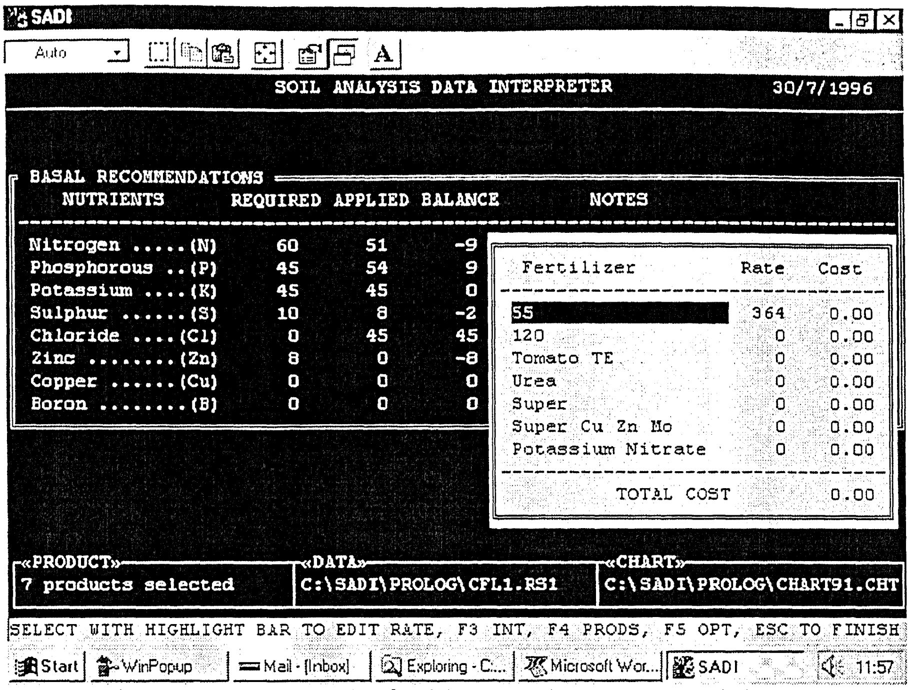


Figure A5.23 Pressing enter displays the fertilizer product menu and the rates used. In this case the automatic optimization found 364 kg/ha of the product called "55" best met the requirements of the 7 products selected.

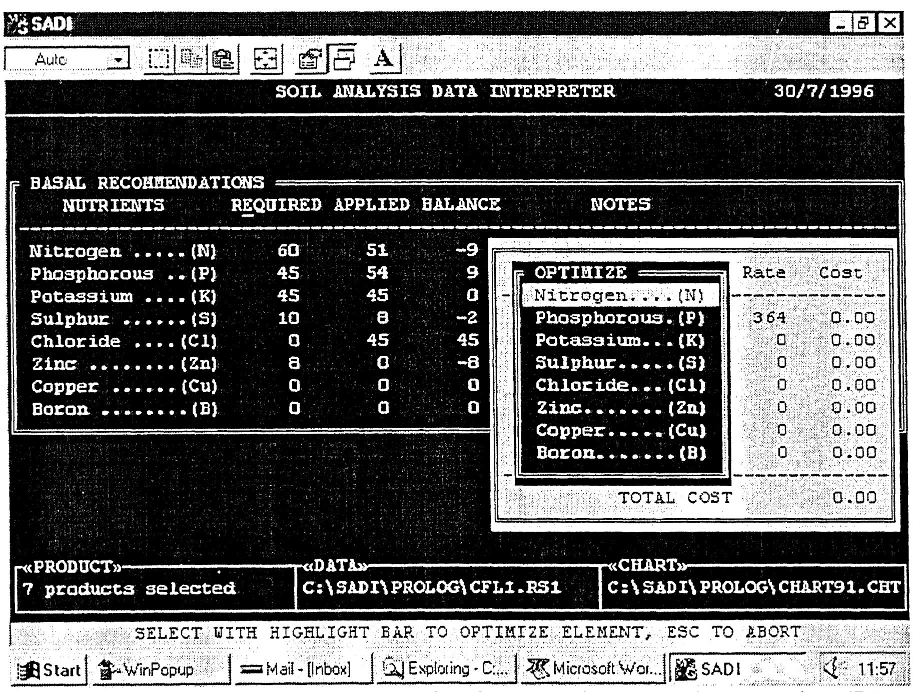


Figure A5.24 Manual directing of the optimization can be done by pressing F5 to bring up a list of nutrients to optimize.

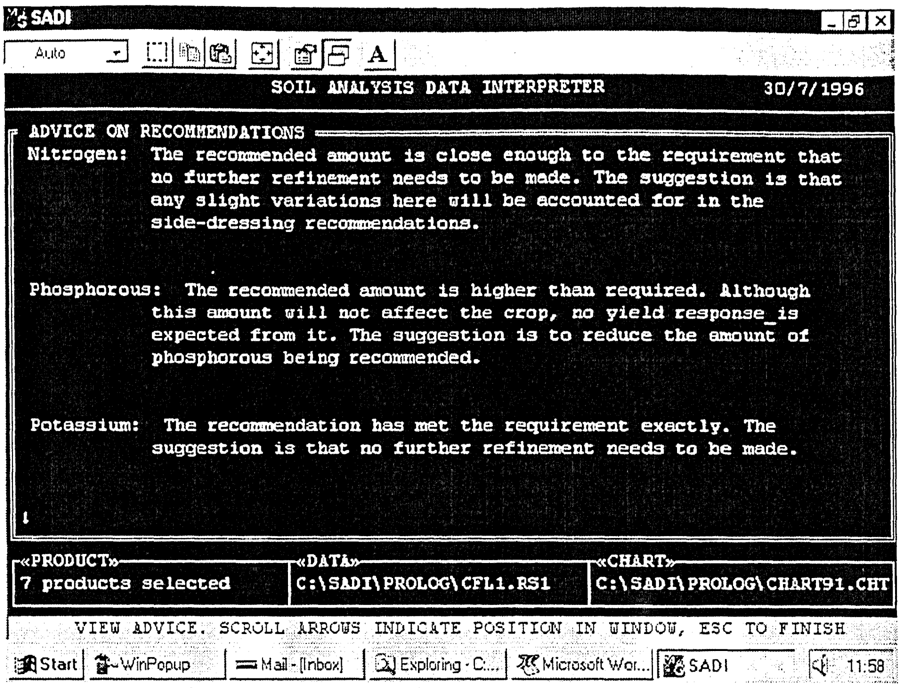


Figure A5.25 Pressing F6 from the nutrient balance sheet screen gives expanded advice on the notes regarding the validity of the recommendation.

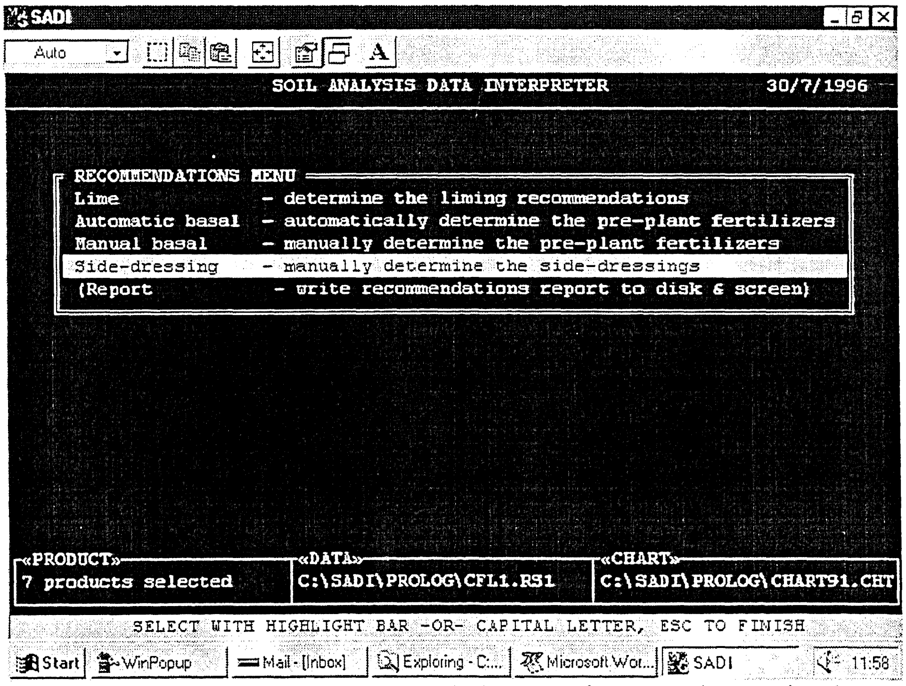


Figure A5.26 Having made a basal recommendation the side-dressing option is now available.

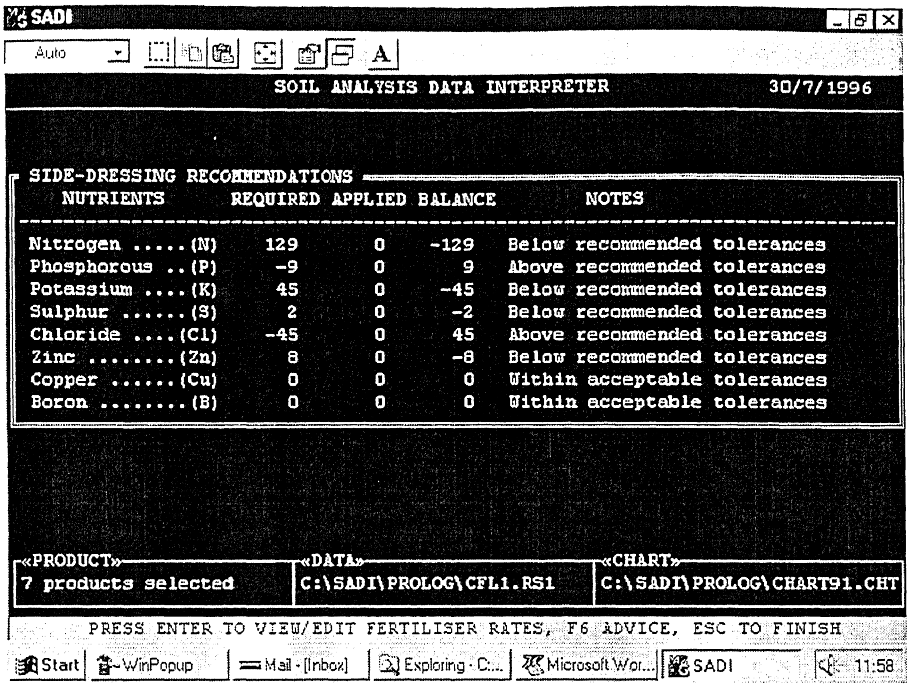


Figure A5.27 The side-dressing recommendation screen opens with the nutrient balances left over from the basal recommendation.

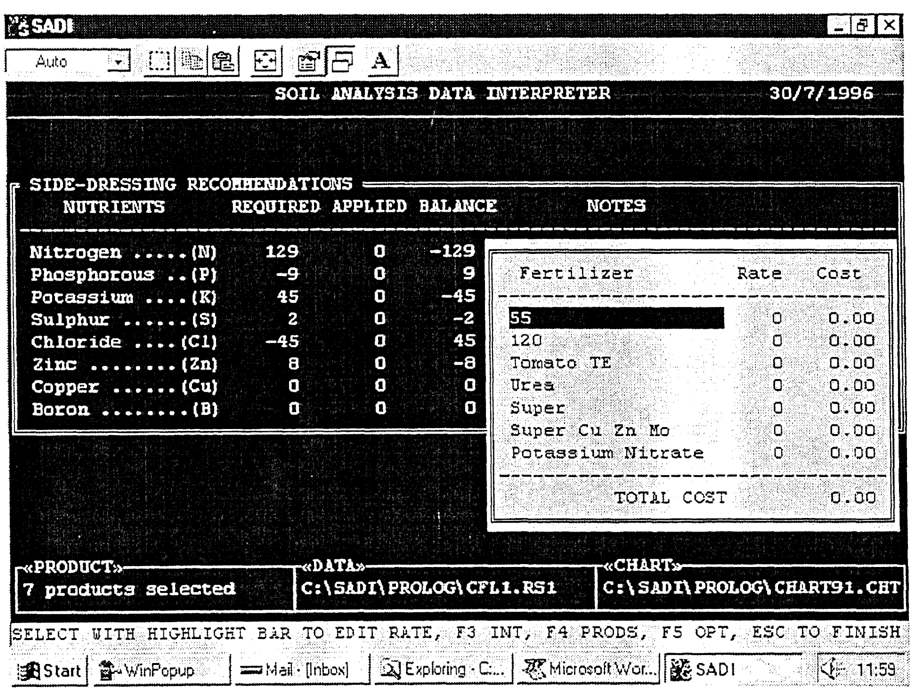


Figure A5.28 Pressing enter brings up the product range to work with.

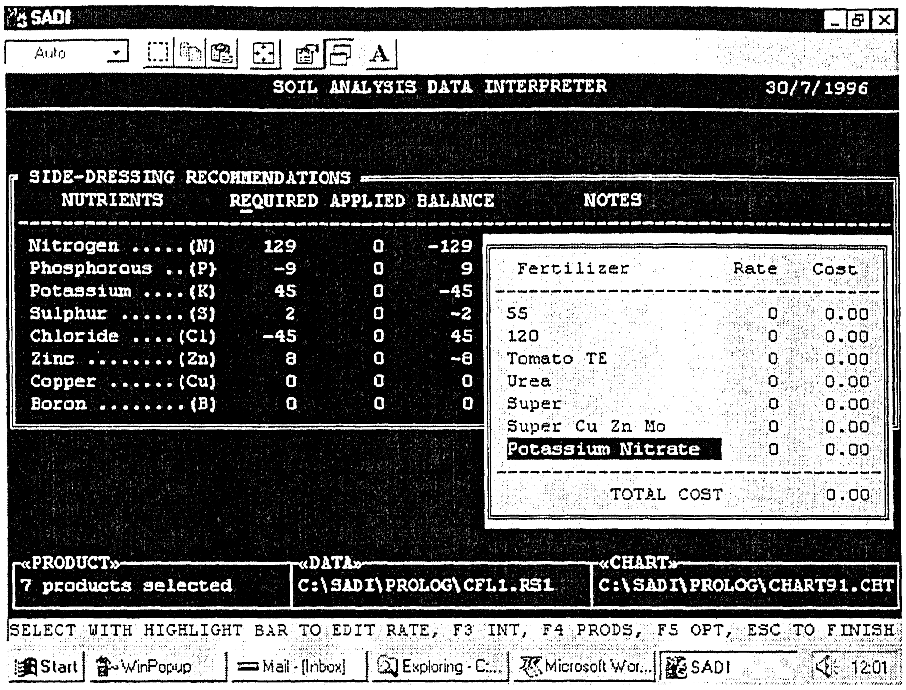


Figure A5.29 Select using the keyboard arrow keys the product you wish to use. Pressing F3 will show the interpretation report, pressing F4 will show the nutrient contents of the products.

