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**UNIVERSITY OF CAPE TOWN**

**DEPARTMENT OF ENVIRONMENTAL AND  
GEOGRAPHICAL SCIENCE**

**Dissertation submitted in fulfilment of the  
requirement for a Masters degree (MSc) in  
Environmental Science**

**THE CONSTRUCTION OF A SOUTH AFRICAN  
KNOWLEDGE BASE FOR ENVIRONMENTAL  
MANAGEMENT AND MONITORING OF  
TRANSGENIC SOYBEAN, MAIZE AND  
COTTON**

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October 2006**

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## ABSTRACT

Bauer and Gaskell (2002) state that biotechnology is one of the fastest growing areas of scientific, technical and industrial innovation, while being one of the most widely publicised new technologies. Varied innovations such as the development of genetic testing and therapies, genetically modified food crops, animal and stem cell cloning have given rise to increasingly prominent public debate, leading to world-wide controversies (Bauer and Gaskell, 2002). In 2005 the billionth acre (400 millionth hectare) of biotechnologically derived crop was planted by one of 8.5 million farmers in one of 21 countries. By 2005 South Africa was ranked as the 8<sup>th</sup> largest producer of transgenic crops, with 0.5 million hectares planted to maize, soybean and cotton (James, 2005). A need is recognized for environmental scientists to engage with the technology and understand its place in the agroecosystem and broader environment, and for environmental education to engage agricultural biotechnology so that the benefits and hazards of the new technology are communicated to farmers, regulators and the public. Modern information technology provides a possible means of such communication. Expert systems provide excellent educational tools and structured databases of knowledge. Current environmental concerns, management and monitoring pertaining to transgenic maize, cotton and soybean crops were researched and information consolidated into a structured expert system knowledge base. Knowledge modelling was based on a hybrid of two models, alongside knowledge acquisition techniques of Babbi and Mouton (2001). The primary model adopted was the PreSERVe method (Prepare, Scope, Elicit, Render, Verify) used by Coffey et al. (2003) and the model for intelligent computer-aided education (ICAE) systems designed by du Plessis et al. (1995) was the second model used. The research constructed for educational purposes a South African knowledge base of environmental management and monitoring of transgenic maize, cotton and soybean. The outcome of the research was a knowledge base capable of delivering user reports tailored to the knowledge level of the user.

## ACKNOWLEDGEMENTS

There are many people who have aided in making this thesis a reality, and without their support and encouragement the body of work would not have been completed.

The author is deeply grateful for the hours of work put in by the project supervisors, Professor Richard Fuggle, Kerry Murphy and Professor Jane Morris. Professor Fuggle has been the chief supervisor for the project, with his insight and experience in the environmental sciences proving to be of absolute necessity. Kerry Murphy supervised the expert system work, without whom the author would never have realized a functional prototype. Professor Jane Morris aided in networking with the appropriate sources in order for experts to be established. It must be mentioned that their patience seemed infinite.

Many thanks must also go to the experts involved in the project. Dr Wally Green of Monsanto and Dr Kulani Machaba of Syngenta were unfailing in their helpful attitude. Always approachable, their insight and expertise was crucial to the project. Their guidance and evaluation of the prototype allowed the project's aims to be fulfilled.

Dr Ian Morrison of Acquire must also be thanked for the help and guidance in using the Acquire expert system shell. Kevin Winter of the Environmental and Geographical Science Department at the University of Cape Town continually gave freely of his time, with many discussions and encouragement. Sandy Paterson of the University of Cape Town Law Faculty deserves many thanks for all the input and discussion regarding the legislation pertinent to the project. Professor Sagadevan Mundree was instrumental in guiding the author in the research into transgenic crops.

Special thanks must go to the author's family for all the support and encouragement through a personally difficult two years. Without this support the project may well have been abandoned. The author is deeply grateful to Claire Buerger, who was instrumental in all aspects of the project, with insightful discussion of topics and giving endless encouragement and support. Finally the author would like to thank Sue Buerger, who struggled during the work of this project. She was a shining example of courage in the face of adversity and challenge. An example, which the author will carry in all work and life.

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## 1. INTRODUCTION

### 1.1 BIOTECHNOLOGY

#### 1.1.1 BIOTECHNOLOGY OVERVIEW

##### Introduction

Smith (2004) states that the twentieth century was the age of chemistry and physics, which spawned huge industrial activities such as petrochemicals, pharmaceuticals, fertilisers, the atomic bomb, transmitters, the laser and microchips. He further states that “there can be little doubt that the huge understanding of the fundamentals of life processes achieved in the latter part of the twentieth century will ensure that the twenty-first century will be dominated by biology and the associated technologies”.

The Spinks Report (1980) defined biotechnology as “the application of biological organisms, systems or processes to manufacturing and service industries”, envisaging that biotechnology would create new industries with low energy demands. This report led to a major initiative in the United Kingdom for the exploitation and development of biotechnology.

Research in the biotechnology field has progressed considerably. The work of Wiseman et al. (1983) already considered the interdisciplinary nature of biotechnology, investigating the application of principles of industrial microbiology, microbial genetics, fermentation engineering, enzymology and enzyme engineering to the biotechnology field. Ratledge and Kristiansen (2001) recently produced a work ranging in scope from molecular biology to the ethical issues, commercial aspects and public perceptions of biotechnology.

Moses and Moses (1995) regard biotechnology as not just genetics, but a technology based on a set of techniques for doing practical work, with implications for the commercial and public sectors. Considering the exploitation of biotechnology, Moses and Moses (1995) recognise that the fundamental scientific advances in biotechnology proceed hand-in-hand with industrial development and commercial exploitation. However, Rudolph and McIntire (1996) go further to recognise biotechnology’s greater impact in society, with their work considering the challenges of technology transfer, ethical issues of biotechnology, behaviour and values in science and society and the role of government in the development of biotechnology.

Bauer and Gaskell (2002) state that biotechnology is one of the fastest growing areas of scientific, technical and industrial innovation, while being one of the most widely publicised new technologies. Varied innovations such as the development of genetic testing and therapies, genetically modified food crops, animal and stem cell cloning have given rise to increasingly prominent public debate, leading to world-wide controversies (Bauer and Gaskell, 2002). Bauer and Gaskell (2002) consider that the biotechnology industry initially assumed that regulatory processes were the sole hurdles, but now

realizes that a second hurdle, national and international public opinion, must be reckoned with. The work of Bauer and Gaskell (2002) comprises a comparative study of public perceptions, media coverage and regulatory frameworks of biotechnology, contributing to the empirical and conceptual analyses of the public debate on biotechnology.

The Organisation for Economic Cooperation and Development (2005) consider biotechnology to have reached a level of maturity, that by the year 2030 many economies will be based on biotechnology, and have produced work giving guidelines for the design of economic policy agendas in the anticipation of such economic changes.

It is argued that currently the impact of new biological developments must be absorbed not just by a minority (in this case the scientists), but also by large numbers of the general public too. Smith (2004) warns that if this does not happen then the majority will be alienated. It is important to understand the consequences of accepting and rejecting new bioscience technology. Therefore from an environmental science perspective, the field of biotechnology must be researched and better understood.

### **What is biotechnology?**

Modern biology can be thought of as the most diversified of all the natural sciences, with subdisciplines including microbiology, plant and animal anatomy, biochemistry, chemical engineering, food science, food technology engineering, mechanical engineering, biochemical engineering, electronics, immunology, cell biology, molecular biology, microbiology, plant and animal physiology, morphogenesis, systematics, ecology, genetics and still others. The life sciences affect over 30% of the global economic turnover in the form of health care, food and energy, and agriculture and forestry. This will only grow as biotechnology influences raw materials processing (Smith, 2004).

Biotechnology is not a new phenomenon. Humankind has been manipulating the biological environment for thousands of years (Smith, 2004). First generation biotechnology involves the use of selected biological organisms in order to produce food and drink such as cheese, beer and yeast, with the main cluster of techniques in the first generation being fermentation, plant and animal breeding and the clonal propagation of plants (NBS, 2001). The Sumerians and Babylonians were producing beer by 6000BC, while the Egyptians were baking leavened bread by 4000BC (Smith, 2004). Second generation biotechnology is considered the use of pure cell or tissue culture in order to yield novel products, with this generation being associated with the production of metabolites such as antibiotics, enzymes and vitamins (NBS, 2001). Anton van Leeuwenhoek first saw microorganisms in the 7<sup>th</sup> Century, and Louis Pasteur (considered the father of biotechnology) demonstrated the fermentative ability of microorganisms between 1857 and 1876. In 1919 Karl Ereky, a Hungarian engineer, coined the term "biotechnology" to refer to the science and methods permitting products to be produced from raw materials with the aid of living organisms. By the 1940's engineering techniques were applied to the mass cultivation of microorganisms in order to exclude other contaminating microorganisms such as the cultivation of antibiotics, amino acids,

organic acids, enzymes, steroids, polysaccharides, vaccines and monoclonal antibodies (Smith, 2004). The major second generation developments include the exploitation of a growing body of scientific knowledge relating to the properties and characteristics of microorganisms such as fungi and bacteria. Characteristics of the second generation include the use of mutagenesis and the selection of strains and cultivars for improvement of metabolite and crop yields. Finally, the third generation (modern biotechnology) is associated with recombinant DNA technology, involving the application of *in vitro* nucleic acid techniques with recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles (NBS, 2001). In 1943 direct evidence that DNA carried genetic information was discovered. The structure of DNA and the method of how genetic information is passed from one generation to the next were discovered by Watson and Crick with their double helix model in 1953. The “modern biotechnology” that we see today began with this discovery (OECD, 1999). The modern biotechnology revolution began in the 1970’s and early 1980’s. It was at this stage that scientists discovered how to alter precisely the genetic constitution of living organisms by processes outside of traditional breeding practices (Smith, 2004). In the agricultural sector the application of third generation technology has focused on the genetic improvement of crops (NBS, 2001). Thus traditional biotechnology (1<sup>st</sup> and 2<sup>nd</sup> generation) refers to the conventional techniques that have been used for centuries. Modern biotechnology (3<sup>rd</sup> generation) refers to the techniques of genetic modification by recombinant DNA and techniques of cell fusion combined with modern developments in the traditional biotechnological processes (Smith, 2004).

Biotechnology as a concept has been defined in several ways. The South African governmental definition of biotechnology is “A set of technologies including, but not confined to, tissue culture and recombinant DNA techniques, Bioinformatics and genomics, proteomics and structural biology, and all other techniques employed for the genetic modification of living organisms, used to exploit and modify living organisms so as to produce new intellectual property, tools, goods, products and services” (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

The definition used by the European Federation of Biotechnology (EFB) states that biotechnology is “the integration of natural sciences and organisms, cells, parts thereof, and molecular analogues for products and services.” This definition encompasses traditional and modern biotechnology. Due to the difficulty in defining biotechnology some prefer not to use the term, and rather to specify exactly what technology or application is being used (Smith, 2004).

Biotechnology can draw on all the subdisciplines and related fields mentioned above, and the full range of bioprocess technologies. The field of biotechnology is not itself a product or range of products such as microelectronics. It is instead regarded as a range of enabling technologies that will find significant application in many industrial sectors. It can be considered technology in search of new applications; therefore much of the benefit will be realized in the future.

McCormick (1996) takes an extreme view, stating, “There is no such thing as biotechnology, there are biotechnologies. There is no biotechnology industry; there are industries that depend on biotechnologies for new products and competitive advantage.” One can view the biotechnology field as a developing and expanding series of technologies dating back thousands of years.

Modern biotechnology of recombinant DNA techniques has enabled a far greater understanding of the role that genes play in biological systems. Geneticists are able to not only move genetic material from one life form to another in a way that was not previously possible, but also to change the function of a single cell in an organism. The ability to transfer genetic material is not new. In traditional plant breeding genes are mixed randomly between parents. Hybridisation resulted in a transfer of genes between species. In more extreme hybridisation sophisticated tissue culture techniques are required. Mutagens have also been used to modify the genes in crop plants in order to obtain desired traits. Modern biotechnology has multiplied the range of possible products and the speed of obtaining these products. Through modern biotechnology techniques, our knowledge of living systems has also increased dramatically. It is now possible to identify the genetic basis of many diseases and develop drugs to counteract the action of many pathogens (NBS, 2001).

### **Biotechnology as an interdisciplinary pursuit**

A characteristic of recent scientific development is the need for multidisciplinary strategies in finding solutions to problems. Biotechnology is a priori interdisciplinary: with new disciplines having identifiable characteristic concepts and methodologies.

The term “multidisciplinary” refers to the gathering of concepts and methodologies from separate disciplines and applying them to a specific problem area. The term “interdisciplinary” refers to the blending of ideas. This occurs during multidisciplinary cooperation, leading to the crystallisation of a new disciplinary area, with its own concepts and methodologies. Multidisciplinary work tends to be mission-orientated, but interdisciplinary work characteristically opens up new areas of investigation. A broad example of this is the combination of the fields of biology and engineering, forming the relatively recent discipline of bioengineering. Biotechnologists typically keep close working relationships with experts from other related fields such as medicine, nutrition, pharmaceuticals, the chemical industry, environmental protection and waste process technology. The biotechnology field requires a skilled workforce and a supportive public. “Economies that encourage public understanding and provide a competent labour force should achieve long-term benefits from biotechnology.” (Smith, 2004)

Biotechnology deals with ‘cross-cutting’ technology, meaning the field is subject to a wide application, across sectors and biological boundaries. Techniques developed and applied in the human health sector can be used in the agricultural sector and vice versa. Economic production management can be organised so as to benefit from this cross-fertilisation of biotechnology. The biotechnology industry is also characterised by research-intensive undertakings. Biotechnology companies spend between 40% and 50%

of revenue on research and development (compared to a 5% industrial average and the pharmaceuticals industry spending 13%) (NBS, 2001). The biotechnology industry also requires a convergence of skills from varying disciplines. The biotechnology industry is a 'highly-networked' endeavour, requiring the establishment of links between science, engineering and technology institutions (SETI's) and private companies (NBS, 2001).

As biotechnology has been evolving for centuries, why the recent escalation of public awareness? The answer is mostly due to the rapid advances that have occurred in molecular biology, particularly recombinant DNA technology. With recombinant DNA technology it is possible to manipulate directly the heritable material (DNA) of cells between different types of organisms *in vitro*, thereby creating new hybrid DNA molecules not previously known to exist in nature. While the potentials are immense, the inherent dangers must be respected (Smith, 2004).

There are numerous constraining factors in transferring DNA from one organism to another, including which genes can be cloned and how they can be selected. The limiting factor is the dearth of basic scientific knowledge of gene structure and function. The biotechnology industry's growth and awareness parallels worldwide economic changes as a consequence of the escalation of oil prices since 1973. In society there is a growing realization that fossil fuels and other non-renewable resources will eventually be in limited supply, requiring cheaper and more secure energy sources and chemical feedstocks. Biotechnology is contributing to this quest (Smith, 2004).

It is obvious that biotechnology has the potential to improve the quality of lives and the environment. There is huge potential for advances in health, nutrition and remediation. However, in order to realise such benefits the technology will have to be used judiciously, avoiding those technologies that challenge our ethical values. It is important to focus on those technologies offering the greatest advances with minimal risk. It is therefore imperative that the public be engaged continuously and public understanding increased, avoiding misunderstanding (NBS, 2001).

"Biotechnology poses a number of unique challenges for politicians, scientists, policy makers and members of the public; sustainable progress will be possible only with the active collaboration of all these role players." (NBS, 2001)

### **Biotechnology in South Africa**

Although South Africa has developed genetic engineering technology and capacity over the last 20 years, biotechnology in South Africa is only now being applied or commercialised. There are only a few local biotechnology products that have been developed, despite approximately R100 million being spent on biotechnology research annually ([www.africabio.com/policies/biotechsa.shtml](http://www.africabio.com/policies/biotechsa.shtml)). In South Africa there are over 600 biotechnology research projects currently running. There are approximately 55 companies involved in the biotechnology sector with locally commercialised products generally centred on plant and medical technologies. Examples of local products include

fungal resistant strawberries, insect resistant sugar cane, virus resistant potatoes and fungal resistant maize and sorghum ([www.africabio.com/policies/biotechsa.shtml](http://www.africabio.com/policies/biotechsa.shtml)).

The key issues that challenge biotechnology in South Africa include;

- Institutional arrangements
- Human resource considerations
- Funding biotechnology Research and Development (R&D)
- Commercialisation of biotechnology
- Policy and legal instruments
- Ethics
- The public understanding of biotechnology

South Africa as a developing country possesses its own set of problems, requiring technological solutions in order to increase agricultural output and improvement of quality. The majority of South African citizens have not yet benefited from biotechnology (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

“Undoubtedly, modern biotechnology can only maximize its full potential to benefit mankind through achieving a basis of public understanding and awareness and knowledge of the technologies. Participating scientists must learn to communicate openly with the public and attempt to demystify the complex nature of living systems. By doing so they will generate a greater level of confidence and trust between the scientific community and the public at large” (Smith, 2004).

It is clear that biotechnology will play a significant role in the 21<sup>st</sup> century. It is equally clear that no matter how controversial, modern biotechnology as a research and applied field is here to stay. From an environmental perspective, there are certain burdens placed on environmental scientists. Firstly, there is the burden of knowledge acquisition. Environmental scientists must begin to engage with and understand the biotechnology field, and its role in environmental change. Secondly, there is the burden of communication. Environmental scientists must engage with the public and be involved in environmental education and capacity building. All of this should be done with a cautious approach, relying on sound scientific research and the principles of integrated environmental management. It is in this context that this dissertation finds its place as an education tool.

### **1.1.2 AGRICULTURAL BIOTECHNOLOGY**

The challenge for global agriculture is to produce in a sustainable way, sufficient, healthy and safe food for a growing global population. It is estimated that by the year 2020 there will be a world population of nearly 8 billion, with 3.5 billion living in urban areas. In order to meet the demand there will need to be a 40% increase in cereals, 63% increase in meat production and a 40% increase in roots and tubers. Approximately 80% of this will need to be produced in developing countries. However, only about 6% of new virgin soil

can be brought into cultivation. Thus there must be a move to new agricultural systems that are sustainable, yet more intensive (Smith, 2004).

### Global status of commercialised biotechnology/transgenic crops

In 2005 the billionth acre (400 millionth hectare) of biotechnologically derived crop was planted by one of 8.5 million farmers in one of 21 countries. These crops are generally referred to as “genetically modified (GM)” crops. However, the term “genetically modified” is a broad term meaning modification to the genetic code of an organism that would not occur naturally. Thus irradiated crops where genetic modification has taken place can also be referred to as genetically modified. The term “transgenic” is a more specific term meaning an organism that contains genetic code (a transgene) from another species. Therefore the term “transgenic” more specifically describes the crops investigated in this study. Over the last decade transgenic crops have been consistently adopted with double-digit growth rates every year since the first commercialisation in 1996. The global transgenic crop area has increased more than fifty-fold since commercialisation. In 2005 the global area of approved transgenic crops was 90 million hectares (22 million acres). The growth rate between 2004 and 2005 was 11%, as seen in Figure 1 (James, 2005).

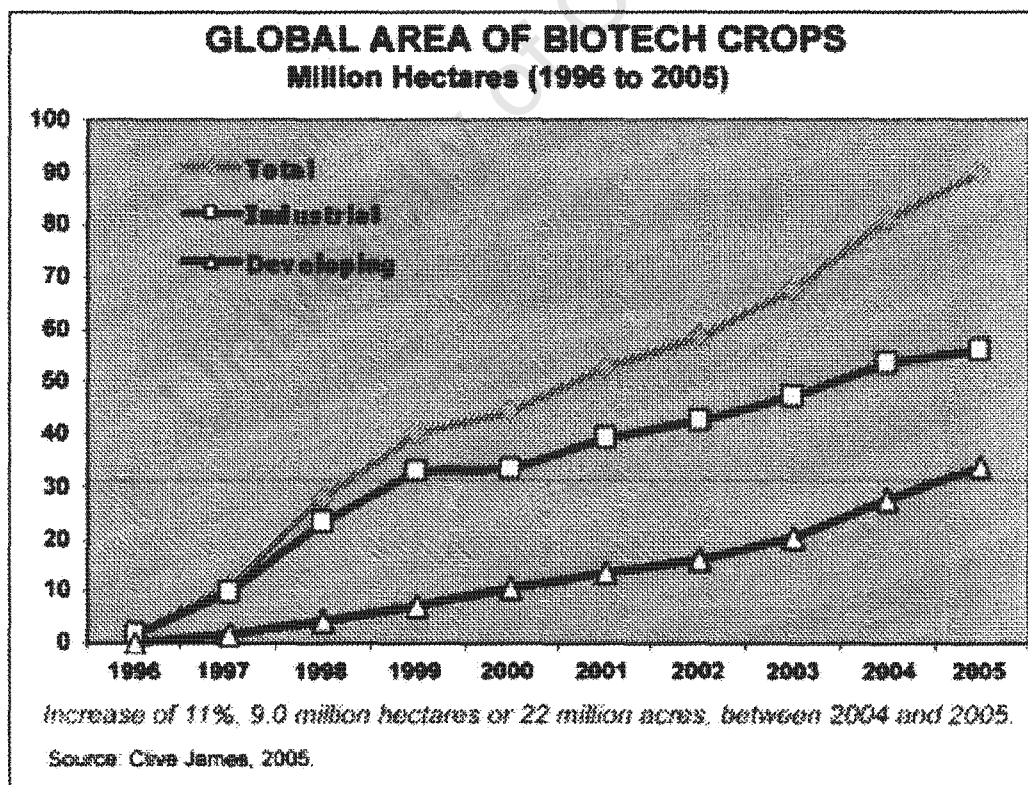


Figure 1: The global area of transgenic crops from 1996-2005 (source James, 2005).

In 2005 the United States, Argentina, Brazil, Canada and China were the principal adopters of transgenic crops. There were 49.8 million hectares planted in the United States (approximately 55% of the global biotech area). 20% of this area in the United States cultivated “stacked products”, transgenic crops containing two or three inserted genes. The first triple stacked transgenic crop made its debut in maize in the United States in 2005. Stacked transgenic crops are a growing trend and are more appropriately quantified as ‘trait hectares’ rather than hectares of adopted transgenic crops as used in Figure 1. The United States, Canada, Australia, Mexico and South Africa deploy stacked products. Transgenic soybean has continued to be the principal crop, occupying 54.4 million hectares (60% of the global transgenic area), followed by transgenic maize occupying 21.2 million hectares (24%), then cotton at 9.8 million hectares (11%) (James, 2005).

From the years 1996 to 2005 the herbicide tolerance trait has been the dominant trait deployed in transgenic crops, with insect resistance the next most common. Herbicide tolerant transgenic soybean, maize, canola and cotton occupied 71% (63.7 million hectares) and transgenic insect resistant crops occupied 18% (16.2 million hectares) of the global transgenic crop area. Approximately 8.5 million farmers in 21 countries grew transgenic crops in 2005. By 2005 South Africa was ranked as the 8<sup>th</sup> largest producer of transgenic crops, with 0.5 million hectares planted to maize, soybean and cotton (James, 2005).

James (2005) states that there is cautious optimism that the growth witnessed between 1996 and 2005 will continue and probably be surpassed in the decade 2006-2015. The number of countries adopting the major transgenic crops is expected to increase. It is expected that in the established industrial county markets stacked trait transgenic crops will increase. New input and output traits will be stacked to create value and to meet the needs of consumers and producers seeking nutritional and healthier food and feed at affordable prices. James (2005) notes that “Adherence to good farming practices with biotech crops will remain critical as it has been during the first decade and continued responsible stewardship must be practiced, particularly by the countries of the South, which will be the major deployers of biotech crops in the coming decade.”

### **Status of transgenic crops in South Africa**

The South African government supports the development of Biotechnology. The country has been conducting research on transgenic crops for the last 20 years. The research and development techniques include plant breeding and selection, tissue culture and genetic engineering. Currently the techniques of genetic engineering are used in more than 50% of all biotechnology research projects ([www.isaaa.org/kc/](http://www.isaaa.org/kc/)). The government ran an interim biosafety assessment and decision-making process between 1990 and 1999, which lead to the establishment of the Genetically Modified Organisms (GMO) Act No. 15 of 1997. Controlled field trials in the country began in 1990; the first conditional commercial release permit was approved in 1997 by the National Department of Agriculture ([www.africabio.com/status/south%20africa.pdf](http://www.africabio.com/status/south%20africa.pdf)). The number of field trials has increased dramatically in South Africa. In 1995 there were 12 field trials, in 1998

there were 45 and in the period from 1999 to 2002 an additional 125 field trials were undertaken ([www.isaaa.org/kc/](http://www.isaaa.org/kc/)).

Currently there are three transgenic crops approved for commercial release in South Africa, namely soybean, maize and cotton. For soybean one transgenic line has been approved, Roundup Ready® Soybean, which is herbicide-resistant and has been developed by Monsanto. There are three transgenic lines of maize approved, Roundup Ready® maize (herbicide resistant) and YieldGard® maize (insect resistant), both developed by Monsanto, and Bt11 maize (insect resistant) developed by Syngenta. There are four transgenic cotton lines approved in South Africa, being Roundup Ready® cotton (herbicide resistant), Bollgard® cotton (insect resistant), BollgardII® cotton (insect resistant, with two insect resistant genes stacked) and Roundup Ready® + Bollgard® cotton (herbicide and insect resistant genes stacked), all of which have been developed by Monsanto.

Currently over 80% of the national cotton crop is genetically modified, with over 90% of small-scale farmers growing GM cotton. Approximately 50% of soybean cultivated is transgenic ([www.africabio.com/status/south%20africa.pdf](http://www.africabio.com/status/south%20africa.pdf)).

**Table 1: The area in South Africa under transgenic crop cultivation in 2004-2005**

CROP PLANT	AREA (ha)	PERCENTAGE OF TRANSGENICS TOTAL CROP
White maize	147 00	8.2
Yellow maize	260 000	24.1
Soybean	70 000	50
Cotton	30 000	85

(modified from [www.africabio.com/status/south%20africa.pdf](http://www.africabio.com/status/south%20africa.pdf)).

### **Agricultural biotechnology in South Africa**

The National Research and Technology Foresight Initiative (NRTF) conducted an Agricultural Foresight study, which highlighted the important factors that will contribute towards a competitive agricultural industry. The study indicated that biotechnology was one of the major tools that could be used for rapid and efficient diversification and improvement of food production although it has failed to extract value from the recent advances of technology such as genomics, bioinformatics and proteomics (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

### **Key challenges to agriculture in South Africa**

The Green revolution of the 20<sup>th</sup> century had a major impact on how animal and plant genetic resources were used for food and agriculture. Towards the latter part of the century there was an introduction of improved animal and plant breeding techniques, relying on genetic resources. Such improvements included the identification and isolation of genes that are responsible for specific traits. It became possible to select for specific

traits through crossbreeding and improved production per unit area. Recombinant DNA technology has further extended agricultural improvement (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

There are many challenges and constraints in the South African agricultural sector. Less than 15% of the land surface is arable. The increasing population increases the demand for food (especially proteins). Rural subsistence farmers operate on a small-scale: most remain poor and obtain their livelihoods from marginal lands. Furthermore there is evidence of increasing damage to the ecological foundations of agriculture, such as land, water, forests, biodiversity and the atmosphere (GN1591 in *Government Gazette* No.27936 dated 26 August 2005). The key challenges facing agriculture in South Africa include;

1. A large, rural, small-scale indigenous farming population that has been by-passed by the green revolution.
2. An increasing population, leading to greater demands for food, and reduced per capita availability of arable land and irrigation water.
3. Rapid growth and expansion of urban areas, leading to higher per capita food requirements (particularly grain and an increased consumption of animal products).
4. Increasing damage to the ecological foundations of agriculture.
5. The environmental, social, economic and agricultural implications of recent biotechnology advances are not yet fully understood.