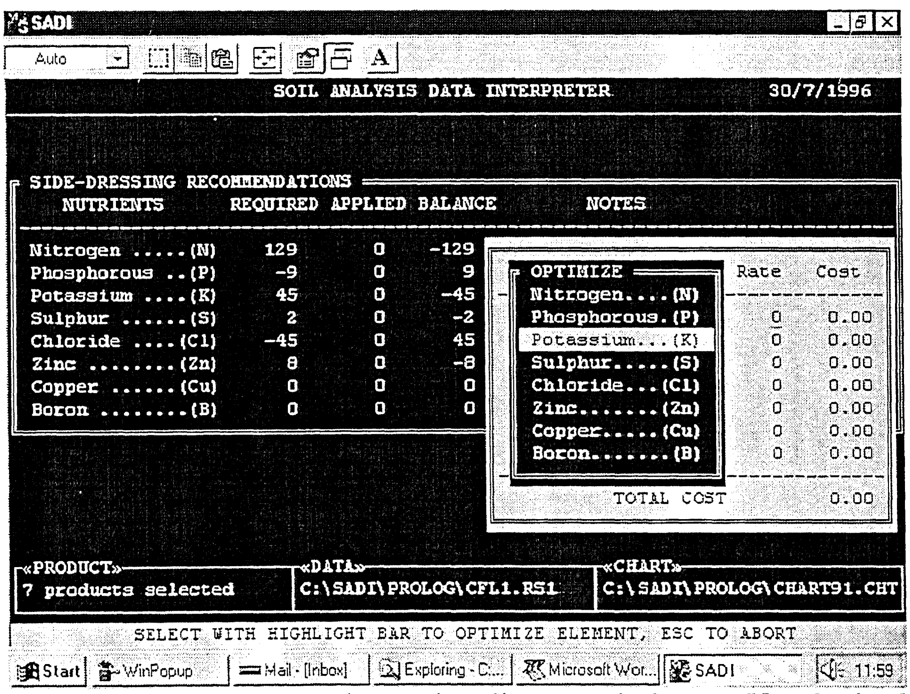


Figure A5.30 Pressing F5 brings up the nutrient list to optimize on. Use the keyboard arrow keys to select the nutrient to optimize (find the rate of the product which meets the required amount).

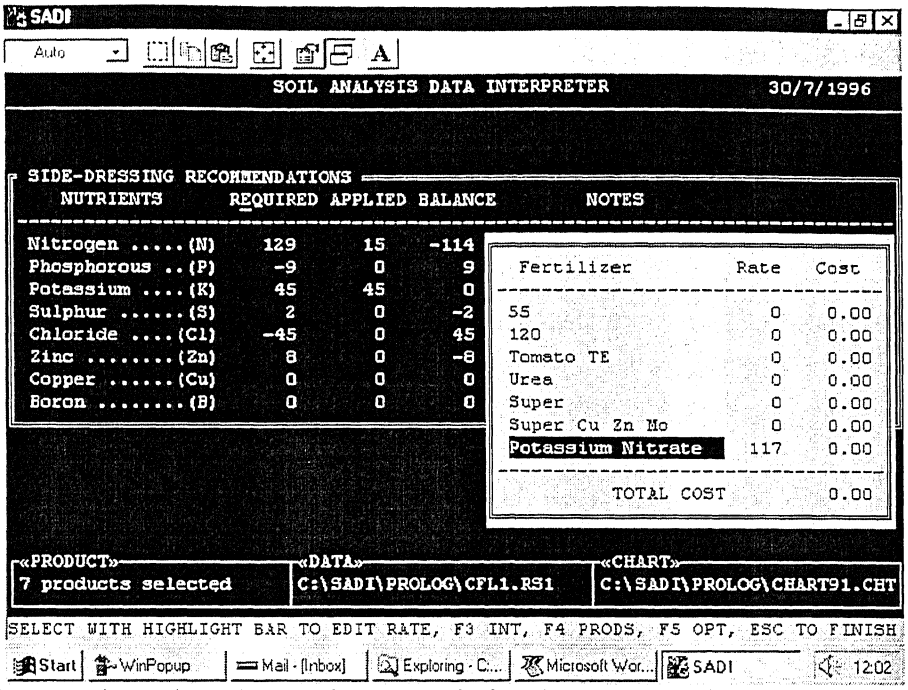


Figure A5.31 Having selected potassium to optimize the linear model calculates that 117 kg/ha of the fertilizer product potassium nitrate applies the 45 kg/ha of potassium required still leaving 114 kg/ha of nitrogen to be applied.

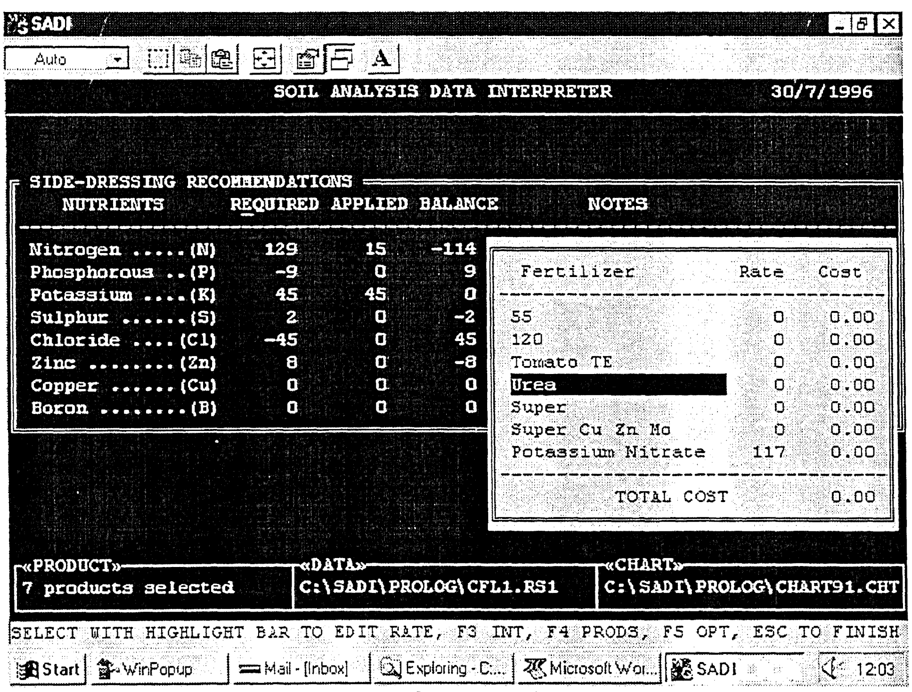


Figure A5.32 Using the same principle as for potassium, press enter to open the products list and select the product you wish to use - in this case urea.

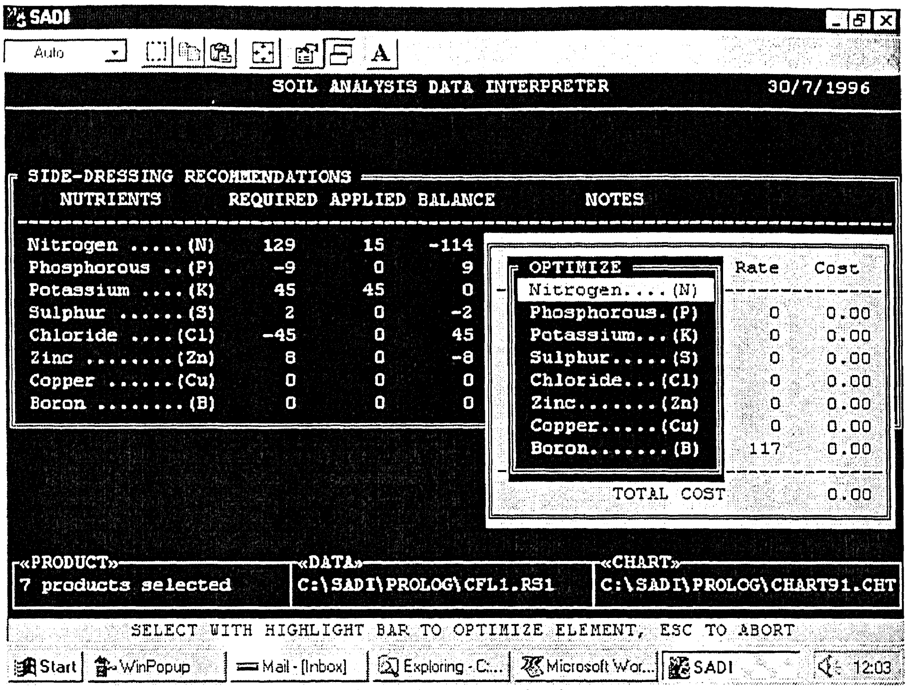


Figure A5.33 Press F5 to open the nutrient list to optimize and select nitrogen.

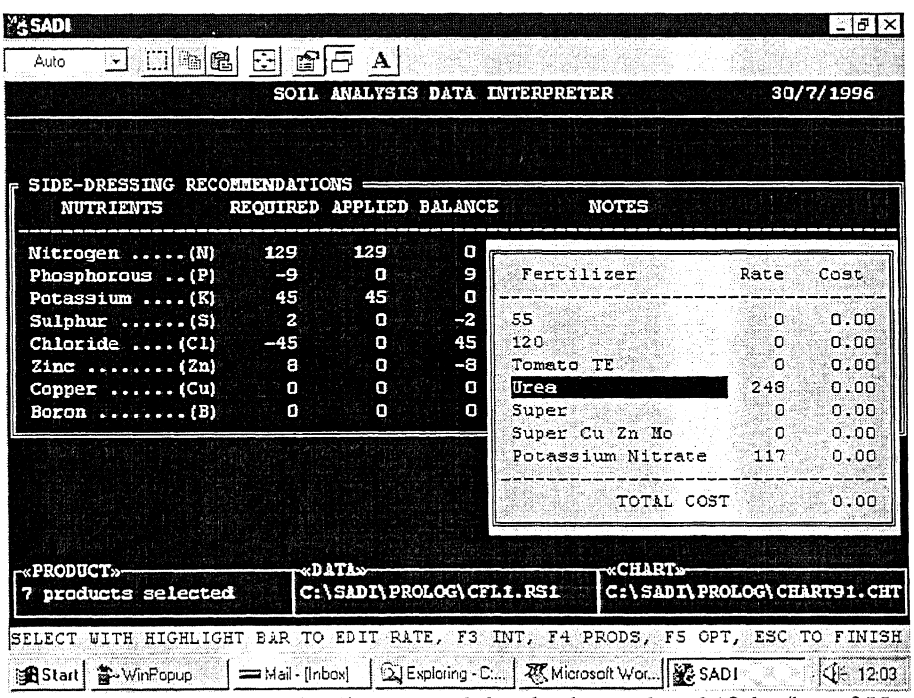


Figure A5.34 On pressing enter, the linear model calculates that 248 kg/ha of Urea meets the requirement of 129 kg/ha of nitrogen.

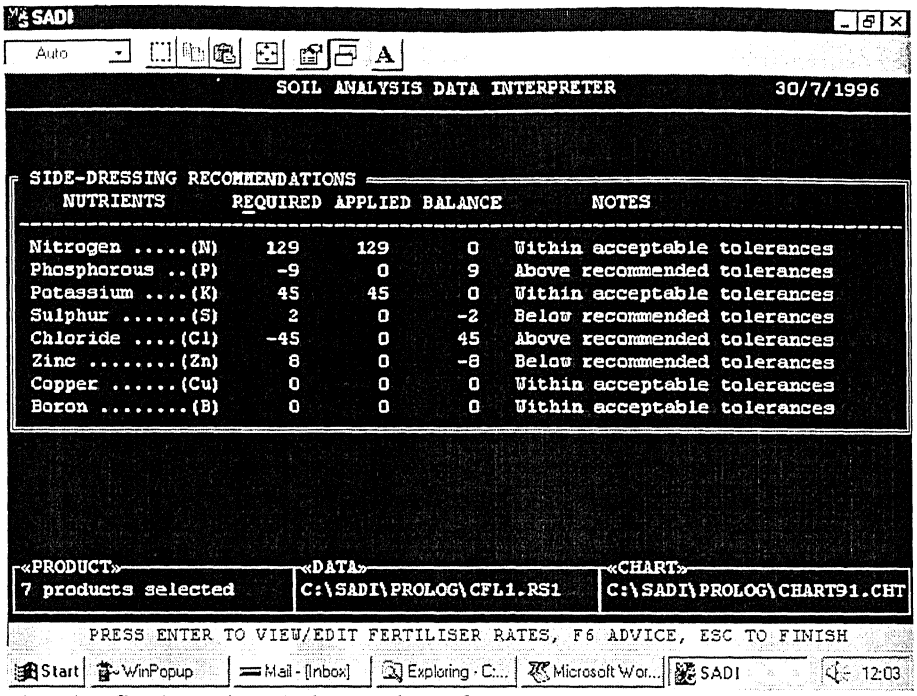


Figure A5.35 The final nutrient balance sheet for the side-dressing recommendations. It is up to the user to accept or reject the recommendation - the system helps make the decision with advice in the notes and more in depth advice available by pressing F6.