The Department of Agriculture has developed an agricultural sector strategy aiming to address poverty alleviation, economic growth and natural resource management in a sustainable manner. Central to this strategy is the ability “to preserve agricultural biodiversity and to promote the sustainable use of soil and water through the enhancement of crop and livestock productivity in intensified and more sustainable farming systems.” (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

Within this strategy soil, water and conservation programmes are to be focused in areas where there is a reasonable chance of success, where the population pressure is high, where the opportunity costs of labour are low, where land availability is high, productive technologies are available and where there will be access to markets, inputs and services. Thus the selection of appropriate technologies is critical. There are several programmes under development for improved sustainability, including (GN1591 in *Government Gazette* No.27936 dated 26 August 2005);

- Development of a biotechnology strategy for the long-term interests of South Africa.
- Development of plant breeding strategies, maintaining and enhancing genetic diversity.
- The *in situ* conservation of endangered agricultural species and varieties in economically viable farming systems.

- Investment programmes in infrastructure and services to support sustainable land use.
- The encouragement of horticultural production.
- Placing production and sustainability within a farming system perspective, supporting environmentally sound production systems, including integrated production, integrated crop management and organic farming.

The agricultural sector strategy has identified biotechnology as central to achieving the objectives of a sector that is globally competitive, profitable and sustainable, and contributing to a better life for all (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

### **Biosafety and environmental sustainability considerations**

Objective assessments are essential to determine the risks of agricultural biotechnology. The risks need to be identified, evaluated and where possible mitigated. In the 1960's the Green Revolution enhanced agricultural productivity through widespread availability of chemicals such as synthetic insecticides, herbicides and fungicides and elite hybrids. However, this had an impact on the environment (GN1591 in *Government Gazette* No.27936 dated 26 August 2005).

Biotechnology should be utilised to mitigate the adverse impacts of agriculture on the environment. In order to replace the Green Revolution paradigm of a maintained pressure on the ecosystem with an approach of sustainable agriculture; there must be a multidisciplinary approach. Key actions include (GN1591 in *Government Gazette* No.27936 dated 26 August 2005):

- An improvement of current integrated pest management systems using an agroecological approach.
- The identification, characterization and conservation of plant and animal genetic resources in order to enhance biodiversity.
- Facilitating the sustainable use of genetic resources in agriculture.
- Determining ecological impacts of agriculture.
- The development and implementation of efficient and environmentally sound biological control systems.
- The improvement of biosafety systems.

From the above it is obvious that the agricultural biotechnology sector is rapidly growing, and in terms of agricultural economics is transforming the sector. Although there are many opponents of this technology, agricultural biotechnology is likely to continue growing and to ultimately dominate the sector. There is thus a need for environmental scientists to engage with the technology and understand its place in the agroecosystem and broader environment. There is an equal need for environmental education to engage agricultural biotechnology so that the benefits and hazards of the new technology are communicated to farmers and the public. The multi-disciplinary nature of biotechnology mitigates against the use of traditional methods of communication due to the extent and

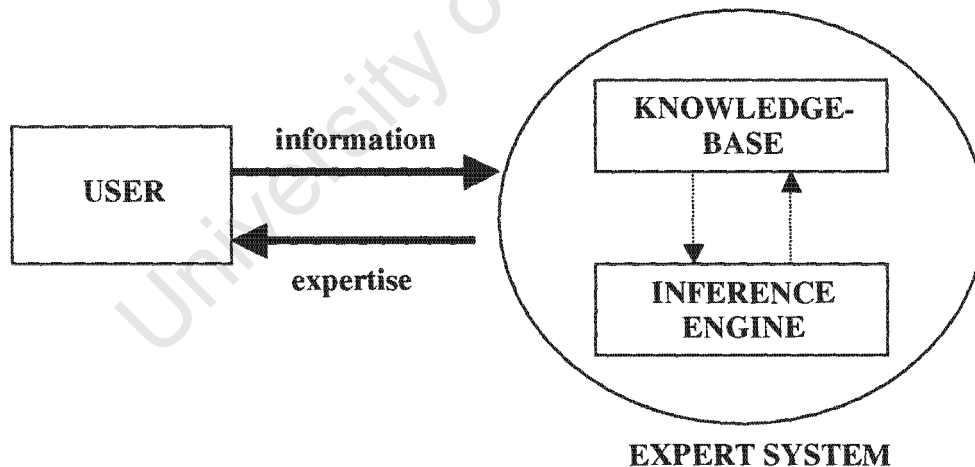
range of data and experience that must be synthesized. Modern information technology provides a possible answer to this dilemma.

## 1.2 EXPERT SYSTEMS

### What is an Expert System?

Professor Edward Feigenbaum, one of the early pioneers of expert systems, has defined an expert system as “an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant expertise for their solution.”(Giarratano and Riley, 1989) An expert system is an Artificial Intelligence computer system that emulates the decision-making ability of a human expert. The program is designed to capture the non-numeric knowledge and reasoning, which are not easily represented in traditional computing approaches (Acquired Intelligence Inc. 2004). The term “expert” refers to the concept of expertise, that is, special knowledge or skill that is not available or known to most people.

Figure 2 shows the basic concept of a knowledge-based expert system. The user supplies information to the expert system and receives expert advice (expertise) in response. The expert system consists of two main components; a knowledge-base which contains the knowledge, and an inference engine which draws conclusions. The conclusions are given to the user as expertise.



**Figure 2: The concept of an Expert System function** (modified after Giarratano and Riley, 1989).

The two part structure of the program allows the system to be modified, updated and expanded readily, making it easier to keep the system at the cutting edge of increasing knowledge: it also allows the system to provide an explanation of the reasoning behind a conclusion. These features provide the credibility and confidence that users require to accept the conclusions of the system (Acquired Intelligence Inc. 2004).

Generally, an expert's knowledge is specific to one **problem domain**. In this case the problem domain is transgenic crops. The knowledge that an expert possesses within a problem domain is known as the **knowledge domain** (Giarratano and Riley, 1989). The knowledge domains in the proposed research are three transgenic crops (maize, cotton and soybean), ecology, and environmental management and legislation on genetically modified organisms.

### General concepts

The building of an expert system is referred to as knowledge engineering, and is carried out by a **knowledge engineer**. Knowledge engineering entails the acquisition of knowledge from human experts and/or other sources and its encoding into the expert system. An expert system differs in respect to conventional programs as the problems to be solved usually have no algorithm for an optimum solution and inferences are relied upon for a reasonable solution. Since inference is relied upon, the expert system should have an **explanation facility** to explain the reasoning so that this reasoning may be checked and the solution justified. Another reason for an explanation facility is to confirm that the knowledge has been correctly acquired and is being correctly used by the program. For the proposed research a new expert system will not be programmed, but an existing **Expert System Shell** utilized. Giarratano and Riley (1989) define an expert system shell as a "special purpose tool designed for certain types of applications in which the user must only supply the knowledge base".

Some of the general functions of an expert system include:

1. An **ORGANISER**, helping to find, organize and interpret information required in order to perform a given task.
2. An **ADVISOR**, embodying and sharing specialized expertise.
3. An **INSTRUCTOR**, assisting in the learning process of a given task.
4. A **GENERAL ASSISTANT**, being used to complete a routine task in order to allow more time to be free for the expert (Acquired Intelligence Inc. 2004).

The current research seeks to use an expert system in an advisory and instruction role.

### Ideal Expert System characteristics

- *High performance*: the response of the expert system must be of a competency equal to or better than an actual expert.
- *Adequate response time*: the response time of the expert system must be equal to or better than an actual expert in the field.
- *Good reliability*: the expert system must be reliable, stable and not prone to crashes in order for it to be properly utilized.
- *Understandable*: Explanation of the reasoning should be given during execution so as to be understandable.

- *Flexibility*: Due to the large amount of knowledge being utilized, there should be an efficient mechanism for adding, changing and deleting knowledge (Giarratano and Riley, 1989).

### **Role of Expert Systems in Education**

Romiszowski (1987) studied Artificial Intelligence (AI) and expert systems in education, finding that the use of AI and experts systems in education goes back as far as AI itself. According to Wilcox (1996) the emergence of the knowledge age has brought with it awesome responsibilities to adjust our sociological and economic structures to provide opportunities for improvement and growth. He further states that for education this means matching the curriculum to the requirements of new job and career directions, and in the case of technological expansion, “knowledge” must be considered a commodity wherein ideas are generated and distributed in the global marketplace. Rafea and Shaalan (1996) assert that knowledge bases can be used as a powerful training tool, with the goal of training to produce a motivated user who has the basic skills needed to apply what has been learned and then continue to learn. The concept and use of knowledge domains creates a constant search for efficiencies in selecting the most strategic information or knowledge serving the problem under investigation (Wilcox, 1996). The work of Rafea and Shaalan (1996), investigating the use of expert systems in the agricultural sector in Egypt as a training tool, has indicated that expert systems can be used for expediting training, and that traditional forms of training are not sufficient to cope with the fast growing technologies in the different agriculture specialities for different crops. The conclusion being that expert systems will reduce training time and enhance training quality.

Grabowski and Harkness (1996), in their work assessing expert systems’ role in statistics education, state that the use of computers for learning is changing, with researchers now thinking of computers as thinking partners in the learning process, enabling the user to be more actively involved in the content. Computer learning systems are being viewed as amplifiers to and modifiers of one’s thinking. The study conducted by Grabowski and Harkness (1996) concluded that the generative nature of creating or using an expert system results in greater learning gains than not using an expert system. Wachter and Gupta (1997) view the expert system as an educational tool valuable in the role of distance education.

Wilcox (1996) further introduces the concept of expert system use regarding “integrated” studies, stating the concepts and applications of expert systems and knowledge-based systems can serve to provide a structure or tool for development if integrated studies, where “integrated” refers to the use of multiple knowledge domains. The argument is made that when knowledge, information and data were scarce or difficult to access, there were valid reasons for defining systems that created narrow, rigid, disciplinary structures, as seen in departmental structures of higher education institutions. However, recently powerful techniques have evolved for knowledge elicitation, repackaging of knowledge and finally the presentation (communication) of concepts and ideas through new media and methods. Integrated curriculum designs require rethinking the instructional process in

light of context-based programs with complex multidisciplinary content. Integrated studies require careful selection of the strategic information or knowledge for the problem at hand (Wilcox, 1996). Wilcox (1996) argues that the precision, with which one can select the strategic areas for study within the broad disciplines under investigation, constitutes the essential, perhaps primary, core competency in the design of integrated or multidisciplinary projects. Expert systems aid in the successful selection of strategic knowledge components due to their continuous focus on knowledge elicitation, restructuring and repackaging. Knowledge bases also offer an ideal technology for capturing, preserving and documenting knowledge, while providing a framework for handling the exchange and integration of knowledge from various sources.

Lundvall and Johnson (1994) establish the concept of a “learning economy” as opposed to a “knowledge economy”, where the difference is associated with the fact that the former considers a dynamic perspective, taking into account some types of knowledge becoming more important while some knowledge becomes less important. Thus there is knowledge creation and knowledge destruction. An expert system used in education can become an integral part of this process, in having the knowledge base continually updated and causing change in the education level of the user.

A further aspect to consider is that of metacognition. Perkins (1991) defined the concept of metacognition to include the strategic repertoire, conceptual development of theories of the mind and autoregulation of the student. Blakey and Spence (1990) define metacognition as the process of thinking about thinking, understanding what is known and not known. Metacognition involves connecting new information to former knowledge, deliberately selecting and monitoring thinking strategies and evaluating these processes. A literature study conducted by Self (1995) on metacognition found that although the importance of metacognition is widely accepted, few Computer Aided Education systems give recognition to metacognition. The aim of metacognition is to externalise the student/user in order to facilitate reflection and encourage critical, creative and corrective self-monitoring and self-managing of student/user behaviour (van Biljon et al., 1999). Self (1995) proposed the method of metacognition as a means of motivating the learner to reflect on his/her own problem-solving strategies, considering other possible goals and plans. In the case of an expert system, metacognition would be the user’s realization of the expert’s logical decision process.

Conceicao and Heitor (2002) recognise the need to promote systems of innovation and competence building based on learning and knowledge networks, where competence is associated with skills and capacities, individual and collective. They differentiate between ideas (content) and skills (the ability to use the ideas in a context, and apply that context to new ideas), defining learning as the interaction between ideas and skills. Freeman and Soete (1997) state that new ideas spur development of the skills required to use those new ideas, and that the bridge from the production of ideas to the usage of ideas is established by producing new skills. The increased use of an idea (in this case content in the knowledge base) requiring its diffusion, will lead to the need for further skills and so on, creating a self-reinforcing cycle leading to the accumulation of knowledge. In the case of an expert system, ideas are provided to the user, while the process of

metacognition (realization of the logical mental framework that experts of the domain utilise in order to solve problems) develops the skills of the user. The user may then go on to use the newly acquired skills (mental framework) in solving similar problems with new ideas (content). Du Plessis (1995) states, “if we can teach the skill of finding the relevant information in a problem-solving situation and using that information to solve a problem, then we are teaching a life skill”.

An expert system as an educational tool can also aid in the self-actualization of the user. Self-actualization is defined by Goble (1970) as “the desire to become more and more what one is, to become everything that one is capable of becoming”. Burleson (2005) states that self-actualization is fundamentally equivalent to the goals for education, learning environments and creativity, espoused by notable educators and psychologists. Burleson (2005) further uses the argument of Kay (1991) that a self-directed “concept of knowledge ownership” and “personal franchise in the culture’s knowledge base” is what develops the self-actualized learner. And that through new technologies learners are able to explore more and more of the world. In terms of an expert system for education, the output of the system is determined by the input of the user. In this sense the user has “ownership” and a “personal franchise” with that educational material.

#### **Advantages of Expert Systems pertinent to the proposed research**

- **Increased availability:** the expert system accesses, organises and filters a mass of information. Therefore many users have the possibility of utilizing such a system.
- **Reduced cost:** the cost of acquiring expertise is lowered.
- **Permanence:** the expert knowledge will last indefinitely. The knowledge can also be restudied and adapted in the future.
- **Multiple expertise:** many fields of expertise can be made available simultaneously. For the proposed research problem fields of biotechnology, ecology and environmental management will be utilized.
- **Increased reliability:** an expert system can be used as a tool for a second opinion. Decisions made by one individual can be analysed by another.
- **Explanation:** Explanation of reasoning can be made in detail every time a conclusion is found. A human expert may be unwilling to do this. This capacity is necessary in a relatively new field such as genetically modified crops.
- **Fast response:** depending on software and hardware used, an expert system may produce an answer faster than a human expert.
- **Steady, unemotional and complete response at all times:** this aspect of the expert system increases reliability of the conclusions reached.
- **Intelligent tutor:** the expert system may act as a tutor allowing students to perform sample runs. As biotechnology increasingly comes into environmental management and other academic curricula, this will prove a useful educational tool.
- **Intelligent database:** the system may be used as a database for information extraction.
- **Revising knowledge:** the knowledge of an expert in implicit form in his/her mind must be encoded in explicit form into the expert system. This process often leads

to an examination of correctness, consistency and completeness of that knowledge. Thus improving the quality of that knowledge. This may be an important step in knowledge about genetically modified crops (Giarratano and Riley, 1989).

### **Is the Selection and Management of Transgenic Crops an appropriate domain for an Expert System?**

- *Can conventional programming solve the problem?* If conventional programming using algorithms can solve the problem then an expert system is not the best choice. If, however, the problem is an ill-structured one, with many possibilities, and heuristic reasoning (rules of thumb) is needed, then an expert system is the correct choice.
- *Is it a well-bounded domain?* It is necessary to have well defined limits to what the expert system is expected to know. The knowledge engineer must be able to set those limits. The more domains, the more complex the expert system will be.
- *Is there a need and desire for an Expert System?* In order for an expert system to function there must be a need for it and for people who would use it. There certainly is a need regarding environmental management and awareness of transgenic crops, with a continuing public debate in the media on the topic, with arguments for transgenic crops (Urbach, 2006, Green, 2005a, Fyvie, 2004, Yeld, 2005 and Bennett, 2005), against transgenic crops (da Costa, 2006, Stuart, 2005, Hattingh, 2005, Gosling, 2005, London, 2004) and a neutral stance (Gosling, 2005a and Leite, 2004). Only recently has research regarding the environmental management of transgenic crops been initiated. Thus an expert system would make current research accessible. Many governments and environmental organisations globally are calling for caution regarding transgenic crops. Thus any agricultural sector showing sound management of their transgenic crops would be favoured in global markets. Therefore a need exists on many different levels for an education tool regarding transgenic crops.

Conventional programming cannot solve the problem of environmental management of transgenic crops, as the problem is ill structured (more than one knowledge domain exists), with many possibilities (many ways of structuring the knowledge) and heuristic reasoning. The domains of the problem can be bounded, and as discussed there is a need for an educational tool in the problem domain of transgenic crops, with an expert system offering a tool capable of providing that.

### **1.3 NEED FOR EXPERT SYSTEMS IN SOUTH AFRICAN BIOTECHNOLOGY EDUCATION**

Biotechnology and agricultural biotechnology is poorly understood by the general South African public. The subject is controversial, with the general public being made aware of many environmental concerns, but with little substantial scientific research backing the arguments. The result being that the general public is often misinformed on many of the issues regarding biotechnology. There is a need for current research to be made available in an easily accessible form to the public. The National Biotechnology Strategy of South

Africa (2001) notes that the lack of public understanding has resulted in a negative backlash in many regions of the world. It further states that through better understanding and communication, the public, and not just specialists in the field can appreciate the field of biotechnology.

The biotechnology field is growing and advancing technologically at a rapid rate as discussed earlier. From an environmental perspective, scientists are required to keep up with this advance in order to aid in sound decision-making. Therefore there is a need for environmental scientists and professionals to have access to protocols in an easily accessible manner. Expert systems provide such a mechanism.

The expert system provides an excellent educational tool and a structured database of knowledge. Due to the structured and directional nature of the decision and education paths within the system, it suits users from different backgrounds, including environmental professionals, politicians, farmers and the general public.

The National Biotechnology Strategy of South Africa (2001) recognizes that South Africa has failed to extract value from more recent advances in 3<sup>rd</sup> generation biotechnology. The expert system offers a tool that can aid in the education and sound application of biotechnology in the country. An objective of the National Biotechnology Strategy of South Africa is to promote a clear understanding of the potential of biotechnology. An expert system offers one means of achieving this.

#### **1.4 THE TRANSGENIC CROPS INVESTIGATED**

The three crops addressed by this project are Soybean, Maize and Cotton. These are the only crops with transgenic varieties approved for commercial release in South Africa. The soybean variety investigated is Roundup Ready® Soybean. This is an herbicide-resistant soybean crop produced by Monsanto. Three maize varieties are investigated. There are two insect-resistant varieties called YieldGard® Maize (produced by Monsanto) and Bt11 Maize (produced by Syngenta), and an herbicide-resistant variety called Roundup Ready® Maize (produced by Monsanto). Finally two cotton varieties are investigated, an insect-resistant variety called Bollgard® Cotton and an herbicide-resistant variety called Roundup Ready® Cotton, both produced by Monsanto. For detailed information found in the knowledge base on the transgenic crops investigated refer to Annexures A – I.

##### **1.4.1 THE HERBICIDE-RESISTANT TRANSGENIC CROPS INVESTIGATED**

The transgenic herbicide-resistant crop plants Roundup Ready® Soybean, Roundup Ready® Maize and Roundup Ready® Cotton developed by Monsanto confer tolerance to glyphosate, the active ingredient in Roundup® herbicides. Glyphosate's primary mode of action is the competitive inhibition of 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS). The EPSPS enzyme is part of the shikimate pathway involved in the production of aromatic amino acids and other aromatic compounds in plants. Plants that are not tolerant of glyphosate cannot produce aromatic amino acids required for survival when

treated with the herbicide. The transgenic soybean line produces the CP4 5-enolpyruvylshikimate-3-phosphate synthase protein (CP4 EPSPS) (Monsanto Company, 2002a, 2002b, 2002e). The EPSPS enzyme used was isolated from the soil bacterium *Agrobacterium tumefaciens* strain CP4 ([www.agbios.com](http://www.agbios.com) Accessed 19/02/2005). This protein is naturally less sensitive to inhibition by the glyphosate herbicide. Therefore plants that produce the CP4 EPSPS protein are tolerant to glyphosate (Monsanto Company, 2002a, 2002b, 2002e). The EPSPS enzyme is present in all plants, bacteria and fungi. It is not present in animals, which do not synthesize their own aromatic amino acids ([www.agbios.com](http://www.agbios.com)).

The Roundup® glyphosate herbicides are used as foliar-applied, non-selective herbicides that are effective against most annual and perennial grasses and broadleaf weeds. The herbicide has no pre-emergence or residual soil activity. Additionally the herbicide is not prone to leaching; it degrades in the soil over time and is considered by Monsanto (2002) to not cause unreasonable adverse effects to mammals, birds or fish under normal use conditions (Monsanto Company, 2002b).

Monsanto (2002) states that the transgenic herbicide-resistant crop lines offer growers an additional tool for improved weed control. Weed control is essential as weeds compete with the crop for sunlight, water and nutrients. Weed control failure will result in decreased yields and a reduced crop quality. Furthermore, weeds in the crop field reduce the efficiency of the mechanical harvest of the crop. A primary reason for grower adoption of the transgenic line is simplicity in weed control due to the fact that Roundup® herbicides are effective against most annual and perennial grasses and broadleaf weeds, farmers that plant the transgenic soybean line are said to be able to reduce the number of herbicides used to control the economically destructive weeds that grow in the crop fields and thus realize savings in weed control costs. The reduction in herbicide use is stated to have benefited the environment by reducing the number of herbicide applications, and by allowing farmers to implement integrated weed management practices, which would generally not be possible when pre-plant or pre-emergence herbicides are used.

The stated benefits of the transgenic line according to the Monsanto Company include:

- *A broad-spectrum weed control.* The Roundup® herbicides are effective against both broadleaf weeds and grasses, including difficult to control weed species.
- *Excellent crop safety.* If used under the labelled instructions the Roundup® glyphosate herbicides control weeds without damaging the Roundup Ready® crop.
- *Herbicide offers favourable environmental properties.* Glyphosate has been used as an agricultural herbicide for almost 30 years. Glyphosate possesses favourable environmental properties, including the fact that it binds tightly to soil thereby making it unlikely that the glyphosate will move to groundwater or reach non-target plants. Glyphosate also degrades over time into naturally occurring materials. Additionally it is considered glyphosate will not cause unreasonable adverse effects to the environment under normal use conditions.

- *Weed control flexibility.* Due to the fact that the Roundup® herbicide is applied onto foliage of the weeds after crop emergence, applications can be treated as necessary when weed infestations reach the threshold level for yield reductions.
- *A high compatibility with integrated pest management and soil conservation.* Conservation tillage improves soil quality, water infiltration, a reduction in soil erosion and sedimentation of water resources, a reduced runoff of nutrients and pesticides into surface water, also improved wildlife habitat, an increase in carbon retention in the soil, reduced fuel usage and the use of sustainable agricultural techniques.
- *Weed control that is cost effective.* Weed control costs using the Roundup Ready® system is competitive with the cost of alternative weed control options. Thus both large- and small-scale producers can benefit from the technology.
- *An additional herbicidal mode of action is available for in-season weed control.* The Roundup® herbicides may only be used in pre-plant applications (in all but a few pre-harvest uses) without the use of Roundup Ready® genetic modification in the crop.
- *An herbicide with a low risk to human health.* It is considered that under present conditions of use that Roundup® herbicides will not cause unreasonable adverse effects on human health. The United States Environmental Protection Agency (EPA) has classified the glyphosate herbicide as a category E herbicide (evidence of non-carcinogenicity for humans). According to the World Health Organization the glyphosate herbicide is not carcinogenic, mutagenic or teratogenic (Monsanto Company, 2002b, 2002e).

#### **1.4.1.1 SOYBEAN WEED COMPLEX**

Tolerance of Roundup Ready® soybeans to glyphosate has been demonstrated since 1991 in field trials conducted across the United States, Canada and Argentina (Monsanto Company, 2002b).

The soybean crop cannot compete effectively in the early growth stages with weeds and must be protected. The current management systems utilize cultural and mechanical practices with herbicide use in order to control weeds. Monsanto Company state that the use of Roundup Ready® soybean provide an additional tool offering environmental benefits associated with the use of conservation-tillage and integrated weed management practices (Monsanto Company, 2002b).

The soybean crop does not compete well with weeds in the seedling stage. Weeds tend to have a fast growth rate and deprive the crop of moisture, minerals and light during the early growth stages. If effective weed control measures are implemented in the early stages then the crop will respond and produce a dense canopy, smothering weeds during the later growth stages. In areas where the soil inherently contains low levels of nitrogen (no nitrogen has been applied) the soybean plants tend to outgrow weeds, as the crop is able to fix its own nitrogen and the weeds cannot (Smit, 2000).

Weeds developing during harvest may influence the harvest quality. The morning glory can entangle in the reel and the drum of the combine harvester causing severe losses. Furthermore, certain weed seeds are difficult to separate and reduce the grade quality and therefore the price of the harvest (Smit, 2000).

Crop rotation practices if done properly will contribute toward lowering weed and disease pressure on the crop. Rotation practices with a grass crop facilitate broad leaf weed control as well as grassy weeds during the soybean cultivation. The waiting period on the label must be followed in such a rotation practice. Optimum planting date, soil moisture, soil fertility, row spacing and population also contribute toward weed control (Smit, 2000).

#### **1.4.1.2 MAIZE WEED COMPLEX**

During the first 6-8 weeks after planting maize weed control is critical, as this is the period in which competition with a crop for nutrients and water is greatest. Direct effects on yield due to weeds emerging later are smaller, although it may have a detrimental effect on soil water during the subsequent season. A plant is considered a weed if it is growing in a place where it is unwanted, even if it is an agronomic crop plant (du Toit, 1999).

Annual yield loss due to weeds is estimated to be approximately 10%. Weeds tend to be good competitors as they emerge and establish quickly, develop rapidly and possess a strongly developed deep root system. Weeds may hinder the harvesting process, pollute grain, transmit odours to grain causing downgrading, or incur additional costs for removal of seeds (du Toit, 1999).

Weed control should be considered as risk management including aspects of seedbed preparation, time of planting, and mechanical and chemical operations. The act of ploughing or inverting the soil deposits seeds deeply, thereby making it difficult for grass seeds to germinate. However, this is favourable for broad-leaved weeds. In the case of shallow or no-till the opposite applies (du Toit, 1999).

The pre-emergence herbicides function poorly on nutgrass, and proper tilling before application is essential. If a rotation system is employed residual affects of herbicides used must be taken into consideration. Due to the fact that maize is part of the *Gramineaceae* family, other grasses are difficult to control after emergence in the maize crop. Grasses should be controlled with pre-emergence herbicides. Weeds may be controlled using physical, cultural, biological and chemical means (du Toit, 1999).

#### **1.4.1.3 COTTON WEED COMPLEX**

Weed control is essential in order to attain a high yield and starts with seedbed preparation. Weeds may also reduce the quality of lint as vegetation stains the lint, thereby reducing its potential uses and value (Monsanto Company, 2002a). The field may be irrigated 2 weeks before planting stimulating weed germination allowing for them

to be tilled. In the first 6-8 weeks after planting weeds compete with young cotton for space, water, sunlight and nutrients. Pre-emergence herbicides may be used to treat these weeds (ARC, 1996).

It must be noted that different areas are characterized by predominant weed species. A specialist should be consulted in order to determine the use of a specific herbicide and weed control program. Chemical herbicides can be divided into broadleaf-killers, grass-killers and nutgrass-killers (ARC, 1996).

Weeds pose a constraint on global cotton production. The crop cannot compete effectively in the early growth stages and needs to be protected. Current management systems interweave cultural and mechanical practices with herbicides in order to overcome the competitive effect. The Roundup ready® cotton variety is stated to have reduced the number and quantity of herbicide applications resulting in improved flexibility with effective control of weeds (Monsanto Company, 2002a).

#### **1.4.2 THE INSECT-RESISTANT TRANSGENIC CROPS INVESTIGATED**

##### **YieldGard® Maize (MON810)**

The Monsanto Company has through modern biotechnology techniques developed an insect-protected maize variety called YieldGard®, event MON810. The plant produces the naturally occurring *Bacillus thuringiensis* (Bt) delta-endotoxin protein, *CryIAb*. The YieldGard® maize is protected from feeding damage by the European corn borer (*Ostrinia nubilalis*), the southwestern corn borer (*Diatraea grandiosella*), the pink borer (*Sesamia cretica*), and in South Africa the stalk borers *Busseola fusca* and *Chilo partellus* (Monsanto Company, 2002d).

The stated benefits of cultivating this insect resistant variety include:

- Reliable control of maize pests.
- The control of target insects while maintaining beneficial species.
- The reduction in use of chemical pesticides.
- The reduction of applicator exposure to chemical pesticides.
- A fit with integrated pest management (IPM) and sustainable agricultural systems.
- A reduction in fumonisin mycotoxin levels in maize kernels.
- No additional labour or machinery requirements, therefore allowing large commercial farmers and small-scale farmers to maximize hybrid yields (Monsanto Company, 2002d).

Food, feed and environmental safety assessment data generated for YieldGard® maize event MON810 have been used in obtaining regulatory approvals in the key maize producing countries and in countries that are likely to import the insect-resistant maize. These assessments included product characterization consisting of molecular analysis of the inserted DNA, protein characterization and determination of protein levels in the maize tissues, protein safety evaluation, compositional analysis of food components

establishing substantial equivalence criteria to commercial varieties and forms of environmental assessment (Monsanto Company, 2002d).

### **Syngenta Bt11 Maize**

Syngenta Seeds Incorporated have developed maize line Bt11 through specific genetic modification to be resistant to lepidopteran insect pests. The Bt11 maize variety produces the insecticidal protein *CryIAb*. The Bt11 maize line is resistant to lepidopteran pests and allows producers to use phosphinothricin-containing herbicides for weed control ([www.agbios.com](http://www.agbios.com)). However, in South Africa phosphinothricin-containing herbicides are not permitted, thus Bt11 maize is cultivated purely as an insect resistant transgenic crop.

### **Bollgard® Cotton**

The cotton crop is the leading plant fibre crop in the world, with lepidopteran pests being the main pest problem on most cotton acres in the world ([www.agbios.com](http://www.agbios.com)). The Monsanto Company have developed cotton lines 531, 757 and 1076, known as Bollgard® and Ingard® cotton, that incorporate a bacterial protein from *Bacillus thuringiensis*, thereby making them resistant to major caterpillar pests of cotton ([www.agbios.com](http://www.agbios.com)). The company states that the cultivar reduces the need to spray chemical insecticides in order to control major caterpillar pests. It is further stated that the cotton has value as a replacement for insecticide applications for specific pests and as a pest management tool, providing benefits above and beyond reduction in insecticide costs (Monsanto Company, 2002c).

#### **1.4.2.1 MAIZE INSECT COMPLEX**

An insect may be classified as a pest when it causes a loss in yield and/or lowering in crop quality unacceptable to the producer. Therefore the producer determines the importance of the pest. A pest control strategy should consist of a few alternatives under an integrated pest management program. Under such a program chemical, cultural and biological controls can be utilized (du Toit, 1999).

#### **1.4.2.2 COTTON INSECT COMPLEX**

Insect pests of cotton may be divided into 3 groups for control purposes;

1. The Bollworm complex
2. The Red spider mites
3. The sporadic and secondary pests

The first 2 categories are considered key pests due to the fact that if controlled efficiently, the control of the 3<sup>rd</sup> group is automatic. Effective control of the Bollworm complex is the key to overall efficiency of insect and mite control, due to the fact that the build-up of mite populations often results from injudicious use of insecticides for bollworm control early in the season. Integrated pest control refers to the use of pesticides sensibly such that factors naturally suppressing pest populations are encouraged to operate. Such

practices include cultural practices like avoiding ratoon cotton, use of scouting, avoiding unnecessary spraying and biological control (ARC, 1996).

## 1.5 CURRENT ENVIRONMENTAL ISSUES PERTAINING TO TRANSGENIC CROPS

Although there are equally important socio-economic concerns regarding the adoption of transgenic crops, these socio-economic aspects are outside the scope of this dissertation, which focuses on physical environmental biosafety concerns. Just as each crop (soybean, maize or cotton) interacts ecologically in the agroecosystem, so the transgenic traits of insect- or herbicide-resistance also interact in the agroecosystem. Thus the necessity of analysing each variety on a case-by-case basis.

The current investigation has taken the currently recognized environmental concerns pertaining to transgenic crops as concept topics and applied them to each variety mentioned in Section 1.4. Some environmental concerns will apply only to either insect-resistant or herbicide-resistant varieties, while others will apply to both. The body of scientific literature on transgenic crops categorizes the environmental concerns in various ways, with terms often being interchangeable or overlapping in scope. An example of this is the broad term 'biosafety', defined variously by different authors. The current investigation categorises environmental concerns based on the extensive study undertaken by the Council for Agricultural Science and Technology (CAST) in the United States (Carpenter et al., 2002). The study resulted in a report on the environmental impacts of transgenic soybean, maize and cotton. This report's categorisation was placed into context by means of a comparative analysis of the environmental impacts of the widely planted transgenic commodity crops with the environmental impacts of traditional varieties and cropping practices of those same crops. The study included individuals with expertise in agronomy, agricultural economics, entomology, environmental science, plant breeding, plant pathology, soil science and weed science. The report was peer reviewed by credited reviewers. In this investigation the categorization was compared against the body of scientific literature on transgenic crops and found to incorporate all the environmental concerns expressed in the literature regarding transgenic crops and biosafety, such as Stewart (2004) and Amand (2004). The categorization was also found to be more specific than many definitions of biosafety. The categorization also accounted for perceived and actual environmental concerns.

The following categorization is used in this study:

### 1. Insect-resistant crops

- **Changes in insecticide use** (concern over the use of different insecticides in the agroecosystem)
- **Insect resistance** (concern over potential resistance development to the Bt toxin by target insects)
- **Gene flow and outcrossing** (concern over the uncontrolled spread of a transgene through the agroecosystem and resultant hybrids)

- **Crop weediness** (concern over the potential for transgenic crops to move outside the agroecosystem)
- **Insect population shifts** (concern over agroecosystem insect population shifts caused by selective Bt toxins)
- **Nontarget and biodiversity impacts** (concern over potential effects on nontarget species in the agroecosystem)
- **Water quality** (concern over water quality impacts from Bt toxin and transgenes)
- **Landuse efficiency** (concern over yield potential of transgenic varieties)

## 2. Herbicide-resistant crops

- **Changes in herbicide use** (concern over the use of different herbicides in the agroecosystem)
- **Herbicide drift** (concern of increased herbicide drift outside of the intended spray area)
- **Herbicide resistance** (concern over potential resistance development to glyphosate by weed complexes)
- **Gene flow and outcrossing** (concern over the uncontrolled spread of a transgene through the agroecosystem and resultant hybrids)
- **Crop weediness** (concern over the potential for transgenic crops to move outside the agroecosystem)
- **Changes in tillage and soil management** (concern of potential environmental impacts due to a change in tillage practices and soil management)
- **Weed population shifts** (concern over agroecosystem weed population shifts due to the predominant use of one herbicide)
- **Nontarget and biodiversity impacts** (concern over potential effects on nontarget species in the agroecosystem)
- **Water quality** (concern over water quality impacts from glyphosate and transgenes)
- **Landuse efficiency** (concern over yield potential of transgenic varieties)

## 1.6 AIMS OF THE STUDY

### 1.6.1 Vision for the study

The overall vision for environmental management of the biotechnology industry is to direct progress in biotechnology to be in accord with environmental goals (Hails, 2002). The vision for this research is that it will construct an expert system prototype knowledge base to be used in the biotechnology and environmental science fields for educational purposes. The research is not pro- or anti-biotechnology: it seeks to be a neutral investigation into a particular field of already existing science.

### 1.6.2 Aim of the study

The overall aim of the research is to produce an expert system prototype knowledge base of the environmental concerns, management and monitoring for the three transgenic

crops: maize, cotton and soybean, specific to South Africa. The knowledge base is considered a prototype as it is a first step toward a completed expert system.

Aims for the expert system prototype knowledge base are to function as an advisor of what the environmental concerns, management and monitoring practices are at the farm level specific to transgenic crops, by assessing the knowledge level of the user and providing appropriate educational information regarding the three transgenic crops. The research does not seek to be a completed expert system, as computer programming expertise is required to achieve this and outside the scope of this study.

Other aims for the research are that it will assist in directing progress in agricultural biotechnology to be in accord with goals of agricultural sustainability, environmental sustainability and building public awareness.

### **1.6.3 Objectives of the study**

1. Select and utilize an appropriate Expert System Shell.
2. Research three transgenic crops (maize, cotton and soybean).
3. Research the relevant environmental management procedures.
4. Consolidate research into a Knowledge-Base.
5. Encode Knowledge-Base into the Expert System Shell.

## 2. METHODOLOGY

The knowledge modelling for this project was based on a hybrid of two models. The primary model adopted was the PreSERVe method (Prepare, Scope, Elicit, Render, Verify) of knowledge modelling used by Coffey et al. (2003) in creating El-Tech, a performance support and training system for electronic engineers. The model for intelligent computer-aided education systems designed by du Plessis et al. (1995) was the second model used. The PreSERVe modelling method consists of initial preparation, followed by an iterative process of examining scope of the project, eliciting knowledge, rendering the knowledge into a knowledge model, and then verifying the results (Coffey et al., 2003).

### 2.1 KNOWLEDGE ACQUISITION

Methods of Knowledge Acquisition were sourced from Pedersen (1989), Smith (1996), Babbi and Mouton (2001) and Coffey et al. (2003). Knowledge acquisition is defined as the process of acquiring knowledge from a human expert or group of experts, and from other sources, such as written sources (Pedersen, 1989, Coffey et al., 2003, Smith, 1996). Coffey et al. (2003) group knowledge elicitation as direct, in which interactions with one or more domain experts occur, or indirect, in which knowledge is culled from texts, reports or other documentation.

#### 2.1.1 SURVEY OF THE LITERATURE

The simplest form of knowledge acquisition is eliciting the knowledge from printed sources. This form of knowledge acquisition is however, very important in the initial stages of knowledge capture, for gaining initial concepts and learning the language of the knowledge domain (Smith, 1996).

##### Source of information

All mediums of literature were researched. Journals, books, magazines, newspapers and the Internet were key sources. The fields of research included biotechnology, agricultural biotechnology, agroecosystem ecology, environmental management and expert systems. Physical visits were made to local libraries in the Western Cape. Electronic searches were carried out to cover South African libraries. General internet searches were carried out for the above mentioned research fields. Searches of relevant journals were conducted. Database platform searches were carried out with EBSCO Host Research Databases, ISI Web of Knowledge, Emerald, JSTOR, Sabinet Online, SwetsWise, Science Direct and WebSPIRS from SilverPlatter.

##### Objectivity, Validity and Reliability

The following methods were employed in the literature research; prolonged engagement, persistent observation, referential adequacy, thick description, purposive sampling and confirmability audit trail (Babbi and Mouton, 2001).

## Problems encountered

When relying on secondary data one must rely on what is, and more importantly what is not, in existence. Any research carried out through literature review is limited to what has been documented. A few research papers could not be obtained from overseas sources; however, the content is not thought to be significantly different from other published works that were obtained. Certain information pertaining to the specifics of each crop variety in a South African context was not available in the publicly accessible scientific literature, and was accessed directly from Monsanto sources.

## 2.1.2 INTERVIEWS

### Source of information

Experts in the field of transgenic crops were interviewed. In order to ensure that the key individuals were consulted the method of **chain referral** was used (Babbie and Mouton, 2001). The two experts found through chain referral are Dr Kulani Machaba and Dr Wally Green.

### Unstructured Interviews

Unstructured interviewing is probably the most widely used knowledge-acquisition method and consists of free flowing dialogue (Smith, 1996). The Unstructured interview is an informal conversation geared toward a common goal, however, having some degree of structure. Structuring questions keeps the discussion from meandering, while the unstructured format allows issues to be addressed that are not on the agenda (Coffey et al., 2003). Interview methodologies and guidelines from Smith (1996), Pedersen (1989), Coffey et al. (2003) and Babbie and Mouton (2001) were followed. The interviews were flexible, iterative and continuous with the respondent doing most of the talking. All interviews were conducted with the highest respect of all interviewees.

The following general interview process was followed (Babbie and Mouton, 2001):

1. **Thematizing:** clarifying the interview process and the concepts to be explored.
2. **Designing:** establishing a process through which one can achieve the interview's purpose, including the ethical dimension.
3. **Interviewing:** carrying out the actual interviews.
4. **Transcribing:** producing a text of the conducted interviews.
5. **Analysing:** determining the meaning of the collected data.
6. **Verifying:** checking the reliability and validity of the collected data.
7. **Reporting:** communicating to others the results of the interviews.

## **Questions**

The majority of questions asked were open-ended questions (initially having no constraint on the answer) (Coffey et al., 2003), allowing the interviewee to give whatever answer they felt best. Questions were made clear and unambiguous. Literature research beforehand minimized ambiguity of questions. Double-barrelled questions were avoided. Only competent “experts” were interviewed. Bias was avoided in all lines of questioning, especially regarding anti- or pro-stance to transgenic crops. Every effort was made not to set the interviewees frame of mind by the construction of questions (Babbie and Mouton, 2001).

## **Decision analysis**

Decision analysis was carried out in the interviews. Experts generated information that included the elements of a problem, relationships among the elements and the types of problems encountered. From this the approach to decision-making was determined and represented in a reasoning model (Coffey et al., 2003).

## **Concept Mapping**

Concept Mapping was carried out in the interviews according to the methodology of Coffey et al. (2003). Graph construction involves creation of conceptual graphs, or Concept Maps. Concept maps are structured, non-textual representations of knowledge in graph format, comprised of concepts on the nodes and linking phrases that elaborate the relationships among the concepts on the arcs. Concept mapping aids in externalising an expert’s key concepts of a knowledge domain, and provides a framework for the structuring of knowledge (Coffey et al., 2003).

## **Problems encountered**

Establishing a convenient time for the interviews to take place proved difficult, as the interviewees were very busy.

## **2.2 EXPERT SYSTEM REQUIREMENTS DEFINED**

The following parameters were set out to define the requirements of the prototype expert system:

1. The system had to have a simple and effective development environment, to accommodate the first knowledge engineering undertaken by the author.
2. The system had to produce a hierarchical representation of the information (Winstanley, 1987), in order to express the structured knowledge modelling undertaken.
3. The system was required to produce a decision tree structure in the form of a graphical output, enabling the logical progression of the decision process to be followed (Winstanley, 1987).

4. Forward chaining was required (reasoning from facts to the conclusions resulting from those facts) (Giarratano and Riley, 1989).
5. Having specified a decision tree to be produced, the system was required to assign a ROOT object (Winstanley, 1987), as a starting point of inference.
6. The system was required to produce an output report determined by the input values of the user, in order to achieve the advisory and educational role, and to achieve the self-actualization of the user encouraged by Burleson (2005).

## **2.3 EXPERT SYSTEM SHELLS EVALUATED**

The evaluation considered the following variables; functionality (can the shell perform the requirements for the prototype), usability (how difficult is the construction and operation of the shell) and cost (is the cost justified by the shell's functionality and usability). The evaluation of the expert system shell is as much part of the research as the knowledge engineering, and the same methodological approach was applied. In the process of expert system shell evaluation, it was required that each shell be studied and functionality understood.

### **2.3.1 JESS VERSION 6.1**

The Jess system supports rule-based development of expert systems that can be tightly coupled to code written in Java language. Version 6.1 of Jess is compatible with all versions of Java, from Java 2.1. This includes JDK 1.4. Versions that are labelled 4.x are compatible with JDK1.0, and the 5.x versions work with JDK 1.1 (Herzberg, 2005).

The Jess system is a programmer's library, the library being written in Java. The library serves as an interpreter to the Jess language. Jess language is similar to the language defined by the CLIPS expert system shell. This language is a highly specialized form of LISP. It is assumed that the expert system developer using Jess is in fact a programmer, with at least a minimal facility with Java. The developer is required to have a Java compiler and runtime system, knowing how to use it at least in a simple fashion. The developer is assumed to know how to do the following;

- Compile a collection of Java source files.
- Run applications on Java.
- To deal with configuration issues such as the CLASSPATH variable.

It is also assumed that the developer is familiar with the general principles of programming (Herzberg, 2005).

### **Jess application**

There are two overlapping ways of using the Jess system. Firstly, it can be used a rule engine (special program efficiently applying rules to data). The rules are applied to the data held in a knowledge base. The rules often represent the heuristic knowledge of a

human expert. The knowledge base represents the state of an evolving field. Together they constitute an expert system (Herzberg, 2005).

The Jess language, however, is also a general-purpose programming language. It can also directly access all Java classes and libraries. Jess is thus also frequently used as a dynamic scripting or rapid application development environment. Java code must generally be compiled before it can be run, but Jess code is executed immediately. This allows the developer to experiment with Java API's and to build programs incrementally. The Jess language can be extended with new commands written in Java or Jess language. The Jess language can thus be customized for specific applications (Herzberg, 2005).

However, although Jess is useful for a wide range of applications, it is not as useful as an applet intended for Internet use. Jess's size (few hundred kilobytes of compiled code) makes it too large to be run, except on high-speed LAN's. Also, some of Jess's capabilities are lost in the browser form, such as access to Java APIs from the Jess language, which may be lost due to security restrictions on some browsers (Herzberg, 2005).

### **Jess performance**

The Jess rule engine uses a well-known algorithm called Rete (meaning "net" in Latin). This algorithm matches rules against the knowledge base. The Jess system tends to be faster than other systems written in C, especially on large problems, where the performance is dominated by algorithm quality (Herzberg, 2005).

The Rete algorithm explicitly trades space for speed. Thus Jess's memory usage is not inconsiderable. However, Jess contains commands that allow the developer to sacrifice some performance to decrease memory usage (Herzberg, 2005).

### **Reasons for not adopting the Jess 6.1 Expert System Shell**

Although Jess 6.1 is an excellent expert system shell and it is open source therefore also free, there was one important reason for not adopting it for this project: The author has little programming experience. The Jess system assumes that experienced programmers will be using the system. Therefore the time it would have taken to learn the programming language was prohibitive. Furthermore the author felt that if one were not competent with the programming of the language into the shell, then the effectiveness of the system would be compromised. Additionally the project seeks to produce a simple expert system, and the vast number of functions available in the Jess 6.1 version would not be utilized.

### **2.3.2 ERDAS IMAGINE PROFESSIONAL®**

Leica Geosystems have developed IMAGINE Professional, an application which is part of the ERDAS IMAGINE® suite. The application provides the tools required by imaging and remote sensing professionals in order to perform data measurement and analysis. The

IMAGINE professional application is Geographic Information System (GIS) based, enabling data to be read from a variety of vector and raster formats, orthorectification of images, production of mosaics and feature extraction. It uses complex image classification algorithms and signature analysis ([www.gis.leica-geosystems.com/store](http://www.gis.leica-geosystems.com/store)).

### **Advanced Image Classification**

The system allows for the developer to 'train' the system to recognize patterns in the image by defining the criteria by which these patterns are recognized and classified. This training can be performed with either unsupervised (the specification of parameters the system uses to uncover statistical patterns in the data) or supervised methods (the developer provides examples of known features by selecting groups of pixels representing recognizable patterns or land cover features). The system allows for the application of classification decision rules to apply the signatures (parameters/examples) across images and sort pixels into classes based on these signatures ([www.gis.leica-geosystems.com/store](http://www.gis.leica-geosystems.com/store)).

### **Expert Classifier**

The system allows problems to be solved by building a knowledge base from which decision rules may be applied to various datasets. The Expert Classifier has two components, the Knowledge Engineer and the Knowledge Classifier. The **Knowledge Engineer** is the interface to capture the process an expert would normally use in order to sift through geographic data. The Knowledge Classifier allows for a user that may not be an expert to apply an expert's process to new data, with the automatic analysis of variables and generation of results in the same manner of an expert. Other features of the system include the Model Maker, providing an intuitive, object-based graphical tool for building models from raster and vector GIS data, and the Radar Interpreter, allowing the preparation and analysis of radar imagery ([www.gis.leica-geosystems.com/store](http://www.gis.leica-geosystems.com/store)).

### **Reasons for not adopting the Erdas Imagine® Professional Expert System Shell**

Although the ERDAS IMAGINE® Professional system is an excellent and powerful tool, it is not suited to the problem under investigation. Firstly, the focus of the system is for GIS application and this research is not GIS based. Therefore the systems functionality would not be utilized. Secondly, the system is complex and possesses features that would not be required. The system is also one of the more expensive available.

### **2.3.3 VISUAL RULES STUDIO**

Visual Rules Studio (VRS) is an object-oriented, rule development environment catering for Windows NT, Windows 99 and Windows 95. It is based on the Production Rule Language (PRL) and Inference Engines of LEVEL5 Object. The PRL Language and Inference Engines are compatible in language representation and engine behaviour to LEVEL5 Object (Rule Machines Corporation, 2005).

## **The Rule Development Process**

VRS is integrated with the Visual Basic development environment, producing output that can interact with many modern development products. VRS is a stand alone editing environment, it includes the PRL Developer, also has testing and debugging facilities that allow the developer to edit, run and test the RuleSets. VRS allows for developers to package rules into component reusable objects called RuleSets (Rule Machines Corporation, 2005).

## **Visual Rule Studio Inferencing Strategies**

Visual Rule Studio inference engines control the strategies that determine how, from where, and in what order a knowledge base draws its conclusions through the expert system. The inference strategies model the reasoning processes that an expert would use when solving a given problem.

The following strategies are used in Visual Rule Studio;

1. Backward-chaining
2. Forward-chaining
3. Hybrid-chaining
4. Procedural

Each of the strategies acts on specific knowledge base components. The backward-chaining strategy starts with a specific hypothesis (or hypotheses) known as the agenda. The inference engine then works backward from the agenda, pursuing a hypothesis via its search order strategies. The forward-chaining strategy starts with known data or conditions and then determines what can be concluded from the given data. The hybrid inference strategy (or mixed mode) is a mixed strategy that combines backward and forward chaining. The procedural strategy allows the writing of methods in PRL, using techniques similar to traditional 3GL programming (Rule Machines Corporation, 2005).

## **Reasons for not adopting the Visual Rules Studio Expert System Shell**

The Visual Rules Studio Expert System Shell is an extremely powerful tool. It was not adopted for two main reasons. First, Visual Rules Studio is one of the more expensive shells available. Second, the shell is extremely complex, and as this dissertation seeks to produce a relatively simple system, many of the functions would lead to user confusion and would not be utilized. Additionally the developer has to encode the RuleSets.

### **2.3.4 ACQUIRE 2.1**

The Acquire system is designed for use with Microsoft Windows 95, 98, 98SE, Me, XP or NT. It is designed to allow non-programmers to articulate, structure and implement their knowledge in an expert system application. Acquire uses a knowledge base which is developed in Acquire and put to work by the Inference Engine (the run-time component) to solve problems called Cases. The Inference Engine also possesses easy-to-use

debugging facilities to test and maintain the knowledge base. Acquire has two main components; the Knowledge Acquisition System, enabling the construction of knowledge, and the Inference Engine, to run knowledge bases on particular Cases where the captured knowledge is applicable (Acquired Intelligence Inc., 2004).

### **The Acquire System**

The first design concept of Acquire is to help the developer effectively organize knowledge, helping structure and focus expertise to reflect the way an expert actually uses knowledge to solve problems. This organization is critical in generating meaningful explanations of the system's decisions and is required in order to earn the confidence of the end user (Acquired Intelligence Inc., 2004).

The second design concept of the system results from the idea that expertise results from extensive experience in recognizing and reacting to specific patterns rather than the application of general rules to specific situations. This concept allows a variety of ways of capturing knowledge, all being focused on a qualitative representation of knowledge. The qualitative representation uses specific patterns of information to describe situations that experts can observe or contemplate. Therefore both explicit and implicit knowledge may be captured, allowing not only the knowledge that the expert already has to be captured, but also what the expert is capable of knowing. It can achieve this by requiring the expert to encounter situations not previously considered, resulting in thorough knowledge bases being constructed (Acquired Intelligence Inc., 2004).

### **Expertise Based on Pattern Recognition**

Many expert system shells only utilize production rules. However, if there is no production rule that matches a specific situation then the system tries to reason from first principles (using more general production rules) or the system fails. Acquire has the ability to support production rules, but also represent expert behavior as specific pairings of input patterns (object values) to a known consequence for another object, within a particular situation. Thus very specific pattern-consequence relationships are accumulated. In a certain situation if the patterns observed lack a known consequence the expert reasons from first principles or other problem solving methods such as analogies in order to isolate a plausible consequence, and thus completes the pairing. In the system the patterns possible for consideration are listed in an action table and the end user assigns a consequence to each pattern (Acquired Intelligence Inc., 2004).

This perspective implies that expert behaviour involves highly specific pattern-recognition behaviour employed in sensation and perception, adapted to a cognitive role. Such a perspective is supported by the idea that pattern recognition is among the best-developed of perceptual and cognitive skills. Experts tend to know what information is relevant and act quickly, with definite decisions and actions. Experts rarely stop to ponder or retract their decisions except in cases lying at the fringe of their expertise, thus engaging in efficient pattern-recognition behaviour (Acquired Intelligence Inc., 2004).

## Reasons for adopting Acquire 2.1 Expert System Shell

The Acquire 2.1 system is the most basic system evaluated. The system was also the most inexpensive system evaluated without being opensource. Another benefit of Acquire is that it is simple to use through the Editors, therefore time taken to learn a programming language is not a concern as with the other systems evaluated. Although the system is relatively basic in terms of functionality, it is sufficient for this project. The system is an appropriate one for the author's entry into expert systems.

## 2.4 KNOWLEDGE REPRESENTATION

Smith (1996) defines Knowledge Representation as the formalizing and storing of knowledge in some suitable structure to allow for subsequent computer processing.

Object-oriented programming is well suited to knowledge base development. Professor Ian Sommerville (Sommerville, 1992) defined an object as an entity which has a state and a defined set of operations to access and modify that state. In this definition the object has both data and code, with the code relating to the functions or rules for processing the data. Objects are independent and can be changed, as all of the relevant information is held within the object itself. This quality of an object is referred to as encapsulation. Object-oriented systems also allow the reuse of objects within the system (Smith, 1996). According to Acquire developers, objects are the basic building blocks of the knowledge base, and are essentially anything that an expert takes into account when solving a problem or reaching a conclusion (Acquired Intelligence Inc., 2004). Knowledge representation was achieved through the object-oriented expert system shell Acquire. For a detailed manual on how Acquire is used the reader is directed to the Acquire Users Guide version 2.1 (Acquired Intelligence Inc., 2004).

### 2.4.1 OBJECTS AND VALUE SETS

Objects were defined through the processes of literature survey of the knowledge domain, decision analysis and concept mapping. Objects were created and maintained in Acquire's Object Editor. Additionally Abbreviations were created for each object, in order for graphic representation of the decision tree to be simplified. Selecting *Editors* then *Objects* activates the Object Editor. An example of the Object Editor is shown in Figure 5, Section 4.4.1.