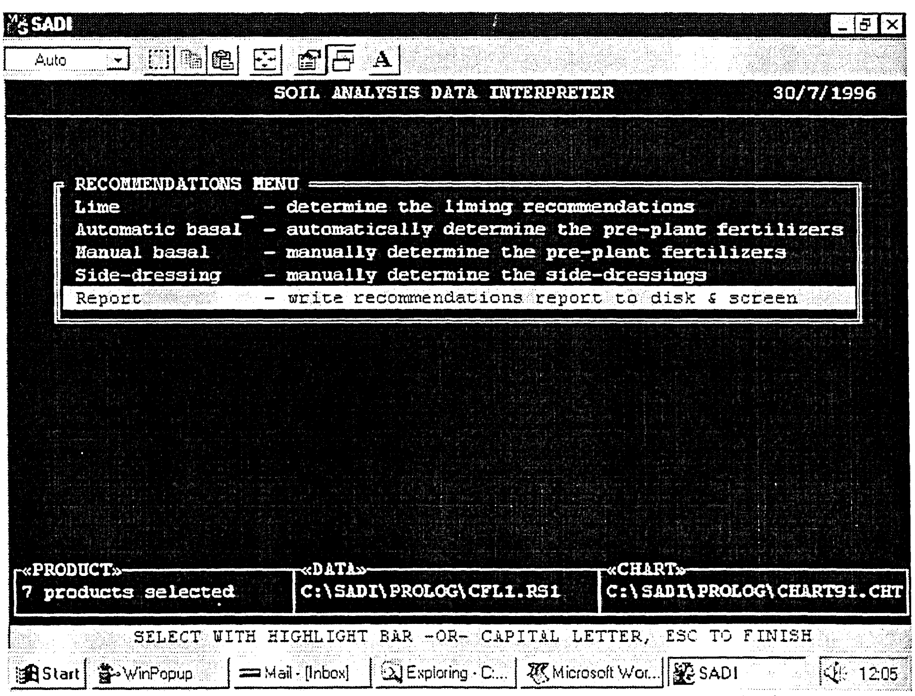


Figure A5.36 Having accepted the recommendation, the recommendation report can now be generated and viewed.

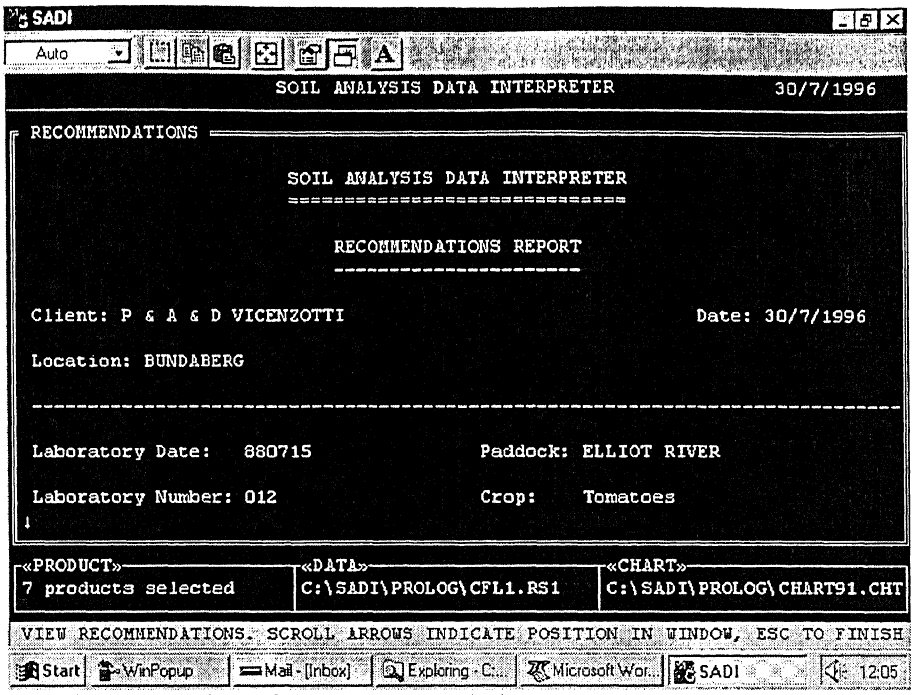


Figure A5.37 The top portion of the recommendations report.

SOIL ANALYSIS DATA INTERPRETER

INTERPRETATION RESULTS

Client: P & A & D VICENZOTTI Date: 30/7/1996

Location: BUNDABERG

Laboratory Date: 880715 Paddock: ELLIOT RIVER

Laboratory Number: 012 Crop: Tomatoes

NUTRIENT	LEVEL	FERTILITY STATUS	NUTRIENT REQUIREMENT
pH	6.50	Optimum	Neutral
Organic Carbon	1.30	Low	
Nitrogen	0.70	Deficient	180 kg/ha N Timing of applications: 60kg at planting 60kg at early flowering 60kg three weeks later
Sulfur	7.10	Moderate	A response to sulfur may be likely
Phosphorous	56.00	High	45 kg/ha P Timing of application: 45kg at planting
Potassium	0.22	Low	90 kg/ha K Timing of applications: 45kg at planting 45kg at early flowering
Calcium	2.72	Moderate	See liming requirements
Magnesium	0.15	Low	See liming requirements
Sodium	0.04	Very Low	No action required
Chloride	5.00	Very Low	No action required
Conductivity	0.02	Very Low	No action required
Copper	1.80	Moderate	No action required
Zinc	0.50	Low	See recommendations Soil applications of zinc are most effective. Apply pre-planting
Manganese	1.00	Very Low	See recommendations Foliar spray of manganese is required
Iron	81.00	Moderate	No action required
Boron	0.05	Very Low	See recommendations Foliar sprays of boron are most effective. Apply just before flowering commences.
Aluminium	0.00		No action required
Molybdenum	0.00		See recommendations Foliar sprays of molybdenum in the seedling stage are most effective.

Figure A5.38 A print-out of the Interpretation Report.

```
                    SOIL ANALYSIS DATA INTERPRETER
                    ==============================

                       RECOMMENDATIONS REPORT
                       ----------------------

Client: P & A & D VICENZOTTI                      Date: 30/7/1996

Location: BUNDABERG

------------------------------------------------------------------------------

Laboratory Date:   880715             Paddock: ELLIOT RIVER

Laboratory Number: 012                Crop:    Tomatoes

------------------------------------------------------------------------------

LIMING REQUIREMENTS:  Soil pH is above 5.9 and
                      Calcium level is between 2.0 & 3.0 meq/100g and
                      Magnesium level is less than 0.4 meq/100g.

      Therefore there is no need to change the pH but soil calcium and
      magnesium levels should be increased.

      ==> Apply 1 t/ha Gypsum plus 200kg/ha Magnesium Sulfate
          just prior to planting.

PRE-PLANT RECOMMENDATIONS: Apply the following fertilizers
                           before planting the crop.

                 55                  364 kg/ha

SIDE-DRESSING RECOMMENDATIONS: Apply the following fertilizers
                               after planting the crop. Time of
                               application as per Interpretation
                               Report.

                 Urea                248 kg/ha
                 Potassium Nitrate   117 kg/ha

MICRO-NUTRIENT RECOMMENDATIONS:

         Zinc:        No zinc has been applied to meet the requirement.
                   Therefore suggest a soil applied zinc treatment.

                   ==> Zinc Sulfate Monohydrate at 20 kg/ha should
                       be applied before planting.

                   Alternatively - Zinc Sulfate Heptahydrate may be
                                   sprayed onto the soil at 40 kg/ha
                                   OR sprayed onto the foliage before
                                   flowering at 1 kg/450 L/ha of spray
                                   solution.

                   WARNING: Avoid foliar sprays on very hot days or
                            during the middle of the day.

         Copper:      No extra applications needed.
         Boron:       No extra applications needed.
         Manganese:   No extra applications needed.
         Iron:        No extra applications needed.
         Molybdenum:  Some molybdenum should be applied.
                   Therefore suggest a foliar applied molybdenum treatment.

                   ==> Apply Sodium Molybdate at 60g/100 L of
                       spray solution, once before transplanting and
                       again two weeks after transplanting.
```

Figure A5.39 A print-out of the Recommendations Report.

APPENDIX SIX

This appendix shows screen captures from a sample session with the Windows prototype.

Data used in this session is fictitious but represents what could be a standard scenario.

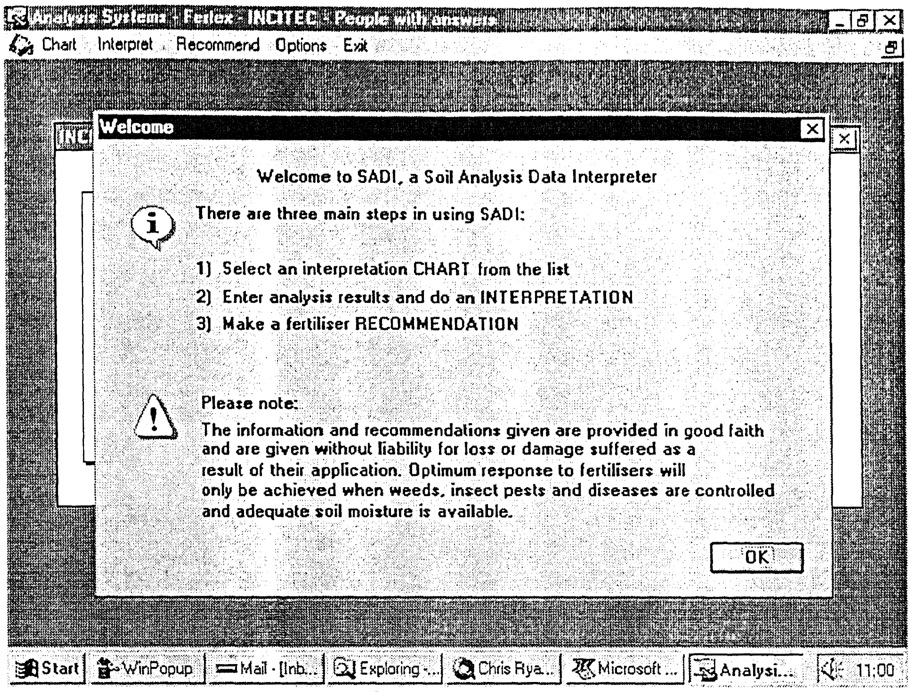


Figure A6.1 The introductory screen of SADI.

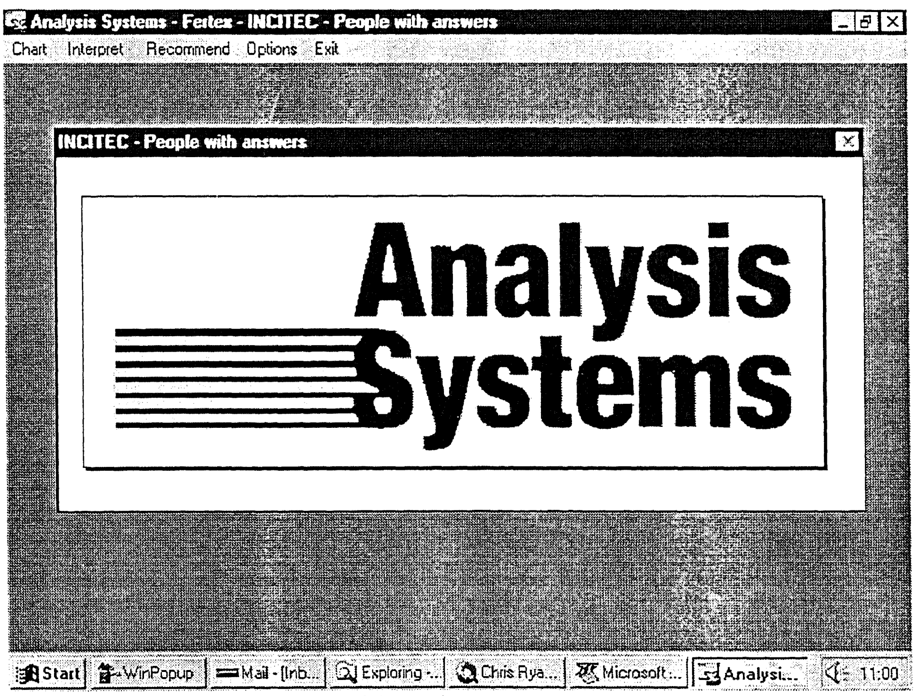


Figure A6.2 The main menu screen of SADI.

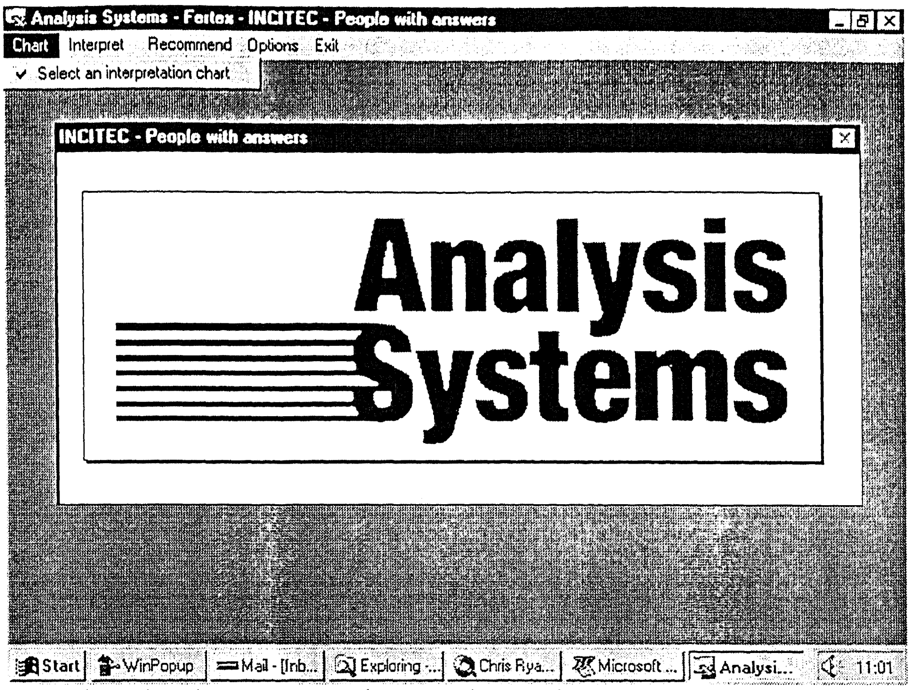


Figure A6.3 Select the chart menu option to select an interpretation chart.