In defining an object, values were specified that the object could assume. All values expressed in Acquire are symbolic, not numeric. The Value Set Editor was used to create and maintain value sets. Selecting *Editors* then *Value Sets* activates the Value Set Editor. Acquire defines value sets independently of objects so that objects can share value sets.

### 2.4.2 SUPPORT IN THE KNOWLEDGE BASE

The next step in building the knowledge base was to state which objects influence, or lend support to other objects. Every object is linked to other objects by relationships of

support. The support network defines how objects are assigned values when the inference engine runs (Acquired Intelligence Inc., 2004). The support links among the objects were created and maintained in the Support Editor. Selecting *Editors* then *Support* activates the Support Editor. An example of the Support Editor is shown in Section 4.4.1, Figure 7. The influence relationships between objects were defined through the processes of decision analysis and concept mapping.

### **2.4.3 DECISION TREE**

Acquire generates a graphical representation of the Support network in the knowledge base in a decision tree format, called the Object Graph. The tree is a graphic representation of the decision paths used by the domain experts in solving domain problems. The Object Graph is viewed by selecting *Graphs* then *Objects*.

### **2.4.4 RULE DEVELOPMENT**

In order to specify how the support relationships work, rules must be developed. Support indicates which objects are used to determine which other objects' values, but rules specify the actual value that an object is given when its supporting objects possess a certain pattern of values. Acquire has two types of rules, Action Table Rules and Production Rules (Acquired Intelligence Inc., 2004). Action Table Rules were used in building the knowledge base of this project. Rules were created and maintained in the Rule Editor. Selecting *Editors* then *Rules* activates the Rule Editor. An example of the Rule Editor is shown in Section 4.4.3, Figure 16.

### **2.4.5 USER REPORT DEVELOPMENT**

A User Report is a report intended to be read by the user of the expert system. The User Report consists mostly of plain text, but also contains Tags, which are codes that are used to customize the report according to the values of the objects in the knowledge base. In generating a User Report, Acquire interprets the Tags and replaces them with plain text, creating a finished report that the user can read (Acquired Intelligence Inc., 2004). In this case the user reports contain educational information pertaining to the knowledge domain. User Reports were created and maintained in the User Report Editor. Selecting *Editors* then *User Reports* activates the User Report Editor. An example of the User Report Editor is shown in Section 4.4.4, Figure 20.

## **2.5 PROTOTYPING**

According to Pedersen (1989), prototyping (rapid prototyping) is a method made up of several steps repeated until the application is finished. The following iterative approach was followed (Smith, 1996):

1. User's basic information requirements were identified and prototyping objectives were defined.
2. A working prototype was designed and developed.

3. The prototype system was implemented and evaluated.
4. The prototype was revised and enhanced.

Prototyping is an iterative, evolutionary and exploratory technique, which has become the most popular medium for developing knowledge base systems (Smith, 1996). The prototypes developed in this project were of the Roundup Ready® Soybean transgenic crop. Several versions were developed and enhanced. The final prototype was expanded to incorporate all the transgenic crop knowledge investigated in this project.

### 3. THE ACQUIRE EXPERT SYSTEM SHELL

#### 3.1 TOP-DOWN KNOWLEDGE STRUCTURING

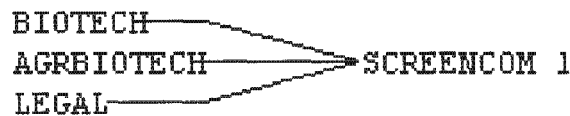
Using Acquire the developer is guided through successive steps of knowledge structuring, yielding models of domain knowledge at varying levels of generality, with the most general model being the Object Network. All things that are relevant to the expert's knowledge are named as objects. An object is anything that occurs, is considered or is concluded by the expert, such as data, observations, variables, hypotheses, conclusions and concepts. Every object has a set of values (or meanings) that are defined by the domain expert (Acquired Intelligence Inc., 2004).

Objects are first named and then linked together in an Object Network. If the value of one object can influence the value of another object then the two are linked. Due to the fact that the actual value of objects is not considered at this stage, the linkage of objects into a network constitutes a general model of the domain showing the flows of influence from one object (or object cluster) to another (Acquired Intelligence Inc., 2004).

The next level of knowledge structuring involves grouping objects connected in the object network into packages that are able to form Rules. Each Rule has a left-hand side (input) and right-hand side (result of the rule). Values of the right-hand side objects depend on the values of the left-hand side objects. In forming the Rule, the left-hand side objects chosen to affect the right-hand side object may only be selected from the set of objects linked to the right-hand side object in the Object Network. The rules are linked when the right-hand side object of a particular rule feeds in as a left-hand side object of another rule. These rule links form the Rule Network. The following is an example of the structure of a rule, consisting of a collection of objects on the left-hand side that compute a value (meaning) for the object on the right-hand side:

**input-object<sub>1</sub> input-object<sub>2</sub> ... input-object<sub>n</sub> → output-object**

The following is an example of the first rule in the knowledge base of this project as expressed in the Rule Graph, where **BIOTECH** is **input-object<sub>1</sub>**, **AGRIBIOTECH** is **input-object<sub>2</sub>**, **LEGAL** is **input-object<sub>3</sub>** and **SCREENCOM 1** is the **output-object**:



**Figure 3: Example of the SCREENCOM 1 Rule in the knowledge base**

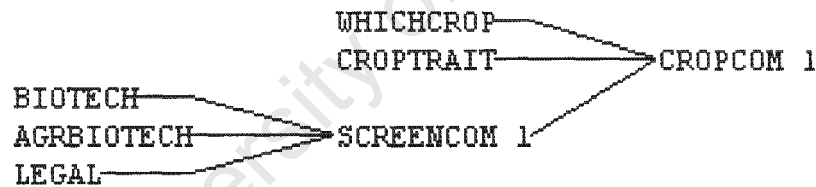
At this stage the details of each rule must be completed. In order to complete the specifications of each rule, all the possible values that each object may assume are specified. The values in turn specify the exact relationship between the objects in a rule (Acquired Intelligence Inc., 2004).

Detailed knowledge can be expressed using two types of rules; the Action Table and the Production Rule. The Action Table consists of highly specified patterns arranged in tabular form (as on a decision table), as shown in Section 4.4.3, Figure 17. The Production Rule expresses knowledge on a more abstract level in the form of an If-Then rule. The following is an example of the SCREENCOM 1 Rule as a production rule:

**IF** BIOTECH and AGRIBIOTECH and LEGAL are inputted (left-hand side objects)  
**THEN** SCREENCOM 1 is outputted (right-hand side object)

The Action Tables are able to automatically enumerate all possible patterns described by the combination of left-hand side objects. However, all these patterns can also be covered by the Production Rule technique, but one must be careful not to miss a pattern, or to assign different consequences to the same input patterns (Acquired Intelligence Inc., 2004).

The final knowledge-structuring step involves controlling the path of reasoning and resolving conflicts between competing paths to a problem solution. A critical tool in defining rules is the Context, which permits the developer to express situational constraints that must be met before the rule is applied. These contexts may be used to subdivide the rule network into connected clusters of rules to explicitly control the reasoning path and to avoid unnecessary conflicts between rules. The following is an example of two connected rules in the knowledge base as expressed in the Rule Graph:



**Figure 4: Example of the connected rules SCREENCOM 1 and CROPCOM 1 in the knowledge base.**

In order for the CROPCOM 1 rule to fire its Context must be fulfilled. The Context for CROPCOM 1 is that SCREENCOM 1 is completed. In the knowledge base this occurs when the value for the object SCREENCOM 1 = Done. Contexts in rule development are further dealt with in Section 4.4.3. However, in certain situations rule conflicts cannot be avoided. The developer therefore is able to express a preference for the rule that should take precedence. However, if such a resolution cannot be made, then the developer may express a bias to sway the decision among competing rules toward values with particular characteristics (Acquired Intelligence Inc., 2004).

Knowledge structuring in Acquire moves from a focus on building the knowledge base to a focus in the final steps on the input-output interfaces. In a normal consultation with an expert the session usually ends with the client receiving advice in a usable form. In Acquire certain utilities deliver reports in a pre-specified or customized formats.

The step-wise process of developing the expert system can be summarized as follows:

Building the knowledge base

Step 1. Object Network

Step 2. Rule Network

Step 3. Rule specification (Action Tables/ Production Rules)

Finishing the application (input/output)

Step 4. Case Setup

Step 5. Report Writing

### **3.2 QUALITATIVE REASONING ABOUT UNCERTAINTY**

The traditional expert systems dealt with uncertainty by numeric methods that quantify expert conclusions by numbers, such as confidence and certainty values. However, research indicates that people are notoriously poor at making such absolute numerical judgments. However, taking the precept that highly skilled behaviour is primarily based on pattern recognition, Acquire attempts to implicitly resolve uncertainty by structuring patterns. Thus no additional numerical methods are used (Acquired Intelligence Inc., 2004).

Experts qualify their conclusions in a relative and qualitative manner in the system. The uncertainty is inherent in the pattern-based units and is extracted without explicitly addressing the issue of uncertainty. The Acquire system resolves uncertainty by having the expert directly assign a consequence to a specific pattern, and by the explicit assignment of preferences for one particular pattern-consequence unit over another within a certain situation, or a bias toward a certain consequence (Acquired Intelligence Inc., 2004). This is shown in the construction of an Action Table, as seen in section 4.4.3, Figure 17, where each row in the Action Table denotes a specific pattern of events.

### **3.3 STEP-WISE KNOWLEDGE ACQUISITION**

As mentioned above Acquire takes the developer through a step-by-step approach to building a knowledge base. However, the steps need not be completed in the order given. As an example, the object details, such as assigning value sets or mappings of numeric ranges to symbolic values, can be completed when objects are created, or left until later. It is often beneficial to simply create the Object Network, and then before focusing on object details, explore different ways of structuring the knowledge in the Object Network. A similar approach can be used for the Rule Network. It may be insightful to explore the structure of the rule network by packaging objects into rules without completing further details. Note that the specific nature of the relationships between the objects in a unit is unknown until details of the rule are completed. It is often advisable to avoid narrowing the focus of attention to this level straight away until a number of objects have been packaged into rule units (Acquired Intelligence Inc., 2004).

### 3.4 ACTION TABLES AND PRODUCTION RULES

Acquire supports two types of rules; Action Table Rules and Production Rules. The advantages of Action Tables include the following:

- More expressive power than production rules.
- Knowledge organization is simpler, giving better overall perspective.
- Encourage completeness of the knowledge.
- Reduce the likelihood of conflicts in the knowledge base.
- Reduce debugging time.

Production rules are easily created as they contain small units of knowledge, but tend to be difficult to maintain in the larger context. Action tables retain a simple format for rules within a cohesive structure, combining similar production rules into a single rule, thereby providing an additional level of abstraction simplifying the rule network (Acquired Intelligence Inc., 2004). This is achieved with the tabular format of the Action Table as seen in Section 4.4.3, Figure 17. Many objects can be tabulated together forming one rule.

No matter which type of rule, the first step in rule construction is the selection of the objects that are involved in the rule. Each rule has left-hand side objects describing the applicable situation and a right-hand side object whose value is determined by the rule, as seen in Figure 3. Production rules may represent a number of different situations through various combinations of permissible values for left-hand side objects. However, the action table can represent all permissible combinations of the left-hand side objects. Again, the reader is directed to Section 4.4.3, Figure 17 to view an example of an Action Table in the knowledge base. In addition, production rules can change the right-hand side object to only one of its allowable values and the rule will produce only this value for all the patterns matched by the left-hand side of the rule. In contrast, the action table allows the developer to assign any one of the right-hand side object's values to each of the individual patterns represented on the left-hand side of the table. Production rules may miss some patterns or several rules may overlap and react to the same patterns with different results. Thus gaps in the knowledge may be created. The rule conflicts may be hidden until cases involving the contradictory rules are processed. Thus the action table allows a greater degree of flexibility and completeness for formatting rules (Acquired Intelligence Inc., 2004). Action Table Rules were used in the research.

### 3.5 FORWARD AND BACKWARD CHAINING IN ACQUIRE

Acquire supports forward and backward chaining inference strategies (Acquired Intelligence Inc., 2004). Giarratano and Riley (1989) define forward chaining as reasoning from facts to the conclusions resulting from those facts. An example of forward chaining logic in the knowledge base is that if there is a valid environmental concern regarding insect resistance to transgenic insect-resistant maize (the fact), then insect-resistance management and monitoring should take place (conclusion). Giarratano and Riley (1989) define backward chaining as reasoning in reverse from hypothesis, a

potential conclusion to be proved, to the facts that support the hypothesis. An example of backward chaining logic is that if management and monitoring for insect-resistance in transgenic insect-resistant maize is required, then insect resistance in transgenic insect-resistant maize is an environmental concern. The forward chaining inference engine collects all the rules that can possibly fire and then tries to fire them. The rules that can possibly fire are those that have values available for each of their left-hand side objects. There are three sources from which values of left-hand side objects can come:

1. The case, where the value is part of the problem description (descriptions of previous cases are used to match characteristics of current problems).
2. Interactively from the user, called keyboard input.
3. The earlier firing of another rule.

The inference engine then fires all the fireable rules in what is known as a cycle. Once the rules fire and the cycle ends, then a new cycle begins and the process repeats itself with a new set of rules that could possibly fire. The entire process is continued until no rules are left that could fire (Acquired Intelligence Inc., 2004).

The backward chaining inference engine strategy first locates a terminal rule (a rule at the end of a decision path). This rule is evaluated as to whether it can fire or not. The rule can fire if all the left-hand side objects have a value. In a case where the terminal rule cannot fire due to the fact that a left-hand side object's value can only be obtained from another rule's inference, then the engine moves to this prior rule and evaluates whether or not that rule can fire. The chaining process continues until the rules fire up to and including the initial terminal rule. At the stage that the terminal rule fires, the entire process is repeated with another terminal rule until there are no more terminal rules (Acquired Intelligence Inc., 2004).

Expert systems have predominantly been developed with backward chaining inference engine strategies, due to the field's early roots in game theory and automated problem solving. However, this dominance has led to the assertion that diagnostic tasks are actually solved by human experts through backward chaining inference. This assertion, however, is not supported by research on human cognition and research comparing experts with novices. The conclusion drawn from these studies is that humans are largely forward chaining when accomplishing diagnostic tasks and many other tasks appropriate for expert systems (Acquired Intelligence Inc., 2004).

In developing knowledge bases it tends to be easier to specify knowledge in a form suitable for forward chaining. By specifying the inputs necessary for an inference and then specifying further inputs that are considered along with the prior inference to yield a further inference towards solving the problem, allows one to more easily follow the decision path (Acquired Intelligence Inc., 2004). Forward chaining was used in this research project. Forward chaining in the knowledge base can be seen in Section 3.1, Figure 4, where the two rules SCREENCOM 1 and CROPCOM 1 are connected. First the value for SCREENCOM 1 is determined, and only then can the value of CROPCOM 1 be determined. Thus the logic flows forward from SCREENCOM 1 to CROPCOM 1.

## **3.6 FURTHER CAPABILITIES**

### **3.6.1 Case-Orientated Reasoning**

Top-down structuring and specific pattern recognition techniques allows for focus on specific and relevant aspects of a particular case. In considering a certain rule (the patterns that may be produced by the combinations of values of the left-hand side objects) the developer is focused on a specific part of the problem, with each pattern representing a different case at that analysis level (Acquired Intelligence Inc., 2004).

The Acquire system allows for not only what the developer/expert currently knows to be included in the knowledge base, but also what the developer/expert is capable of knowing, so that cases can be handled that have not yet been encountered. The developer/expert must make pattern-consequence assignments for each possible pattern of input values within a structuring unit. However, rarely does the developer/expert have to consider the huge number of possible patterns through combination of all object values, as most patterns are rendered irrelevant through the structuring process of object grouping into suitable packages for constructing rules. Structuring units, if considered collectively, describe all possible cases that the developer/expert can address (Acquired Intelligence Inc., 2004). Case-orientated reasoning was not required in this research project.

### **3.6.2 Contexts versus Preferences and Biases**

Legitimate conflicts between rules may exist, but they need to be resolved. These conflicts arise when several rules attempt to set the same right-hand side object to different values. Conflicts are legitimate if the expert does not possess the knowledge necessary to prevent the conflict. However, the expert may possess the expertise to resolve the conflict between the rules. Acquire has three methods to resolve conflicts:

1. Contexts
2. Preferences
3. Biases

Although there is a general tendency to use preferences to solve conflicts, as it is easier to indicate which rules are preferred in a particular conflict than to specify contexts in which situations occur in order to prevent the clashes from occurring in the first place. However, this should be avoided, as expertise should aim to avoid conflicts between knowledge sources completely. Thus the first step in resolving conflicts is to specify preconditions in the Contexts of one or more of the conflicting rules in order to prevent them from being considered. Essentially it is the addition of expertise, restricting situations in which conflicts can arise. Situations may exist where expertise has not yet been developed to avoid conflicts, but can resolve them once they have arisen. In this situation Preferences should be used. It is a case of the knowledge of one rule being known to be superior to knowledge in another rule; however, the reason for the choice may be unknown or too

difficult to specify. A situation may arise where sufficient expertise is not available to choose between knowledge sources. The method of last resort for such cases is called a Bias. The developer can specify a Bias to select a particular value, or value type, for the right-hand side object. However, due to the fact that the bias method does not consider the source of knowledge it is the least preferred (Acquired Intelligence Inc., 2004). Contexts were used for the rule development in this research project.

This chapter has given the general functioning of the Acquire expert system shell and general concepts of knowledge engineering, which can be applied to varied problem domains. The following chapter describes the prototype knowledge base for this project, constructed using the Acquire expert system shell. More specific knowledge engineering examples are given from the prototype knowledge base. A basic instruction guide on how to use the Acquire program is supplied in Appendix D.

An evaluation version of the Acquire® expert system shell can be obtained from Acquired Intelligence Inc. at the following contact details:

Mailing Address: 205-1095 McKenzie Avenue  
Victoria, B.C., Canada, V8P 2L5  
Telephone: (250) 479-8646  
Fax: (250) 479-0764  
Email: info@aiinc.ca  
webmaster@aiinc.ca  
sales@aiinc.ca

## **4. PROTOTYPE EXPERT SYSTEM FOR EDUCATION OF ENVIRONMENTAL CONCERNS, MANAGEMENT AND MONITORING OF THE TRANSGENIC CROPS SOYBEAN, MAIZE AND COTTON**

### **4.1 INTRODUCTION**

This chapter describes the prototype expert system as an educational tool for the transgenic crops Soybean, Maize and Cotton. The focus of the chapter is on the knowledge engineering of the prototype and the rationale behind the specific knowledge representation in the knowledge base. The problem domain and knowledge domains are defined for the prototype. Principles of the knowledge model are discussed. The actual knowledge representation in the prototype is presented under the concepts of Objects, the Decision Tree and User Reports. Certain 'special questions' found in the decision framework are investigated, determining their influence. Toward the end of the chapter possible improvements to the prototype are discussed. The prototype knowledge base is supplied as Appendix G.

### **4.2 PROBLEM DOMAIN AND KNOWLEDGE DOMAINS**

Giarratano and Riley (1989) define a Problem Domain as the special problem area such as medicine, finance or science that an expert can solve problems in. Using this definition, the Problem Domain of the prototype is "transgenic crops" as a general subject.

Giarratano and Riley (1989) go further to define a Knowledge Domain as the expert's specific knowledge about solving specific problems. Using this definition, the Knowledge Domains of the prototype are Biotechnology, Agribiotechnology, Genetically Modified Organism Legislation, Agroecology, Principles of General Ecology, the specific transgenic crops investigated (Roundup Ready® Soybean, Roundup Ready® Maize, YieldGard Maize, Bt11 Maize, Roundup Ready® Cotton and Bollgard® Cotton) and Environmental Management.

Knowledge regarding the above mentioned Knowledge Domains was sourced through the Knowledge Acquisition process described in Chapter 2. The rationale for the Knowledge Domain categories was established through the processes of decision analysis and concept mapping also described in Chapter 2 (Green and Machaba, 2005).

### **4.3 PRINCIPLES OF THE KNOWLEDGE MODEL**

As mentioned in Chapter 2 the knowledge modelling for this project was based on a hybrid of two models, the PreSERVe model (Coffey et al., 2003) and the intelligent computer-aided education systems design model (du Plessis et al., 1995), where the PreSERVe model focuses more on the "process" of knowledge modelling and the intelligent computer-aided education systems design model focuses more on the "knowledge structure" of knowledge modelling. Other knowledge modelling principles were brought into the hybrid model and are discussed.

### 4.3.1 The PreSERVe Model

The PreSERVe model is a method comprising the following steps (Coffey et al., 2003):

1. Initial preparation
2. An iterative process of examining scope of the project
3. Eliciting knowledge (knowledge acquisition)
4. Rendering the knowledge into a knowledge model (knowledge representation in the knowledge base)
5. Verifying results (through case runs in Acquire)

The PreSERVe model is based upon the use of Concept Maps. The use of the contrived technique of creating Concept Maps aided in assessing the project scope, and lending structure to the interviews. Appendix E shows an example of one of the concept maps used for YieldGard® Maize. In this example concepts are organized together with themes running from left to right. The model's iterative nature is a critical aspect. The creation of Concept Maps led to an increased understanding of the efficient reasoning strategies employed by the experts. The process of reassessing the scope of the project aided in knowledge elicitation by uncovering tacit expert knowledge. Retrospection also proved valuable in the verification stage. The iterative nature additionally suited the method of prototyping employed.

### 4.3.2 The Intelligent Computer-Aided Education (ICAE) Systems Design Model

The following attributes of the ICAE model were incorporated into the hybrid model used (du Plessis et al., 1995):

- The dynamic adaptation of assistance to the user.
- An active learning environment, where the user actively controls the learning process and environment.
- Providing a virtual problem-solving world, extending the user's learning environment and adding a dynamic dimension to it.
- Establishing a framework for the improvement of thinking skills.

The following principles of the ICAE model were incorporated into the hybrid model (du Plessis et al., 1995):

- Individual learning: the user has all the attention during a session with the prototype. The user receives advice tailored according to the specific needs and capabilities of the user currently involved with a prototype session.
- Individual control: based on the constructive problem-solving paradigm, the prototype allows the user to be in control of the problem-solving session, directing the interactions and manipulations in ways the user thinks best. In this case 'problem-solving' is discovering knowledge of transgenic crops.
- Supplement teaching: normal teaching activities can be supplemented by using the expert system.
- Stimulation: the prototype offers a virtual-learning world for the user, providing a stimulating educational environment.

- Special identification: knowledge base histories can be viewed assessing exactly what educational information different users have explored.
- Metacognition: the user becomes more efficient when he/she thinks about his/her thinking process. The user is able to recognise the logical decision framework used by experts in the field of transgenic crops. The user can then apply the same logical decision framework to other problems. The metacognition principle was also supported by Perkins (1991), Blakey and Spence (1990), Self (1995) and van Biljon et al. (1999) as discussed in Section 1.2.

The ICAE design philosophy provides a model consisting of modules. Each module has a specialized task to perform. The modules may link and function as one unit (du Plessis et al., 1995).

### 4.3.3 Further Knowledge Modelling Principles

The following principles of knowledge modelling were sourced from authors outside of the two previous knowledge models discussed, and incorporated into the hybrid model of the prototype (these principles are discussed in detail in Section 1.2):

- Principle of Competence building (Conceicao and Heitor, 2002)
- Principle of Integrated knowledge (Wilcox, 1996)
- Principle of Knowledge Creation and Knowledge Destruction (Lundvall and Johnson, 1994)
- Principle of Self-actualisation (Burlison, 2005 and Kay, 1991)
- Principle of Complexity-reduction (Winstanley, 1987), where the complexity of problem-solving is reduced while still achieving the solution to the problem.

## 4.4 KNOWLEDGE REPRESENTATION OF THE PROTOTYPE

### 4.4.1 OBJECTS AND VALUE SETS IN THE KNOWLEDGE BASE

Objects are the building blocks of the expert system. The objects in the prototype knowledge base are of two types; concepts in the Knowledge Domains investigated (such as “general biotechnology knowledge”) and concepts of the decision process of the expert system (such as “crop choice rule complete”). This follows the distinction between domain knowledge and control knowledge defined by Moreno et al. (2001), where domain knowledge includes general concepts of the knowledge domains and control knowledge pertains to the reasoning processes of the system.

Objects in the prototype were created, modified and viewed using the Object Editor, which is activated by selecting *Editors* then *Objects*. At the right side of the editor is also a list of all the Objects in the prototype knowledge base, which is generated as each new object is created and stored in the Acquire knowledge base. Selecting an object in this list fills the rest of the editor with information about the object (Acquired Intelligence Inc., 2004). The objects of knowledge domain concepts were generated from the knowledge acquisition process undertaken (see Section 2.1), and validated through the processes of decision analysis and concept mapping (Green and Machaba, 2005). These objects are the

concepts that the experts utilize in solving problems in the problem domain of transgenic crops. Through the iterative process of knowledge acquisition, the objects (concepts) in the prototype knowledge base were deemed necessary to form an integrated curriculum for the prototype, thereby fulfilling the principle of integrated knowledge. The strategic sourcing of specific knowledge required for the integrated curriculum was a key feature in the knowledge engineering of the prototype. Knowledge domain objects fall into the following categories:

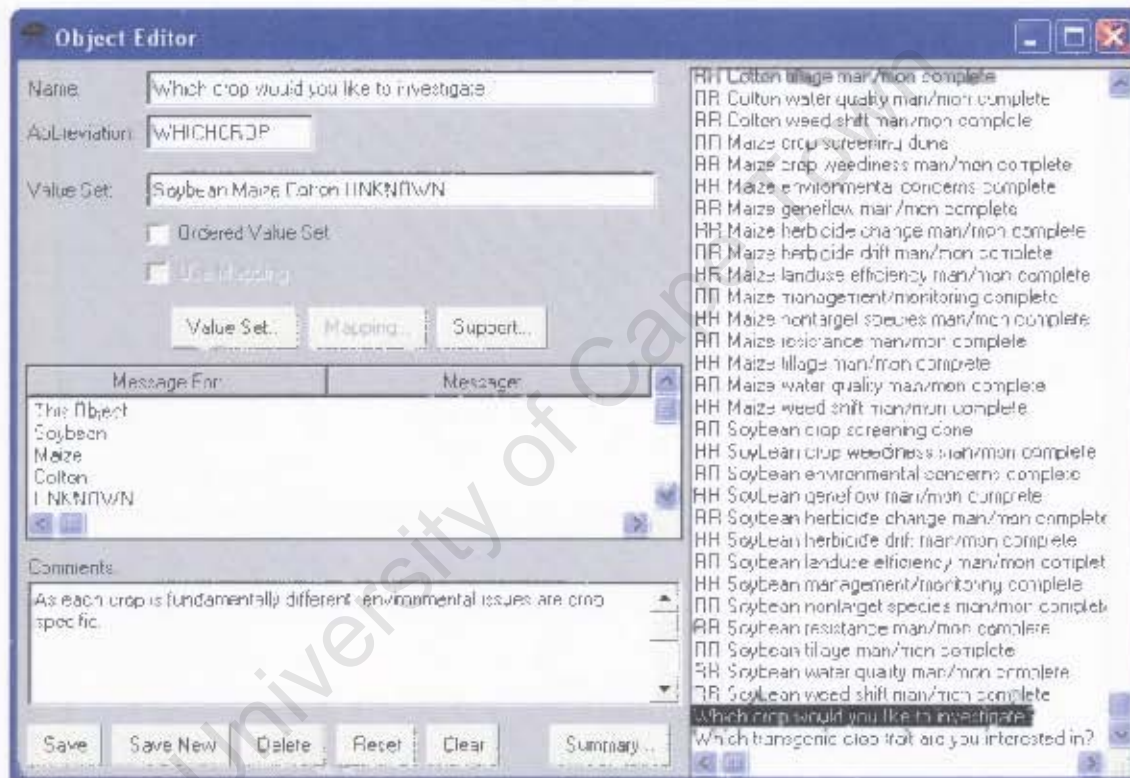
- Knowledge of biotechnology
- Knowledge of agribiotechnology
- Knowledge of legislation pertaining to genetically modified organisms
- Knowledge of the specific transgenic crop's biotechnology
- Knowledge of the specific crop's agronomics
- Knowledge of the specific crop's environmental concerns
- Knowledge of the specific crop's management of those environmental concerns
- Knowledge of the specific crop's monitoring of those environmental concerns

Figures 5 and 6 show examples of domain knowledge objects, while Figure 7 shows an example of a control knowledge object, as presented in the Object Editor of Acquire. The three objects make up the rule "Crop choice completed 1" as shown later. In the knowledge base the RR (Roundup Ready) designation denotes the herbicide-resistant crop concepts, and the Bt (*Bacillus thuringiensis*) designation denotes the insect-resistant crop concepts. A full list of the objects contained in the prototype knowledge base can also be viewed as a report by selecting *Reports* then *Objects*, activating the *Object Report*. Selecting an object or group of objects from the list on the left-hand side and clicking the *Start* button will generate a report of the details of the selected object(s).

The *Name* field contains the object's unique name, which every object must have. The *Abbreviation* field contains the object's unique abbreviation, which every object must also have. The *Value Set* field contains the object's value set, which may not be unique. To edit the value set, the *Value Set* button must be selected and a new set from the list that appears must be chosen. Value sets are modified in the *Value Set Editor*. The *Ordered Value Set* option must be checked if the object's values possess meaning in a certain order. By default value sets are not ordered. The *Use Mapping* option must be checked if numeric values are used as values in the knowledge base. The *Mapping* button activates a dialog for the choice of a mapping for the object. Numeric values were not directly used in the prototype knowledge base. The *Support* button activates a dialog that shows the support structure for the object. The *Messages For* and *Message* fields contain messages for the object. The messages themselves are found in the right column, while the item corresponding to each message is given in the left column. Messages are optional in the knowledge base. The *Comments* field is a free text area where comments about the object can be entered (Acquired Intelligence Inc., 2004).

Each object has an associated Value Set. A Value Set is a collection of values, and any one of them can become the object's value. The Values in Acquire are symbolic values, expressing the value of an object in a qualitative way (Acquired Intelligence Inc., 2004). As an example the object "Which crop would you like to investigate? WHICHCROP"

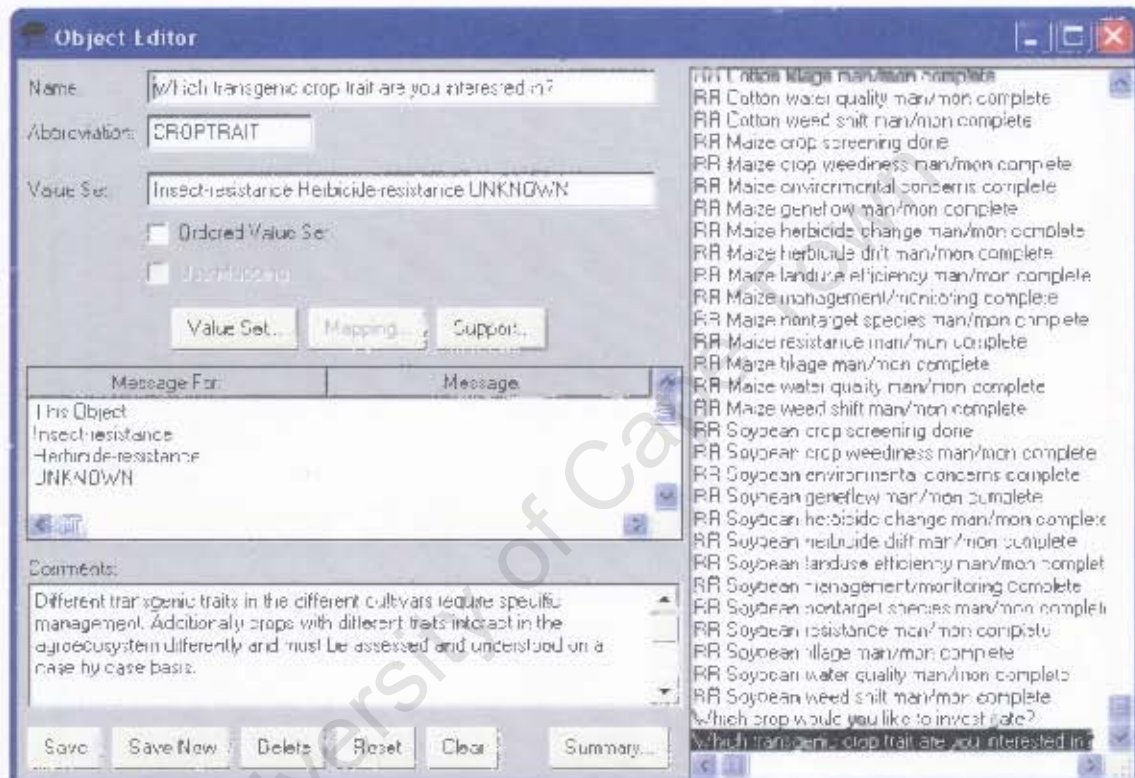
has the value set: Soybean, Maize, Cotton, UNKNOWN, as seen in Figure 5. The object can assume any of those values. The user determines which value the object assumes in a session, as it is a knowledge domain object, likewise with the object shown in Figure 6. Figure 7 shows the control knowledge object, "Crop choice completed CROPCOM". This object has the value set: Roundup Ready Soybean, Roundup Ready Maize, YieldGard/Bt11 Maize, Roundup Ready Cotton, Bollgard Cotton. Unlike the knowledge domain objects, this object's value is computed by the system using the "Crop choice complete 1" rule, from the values inputted by the user for the objects shown in Figures 5 and 6.



**Figure 5:** Example of Which crop would you like to investigate? (WHICHCROP) object in the Object Editor.

Value Sets were created, modified and maintained in the *Value Set Editor*. Selecting *Editors* then *Value Sets* activates the Value Set Editor. Figure 8 is an example of the Value Set Editor in the prototype. The list on the right side of the Value Set Editor contains the existing value sets. Value sets are created independent of objects in Acquire so as more than one object can use the same value set. Selecting an item from the list on the right fills the other controls of the Value Set Editor with information about that item (Acquired Intelligence Inc., 2004). The Value Set Editor to all value sets appends the value "UNKNOWN". A key characteristic of an expert is the ability to reason with missing information. The UNKNOWN value is used when information is missing but a conclusion is still to be reached. The setting of an object to UNKNOWN is different from

not giving the object a value at all. An object without a value is indicated as UNSET. A rule is not able to fire if any of its left-hand side objects are UNSET, however, if an object is given the value UNKNOWN, the rule that the object is part of can still fire. In the Run Case format of the knowledge base, the option of UNSET is available to the developer. However, in a programmed user interface, the UNSET option is not available as a value (Acquired Intelligence Inc., 2004).



**Figure 6: Example of Which transgenic crop trait are you interested in? (CROPTRAIT) object in the Object Editor.**

The *Values* field contains the value set that is currently being edited. The *Insert* button opens a blank line above the selected item in the Values list. The *Delete* button deletes the selected item in the Values list. The *Move Up* button moves the selected item in the Values list up by one position, while the *Move Down* button moves the selected item in the Values list down by one position. The *Comment* field is an open text field where comments on the value set can be entered (Acquired Intelligence Inc., 2004).

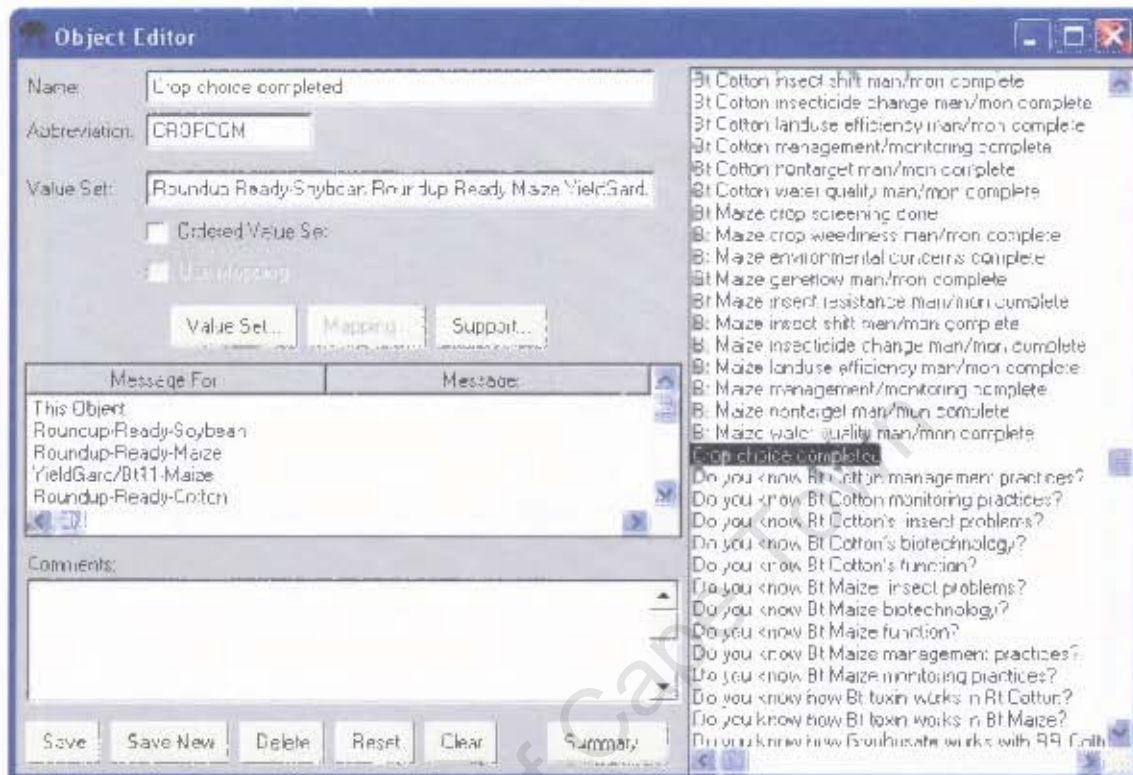


Figure 7: Example of Crop choice completed (CROPCOM) object in the Object Editor.

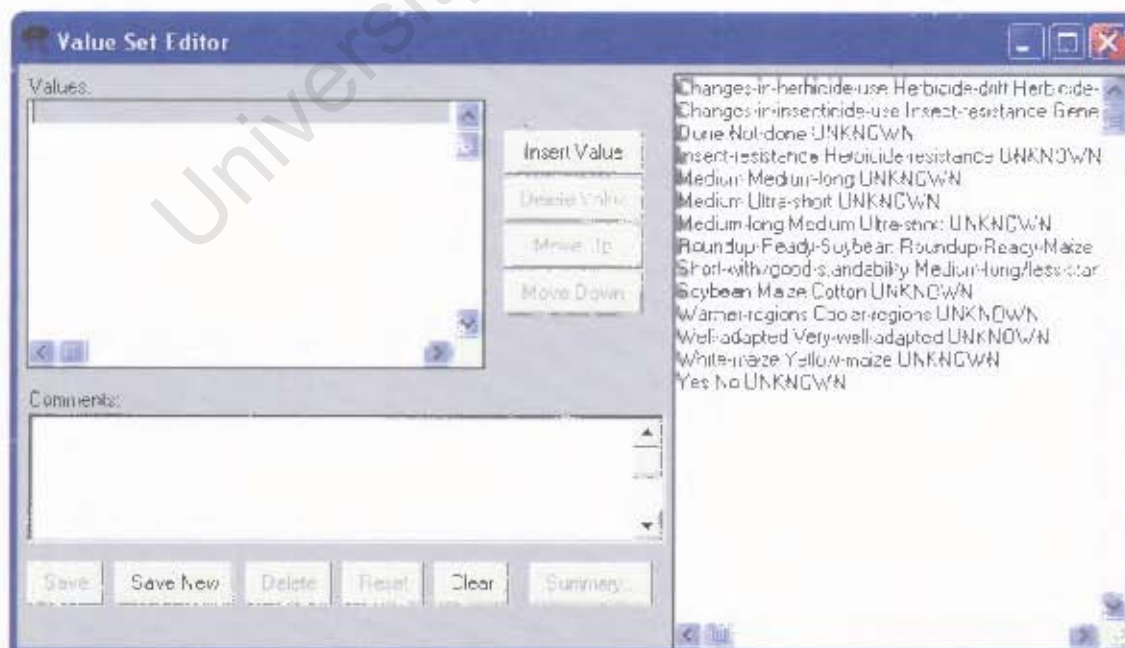
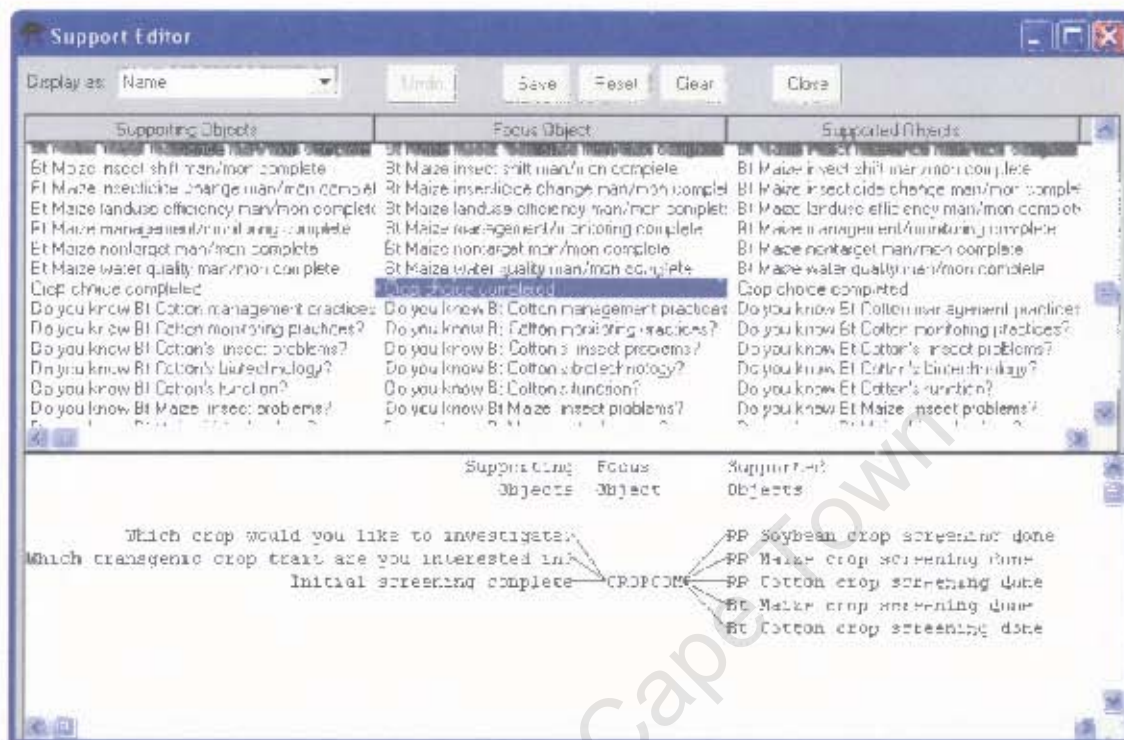


Figure 8: Example of the Value Set Editor in the prototype knowledge base.

Objects rarely exist in isolation in a knowledge base. There are usually relationships among objects in a knowledge base. Figure 9 shows an example of the object “Crop choice completed (CROPCOM)” in the prototype knowledge base, and the other objects that it has a relationship with, as shown in the *Support Editor* of Acquire. The relationships are based on influence (termed *Support* in Acquire). An Object is linked by a *Support link* to each Object that directly influences it. The Object also has Support Links to each Object that it in turn directly influences. Considered as a whole, the Objects and Support links form what is termed the *Support Network*, and can be viewed in the Object Graph. An object whose value determines the value of another object is said to support that object, while an object whose value is determined by the value of another object is said to be supported by that object. Support links are created, modified and maintained in the *Support Editor*. Selecting Editors then Support activates the Support Editor (Acquired Intelligence Inc., 2004).

The table at the top of the Support Editor is comprised of three columns, containing the names of the objects in the knowledge base. The centre column labelled as the *Focus Object* field allows the developer to select one object at a time. This object’s local support network is graphically displayed in the bottom portion of the Support Editor. In the left *Supporting Objects* column, the selected items are the supporting objects of the focus object. In the right *Supported Objects* column, the selected items are the objects that are supported by the focus object. The bottom portion of the Support editor that graphically displays the focus object’s local support network, reiterates the columns of the table above it (Acquired Intelligence Inc., 2004). The relationships between the objects in the prototype knowledge base were determined through the processes of decision analysis and concept mapping (Green and Machaba, 2006).



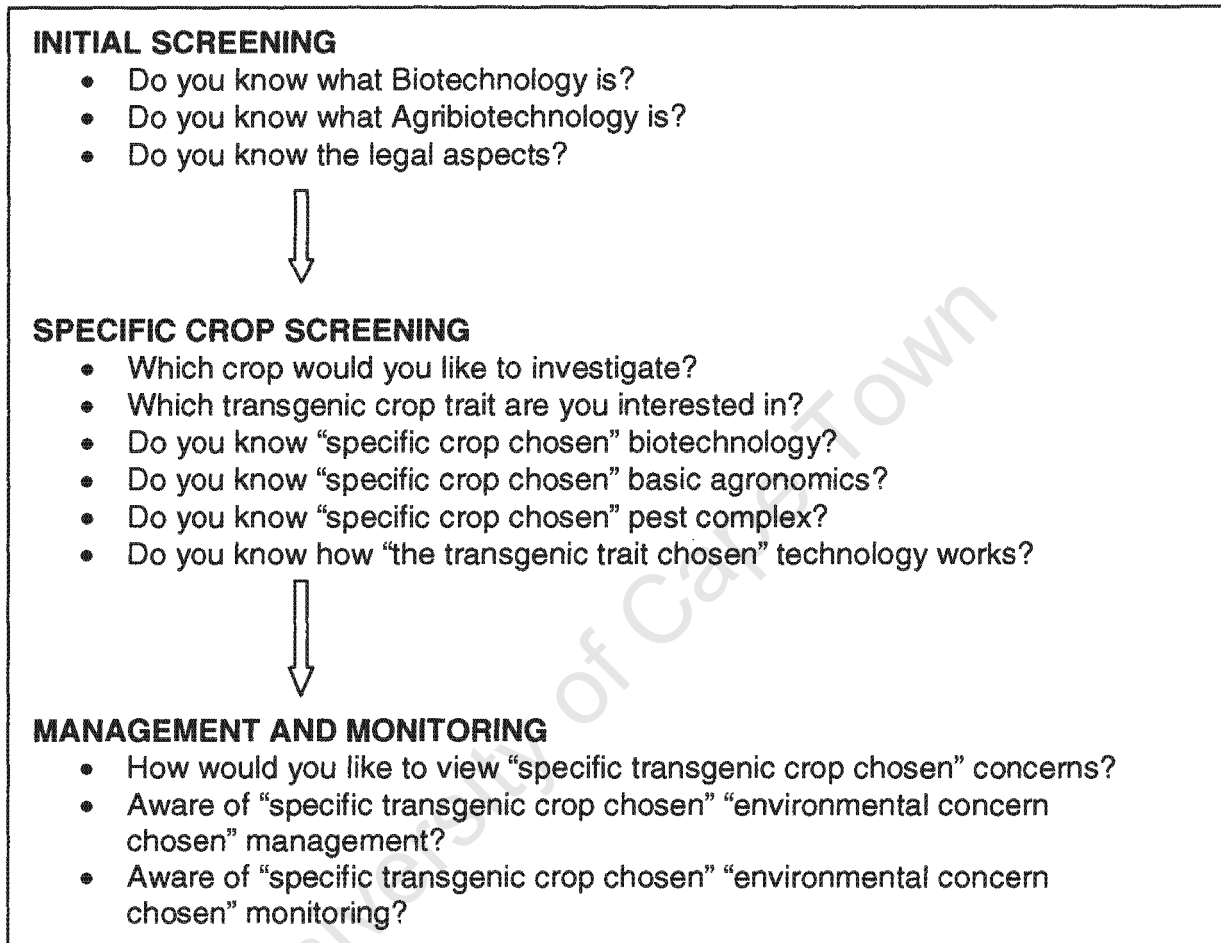
**Figure 9: Example of Support for Crop choice completed (CROPCOM) object in the Support Editor.**

#### 4.4.2 DECISION FRAMEWORK OF THE PROTOTYPE

##### 4.4.2.1 A Three-Phase Framework

The prototype expert system decision framework has three distinct phases, following the modular design philosophy of the ICAE model of du Plessis et al. (1995): an Initial Screening phase, a second Specific Crop Screening phase, and a third Management and Monitoring phase. The purpose of the Initial Screening phase is to determine the knowledge level of the user with respect to general biotechnology, agricultural biotechnology and the legal aspects of transgenic crops in South Africa. The input given by the user in this phase determines what information is supplied to the user in the Initial Screening Report. The purpose of the Specific Crop Screening phase is to allow the user to choose a specific crop to investigate (thereby also emphasising the importance of assessing any transgenic crop on a case-by-case basis) and then to determine the knowledge of the user about the chosen transgenic crop. The input given by the user determines what educational information is supplied to the user in the specific crop screening reports labelled Knowledge Reports. The final phase is the Management and Monitoring phase. The purpose of this phase is to determine the user's knowledge of environmental concerns, as well as management and monitoring of the crop chosen. This phase also allows the user to isolate and investigate a particular environmental concern, or to view all concerns related to the transgenic crop. The input given by the user

determines how the environmental concerns, management and monitoring will be investigated and what information pertinent to that line of investigation will be given in the Management/Monitoring Reports.



**Figure 10: The Three-Phase Framework of decision logic modelled in the prototype**

The process of iterative knowledge acquisition of the literature survey, decision analysis and concept mapping yielded knowledge of three main context areas that were used by experts in making decisions regarding environmental concerns, management and monitoring of transgenic crops. The first knowledge type required formed the broad context of biotechnology, agribiotechnology and the pertinent legislation. Without this first broad level context, fundamental errors in decision-making may result. The second context level consisted of knowledge specific to a particular crop variety. It became clear that transgenic crops had to be assessed on a case-by-case basis, generalizing the topic of “transgenic crops” again led to fundamental errors in decision-making. Equally, it became clear that a lack of technical knowledge regarding the specific transgenic crop led to fundamental errors in decision-making. Therefore this context level was constructed in order for a user to focus on a transgenic crop on a case-by-case basis and interact with technical knowledge. The third context level addressed the knowledge of the currently recognized environmental concerns, management and monitoring specific to transgenic

crops. It was found that once the knowledge of the first and second level contexts was in place, the knowledge of the third level context could be appropriately and efficiently assessed and utilized for decision-making. Thus the three knowledge context levels form the simplified mental framework of the decision-making process of an expert's decision path in the problem domain of transgenic crops.

#### 4.4.2.2 Framework Structure

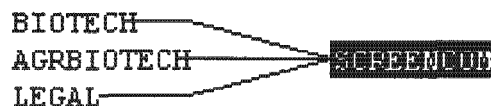
The building blocks of the decision framework are the objects that are encoded into the system as discussed earlier, with each object possessing a certain value. The framework becomes what is known as a Decision Tree when the objects are linked together in a Support Network, forming decision paths. The tree is based on logical steps of reasoning to attain an end goal. The first level of the tree is the Initial Screening phase, the mid-level is the Specific Crop Screening phase and the base level of the tree is the Management and Monitoring phase. The tree functions according to prescribed rule sets as mentioned in Section 3.4. Certain objects are clustered together in order to complete a given Action Table rule. Completed rule objects (objects on the right-side of the Action Tables form the nodes of the decision tree (i.e. junctions in the tree between different phases).

The decision tree can be viewed as a graph, known as the *Object Graph*. This graph is a representation of the links defined by the support structure created in the Support Editor (Acquired Intelligence Inc., 2004). The Object Graph is shown in Appendix A, and viewed in the Acquire knowledge base by selecting *Graphs* then *Objects*.

#### An Example of a Path through the Decision Tree

As an example one can follow one decision path through the framework of the decision tree. The Initial Screening consists of the following objects (with accompanied abbreviations):

- Do you know what Biotechnology is? BIOTECH
- Do you know what Agricultural Biotechnology is? AGRBIOTECH
- Do you know the Legal aspects? LEGAL
- Initial screening complete SCREENCOM

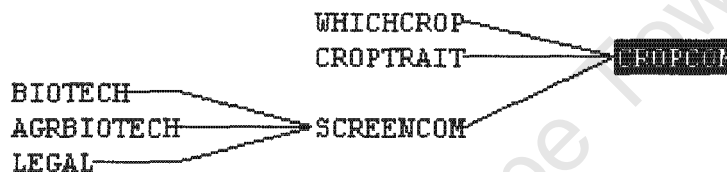


**Figure 11: Example of the Initial Screening objects in the Object Graph**

These objects form an Action Table with the objects BIOTECH, AGRBIOTECH and LEGAL being the left-hand side objects whose values compute the value of the right-hand side object, SCREENCOM. This completes the Initial Screening phase. Only once the object, SCREENCOM, has a value, will the next rule fire and the path in the decision tree continue. Whether or not the user is supplied with the information pertaining to the three left-hand side objects is dependent on the input values of those objects.

The next step of reasoning in the decision tree is the choice of a specific crop to investigate. This Action Table consists of the following objects:

- Which crop would you like to investigate? WHICHCROP
- Which transgenic crop trait are you interested in? CROPTRAIT
- Crop choice complete CROPCOM

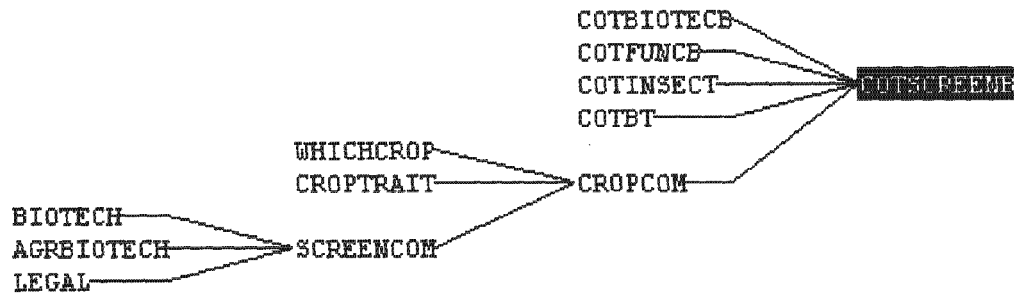


**Figure 12: Example of the crop choice complete Action Table in the Object Graph**

The objects WHICHCROP and CROPTRAIT are the left-hand side objects whose input values determine the value of the right-hand side object, CROPCOM. Note that there is a Context for this Action Table. In order for this Action Table's rule to fire the specified context must be true. In this case the context is that the value of the object Initial screening complete (SCREENCOM) must be "done". The Action Table rules and Contexts are encoded in the Rule Editor. The Crop choice complete (CROPCOM) object is a node in the tree and the value computed determines which path the line of reasoning will follow. In this example the value of WHICHCROP = Cotton and the value of CROPTRAIT = Insect resistance, therefore the computed value of CROPCOM = Bollgard cotton.