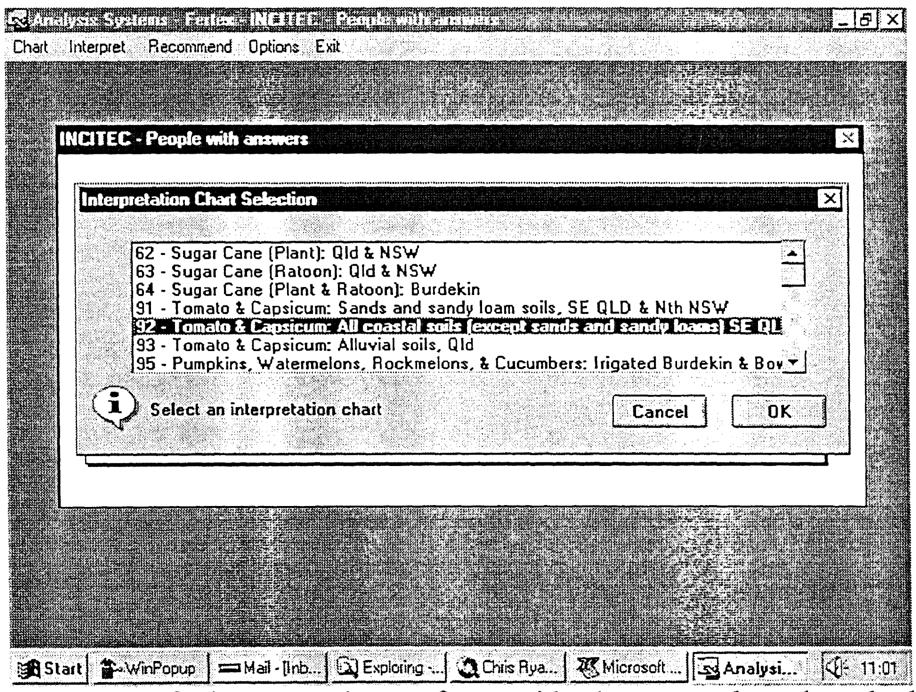


Figure A6.4 A list of charts to choose from with the currently selected chart as the highlighted option.

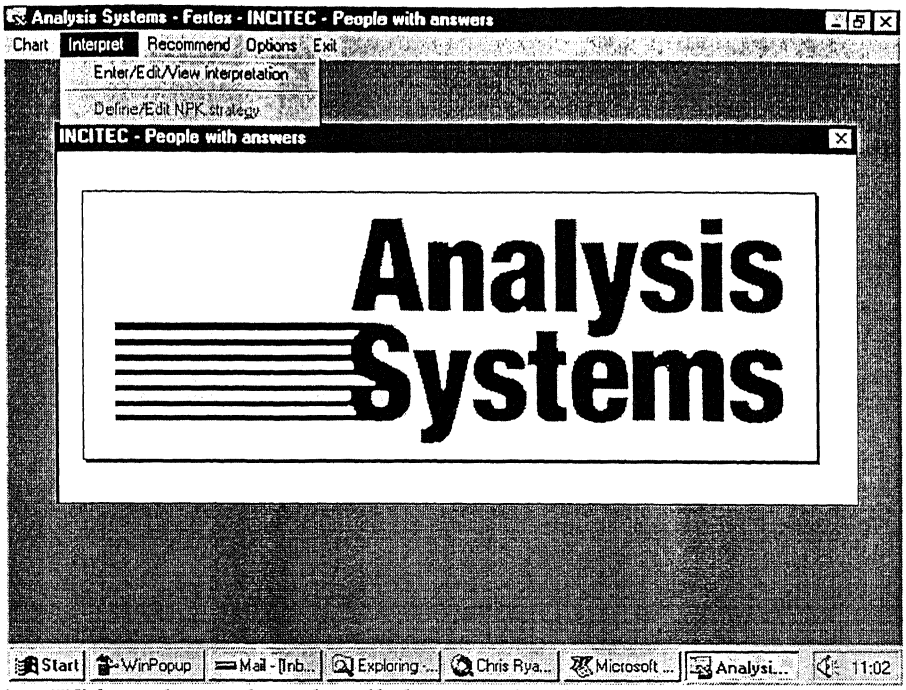


Figure A6.5 With a chart selected, soil data can be directly entered onto the interpretation report.

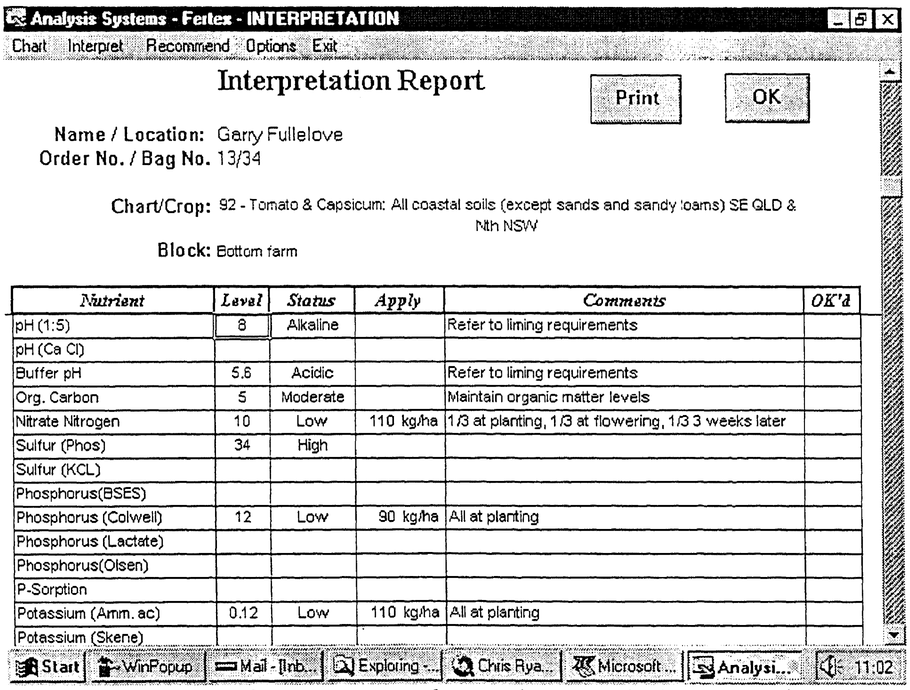

Analysis Systems - Fertex - INTERPRETATION

Chart Interpret Recommend Options Exit

Interpretation Report

Print OK

Name / Location: Garry Fullelove
Order No. / Bag No. 13/34

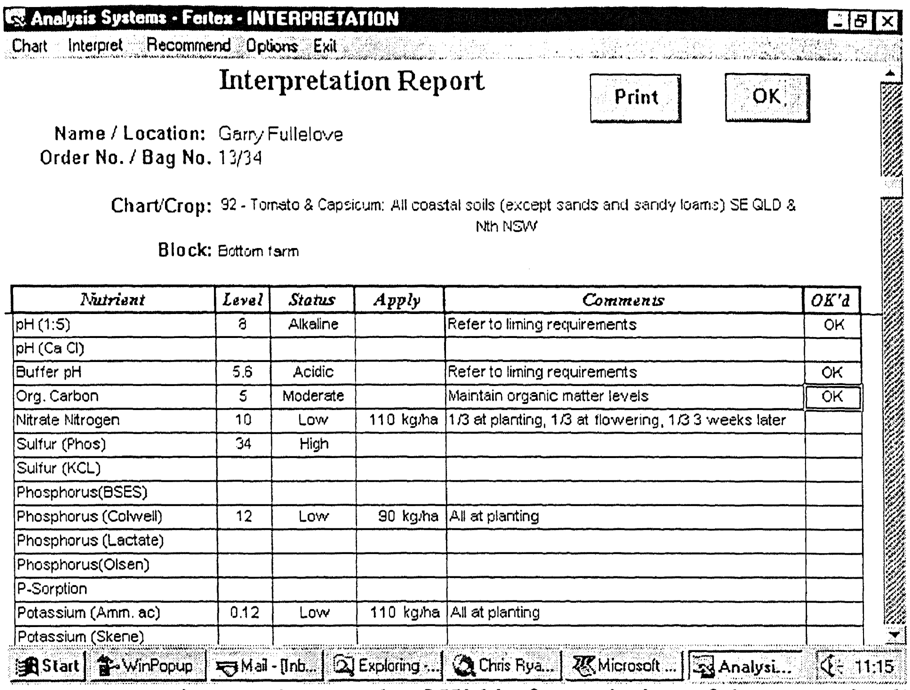
Chart/Crop: 92 - Tomato & Capsicum: All coastal soils (except sands and sandy loams) SE QLD & Nth NSW

Block: Bottom farm

Nutrient	Level	Status	Apply	Comments	OK'd
pH (1:5)	8	Alkaline		Refer to liming requirements	
pH (Ca Cl)					
Buffer pH	5.6	Acidic		Refer to liming requirements	
Org. Carbon	5	Moderate		Maintain organic matter levels	
Nitrate Nitrogen	10	Low	110 kg/ha	1/3 at planting, 1/3 at flowering, 1/3 3 weeks later	
Sulfur (Phos)	34	High			
Sulfur (KCL)					
Phosphorus(BSES)					
Phosphorus (Colwell)	12	Low	90 kg/ha	All at planting	
Phosphorus (Lactate)					
Phosphorus(Olsen)					
P-Sorption					
Potassium (Amm. ac)	0.12	Low	110 kg/ha	All at planting	
Potassium (Skene)					

Start WinPopup Mail - [Inb... Exploring -... Chris Rya... Microsoft ... Analysi... 11:02

Figure A6.6 The interpretation report where data and interpretation results can be entered/edited/viewed.



Analysis Systems - Fertex - INTERPRETATION

Chart Interpret Recommend Options Exit

Interpretation Report

Print OK

Name / Location: Garry Fullelove
Order No. / Bag No. 13/34

Chart/Crop: 92 - Tomato & Capsicum: All coastal soils (except sands and sandy loams) SE QLD & Nth NSW

Block: Bottom farm

Nutrient	Level	Status	Apply	Comments	OK'd
pH (1:5)	8	Alkaline		Refer to liming requirements	OK
pH (Ca Cl)					
Buffer pH	5.6	Acidic		Refer to liming requirements	OK
Org. Carbon	5	Moderate		Maintain organic matter levels	OK
Nitrate Nitrogen	10	Low	110 kg/ha	1/3 at planting, 1/3 at flowering, 1/3 3 weeks later	
Sulfur (Phos)	34	High			
Sulfur (KCL)					
Phosphorus(BSES)					
Phosphorus (Colwell)	12	Low	90 kg/ha	All at planting	
Phosphorus (Lactate)					
Phosphorus(Olsen)					
P-Sorption					
Potassium (Amm. ac)	0.12	Low	110 kg/ha	All at planting	
Potassium (Skene)					

Start WinPopup Mail - [Inb... Exploring -... Chris Rya... Microsoft ... Analysi... 11:15

Figure A6.7 Interpretation results must be OK'd before printing of the report is allowed.

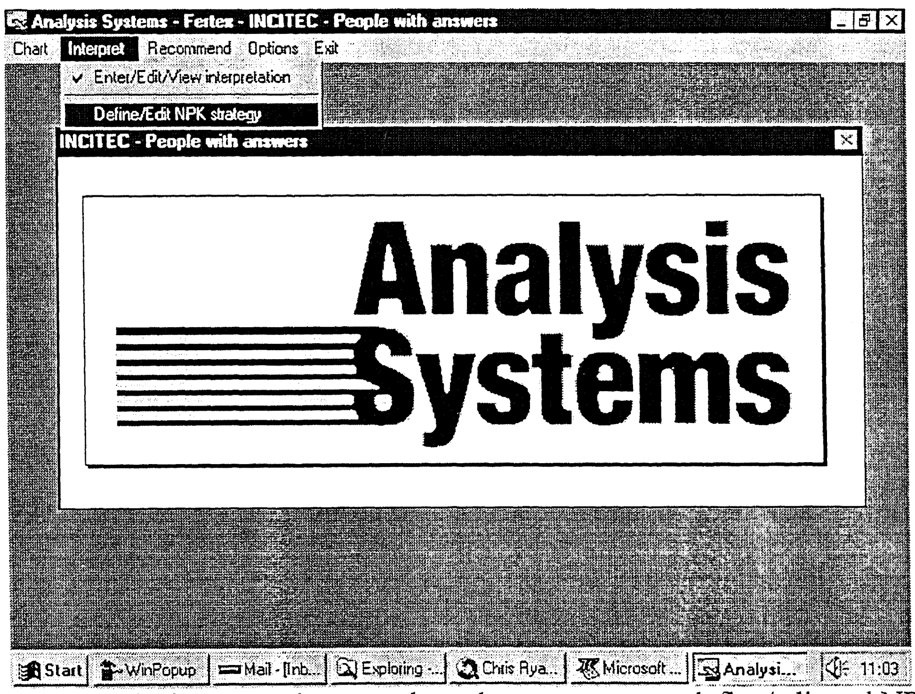
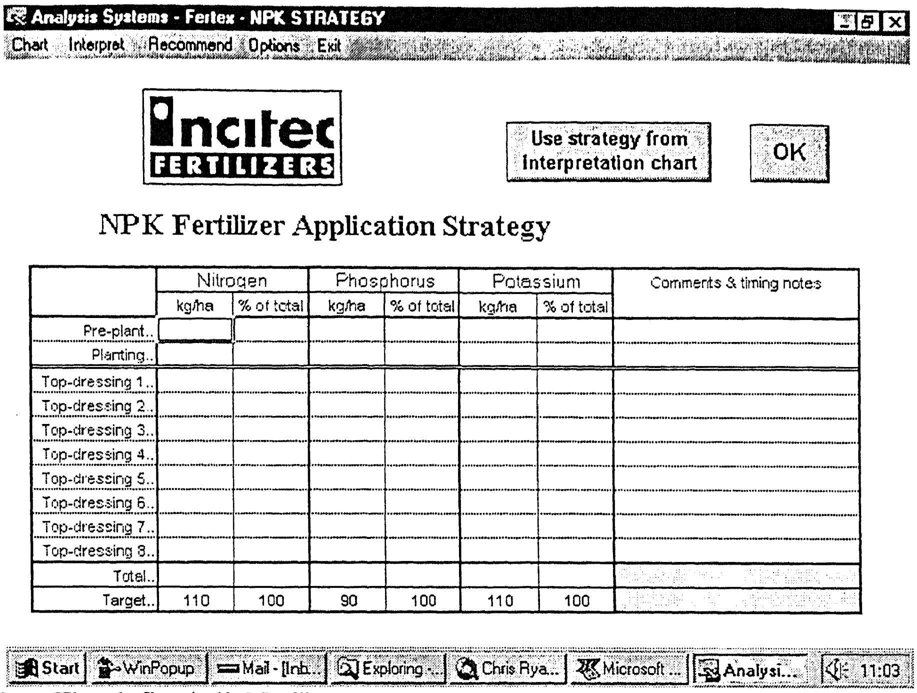
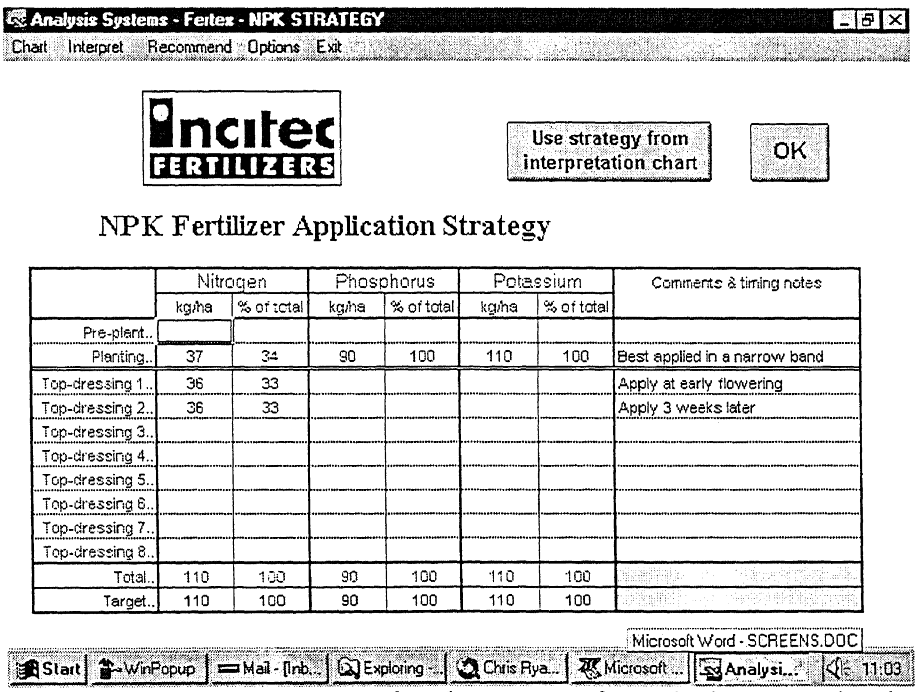


Figure A6.8 With the interpretation complete, the user can now define/edit and NPK strategy.



	Nitrogen		Phosphorus		Potassium		Comments & timing notes
	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total	
Pre-plant..							
Planting..							
Top-dressing 1..							
Top-dressing 2..							
Top-dressing 3..							
Top-dressing 4..							
Top-dressing 5..							
Top-dressing 6..							
Top-dressing 7..							
Top-dressing 8..							
Total..							
Target..	110	100	90	100	110	100	

Figure A6.9 The define/edit NPK strategy screen.



	Nitrogen		Phosphorus		Potassium		Comments & timing notes
	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total	
Pre-plant..							
Planting..	37	34	90	100	110	100	Best applied in a narrow band
Top-dressing 1..	36	33					Apply at early flowering
Top-dressing 2..	36	33					Apply 3 weeks later
Top-dressing 3..							
Top-dressing 4..							
Top-dressing 5..							
Top-dressing 6..							
Top-dressing 7..							
Top-dressing 8..							
Total..	110	100	90	100	110	100	
Target..	110	100	90	100	110	100	

Figure A6.10 The NPK strategy screen after the strategy from the interpretation has been used by pressing the on-screen button.

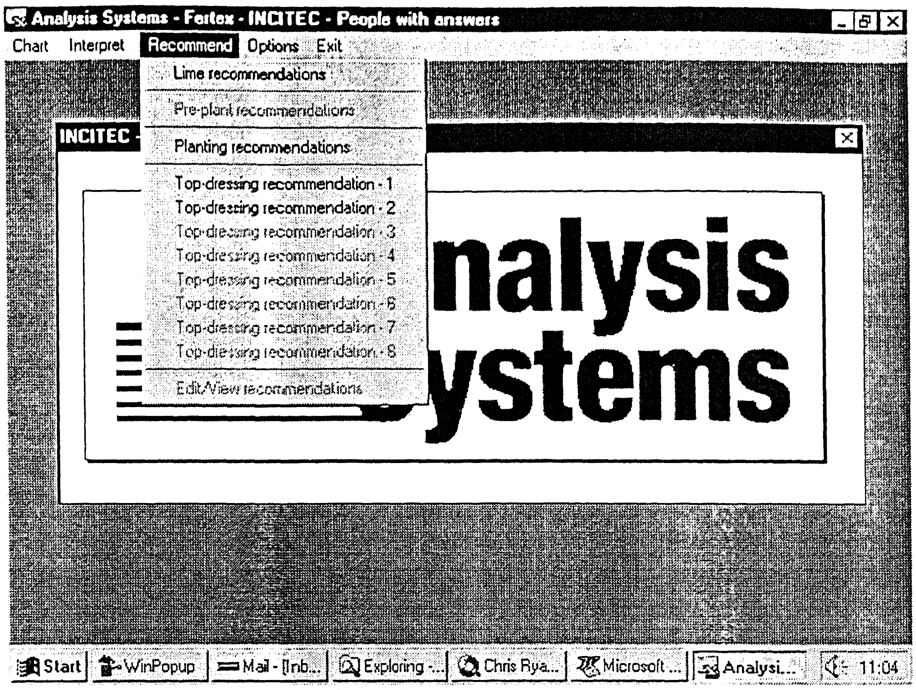


Figure A6.11 The recommendation drop-down menu.

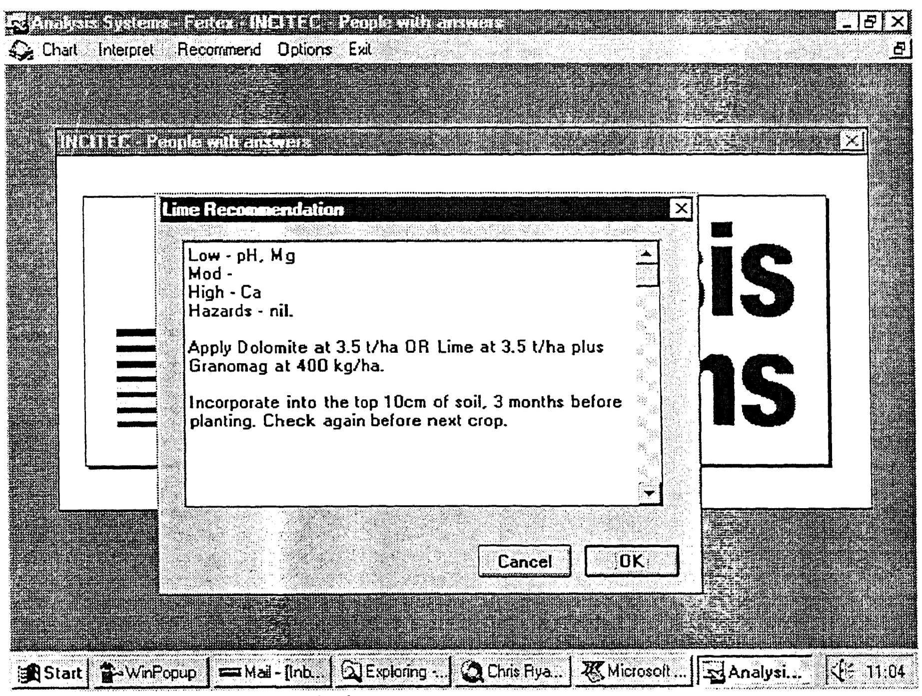


Figure A6.12 The lime recommendation.

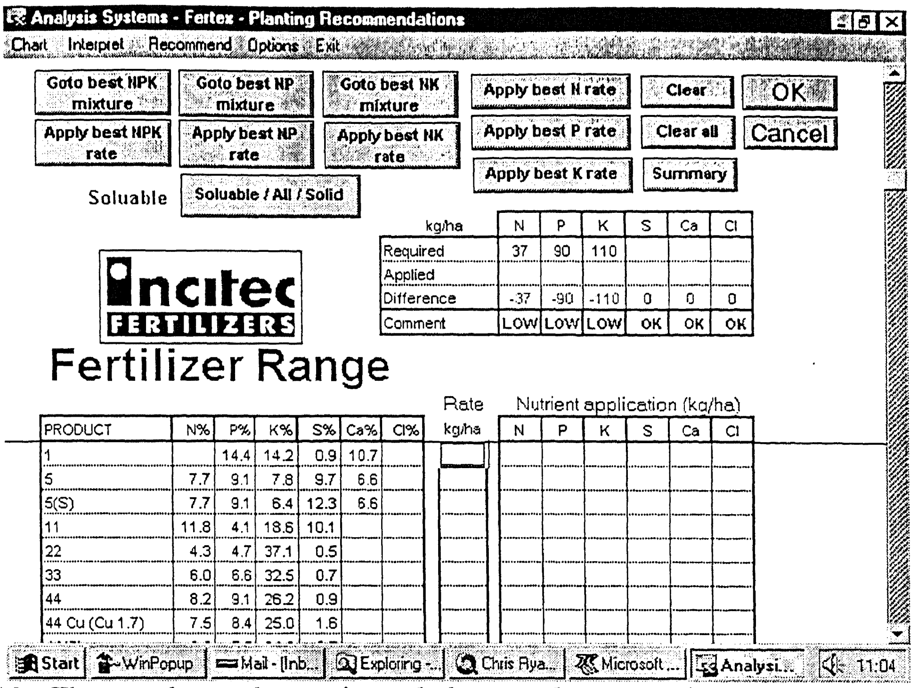


Figure A6.13 The tools and nutrient balance sheet used to generate a planting recommendation.

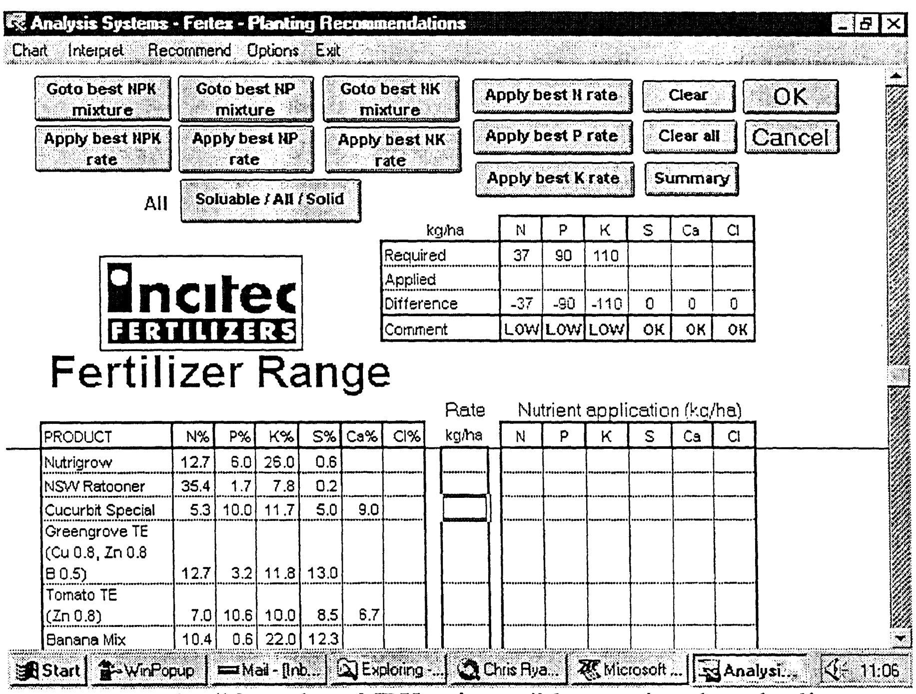


Figure A6.14 Pressing the "Goto best NPK mixture" button invokes the linear model and the fertilizer product which best meets the requirements is selected.

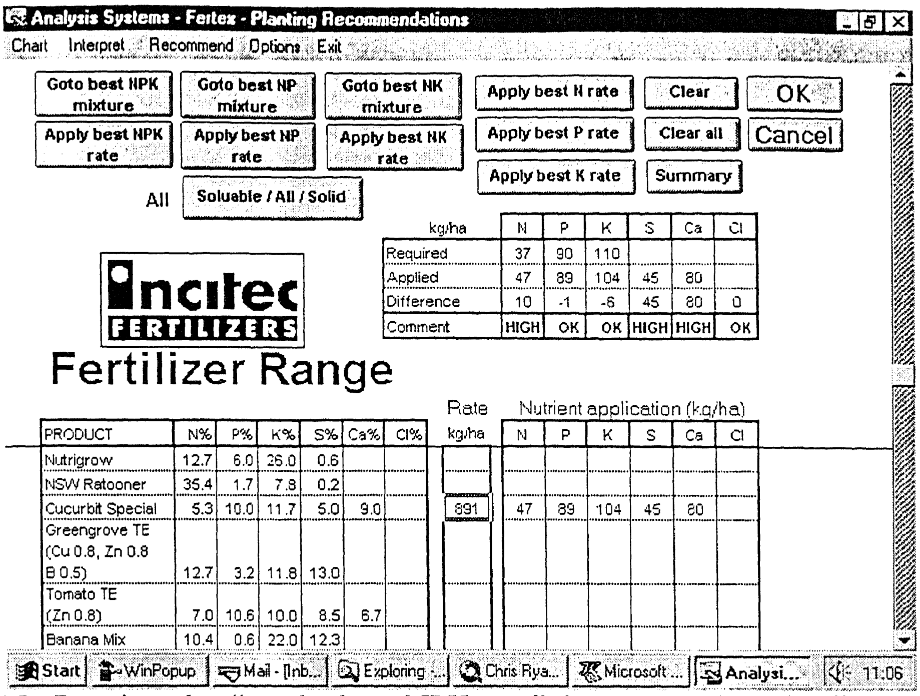


Figure A6.15 Pressing the "Apply best NPK rate" button invokes the linear model and calculates the rate the of fertilizer product which best meets the requirements.