Due to the fact that CROPCOM = Bollgard cotton, the next Action Table in the decision tree consists of the following objects:

- Do you know Bt Cotton's biotechnology? COTBIOTECHB
- Do you know Bt Cotton's function? COTFUNCB
- Do you know Bt Cotton's insect problems? COTINSECT
- Do you know how Bt toxin works in Bt Cotton? COTBT
- Bt Cotton crop screening done COTSCREENB

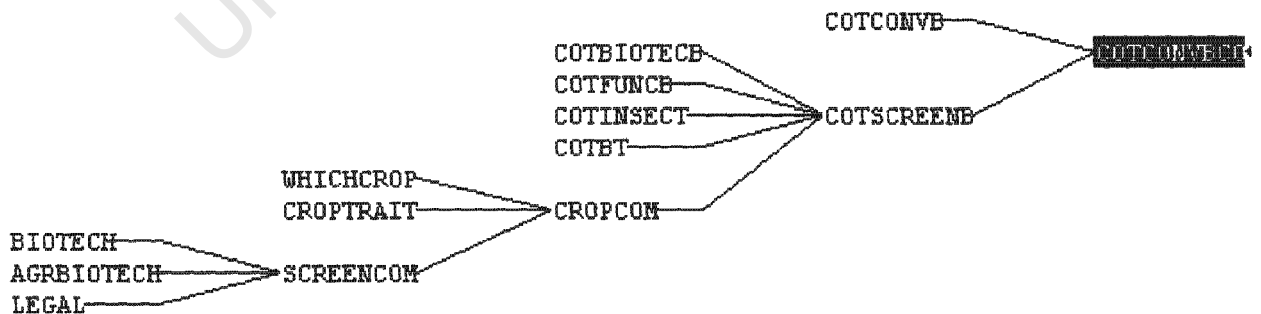


**Figure 13: Example of the Bt Cotton crop screening done Action Table in the Object Graph**

The objects COTBIOTECEB, COTFUNCEB, COTINSECT and COTBT are the left-hand side objects, whose input values determine the value of the right-hand side object, COTSCREENB. The information given to the user pertaining to the left-hand side objects is determined by the input values of those objects. The Context of this Action Table is that the value of the object Crop choice complete (CROPCOM) must equal “done”. This completes the Specific Crop Screening phase.

The decision tree now moves into the third phase of the framework, the Management and Monitoring phase. The next Action Table acts as a node, joining phases 2 and 3 of the framework. The Action Table allows the user to choose how he/she would like to investigate the specific environmental concerns of the transgenic crop chosen and the associated management and monitoring required. The user has a choice of viewing individual concerns with associated management and monitoring, or all the environmental concerns with all management and monitoring. The Action Table consists of the following objects:

- How would you like to view Bt Cotton concerns? COTCONVB
- Bt Cotton environmental concerns complete COTCONVBCO



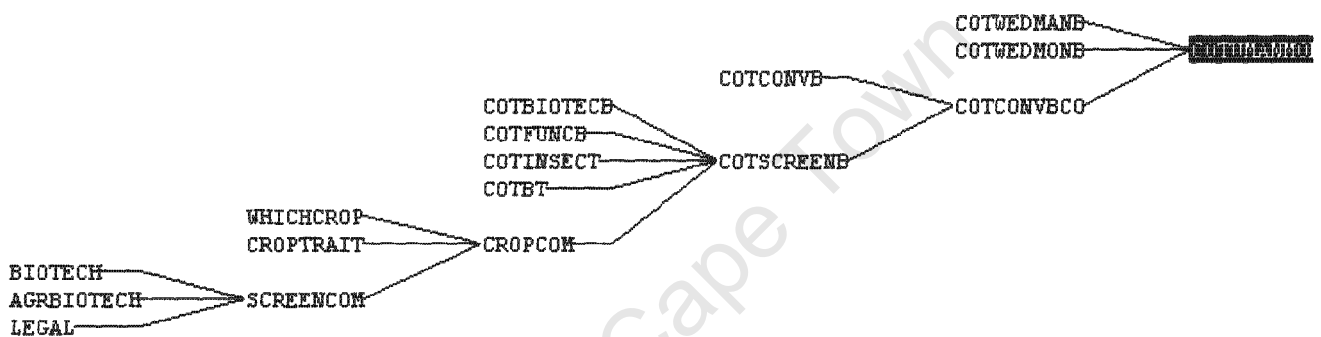
**Figure 14: Example of the Bt Cotton environmental concerns compete Action Table in the Object Graph**

The object COTCONVB is the right-hand side object and the input value determines the left-hand side object’s value, COTCONVBCO. The Context for this Action Table is that the object value of COTSCREENB must equal “done”. The information supplied to the

user in the end report pertaining to environmental concerns is dependent on the input value for the object, How would you like to view Bt Cotton concerns? COTCONVB.

In this example it will be taken that the user input a value such that COTCONVBSCO determined a value to specifically investigate the environmental concern of crop weediness with Bt Cotton. This is represented in the uppermost right side of the decision tree. The Action Table that follows consists of the following objects:

- Aware of Bt Cotton crop weediness management? COTWEDMANB
- Aware of Bt Cotton crop weediness monitoring? COTWEDMONB
- Bt Cotton crop weediness man/mon complete COTWMANMOB



**Figure 15: Example of Bt Cotton crop weediness man/mon complete Action Table in the Object Graph.**

The objects COTWEDMANB and COTWEDMONB are the left-hand side objects whose input values determine the value of the right-hand side object, COTWMANMOB. The Context of this Action Table is that the value for the object, Bt Cotton environmental concerns complete (COTCONVBSCO), must equal "Crop weediness". If another value was determined for COTCONVBSCO, then another branch of the decision tree would have been followed and another Action Table determined, as seen in Appendix A.

### Special Objects (Questions) in the decision tree

A list of all questions that a user could be asked in a case run are the Objects in the knowledge base that require input values. These can be viewed in the prototype knowledge base by selecting *Reports* then *Objects*. However, there are certain special questions which function as nodes in the decision tree and not only decide what information is supplied to the user, but also decide which path is followed in the decision process.

The following are questions that function as the nodes between the Initial Screening phase and the Specific Crop Screening phase of the decision framework, with the purpose of achieving a case-by-case investigation of the transgenic crops with the user:

- Which crop would you like to investigate? (WHICHCROP)  
Possible values; Soybean Maize Cotton UNKNOWN

- Which transgenic crop trait are you interested in? (CROPTRAIT)  
Possible values; Insect-resistance Herbicide-resistance UNKNOWN

The following are questions that function as the node between the Specific Crop Screening phase and the Management and Monitoring phase of the decision framework:

- How would you like to view Bt Cotton concerns? (COTCONVB)  
Possible values; Changes-in-insecticide-use Insect-resistance Geneflow-and-outcrossing Crop-weediness Insect-population-shifts Nontarget/biodiversity-impacts Water-quality Landuse-efficiency All-environmental-concerns UNKNOWN
- How would you like to view RR Cotton concerns? (COTCONV)  
Possible values; Changes-in-herbicide-use Herbicide-drift Herbicide-resistance Geneflow-and-outcrossing Crop-weediness Changes-in-tillage Weed-population-shifts Nontarget/biodiversity-impacts Water-quality Landuse-efficiency All-environmental-concerns UNKNOWN
- How would you like to view Bt Maize concerns? (MAIZCONVB)  
Possible values; Changes-in-insecticide-use Insect-resistance Geneflow-and-outcrossing Crop-weediness Insect-population-shifts Nontarget/biodiversity-impacts Water-quality Landuse-efficiency All-environmental-concerns UNKNOWN
- How would you like to view RR Maize concerns? (MAIZCONV)  
Possible values; Changes-in-herbicide-use Herbicide-drift Herbicide-resistance Geneflow-and-outcrossing Crop-weediness Changes-in-tillage Weed-population-shifts Nontarget/biodiversity-impacts Water-quality Landuse-efficiency All-environmental-concerns UNKNOWN
- How would you like to view RR Soybean concerns? (SOYCONV)  
Possible values; Changes-in-herbicide-use Herbicide-drift Herbicide-resistance Geneflow-and-outcrossing Crop-weediness Changes-in-tillage Weed-population-shifts Nontarget/biodiversity-impacts Water-quality Landuse-efficiency All-environmental-concerns UNKNOWN

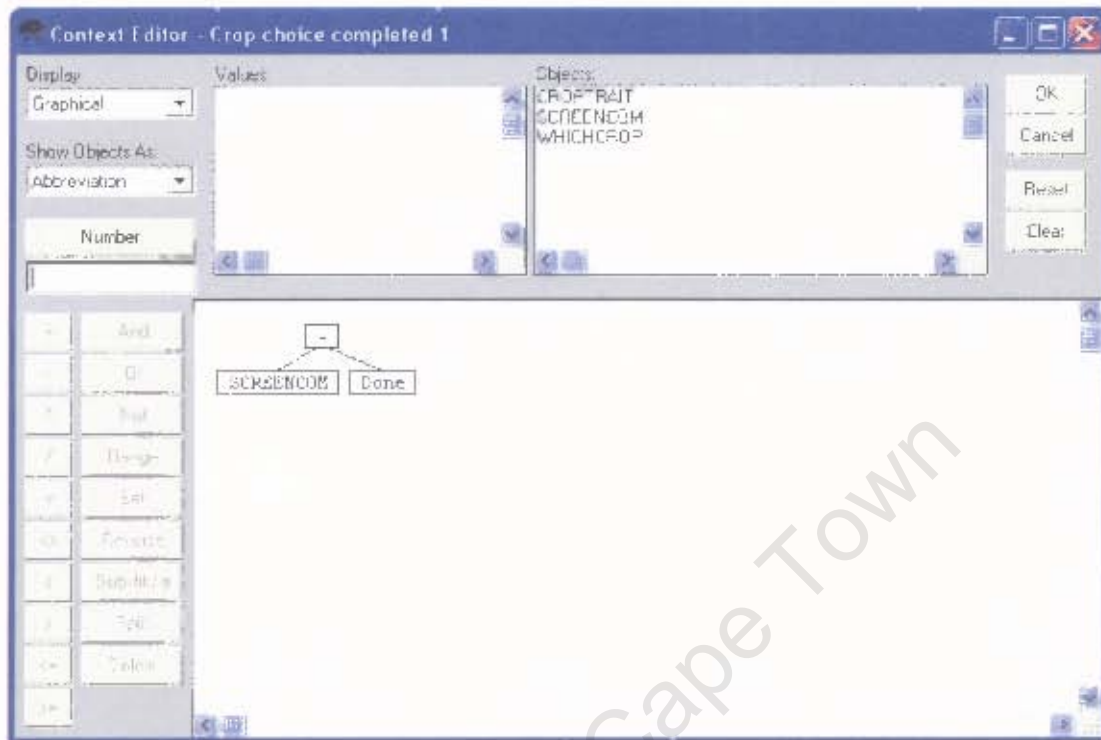
The ability of the prototype to establish the knowledge of the user and supply educational information tailored to the specific needs of the user achieves the knowledge modelling principles of an integrated curriculum (Wilcox, 1996), individual learning, special identification and supplement teaching (du Plessis et al., 1995). The ability of a second time user to choose specific paths within the system and focus on certain knowledge achieves the principles of individual control and stimulation (du Plessis et al., 1995), and self-actualisation (Burlerson, 2005 and Kay, 1991). The user's realization of the expert decision framework logic employed by the prototype achieves the knowledge modelling principles of metacognition (Perkins, 1991, Blakey and Spence, 1990, Self 1995 and van

Biljon et al., 1999), competence building (Conceicao and Heitor, 2002), as the decision framework logic can be applied to other issues in the problem domain of transgenic crops. The consolidation of knowledge domains into a three-phase framework, and the completion of an educational end goal in a five level decision tree, achieved the principle of complexity reduction (Winstanley, 1987). The simpler the decision tree, while still completing the goals of the expert system, the better the knowledge engineering (Murphy, 2006 pers comm.).

#### 4.4.3 RULE DEVELOPMENT IN THE KNOWLEDGE BASE

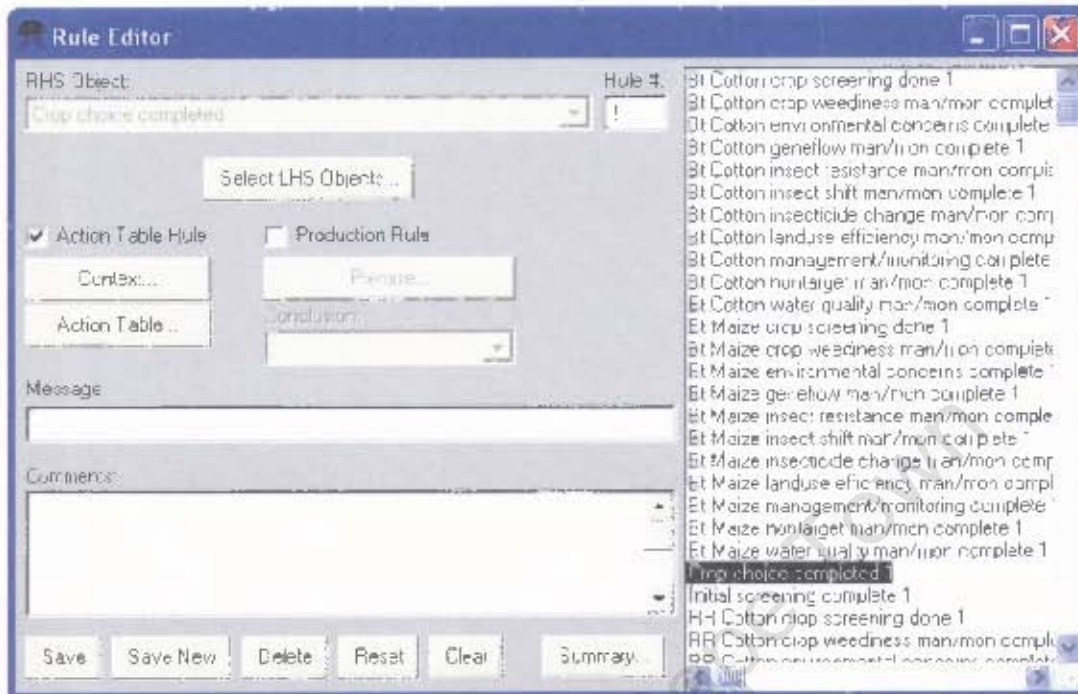
Objects that influence each other do so via prescribed rules. Consider Figure 12 again, where the relationships of the objects WHICHCROP, CROPTRAIT and CROPCOM are shown as they appear in the Object Graph. Action Table rules were used in the prototype's knowledge base instead of production rules due to the fact that Action Tables offer of ease of use, and a more thorough knowledge base building process. Figure 17 shows an example of the Crop choice complete (CROPCOM) Action Table as seen in the Action Table Editor of Acquire. A Rule computes a value for an object in the knowledge base, by using the values of the objects that support the object in question. The support network (decision tree) defines the relationships among the objects in a general, high-level way, while the rules specify the relationships in a specific, highly detailed way. In a rule the supported object is the *right-hand side* object and the supporting objects are the *left-hand side* objects. The left-hand side objects are the rule's *premise* and the *conclusion* is assigned to the right-hand side object. Action Tables rules achieve the most in Acquire by using a simple format for rules within a cohesive structure. Action tables enumerate all possible values for all left-hand side objects in a tabular format, as seen in Figure 17 (Acquired Intelligence Inc., 2004).

Rules were created, modified and viewed in the *Rule Editor*. Selecting *Editors* then *Rules* activates this editor. Figure 16 shows an example of the Rule Editor with the rule "Crop choice complete 1" selected. On the right of the Rule Editor is a list of rules contained in the knowledge base, which is generated by Acquire as new rules are created. Clicking on an item in this list fills the rest of the editor with information about the selected rule. The *RHS Object* field is a list that contains the objects that are capable of having rules. The *Rule #* field contains a number that distinguishes the rule from other rules with the same right-hand side object. This value is automatically set by Acquire. The *Select LHS Object* button activates a dialog that allows the developer to choose the rule's left-hand side objects. The *Action Table Rule* field if checked makes the rule an action table and enables the *Context* and *Action Table* buttons. The *Context* button activates the *Context Editor* as seen in Figure 18, which is used to build a context for an action table. The *Action Table* button activates the *Action Table Editor*, as seen in Figure 17. The *Production Rule* field if checked makes the rule a production rule and enables the *Premise* and *Conclusion* buttons, which are used in the building of production rules. The *Message* field is an open text field where short messages about the rule can be entered. The *Comments* field is an open text area where comments about the rule can be entered (Acquired Intelligence Inc., 2004).



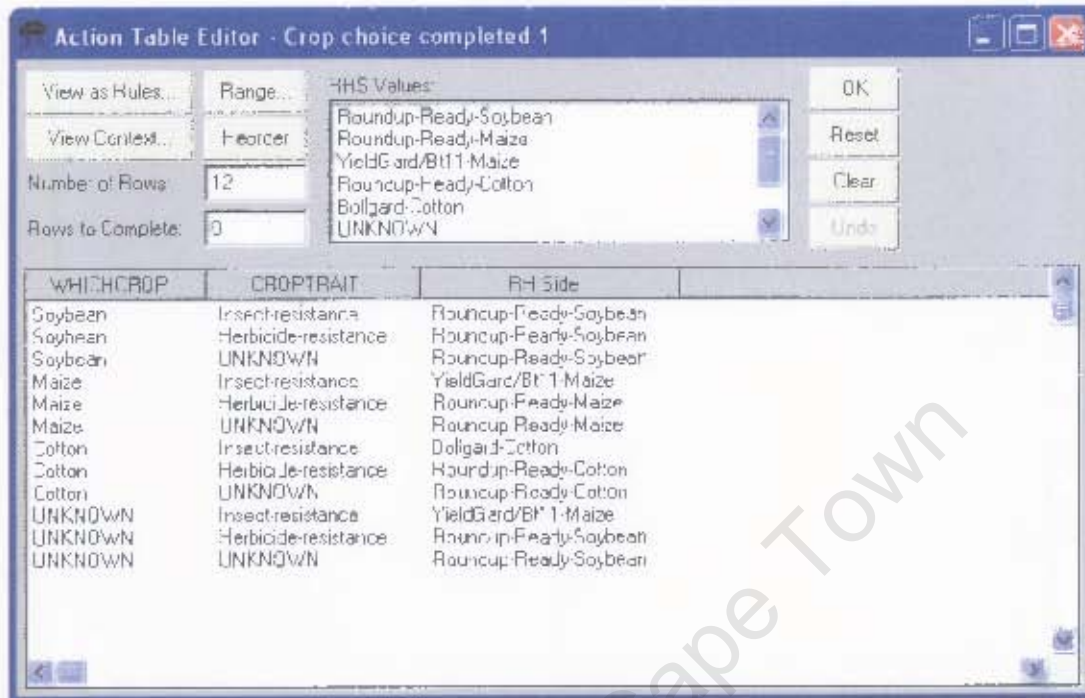
**Figure 18: Example of Crop choice completed rule Context (viewed by selecting Context... in the Rule Editor).**

A list of Rules in the prototype knowledge base is graphically expressed in the *Rule Graph*, which is automatically generated by Acquire as rules are created. The Rule Graph can be seen in Appendix B, and is viewed in the Acquire system by selecting *Graphs* then *Rules*. The Rule Graph graphically displays the relationships (links) between the rules contained in the knowledge base. There is also a list of the rules in the knowledge base on the right side of the Rule Editor (Acquired Intelligence Inc., 2004). Figure 19 shows an example of the relationship between certain rules, as graphically expressed in the Rule Graph. In this example SCREENCOM 1 influences CROPCOM 1, which in turn influences SOYSCREEN 1 (and other screening rules below this in the graph). SOYSCREEN 1 influences SOYCONVCOM 1, which in turn influences SOYMANMON 1.



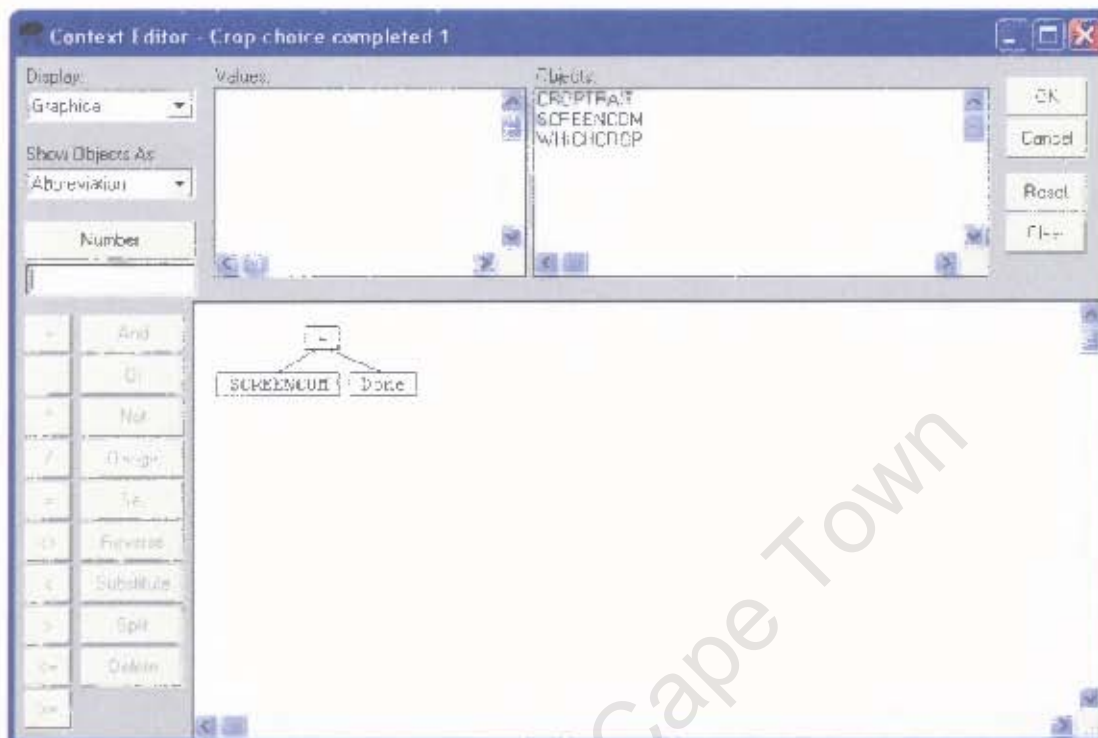
**Figure 16: Example of Crop choice completed rule in the Rule Editor.**

Action Tables were created, modified and maintained in the *Action Table Editor*, as seen in Figure 17. Selecting the *Action Table* button in the *Rule Editor* activates the *Action Table Editor*. The rule's name is included in the title bar of the *Action Table Editor* as a reference. The *Range* button allows the developer to set a value for multiple rows in one step. The *Reorder* button reorganizes the table by first ordering rows on the right-hand side values and then on all left-hand side values. The *View As Rules* button activates a dialog that gives the production rule depiction of the action table. The *View Context* button activates a dialog containing the rule's context. The *Number Of Rows* button gives the total number of rows in the action table, while the *Rows to Complete* button gives the number of empty rows that remain in the action table. The *RHS Values* field contains the right-hand side object's value set. A value from this list is selected to insert into the action table. The actual table is the area at the bottom of the *Action Table Editor*. The *Undo* button undoes the last change made in the editor. The *Reset* button undoes all the changes made in the editor, while the *Clear* button sets every value in the *RHS Values* column to its undefined state. Finally the *OK* button saves the changes to the action table and closes the *Action Table Editor* (Acquired Intelligence Inc., 2004).



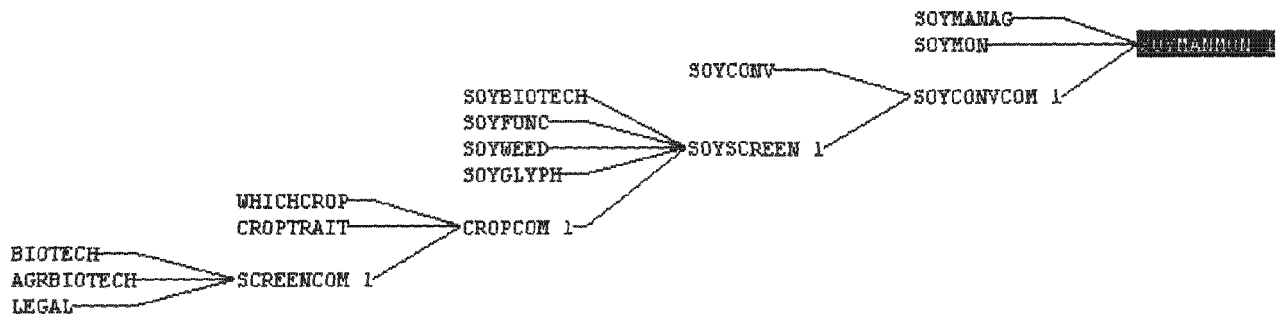
**Figure 17: Example of Crop choice completed Action Table rule (viewed by selecting Action Table... in the Rule Editor).**

The Action Table Rule contexts were created, modified and maintained in the *Context Editor* of Acquire. Figure 18 shows an example of the Context for the rule “Crop choice completed 1”. Contexts are edited graphically using an *expression tree*. Contexts are always evaluated from left to right. In this example the expression tree depicts the context `SCREENCOM = done`. The area in the Context Editor where the expression tree is constructed is called the *canvas*. Selecting objects and values onto the canvas and then joining them together with operators create the contexts. Above the canvas are the *Values* and *Objects* fields, where the developer can select objects and values to add to the context. At the top left are the *Display* and *Show Objects As* fields, which allow the developer to customize the display of the canvas and the *Objects* field. The *Number* button allows the developer to add a numeric constant to the context. Down the left side of the editor are the *arithmetic operators* used in constructing contexts, and down the right side are the *logical operators* *And*, *Or* and *Not* and the *set operators* *Range* and *Set*. Below these are the editing buttons *Reverse*, *Substitute* and *Delete* which are used in editing an already constructed context (Acquired Intelligence Inc., 2004). In Figure 20, the context depicted has the object `SCREENCOM`, with an associated value *Done*. In this example in order for the rule “Crop choice completed 1” to fire, the context `SCREENCOM = Done` must be *true*.



**Figure 18:** Example of Crop choice completed rule Context (viewed by selecting Context... in the Rule Editor).

A list of Rules in the prototype knowledge base is graphically expressed in the *Rule Graph*, which is automatically generated by Acquire as rules are created. The Rule Graph can be seen in Appendix B, and is viewed in the Acquire system by selecting *Graphs* then *Rules*. The Rule Graph graphically displays the relationships (links) between the rules contained in the knowledge base. There is also a list of the rules in the knowledge base on the right side of the Rule Editor (Acquired Intelligence Inc., 2004). Figure 19 shows an example of the relationship between certain rules, as graphically expressed in the Rule Graph. In this example SCREENCOM 1 influences CROPCOM 1, which in turn influences SOYSCREEN 1 (and other screening rules below this in the graph). SOYSCREEN 1 influences SOYCONVCOM 1, which in turn influences SOYMANMON 1.