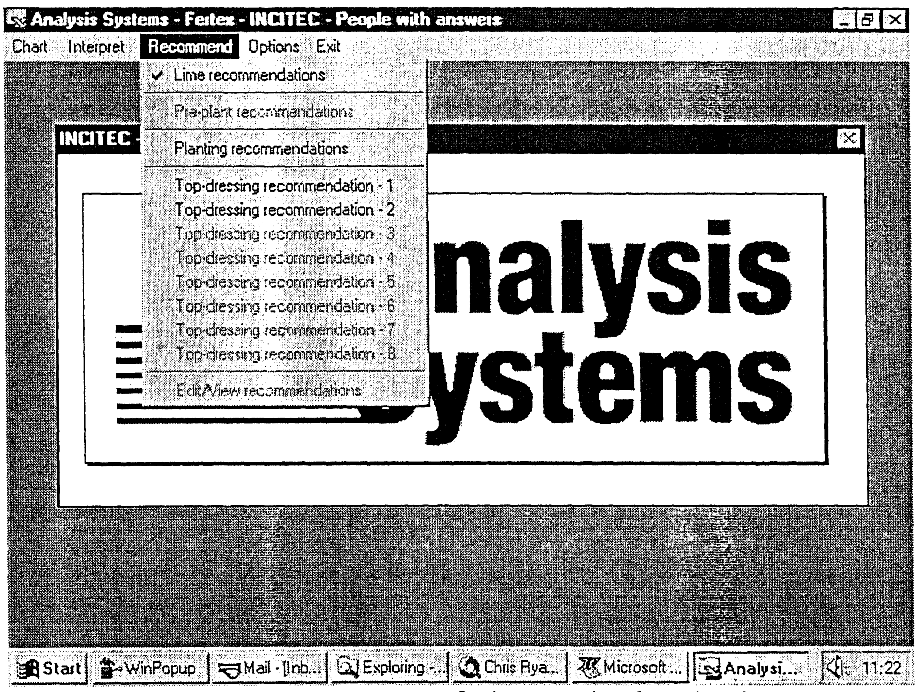


Figure A6.16 Because there was an excess of nitrogen in the planting recommendation, the planting recommendation option is not ticked.

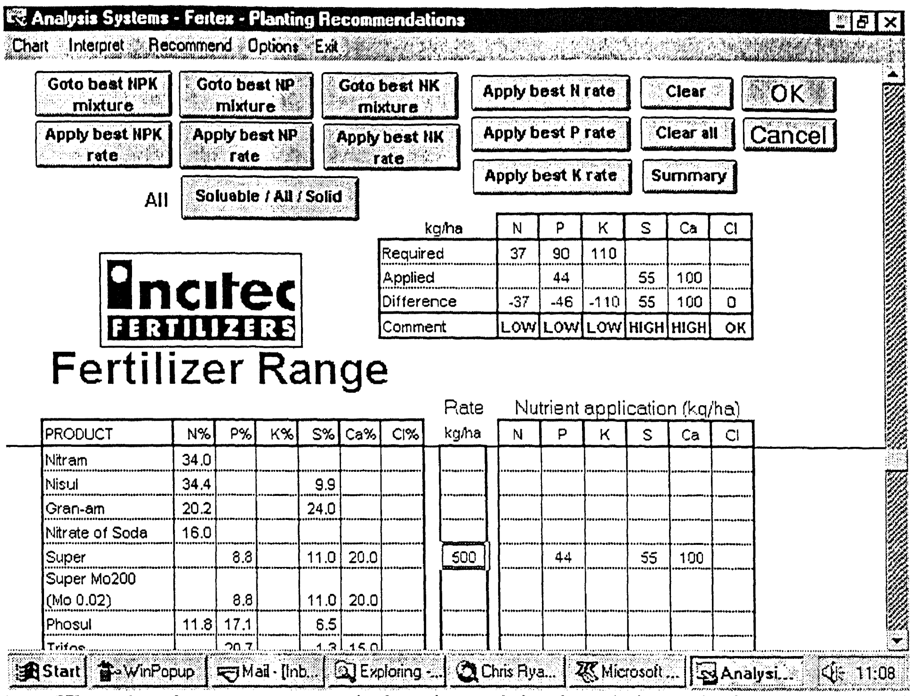


Figure A6.17 The planting recommendation is revisited and the solution space explored.

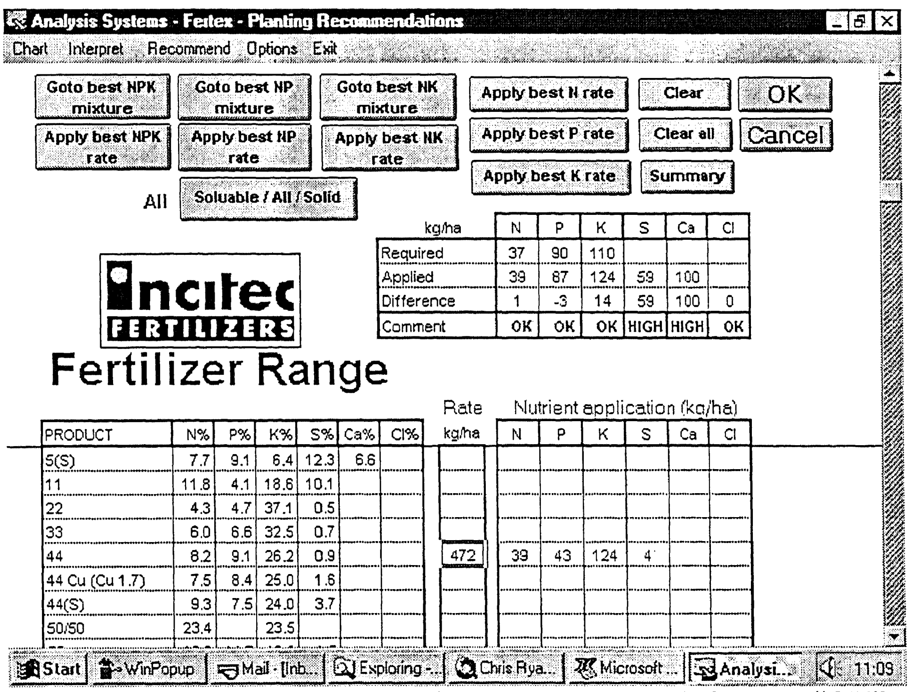


Figure A6.18 The balance sheet now shows the NPK recommendations are “OK”.

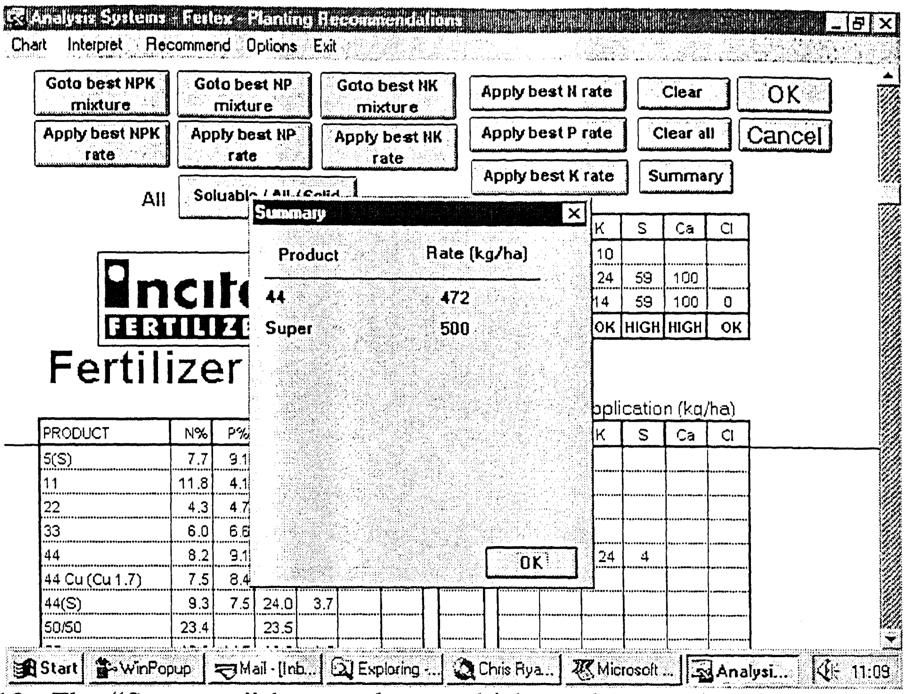


Figure A6.19 The "Summary" button shows which products and their rates that have been used in reaching a valid planting recommendation.

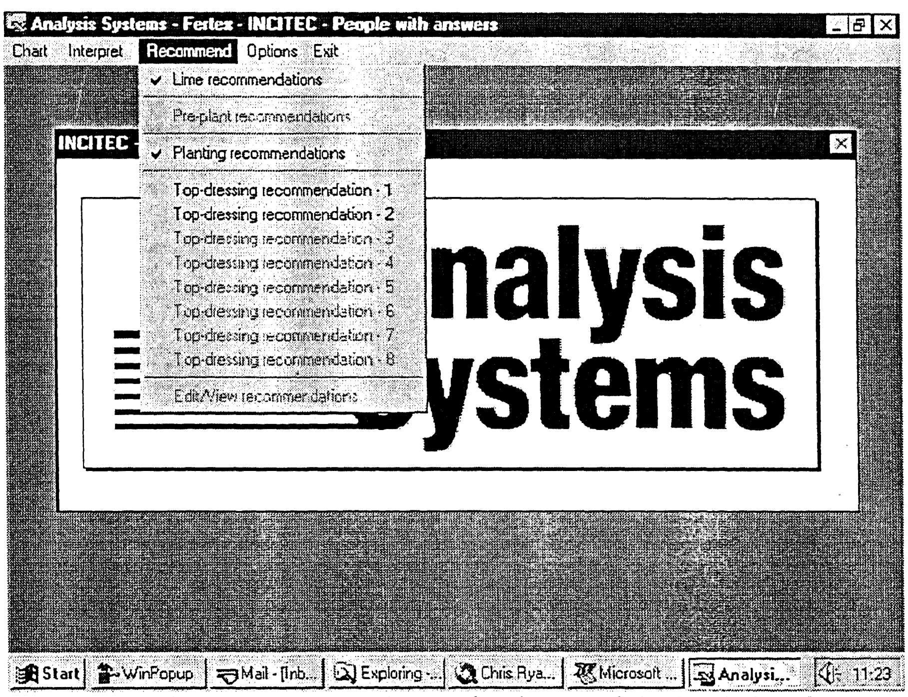


Figure A6.20 The planting recommendation option is now ticked as being done.

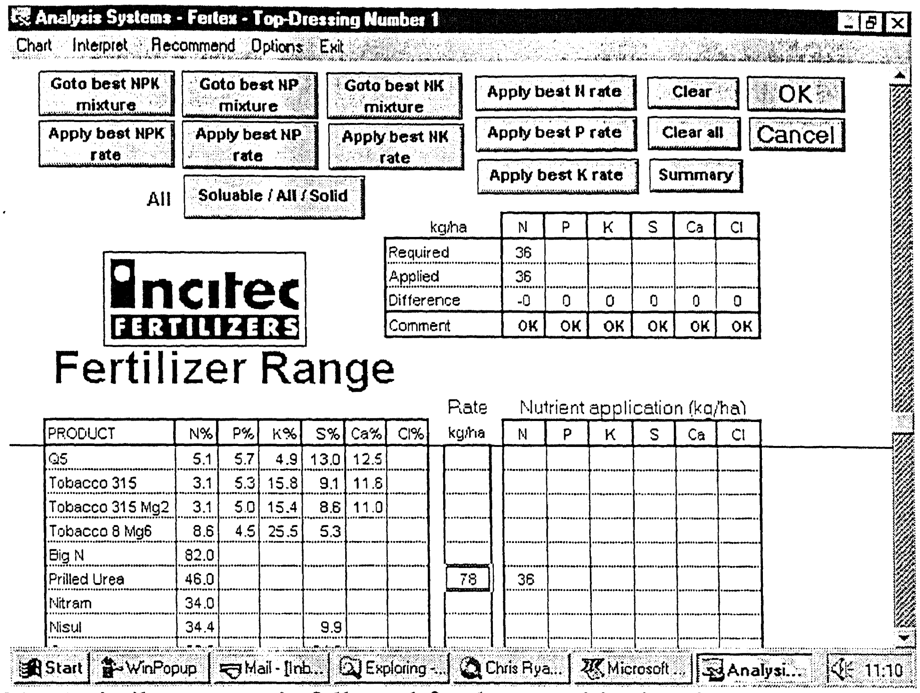


Figure A6.21 A similar process is followed for the two side-dressing recommendations.

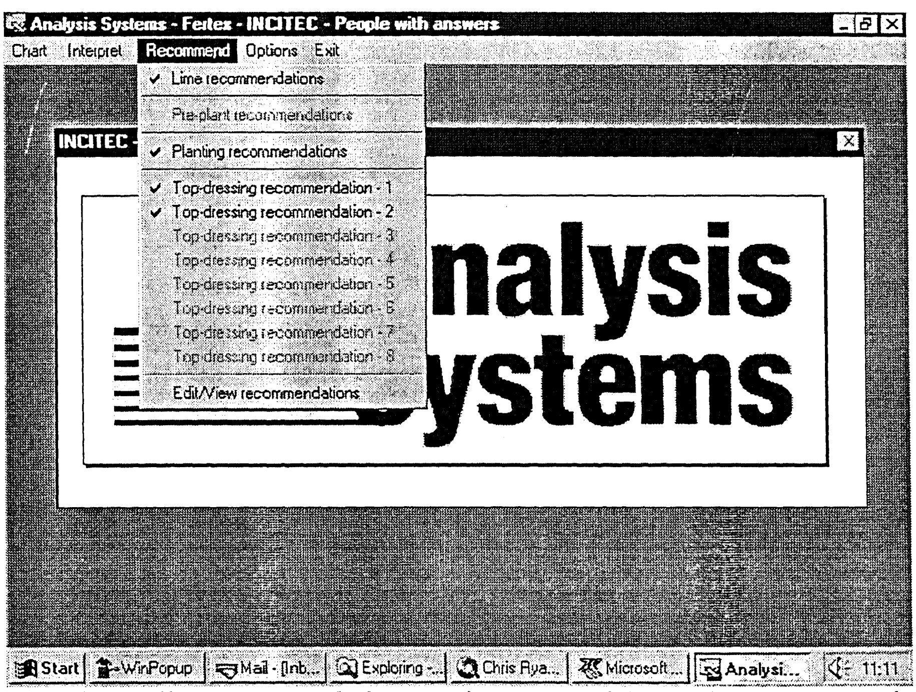


Figure A6.22 When all recommendation options are ticked, the report option becomes available.

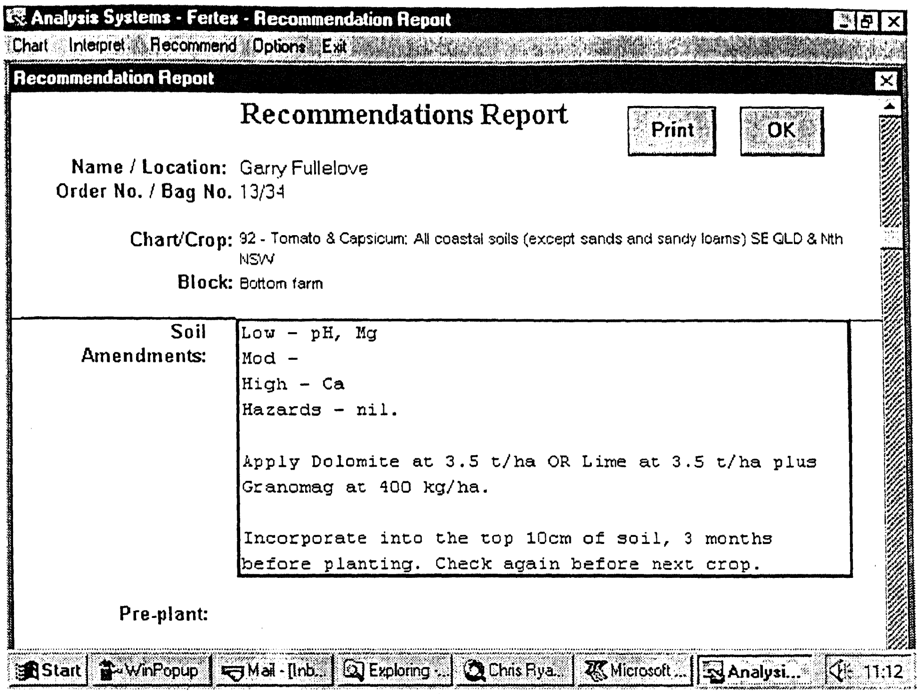


Figure A6.23 The top part of the recommendation report.

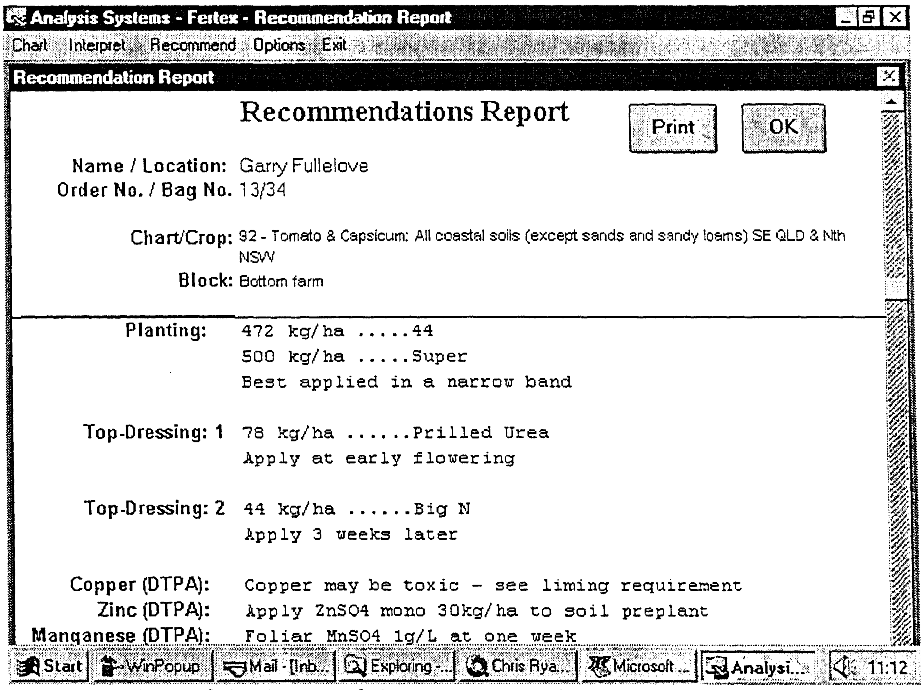


Figure A6.24 A portion of the body of the recommendation report.

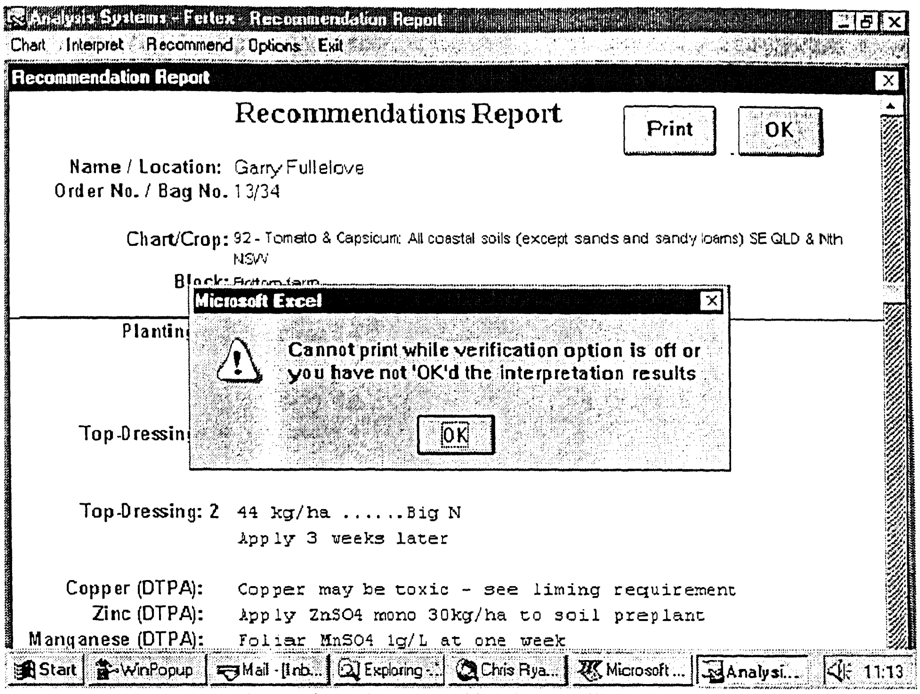


Figure A6.25 Reports cannot be printed out until all validity checks are completed.

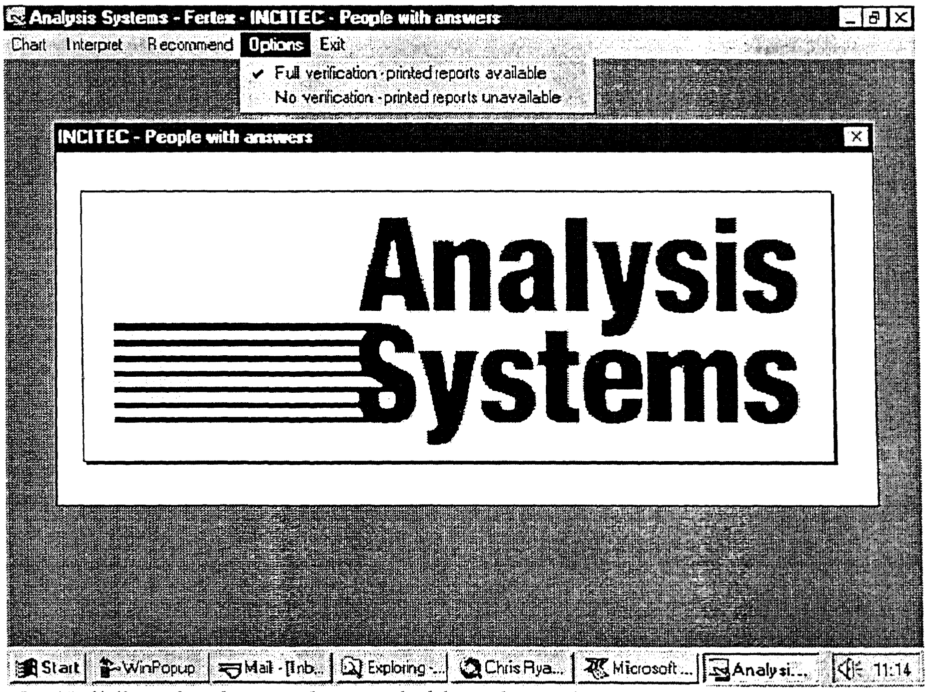


Figure A6.26 Validity checks can be toggled but they also toggle the print option.

Interpretation Report

Name / Location: Garry Fullelove
Order No. / Bag No. 13/34

Chart/Crop: 92 - Tomato & Capsicum: All coastal soils (except sands and sandy loams) SE QLD & Nth NSW

Block: Bottom farm

Nutrient	*Level*	*Status*	*Apply*	*Comments*	*OK'd*
pH (1:5)	8	Alkaline		Refer to liming requirements	OK
pH (Ca Cl)					OK
Buffer pH	5.6	Acidic		Refer to liming requirements	OK
Org. Carbon	5	Moderate		Maintain organic matter levels	OK
Nitrate Nitrogen	10	Low	110 kg/ha	1/3 at planting, 1/3 at flowering, 1/3 3 weeks later	OK
Sulfur (Phos)	34	High			OK
Sulfur (KCL)					OK
Phosphorus(BSES)					OK
Phosphorus (Colwell)	12	Low	90 kg/ha	All at planting	OK
Phosphorus (Lactate)					OK
Phosphorus(Olsen)					OK
P-Sorption					OK
Potassium (Amm. ac)	0.12	Low	110 kg/ha	All at planting	OK
Potassium (Skene)					OK
Potassium (Nitric)					OK
Calcium (Amm. ac)	5	High		See liming recommendations.	OK
Calcium (Ba Cl)					OK
Magnesium (Amm. ac)	0.1	Low		See liming recommendations.	OK
Magnesium (Ba Cl)					OK
Aluminium (KCl)	3			Refer to Al % sat'n	OK
Aluminium % sat'n	3	Low		No action	OK
Sodium (Amm. ac)	3	Moderate		See liming requirement	OK
Sodium (Ba Cl)					OK
Sodium % of cations	3	Low		No action	OK
Chloride	50	Low		No action	OK
Elec. Cond. (Sat Ext.)	2	Low		No action	OK
Copper (DTPA)	23	V. high		Copper may be toxic - see liming requirement	OK
Zinc (DTPA)	1	low		Apply $ZnSO_4$ mono 30kg/ha to soil preplant	OK
Zinc (BSES)					OK
Manganese (DTPA)	1	Low		Foliar $MnSO_4$ 1g/L at one week	OK
Iron (DTPA)	1	Low		Test foliar Fe Chelate 1g/L at one week	OK
Boron (Ca Cl)	0.01	Low		2-3 foliar Solubor at 1g/L starting at one week	OK
Boron (Hot Water)					OK
Cation Exch. Cap.	1	V. low		See liming requirement	OK
Ca:Mg Ratio	1	Low		See liming requirement	OK
Slaking (1, 2, 3)					OK
Clay Dispersion Index					OK

Micronutrients - Absorption of nutrient improves with the addition of 2 kg Urea to 450L of spray solution per hectare

Additional sprays at 2 week intervals may be necessary

Figure A6.27 Print-out of the interpretation report (Windows version).

Recommendations Report

Name / Location: Garry Fullelove
Order No. / Bag No. 13/34

Chart/Crop: 92 - Tomato & Capsicum: All coastal soils (except sands and sandy loams) SE QLD & Nth NSW

Block: Bottom farm

Soil Amendments:

Low - pH, Mg
Mod -
High - Ca
Hazards - nil.

Apply Dolomite at 3.5 t/ha OR Lime at 3.5 t/ha plus Granomag at 400 kg/ha.

Incorporate into the top 10cm of soil, 3 months before planting. Check again before next crop.

Pre-plant:

Planting:

472 kg/ha 44
500 kg/ha .....Super
Best applied in a narrow band

Top-Dressing: 1

44 kg/ha ......Big N
Apply at early flowering

Top-Dressing: 2

44 kg/ha ......Big N
Apply 3 weeks later

Copper (DTPA): Copper may be toxic - see liming requirement
Zinc (DTPA): Apply ZnSO4 mono 30kg/ha to soil preplant
Manganese (DTPA): Foliar MnSO4 1g/L at one week
Iron (DTPA): Test foliar Fe Chelate 1g/L at one week
Boron (CaCl): 2-3 foliar Solubor at 1g/L starting at one week

Extra Comments:

Figure A6.28 Print-out of the Recommendation Report (Windows version).