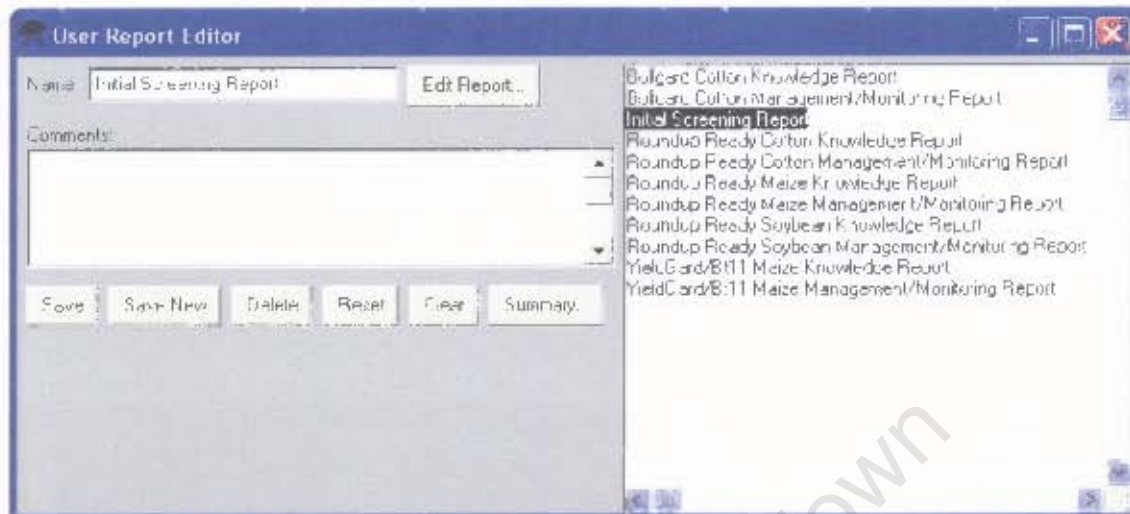
**Figure 19: Example of a forward chaining rule path as displayed in the Rule Graph**

Rules in the prototype knowledge base have been constructed to enable the forward chaining decision process. The forward chaining paths move through the three-phase framework discussed earlier. The three-phase logical decision framework was found to be satisfactory by Green (2006) and Machaba (2006).

#### 4.4.4 USER REPORT DEVELOPMENT IN THE KNOWLEDGE BASE

A *User Report* is a report intended to be read by the user of the expert system. The report is the educational information, which the user receives after completing a session with the knowledge base. Exactly what knowledge is supplied in the user report is dependent on the input values given to objects by the user in a case run.

User Reports are created, modified and maintained in the *User Report Editor*. Selecting *Editors* then *User Reports* activates the User Report Editor. Figure 20 shows an example of the User Report Editor in the prototype, where the “Initial Screening Report” has been selected. On the right side of the User Report Editor is a list containing the names of the user reports in the knowledge base. This list is automatically generated as new reports are created. Selecting an item in this list fills the rest of the editor with information about that user report. The *Comments* field is an open text area for comments to be entered about the report. Below the Comments field are operator buttons used to modify the user reports. The actual content of the user report is constructed in a second editor, the *User Report Details Editor*. The *Edit Report* button activates the User Report Details Editor (Acquired Intelligence Inc., 2004).



**Figure 20:** Example of the User Report Editor in the prototype knowledge base.

Figure 21 gives an example of the User Report Details Editor in the prototype knowledge base. The report template is constructed in the *Report* field. The report template consists mainly of plain text with tags (such as <BEGIN CONTEXT>, <OBJECT NAME>, <PARAGRAPH BREAK>). These tags are codes that are used to customize the report according to the values of the objects in the knowledge base. In generating a specific, tailored user report from a case run the expert system interprets the tags and replaces them with plain text, thereby creating a finished report that the user can read (Acquired Intelligence Inc., 2004).

The *Phrase* field is a text area where phrases for the report can be composed. The *Report* field is where the contents of the report template are displayed. The *Cut* button deletes the highlighted item from the Report field, while the *Paste* button takes the item that has been cut and inserts it into the Report field. The *Add Phrase* button inserts the text in the Phrase field into the Report field, and the *Replace Phrase* button replaces the text of a selected phrase in the report with contents of a new phrase composed in the Phrase field. *Clear Phrase* clears the Phrase field, allowing a new phrase to be composed. The *Begin Context* button inserts a <BEGIN CONTEXT> tag, marking the beginning of a context block. The *End Context* button inserts an <END CONTEXT> tag, marking the end of a context block. The *Else Context* button inserts an <ELSE CONTEXT> tag. This was not used in the prototype. The *Edit Context* button activates a dialogue that edits the Boolean expression that controls the inclusion of the context block in the final report. The *Find Context* button allows the developer to locate matching contexts in large report templates. The *Object Name* button inserts the <OBJECT NAME> tag into the report template, which is replaced with the name of the object when the report is generated. The *Object Value* button inserts the <OBJECT VALUE> tag into the report template, which is replaced with the value of an object when the report is generated (Acquired Intelligence Inc., 2004).

Within the final User Reports, spacing between text is created by either a <LINE BREAK> or <PARAGRAPH BREAK> (Acquired Intelligence Inc., 2004). The Line Break function will result in text displayed in the end User Report thus:

BIOTECHNOLOGY OVERVIEW

Smith (2004) states that the twentieth century was the age of chemistry and physics, which spawned huge industrial activities such as petrochemicals, pharmaceuticals, fertilisers, the atomic bomb, transmitters, the laser and microchips. He further states that “there can be little doubt that the huge understanding of the fundamentals of life processes achieved in the latter part of the twentieth century will ensure that the twenty-first century will be dominated by biology and the associated technologies”.

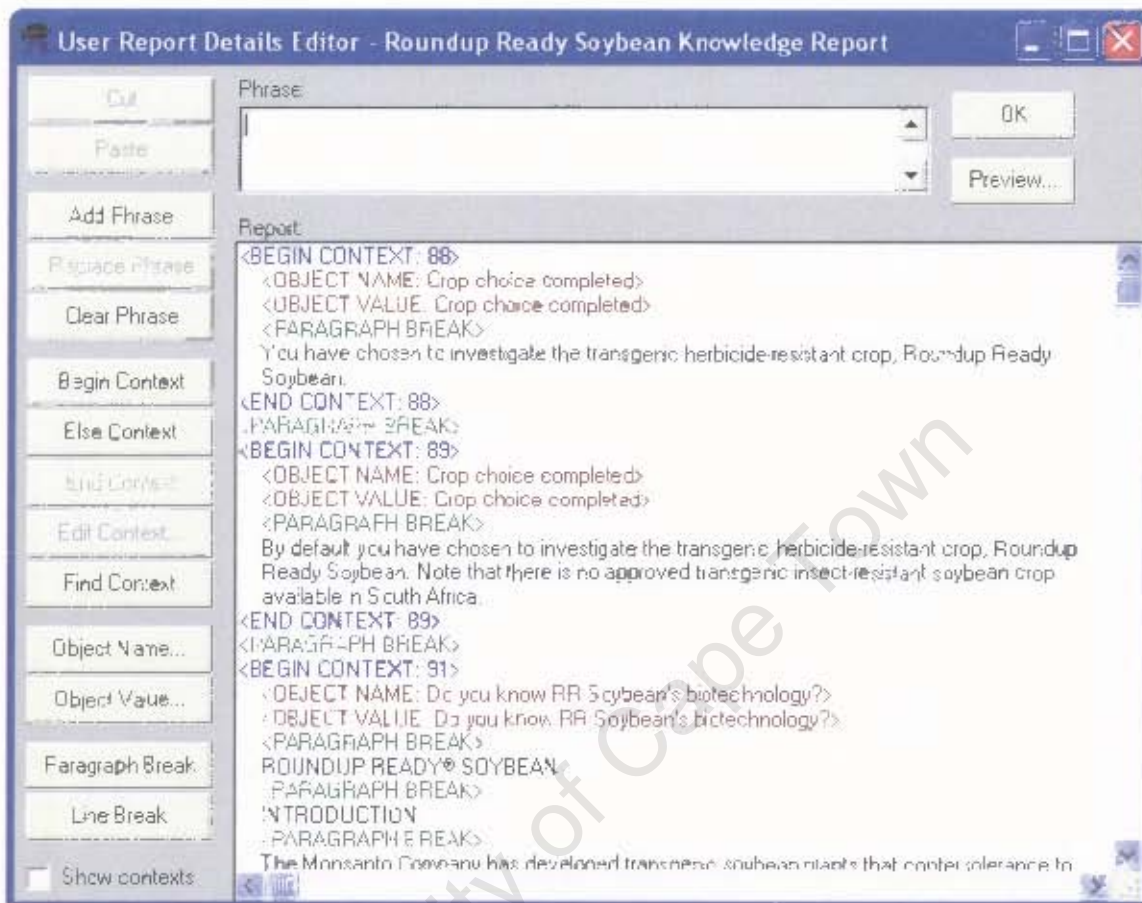
The Paragraph Break function will result in text displayed in the end User Report thus:

BIOTECHNOLOGY OVERVIEW

Smith (2004) states that the twentieth century was the age of chemistry and physics, which spawned huge industrial activities such as petrochemicals, pharmaceuticals, fertilisers, the atomic bomb, transmitters, the laser and microchips. He further states that “there can be little doubt that the huge understanding of the fundamentals of life processes achieved in the latter part of the twentieth century will ensure that the twenty-first century will be dominated by biology and the associated technologies”.

The Paragraph Break button inserts a <PARAGRAPH BREAK> tag into the report field, while the Line Break button inserts a <LINE BREAK> tag into the report field.

In the example shown in Figure 21, the first Object is “Crop choice completed (CROPCOM)” denoted by the <OBJECT NAME> and <OBJECT VALUE> tags, and in order for the user to receive this section of text in the end User Report CONTEXT 88 must be fulfilled. This context can be viewed in the Acquire system by selecting the CONTEXT 88 tag and clicking the *Edit Context* button. In this case CONTEXT 88 is WHICHCROP = Soybean AND CROPTRAIT = Herbicide-resistance AND CROPCOM = Roundup-Ready-Soybean...OR...WHICHCROP = Soybean AND CROPTRAIT = UNKNOWN AND CROPCOM = Roundup-Ready-Soybean. The Contexts for each Object can be viewed in the Context Editor of the system by selecting the Context in question within the Report field and then pressing the Edit Context button.



**Figure 21: Example of a section from the Roundup Ready Soybean Knowledge User Report template (activated by selecting Editors, then User Reports, then Edit Report...).**

There are 11 User Report templates in the knowledge base of the prototype, with certain User Reports associated with one of the three phases within the decision framework. The following are the User Report templates in the knowledge base:

1. Initial Screening phase
  - Initial Screening Report
2. Specific Crop Screening phase
  - Bollgard Cotton Knowledge Report
  - Roundup Ready Cotton Knowledge Report
  - YieldGard/Bt11 Maize Knowledge Report
  - Roundup Ready Maize Knowledge Report
  - Roundup Ready Soybean Knowledge Report
3. Management and Monitoring phase
  - Bollgard Cotton Management/Monitoring Report
  - Roundup Ready Cotton Management/Monitoring Report

- YieldGard/Bt11 Maize Management/Monitoring Report
- Roundup Ready Maize Management/Monitoring Report
- Roundup Ready Soybean Management/Monitoring Report

An example of a finished user report is viewed by selecting *Reports* then *User Reports* in the Acquire program. The Initial Screening Report supplies educational material pertaining to the first broad knowledge context of the three-phase framework. The reports in the Specific Crop Screening phase supply educational material in the second knowledge context of the three-phase framework, and the reports in the Management and Monitoring phase supply educational material pertaining to the final knowledge context of the three-phase framework. Thus there is a hierarchy of knowledge specificity between the three levels of reports. This hierarchy mimics the knowledge used by experts in logically solving problems in the problem domain of transgenic crops. The concept of the three-levelled reports was obtained through the knowledge acquisition process, decision analysis and concept mapping, and validated through evaluation of the reports (Green and Machaba, 2005).

#### **Other Reports in the knowledge base**

Reports providing information on the Knowledge Base, Objects, Rules, User Reports and Value Sets can be viewed by selecting Reports then the particular report of interest.

### **4.5 SUGGESTED IMPROVEMENTS TO THE PROTOTYPE KNOWLEDGE BASE**

#### **4.5.1 A move from a prescriptive to a diagnostic environmental assessment tool**

Although the current prototype is diagnostic in the sense that one of its functions is to determine and “diagnose” exactly what information to supply the user, it is not a true diagnostic expert system in the sense of diagnosing towards a certain problem and then supplying a solution. At this stage the current research does not allow for such a system, as there is not enough baseline data available of what a satisfactory transgenic crop agroecosystem would be in South Africa. In order to diagnose towards a problem, the system requires baseline data to diagnose against. The hope is that in a few years such a system will be possible.

#### **4.5.2 Updating the knowledge base**

The prototype’s knowledge base will continually need to be updated with current research and the ever-increasing number of approved transgenic crops. This process is not as difficult as constructing the system in the first place, as the logic and knowledge engineering has already been completed and a working framework created.

#### **4.5.3 A move to web format**

The Acquire system can be programmed so that it functions on the Internet. This form of the system is probably the most accessible to a wide range of users. However, a computer programmer with a background in web development may be required to achieve this.

#### **4.5.4 Target audiences**

The two experts consulted suggested that future versions of the system target different audiences, at differing levels of technical knowledge. In this manner a more effective educational experience can be achieved (see Appendix C) (Green and Machaba, 2006).

### **4.6 CONCLUSION**

A prototype knowledge base as an educational tool for the environmental concerns, management and monitoring for the transgenic crops Soybean, Maize and Cotton has been successfully constructed. The knowledge base incorporates the knowledge domains of biotechnology, agribiotechnology, agroecosystems of soybean, maize and cotton, general principles of ecology and environmental management.

The knowledge modelling principles discussed in Section 5.3 have been achieved. The decision framework used was found to be logical and appropriate for the purposes of the educational system. The content of the knowledge base was found to be satisfactory, based on the current body of scientific literature (Green and Machaba, 2006 pers comm.). There have been suggested improvements that can be applied to future versions of the system (see section 5.5). The prototype has been found to be valuable in the field of transgenic crops and environmental science (Green and Machaba, 2006 pers comm.).

## **5. SUMMARY AND CONCLUSIONS**

### **5.1 INTRODUCTION**

This chapter deals with the final conclusions of this project and the constructed prototype knowledge base. The original concept for the study was to develop an environmental assessment diagnostic tool for transgenic crops, mimicking an Environmental Impact Assessment process. However, in order to have achieved this two critical elements were required. Firstly, a defined problem was needed in order to structure the diagnostic tool. Secondly, baseline data was required in order to evaluate input data against that baseline. Both of these elements are missing in the current body of scientific knowledge relating to transgenic crops in South Africa. Therefore, after becoming familiar with the current body of scientific knowledge on transgenic crops as well as the advantages and limitations of expert systems, the study metamorphosed into the development of an expert system that would serve as an educational tool for persons considering growing transgenic crops in South Africa as well as to those involved in granting approval for such crops to be grown.

### **5.2 THE RESEARCH**

Biotechnology is undoubtedly an emerging field of interest in environmental science. However, there is a need for education and understanding of biotechnology and in particular agribiotechnology. Equally, the current research has found that there is a need for knowledge of biotechnology and agribiotechnology to be placed in the correct context of decision frameworks in order to achieve objective and balanced decision-making.

The overall aim of the research was to construct an expert system prototype knowledge base of the environmental concerns, management and monitoring for the three transgenic crops: maize, cotton and soybean, specific to South Africa. The prototype knowledge base was to function as an advisor as to environmental concerns, management and monitoring at the farm level specific to transgenic crops. Additionally, the prototype was required to establish the knowledge level of the user and provide appropriate educational information. The specific objectives of the research were to select and utilize an appropriate expert system shell, to research transgenic maize, cotton and soybean, to research the relevant environmental management procedures, to consolidate the research into a knowledge base, and finally to encode this knowledge base into the expert system shell.

A research methodology was undertaken, following the knowledge modelling techniques of Coffey et al. (2003) and du Plessis et al. (1995), and knowledge acquisition methodologies of Babbie and Mouton (2001). Four expert system shells were evaluated and the Acquire® expert system shell was found to be the most appropriate shell for the project.

Using the Acquire® expert system shell a prototype expert system knowledge base was constructed for education of environmental concerns, management and monitoring of

transgenic maize, cotton and soybean in South Africa. A hybrid knowledge model was formed combining the PreSERVe Model of Coffey et al. (2003) and the Intelligent Computer-Aided Education (ICAE) Systems Design Model of du Plessis et al. (1995). Research on the three transgenic crops was encoded into this knowledge base. The above mentioned research aims and objects were achieved, with the output of the prototype knowledge base in the form of advisory user reports, tailored to the input and knowledge level of the user. The number of permutations possible in generating the tailored user reports is  $11^{245}$ , with 265 pages of consolidated knowledge contained in the knowledge base. Appendix F is an example of such a report, with an Object Report showing the input the “user” would have given and then the End User Report, which is given to the user in response to the input. The Object Report indicates that the user in this example would only have been interested in information pertaining to herbicide resistance associated with the use of transgenic herbicide-resistant Roundup Ready® Maize.

Regarding the current environmental concerns pertaining to transgenic crops, the research found that there were many perceived concerns. However, the current scientific literature indicates that as yet there is no in field evidence of a significant environmental threat. Baring this in mind, the role of monitoring was found to be of utmost importance. It must also be noted that the agroecosystem is already a disturbed and altered environment, and any decision-making process should be approached with this as a context. The research also found that many incorrect conclusions drawn regarding environmental concerns of transgenic crops are due to a lack of technical information. Thus, there is a need, when approaching problems in the biotechnology field, to have a sound understanding of the technical aspects involved. This was found to pose the greatest challenge in designing an educational tool to be understood by many.

Although the scientific literature at this stage does not indicate any significant environmental threats from the currently approved transgenic crops in South Africa, the legislation and regulatory framework of genetically modified organisms is under significant scrutiny. From an environmental perspective there are many concerns regarding the legislation pertaining to genetically modified organisms. A sound regulatory framework needs to be developed in order to adequately assess environmental threats of all future transgenic crops that will be subject to the approval process. The research found that the government, farmers, environmental scientists and managers, and the concerned public all have a valid role to play in the approval process and that a tool that could provide accurate and reliable information tailored to the needs of each of these parties would be helpful.

### **5.3 FINAL CONCLUSIONS**

A South African knowledge base prototype for management and monitoring of transgenic soybean, maize and cotton has been successfully constructed. The system has been found to be valuable in the fields of transgenic crops and environmental science, especially in an educational role (Green and Machaba, 2006).

Applications to grow more transgenic crops are only going to accelerate. There is a responsibility on environmental scientists to recognize this growth as well as potential environmental threats. Continual research in the biotechnology field to establish environmental consequences is essential. Even more important is the responsible dissemination of soundly researched information to the public. The current study has consolidated scientific literature from the research fields of biotechnology, agribiotechnology, agroecosystems, ecology and environmental management, and structured this using an expert system to provide an educational tool. It is hoped that this tool will assist agricultural biotechnology to meet the goals of agricultural sustainability, environmental sustainability and public awareness.

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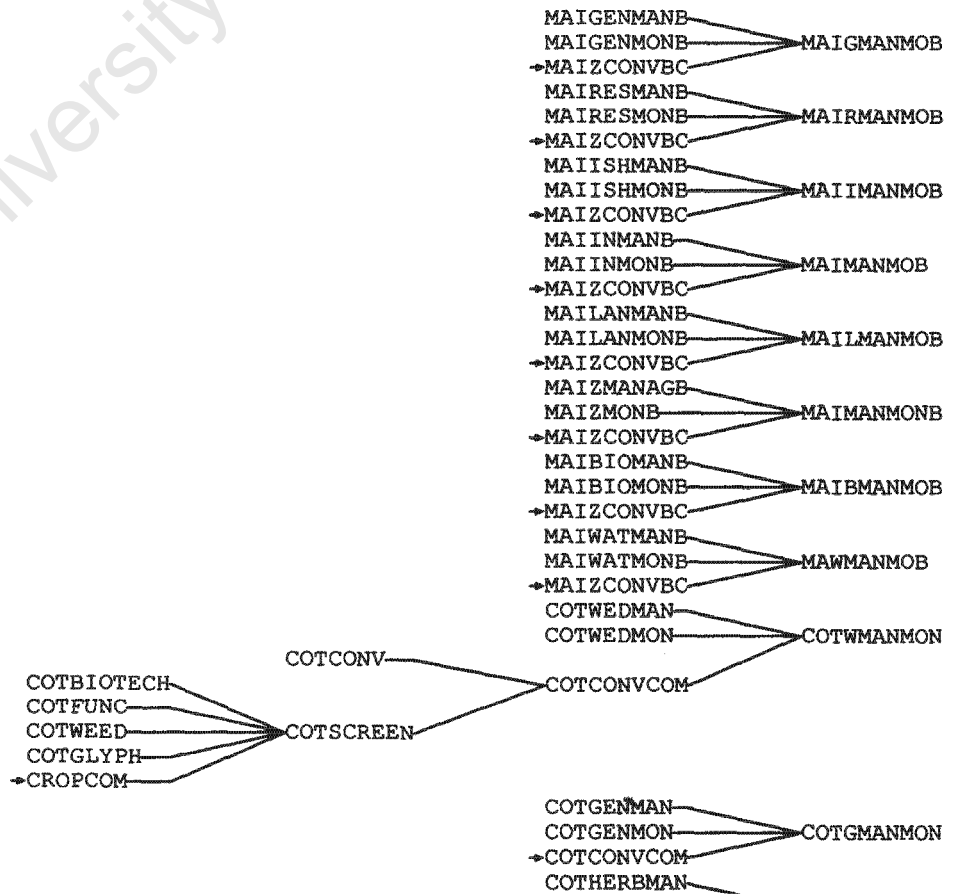
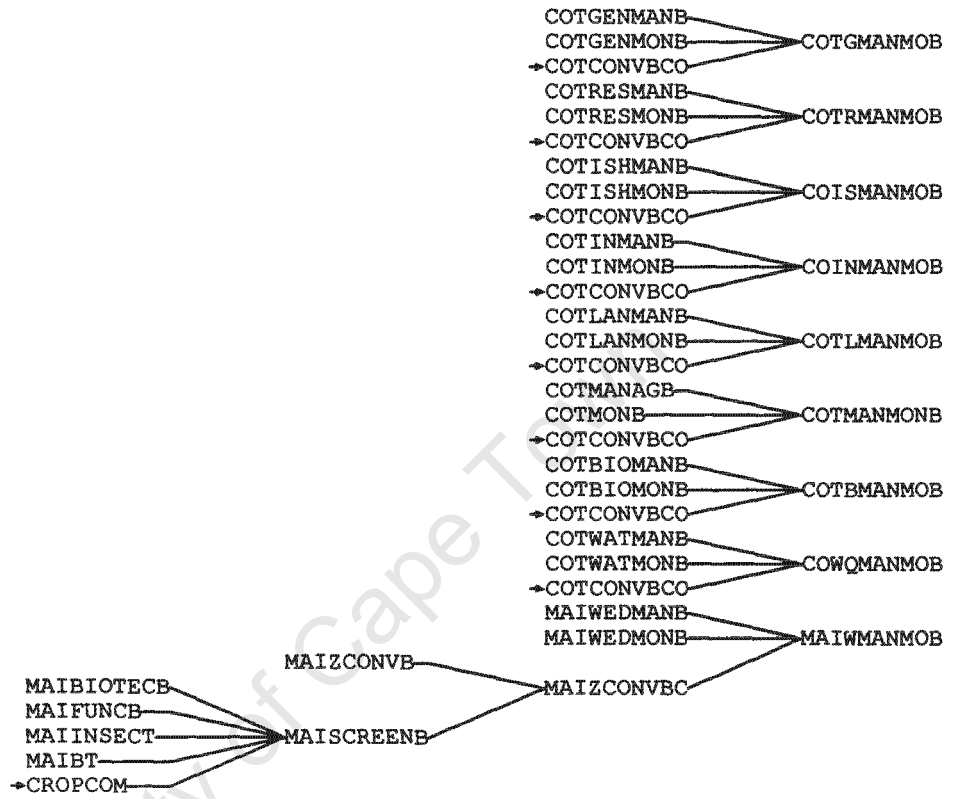
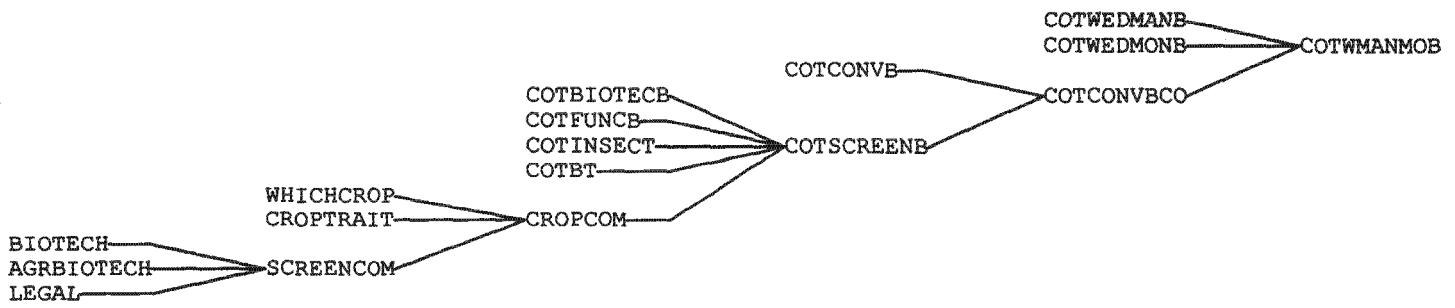
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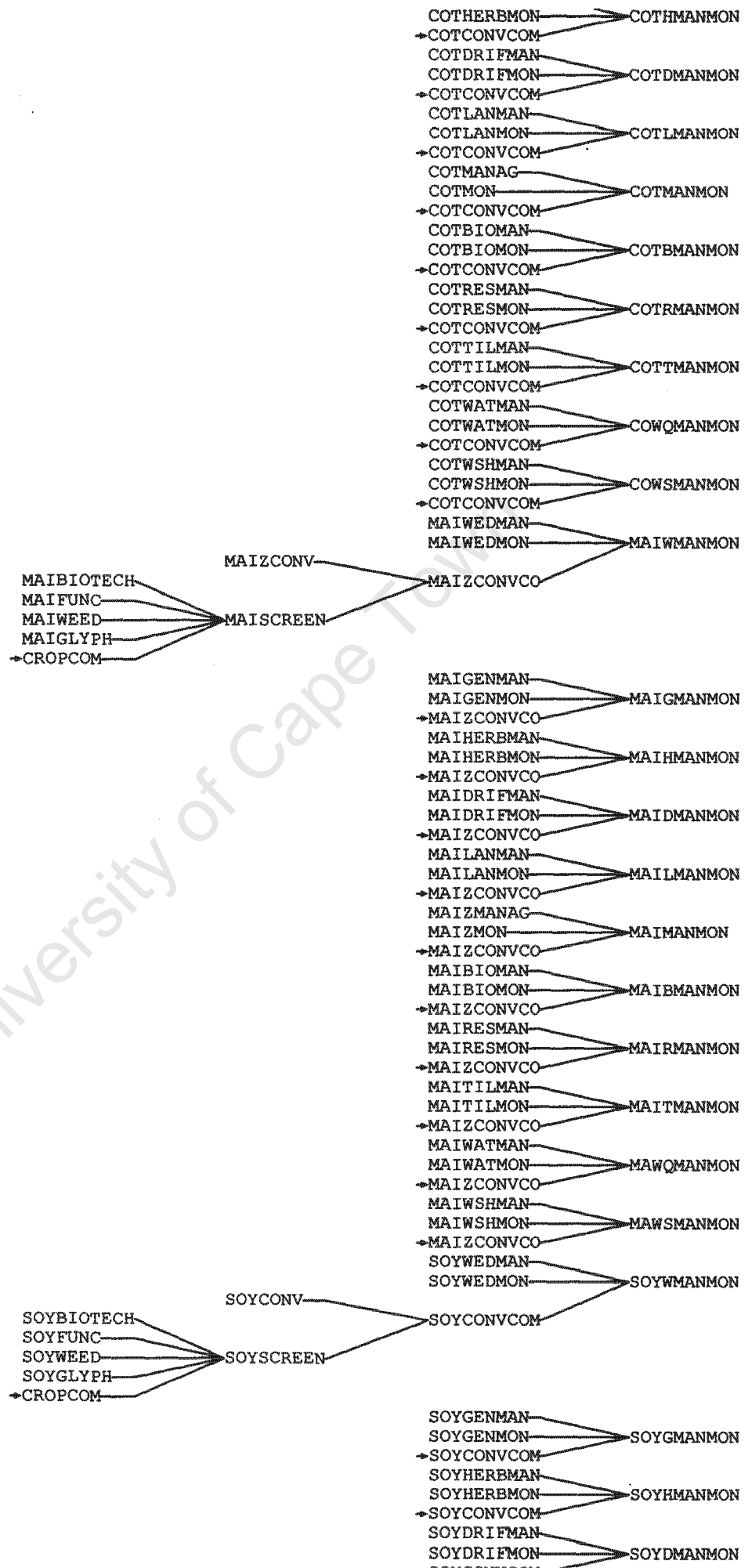
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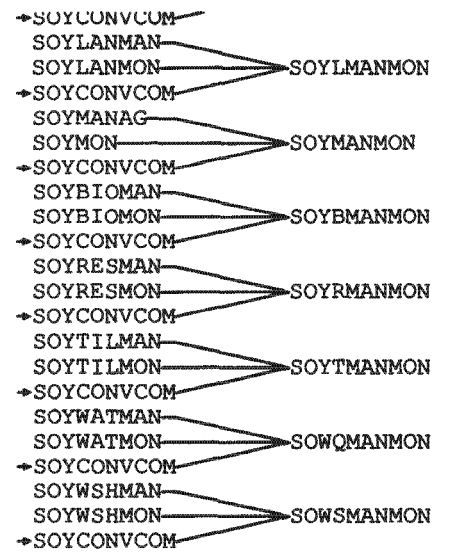
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**APPENDIX A**  
**OBJECT GRAPH**