APPENDIX SEVEN

The successful proposal for the commercialization of SADI as submitted to the HRDC and Incitec (following).

HORTICULTURAL RESEARCH AND DEVELOPMENT CORPORATION

1. Project title: A Pilot Study into the Commercialisation of a Computer Expert System for Recommending Fertilisers in Horticultural Crops

2. Organisation : Queensland Department of Primary Industries
GPO Box 46 Brisbane 4001

Admin contact: Mr. K. Jorgensen
Deputy Director of Horticulture
Phone (07) 2393319
Fax (07) 2393379

3. Project chief investigator: Mr. G. Fullelove
Address: P.O. Box 1143, Bundaberg 4670
Phone (071) 538111
Fax (071) 512320

Location of research: Burdekin/Bowen, Bundaberg, Lockyer Valley, Tweed River areas.

Name of additional researchers:
Mr. G. Price, Incitec Ltd
Mr. J.D. Smith, University College of Central Queensland
Mr. C.R. McMahon, QDPI

4. Commencement date: 1 July 1991
Anticipated completion date: 31 December 1991

5. Total Project cost in 1991/1992: $10 000

6. Synopsis

Chemical soil analysis has been available as a tool in vegetable agronomy for some years. Interpretations of soil analysis data and the ensuring fertiliser recommendations for small crops are generally prepared by fertiliser company field staff. This process has many real advantages but can be time consuming for the staff involved. There is also the very real danger of inconsistency and oversights particularly considering the numerous interrelations of soils, nutrients and crop sensitivity. A prototype computer expert system has been developed as part of masters course to automate the process of making fertiliser recommendations from soil analyses. The advantages of this are a more timely, accurate and consistent delivery of fertiliser recommendations to small crop growers. This project seeks to develop and field test a pilot system based upon the prototype in conjunction with the fertiliser company Incitec and the UCCQ. Positive results from the evaluation of the pilot system may lead to full commercialisation of the system to the benefit of horticultural producers.

7. Brief statement of objectives for each year of the project:

Year 1.

a) To develop computerised interpretation charts for the expert system about tomatoes and cucurbits based on current Incitec nutritional standards.

b) To enhance the user-interface of the prototype expert system to better reflect the processes that a user would be comfortable with.

c) To train Incitec representatives and product distributors in the use of the system in selected centres in Queensland and Northern New South Wales.

d) To run a field test program in the selected centres of the system to gain insights into the full potential and use of the system.

e) To evaluate the system against set criteria in terms of costs and benefits in an attempt judge whether further full commercialisation of the system is warranted.

Project Schedule of Operations

Task	Task Description	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
1.	Create standard computerised interpretation chart format.	X			
2.	Complete charts for tomatoes and cucurbits.	X			
3.	Code these charts into the expert system.	X			
4.	Test charts for validity.	X			
5.	Develop a training package.	X			
6.	Train a subset of company representatives and fertiliser distributors. Evaluate training package.		X		
7.	Develop a full training package.		X		
8.	Train all representatives and distributors involved in pilot study in Bundaberg.		X		
9.	Incitec representatives train distributors in other regions.		X		
10.	Conduct full field test of pilot expert system.		X		
11.	Evaluate results of full field test			X	

8. Industry Financial Support

Support for this project is available from the major manufacturer and wholesaler of fertilisers in Queensland, Incitec.

Industry Contributor:	Incitec Ltd.
Contact Person:	Garry Kuhn, Technical Services Manager
Address:	P.O. Box 140, Morningside, Qld, 4170
Phone:	(07) 390 9466
Fax:	(07) 390 9434

Funds to be provided:

Year	Incitec Funds $	HRDC Funds $	Project Income $	Total $
91/92	5 000	5 000		10 000

A signed statement from the industry contributors is attached to this application.

9. Detailed Budget

Item	Budget 1991/92
Salaries & Wages	-
TOTAL Salaries	NIL
Travelling Costs	
Fares	800
Allowances/Accommodation	800
Vehicle costs	2 000
TOTAL Travel	3 600
Operating Costs	
Updating of computer facilities to project requirements.	4 000
Computer consumables	1 000
Training materials	660
TOTAL Operating	5 660
Capital Costs	-
TOTAL Capital	NIL
TOTAL PROJECT	9 260
HRDC ADMIN. CHARGE	740
TOTAL COST	10 000
INDUSTRY CONTRIBUTION	5 000

Date of compilation of budget data: May 1991

II. DESCRIPTION OF THE PROJECT

i) General Objectives

a) To deliver to horticultural producers, more timely, accurate and consistent fertiliser recommendations.

b) To establish a complete and standard method for the expression of plant nutritional knowledge relating soil analysis results to fertiliser requirements.

c) To test the feasibility of delivering this knowledge via a computerised expert system.

ii) The Problem/Opportunity

Chemical soil analysis has been available as a tool in vegetable agronomy for many years. Soil samples are taken in the appropriate manner and time, then despatched to a commercial laboratory for chemical analysis. The results indicate the level of a range of plant nutrients in the soil as well as several other factors affecting plant nutrition. While some of this information is directly useful to the grower, a complete understanding of the implications of the various results, their relative importance and their interactions require detailed knowledge of soil science and plant nutrition.

To provide a meaningful service to the grower, it is necessary for the analysis results to be interpreted by staff skilled in plant nutrition who prepare fertiliser recommendations based upon their interpretation.

To do this the plant nutritionist assess the analysis data by comparing it with standards which indicate whether the levels in the analysis are low, average, high etc. Further, the person must assess the influence of other factors such as soil pH, conductivity and buffering capacity. The person must account for complex interactions which occur between plant nutrients and beware of the effects of various fertilisers on these plant nutrient interactions.

The task is complex. Despite this the standards and nutritional knowledge are well documented and the nutritionist does not have to rely upon intuition.

A prototype computerised expert system has been developed at UCCQ to do this task. In order to better serve small crop growers, the fertiliser company Incitec sees merit in commercialising the system. To justify such a large project, this pilot project is being undertaken to test the technological and social feasibility of such a system.

iii) Procedure

The specific objectives of the project will be addressed by staff from QDPI, UCCQ and Incitec. These staff are recognised sources of expertise in plant nutrition, fertiliser use and computer systems design and implementation.

Nutritional standards for tomatoes and cucurbits currently held by Incitec, will be further refined to compile a complete knowledge base on the fertiliser requirements of these crops. These will be computerised to provide the knowledge for the computer system to make fertiliser recommendations.

An appropriate user-interface and training package will enable a field test in several sites of the system by company representatives and fertiliser distributors.

Evaluation of the system will seek to identify whether a better cost effective method of delivering more accurate, timely and consistent fertiliser recommendations to horticultural producers has been achieved.

iv) Chances of Success

A manual system of interpreting soil analysis data and making fertiliser recommendations for horticultural producers has been used by Incitec representatives for some years now. The technology exists and the quality of fertiliser recommendation depends mainly on the skill of the practitioner in applying that technology.

Expert systems have shown themselves in other fields such as medical diagnosis, geological studies, molecular chemistry and process control to be effective tools for the storage and delivery of knowledge. This particular application of expert systems technology to a well defined and structured problem must be looked upon as having a good chance of success. The system prototype gives some indication of this likelihood of success.

v) Extension

Very little if any extension of the results of this project will occur to the final benefactors of this project, horticultural producers, apart from some company promotion of the system should it become commercial. Training of company staff and fertiliser distributors in the systems use so as horticultural producers may gain its maximum benefit will be undertaken.

vi) Associated Research

This pilot study will extend the work already done as a masters program in developing the prototype system. The emphasis of the pilot study will switch from the computer research based work of the masters program to more commercially based research into the application of the technology and its evaluation in meeting both the service suppliers (Incitec) and the service recipients (horticultural producers) needs.

vii) Other Granting Bodies

No other funding bodies have been approached. Each cooperator will supply salaries for project staff and the capital infrastructure of staff accommodation and administrative backup to implement the research.

viii) Investigation Team

This project is seen as a joint project between the fertiliser company Incitec Ltd., Maths and Computing Department (UCCQ) and Horticulture Branch (QDPI).

Chief Investigator:	Mr. G.D. Fullelove
Position in Organisation:	Extension Horticulturist
Postal Address:	P.O. Box 1143 Bundaberg 4670
Telephone Number:	(071) 538111
Facsimile Number:	(071) 512320
Research Experience:	Mr. Fullelove has had extensive experience in plant nutrition and making fertiliser recommendations in his position of Extension Horticulturist in the QDPI over the last eight years. He has also worked considerably in the area of computer applications for assisting horticultural producers, more notably in tutoring on the subject and in publishing economic crop models for small crop producers in the Lockyer Valley and Coastal Burnett regions of Queensland.
Other Projects:	Mr. Fullelove is also supervising a tomato management systems project aimed at identifying and producing decision aids for the critical strategic and tactical decisions producers make in growing tomatoes.

Other Investigators: Mr. G. Price, Incitec Ltd.

Mr. Price has been responsible for the establishment and maintenance of the nutritional interpretation charts used by Incitec representatives to manually produce fertiliser recommendations.

Mr J.D. Smith, UCCQ.

Mr. Smith is head of the Maths and Computing Department at UCCQ and is currently overseeing the research and commercialisation of several other expert systems into industry.

Mr. C.R. McMahon, QDPI.

Mr. McMahon is the Research Horticulturist based at Gatton, Qld. He has wide experience in small crop nutrition and has cooperated with Incitec over many years in the development of crop nutritional standards.

ix) Co-ordination with others:

Research results and expertise in the area of this project from within all three co-operating groups of this project will be used to enhance this project. Co-ordination of this integration will be possible through the formal corporate structures that exist in each of the three cooperating groups.

x) Facilities/Staff

Incitec Ltd. has many staff skilled in the provision of nutritional information to horticultural producers. Many of these staff have now been issued with laptop computers to enhance the services provided to their clients. Mr. Price is based with this company.

UCCQ has developed through applied research and commercialisation of research a strong expertise in the provision of expert systems to industry. Mr. Smith heads this team at UCCQ.

QDPI has extensive contact with horticultural producers and is endeavouring to provide them with superior knowledge and expertise to sustain the long term viability of this industry. Mr. Fullelove has worked in this area for nine years and has extensive experience in developing information packages, both written and computerised for the horticultural sector.

xi) Special Features

a) Expert systems represents an exciting new innovation in the delivery of knowledge to the rural sector.

b) The establishment of this joint project between a private sector company, an educational institution and a government department represents the broad interest in the success of this project.

III. ECONOMIC ANALYSIS / INDUSTRY SIGNIFICANCE

i) Industry to benefit:

Through the provision of more timely, accurate and consistent fertiliser recommendations the horticultural industry as a whole will receive the primary benefit of this project.

ii) Benefits likely to accrue to the industry:

Better fertiliser recommendations based on sound scientific principles and management guidelines will result in benefits to the horticultural industry in several ways;

- more efficient use of fertilisers leading to reduced input costs for crops.
- more accurate fertiliser recommendations leading to higher yields and/or less crop failures.
- better understanding and documentation of crop nutritional standards in various situations.

iii) Consequences of not doing the proposed project:

The results of this project will show whether the full commercialisation of the expert system is justified. Without this project, the decision to proceed with commercialisation may be ill founded and may cost the industry, through a large project failure, many fold more than this small expense.

IV. FINANCIAL INFORMATION

i) Justification of Information in the Budget Table:

a) Salaries and Wages - NIL.

b) Travel - Meetings of the research team is an integral part of this project. Tasks 1, 4, 5, 6, 8, 10 and 11 involve more than one researcher being present during that phase of the project. It is necessary for the project leader to liaise with field testing personnel to provide positive feed back to the team during that phase of the project. On some occasions, travel will involve considerable usage of government vehicles hence the provision for vehicle allowance and maintenance costs.

c) Operating - These expenses are necessary to upgrade and maintain project equipment and materials. Upgrading of computing facilities available to the project leader is necessary to enable the development, implementation and staff training necessary in this project. The development and provision of a training package which includes a user guide and tutorials is seen as a necessary part of transferring this technology to end users.

d) Capital Items - NIL.

ii) HRDC Payments:

As the bulk of the project work will be carried out in the first half of the year of funding, a request is made for all funds to be made available in the first instalment.

iii) Other Funds:

There are no other external funds for this project.

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APPENDIX EIGHT

A copy of the minutes from a end-user team meeting with the author held on the 3rd of April 1995, indicating the detail and outcomes of such meetings (following).

Incitec Ltd

MINUTES

SADI PREVIEW MEETING

PRESENT : G. Fullelove, G. Kuhn, G. Price, A. Hill.

ACTIONS ARISING :

1. Change METRIX Report to include method specified immediately after analyte, to ensure that interpreter puts data in the corrcet row of SADI.
   Action A.Hill

2. Set tolerances of 15% for the acceptance of an Applied NPK vs Target in the Recommendations section. Apply a weighting to P, five times that of N or K, in the calculation of best NPK solution in Recommendations section.
   Action G.Fullelove

3. Locate SADI support staff within ITG to learn the system, and start inputting other charts. Time with GF best on Mondays or Wednesdays. Investigate security with Dongles or equivalent ...
   Action A.Hill

4. Provide liming recommendations guidelines, additional rules on Ca:Mg etc
   Action G.Price to provide to GF

5. Add Solubles vs Solids selection buttons to pre-select the appropriate sub set of potential products on which to work the recommendations section.
   Action G. Fullelove

6. Provide notes for Cu, Zn, Mn, Fe, B, Mo for use in transferring to the recommendations report.

   Also provide notes for placement instructions for NPK, which will be used in transferring this detail from Interpretation chart to Recommendations, on a chart-specific basis.
   Action G.Price to provide to GF.

7. *As a future enhancement ..... include kg/ha as well as % in determining the split between PRE PL, PLANTING, POST PL, in Nitrogen and Potassium strategies..... together with a WARNING if the maximum rate at any stage, specified on the chart, is exceeded.*

A. Hill also to co ordinate training with Area Manager group as soon as:
They have 486 PC's....
ITG support member is well underway with inputting charts.

[signature] 3/4/95