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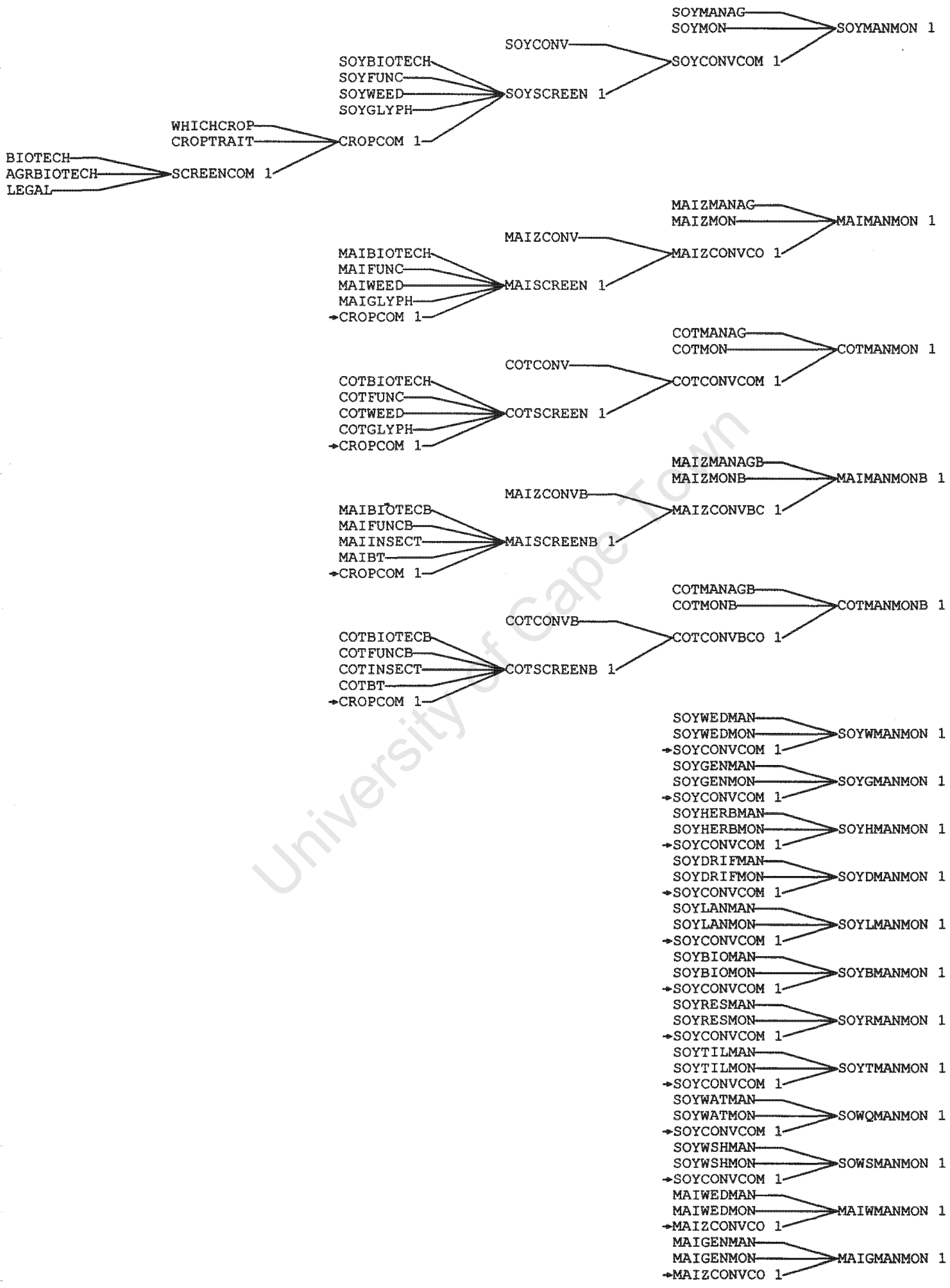


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**APPENDIX B**

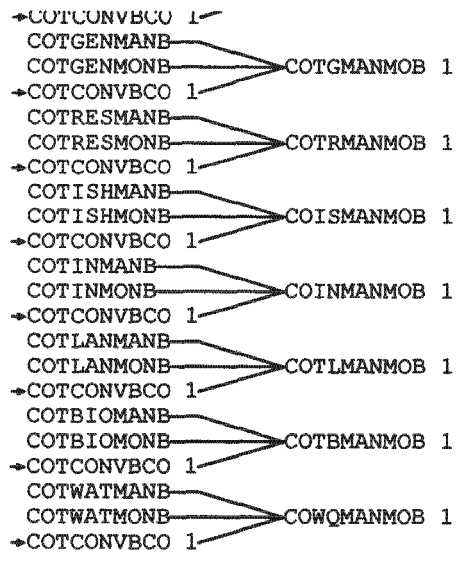
**RULE GRAPH**

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MAHERBMAN  
 MAHERBMON  
 →MAIZCONVCO 1  
 MAIDRIFMAN  
 MAIDRIFMON  
 →MAIZCONVCO 1  
 MAILANMAN  
 MAILANMON  
 →MAIZCONVCO 1  
 MAIBIOMAN  
 MAIBIOMON  
 →MAIZCONVCO 1  
 MAIRESMAN  
 MAIRESMON  
 →MAIZCONVCO 1  
 MAITILMAN  
 MAITILMON  
 →MAIZCONVCO 1  
 MAIWATMAN  
 MAIWATMON  
 →MAIZCONVCO 1  
 MAIWSHMAN  
 MAIWSHMON  
 →MAIZCONVCO 1  
 COTWEDMAN  
 COTWEDMON  
 →COTCONVCOM 1  
 COTGENMAN  
 COTGENMON  
 →COTCONVCOM 1  
 COTHERBMAN  
 COTHERBMON  
 →COTCONVCOM 1  
 COTDRIFMAN  
 COTDRIFMON  
 →COTCONVCOM 1  
 COTLANMAN  
 COTLANMON  
 →COTCONVCOM 1  
 COTBIOMAN  
 COTBIOMON  
 →COTCONVCOM 1  
 COTRESMAN  
 COTRESMON  
 →COTCONVCOM 1  
 COTTILMAN  
 COTTILMON  
 →COTCONVCOM 1  
 COTWATMAN  
 COTWATMON  
 →COTCONVCOM 1  
 COTWSHMAN  
 COTWSHMON  
 →COTCONVCOM 1  
 MAIWEDMANE  
 MAIWEDMONE  
 →MAIZCONVBC 1  
 MAIGENMANE  
 MAIGENMONE  
 →MAIZCONVBC 1  
 MAIRESMANE  
 MAIRESMONE  
 →MAIZCONVBC 1  
 MAIISHMANE  
 MAIISHMONE  
 →MAIZCONVBC 1  
 MAIINMANE  
 MAIINMONE  
 →MAIZCONVBC 1  
 MAILANMANE  
 MAILANMONE  
 →MAIZCONVBC 1  
 MAIBIOMANE  
 MAIBIOMONE  
 →MAIZCONVBC 1  
 MAIWATMANE  
 MAIWATMONE  
 →MAIZCONVBC 1  
 COTWEDMANE  
 COTWEDMONE  
 →COTCONVCOM 1

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**APPENDIX C**

**INTERVIEWS WITH EXPERTS**

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## **INTERVIEWS WITH EXPERTS**

**Note:** Due to the fact that the experts consulted had no prior experience with expert systems, although the interviews worked off a structured line of questioning, much of the interviews were also of a workshop basis in order for the interviewer and interviewee to gain an increased understanding of the project.

The two experts consulted were Dr Wally Green of Monsanto and Dr Kulani Machaba of Syngenta.

### **FIRST INTERVIEWS WITH EXPERTS**

The purpose of these interviews was to ascertain if it would be possible to construct an environmental management protocol expert system for the transgenic crops cotton, maize and soybean.

#### **Dr Wally Green**

Response to categorized environmental impacts:

- The categorization is satisfactory.
- Noted that geneflow and crop weediness were not considered issues with the currently approved transgenic crops in South Africa. There are no wild relatives for maize or soybean, while cotton has a sexually incompatible wild relative.
- Crop weediness not considered a threat, as cultivated crops do not compete effectively in natural ecosystems.
- Expressed the view that resistance is in fact a farming/commercial problem and not an environmental problem.
- Some of the categories such as tillage and water quality were also conventional cropping issues.
- There have been no indications in studies in the field of nontarget impacts; in fact studies have shown an increase in non-selected insect populations in the agroecosystem with transgenic insect-resistant crops.

Response to monitoring procedures:

- Monsanto is responsible for monitoring.
- Generally farmers are unable to carry out technical monitoring procedures.
- The farmer should inform the technology provider in cases of observed abnormalities.

Response to auditing:

- Monsanto conducts audits.

Response to cultivar selection:

- There are five approved transgenic varieties in South Africa. For soybean there is one approved variety called Roundup Ready®, which is herbicide-resistant. Maize has two varieties approved, Roundup Ready® maize that is herbicide-

resistant and YieldGard® maize that is insect-resistant. Cotton has two varieties approved, Roundup Ready® cotton that is herbicide-resistant and Bollgard® cotton that is insect-resistant. One must take **not** of the different Cry proteins utilized in the maize and cotton insect-resistant varieties.

- The codes of the varieties investigated pertain to the parent lines used in producing the current varieties of transgenic crops.
- Expressed concern as to why transgenic crops were being solely investigated and not conventional crops included in the study.
- Indicated the importance of having a balanced view and comparing conventional and transgenic crops.

Response to the idea of an expert system:

- The logic of the decision tree at that stage was satisfactory.
- Believed that an expert system could be achieved in the transgenic crop study field.

(Green, 2005 pers comm.)

**Dr Kulani Machaba**

Response to categorized environmental impacts:

- Geneflow and outcrossing is not an issue with Bt11 maize in South Africa.
- There are no wild relatives of maize in South Africa.
- There has been no farmer in South Africa that has complained of his/her seed purity and this issue is based on market demand of purity.
- In terms of bacteria, Bt Cry proteins are in the soil continuously and gene flow occurs "naturally".
- Crop weediness is not an issue, as maize is not known to be competitive in natural ecosystems.
- Noted that the herbicide tolerant function of Bt11 is not used in South Africa, as glufosinate cannot be used.
- These are generally the correct environmental concerns.

Response to monitoring procedures:

- Farmers do not generally possess the scientific expertise to carry out elaborate non-target or biodiversity monitoring procedures. The best a farmer can do is to inform Syngenta (technology provider) if changes are observed in the agroecosystem.
- Syngenta themselves carry out monitoring programs.

Response to auditing:

- Syngenta are responsible to carry out auditing.

Response to cultivar selection:

- The Bt11 maize NKMayerB is the correct cultivar, with the X4334CBR and X4734CBR codes pertaining to the parent lines used in producing the current Bt11 cultivar.

- Noted that in order for the transgenic crops to be economically viable, environmental regulations must be realistic in terms of cost to the farmer.
- Legal conditions should be practical and not too restrictive.
- The legal conditions given to the farmers by the company in terms of crop management and refugia.
- There must a balanced consideration of conventional versus biotechnology-derived crops.
- Most practices are carried over from the United States of America and few studies have specifically been conducted in South Africa.
- EUROGAP is the set of standards for pesticides and herbicides, however, not all producers follow these standards.

Response to the idea of an expert system:

- A computer-assisted tool could be valuable in the study field of transgenic crops.
- An expert system could be constructed.

(Machaba, 2005 pers comm.)

## **SECOND EVALUATORY INTERVIEWS WITH EXPERTS**

The purpose of these interviews was for the experts to evaluate the prototype expert system and give input and suggested improvements. It was explained that the system had moved away from a diagnostic assessment tool to an informative protocol and educational tool due to the nature of knowledge currently available.

### **Dr Wally Green**

- Expressed the fact that the three-phase model of the prototype was logical and satisfactory.
- The decision framework and paths of reasoning in the decision tree was found to be logical and satisfactory.
- Content of the knowledge base was generally found to be satisfactory.
- Expressed the system was valuable and necessary in the current climate of transgenic crops in South Africa.
- Suggested that the system could be used for other issues where a lack of knowledge exists, and a new content to the knowledge base could be supplied.
- The role of the general public:
  - Should distinguish between the general public and the “concerned public”, as much of the general public are not interested in issues of transgenic crops.
  - The concerned public have a responsibility to educate themselves; it is not the responsibility of private companies or the government.
  - The concerned public have to make the effort of education themselves.
  - The concerned public must apply a balanced view to the issue of transgenic crops, where transgenic and conventional crops are weighed against one another, and sources of information are weighed.

- The role of farmers:
  - Farmers need to use the transgenic crops as per the product guidelines and labels.
  - Farmers need to monitor the crops and contact the crop suppliers if an abnormality arises.
  - Farmers should be generally environmentally aware.
- Role of environmental managers:
  - Noted that environmental managers have a limited role currently regarding transgenic crops.
  - Environmental managers should have a role in cases where new lands are being opened up for agriculture.
  - Environmental managers should approach the issues of transgenic crops with a broader view of the agricultural system as a whole, and not merely focus on transgenics.

**Suggested improvements:**

- In the objects of crop function (e.g. Do you know Bt Cotton's function? (COTFUNCB)), the term "function" should change to "agronomics" and that the object should not only pertain the transgenics as the agronomics of the transgenic varieties are the same as conventional varieties.
- In the objects of insect/weed problems (e.g. Do you know Bt Cotton's insect problems? (COTINSECT)), the term "problems" should change to "complex" and that the object should pertain to both the transgenic varieties and conventional varieties as the insect/weed complexes affect both the transgenic and conventional varieties.
- Future versions of the expert system should look at differentiating the level of knowledge supplied according to different target audiences (e.g. general public, university students, scientists, regulators).
- Noted that the use of figures would be an improvement to the system.

(Green, 2006 pers comm.)

**Dr Kulani Machaba**

- The three-phase model was found to be satisfactory.
- Decision framework and paths of reasoning through the decision tree was found to be logical and satisfactory.
- Content of the prototype was found to be generally satisfactory.
- Expressed a concern that the environmental concern category of "Water Quality" is difficult to determine for Bt11, as Bt is ubiquitous in nature and any testing would not be able to ascertain whether or not the source of the Bt was from the soil or the transgenic crops. Additional Dr Machaba was unaware of any studies relating to this environmental concern.
- Expressed a concern as to the validity of having the environmental concern category of "Insect Resistance", stating his opinion that there is no environmental concern with insect resistance, merely a commercial concern. (Note: Regarding the above two points, firstly, it was explained that the system had to deal with all "perceived" environmental concerns pertaining to transgenic crops, not just the

concerns thought valid by leading scientists. Secondly, the argument was put forward that if the transgenic crops were viewed as environmentally beneficial, then the loss of the technology due to resistance would cause a loss of an environmentally beneficial technology. Therefore resistance can be viewed as an indirect environmental concern).

- Noted that challenge of disseminating technical information to the general public in an understandable format, and without causing information overload. However, in order for the necessary knowledge to be supplied for sound conclusions to be drawn this problem could not be overcome easily.
- Regarding the use of the expert system as an educational tool and protocol, expressed his view that this was more appropriate than an environmental assessment tool, as Environmental Impact Assessments were not appropriate on each farm for transgenic crops.
- Stated that they are still in the process of finalizing monitoring procedures for transgenic crops. In order to monitor target organisms (in this case the stalk borers, *Chilo partellus* and *Busseola fusca*), there is required monitoring ensuring that refugia are being properly utilized, that *Busseola fusca* are being used to establish baseline resistance as this species is more common than *Chilo partellus*, monitoring is of expected versus unexpected damage and that every few years samples are taken to retest the baselines. In terms of monitoring nontargets, the monitoring is usually done prior to commercialisation and that post commercialisation every few years samples are taken to assess the potential impact on the nontargets.
- The role of the general public:
  - The general public should make an effort to be informed.
  - The civil society groups should be balanced in views pertaining to environmental issues regarding transgenic crops.
  - The media should be responsible in giving balanced views to the public.
- The role of farmers:
  - Farmers should undertake the correct management regarding refugia (concerning Bt11).
  - Farmers should undertake the practices as per the guidelines of the transgenic crops.
  - Farmers should monitor for unexpected levels of damage and inform the crop provider.
- Role of environmental managers:
  - Should ensure comprehensive reviews of GMO applications.
  - The reviews should be of a scientific basis.
  - Managers should seek to involve the general public.

#### Suggested improvements:

- The term “problem(s)” in the objects concerning insect/weed concepts should be changed to another less negative term, such as “concern/issue”.
- Suggested that the content of the knowledge base include information on the Risk Assessment Framework used for transgenic crops, and supplied this framework.
- Suggested that future versions of the system consider specific target audiences.

(Machaba, 2006 pers comm.)

**APPENDIX D**

**BASIC INSTRUCTIONS FOR THE ACQUIRE® PROGRAM: VIEWING THE  
PROTOTYPE KNOWLEDGE BASE**

University of Cape Town

## **BASIC INSTRUCTIONS FOR THE ACQUIRE® PROGRAM: VIEWING THE PROTOTYPE KNOWLEDGE BASE**

### **A. OPENING THE PROTOTYPE KNOWLEDGE BASE**

1. An accompanying CD named **Appendix G Transgenic Crop Educational Tool.kbs** should be found at the end of the dissertation.
2. An evaluation version of the Acquire® expert system shell can be obtained from Acquired Intelligence Inc. ([www.aiinc.ac](http://www.aiinc.ac)) or email [info@aiinc.ac](mailto:info@aiinc.ac).
3. Open the Acquire® program
4. Select **File** then **Open...**
5. **Open Knowledge Base** window is displayed
6. Double click on **Transgenic Crop Education Tool.kbs**

### **B. RUNNING A SESSION**

1. Click **Engine**
2. Select **Run Case**
3. **Run Case** window is displayed
4. Click **Run** button
5. Answer questions by selecting one of the symbolic values (not UNSET) and clicking **OK** button
6. At the end of the session the **Run Case** window is displayed again with the results of the session
7. To view the appropriate user report click on the **Report field list** and a drop down menu appears
8. All sessions produce an **Initial Screening Report**, by clicking on **Initial Screening Report**, the report will be displayed and content is dependent on input values given during the session.
9. Depending on which crop (Soybean, Maize, Cotton) was chosen in the session the appropriate "**Crop**" **Knowledge Report** can be selected, with "RR" representing Roundup Ready® crops and "Bt" representing YieldGard®/Bt11 Maize or Bollgard® Cotton.
10. The appropriate Management and Monitoring report can be viewed by selecting "**Crop**" **Management/Monitoring Report**.

### **C. VIEWING EDITORS**

1. Click **Editors** and a drop down menu appears
2. Select the editor of interest

### **D. VIEWING GRAPHS**

1. Click **Graphs** and a drop down menu appears
2. Select either the **Object** or **Rule Graph**
3. The **Object Graph** or **Rule Graph** window will be displayed
4. Click full graph to view

### **E. VIEWING REPORTS**

1. Click **Reports** and a drop down menu appears
2. Select the report of interest and a report window will be displayed
3. Click **Start** and the report will appear

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**APPENDIX E**  
**CONCEPT MAP OF YIELDGARD® MAIZE**

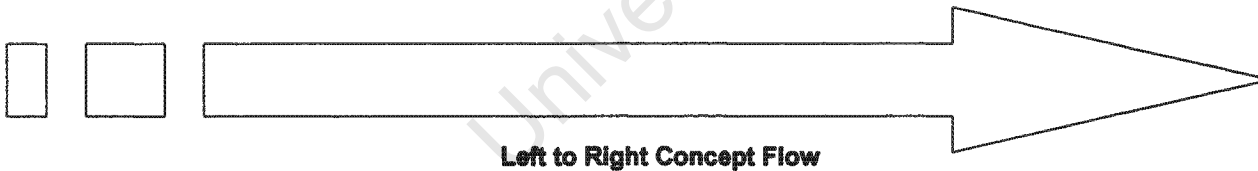
## Concept Map of YieldGard® Maize

VARIETY
Maize
Glycine max L.
MON-00810-6
(MON810)
YIELDGARD®
IR European corn borer

DESCRIPTORS
Biotechnology of variety
Modification method
Characteristics of modification
Genetic stability
Expressed material
Donor organisms
Proposed use
Bt information
Insect pest problems
Origin and history
Biology and reproduction
International and SA extent
SA approvals
Company

POTENTIAL ENVIRONMENTAL IMPACTS
CHANGES IN PESTICIDE USE
PESTICIDE DRIFT
CHANGES IN TILLAGE AND SOIL MANAGEMENT
GENEFLOW AND OUTCROSSING
CROP WEEDINESS
INSECT RESISTANCE
INSECT POPULATION SHIFTS
NON-TARGET AND BIODIVERSITY IMPACTS
WATER Movement of Cry1Ab Pesticide contamination
SOIL ECOLOGY IMPACTS
RESISTENCE TO CROP DISEASES
LAND-USE EFFICIENCY IMPACTS

SA LEGISLATION
PESTICIDE USE
PESTICIDE DRIFT
SOIL MANAGEMENT
GENEFLOW
CROP WEEDINESS
INSECT RESISTANCE
POPULATION SHIFTS
NON-TARGET AND BIODIVERSITY IMPACTS
WATER QUALITY
SOIL MANGEMENT
DISEASE IMPACTS
LAND-USE?



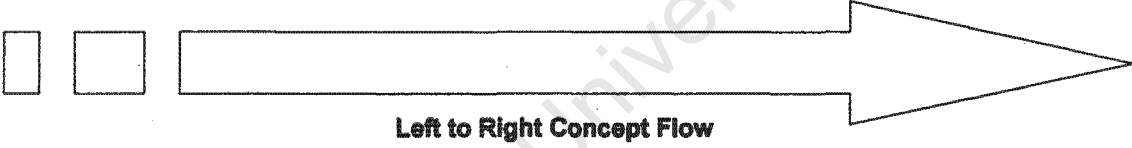
**SA GOVERNMENT REGULATIONS**  
 EIA REGULATIONS  
 GM AS LISTED ACTIVITY  
 APPLICATION FORMS  
 WHO TO CONTACT  
 INDUSTRY CONTACTS

**ENVIRONMENTAL MANAGEMENT/MITIGATION PROCEDURES**

PESTICIDE USE  
 PREVENTING PESTICIDE DRIFT  
 ENV. TILLAGE AND SOIL MANAGEMENT  
 PREVENTING GENEFLOW AND OUTCROSSING  
 PREVENTING CROP WEEDINESS  
 PREVENTING INSECT RESISTANCE  
 MANAGING INSECT POPULATION SHIFTS  
 PREVENTING NON-TARGET AND BIODIVERSITY IMPACTS  
 MANAGING WATER QUALITY  
 MANAGING SOIL ECOLOGY  
 MANAGING CROP DISEASE RESISTANCE  
 LAND-USE EFFICIENCY BEST PRACTICE

**ENVIRONMENTAL MONITORING PROCEDURES**

PESTICIDE USE  
 PESTICIDE DRIFT  
 TILLAGE AND SOIL MANAGEMENT  
 GENEFLOW  
 CROP WEEDINESS  
 INSECT RESISTANCE  
 INSECT POPULATION SHIFTS  
 NON-TARGET AND BIODIVERSITY  
 WATER QUALITY  
 SOIL ECOLOGY  
 CROP DISEASE RESISTANCE  
 LAND-USE EFFICIENCY



**APPENDIX F**

**EXAMPLE ROUNDUP READY® MAIZE MANAGEMENT/MONITORING  
USER REPORT**

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Cycle	Object Information	Value
Input	Which crop would you like to investigate?	Maize
Input	Do you know what Biotechnology is?	Yes
Input	Which transgenic crop trait are you interested in?	Herbicide-resistance
Input	Do you know the legal aspects?	Yes
Input	How would you like to view RR Maize concerns?	Herbicide-resistance
Input	Aware of RR Maize resistance management?	No
Input	Aware of RR Maize resistance monitoring?	No
Input	Do you know what Agricultural Biotechnology is?	Yes
Input	Do you know RR Maize biotechnology?	Yes
Input	Do you know Maize's basic agronomics?	Yes
Input	Do you know Maize weed complex?	Yes
Input	Do you know how Glyphosate works with RR Maize?	Yes
1	Initial screening complete	Done
2	Crop choice completed	Roundup-Ready-Maize
3	RR Maize crop screening done	Done
4	RR Maize environmental concerns complete	Herbicide-resistance
5	RR Maize resistance man/mon complete	Done

University of Cape Town

ID: ERH, 32  
B Name: Environmental Management Protocol for Transgenics  
Run Date: 2006/10/09 17:27:26  
Report Name: Roundup Ready Maize Management/Monitoring Report

How would you like to view RR Maize concerns?

herbicide-resistance

#### HERBICIDE RESISTANCE

According to Prather et al. (2000) herbicide resistance is "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild type". Resistance may occur naturally due to selection or induced through genetic engineering. However, resistance may also occur in plants due to random infrequent mutations. Note that there has been no evidence indicating herbicide-induced mutation. Under selection pressure from an herbicide susceptible plants are killed while herbicide-resistance plants survive to reproduce without the competition from the susceptible types. In the case of the herbicide consistently being used, the herbicide-resistant plants successfully reproduce and become dominant in the population (Prather et al., 2000). Resistance to pesticides decreases the ability of farmers to control economically damaging pests (Carpenter et al., 2002). Note that herbicide-resistance in weeds is not unique to transgenic crops.

Advantages of herbicide-resistant crops include:

1.  Simpler weed management strategies, based on fewer herbicides
2.  Glyphosate and Glufosinate are ideal herbicides for no-tillage agriculture
3.  Lower the cost of weed control
4.  Overall environmental impact is lower.
5.  Useful in the eradication of parasitic weeds
6.  May also have activity against plant pathogens.

The problems with herbicide-resistant crops include:

1.  Over reliance on a single weed management strategy gives more opportunity for resistance to evolve.
2.  Overuse of one strategy may allow other weed species to become adapted in the ecological vacuum created by effective control of the weed species now present.
3.  Population shifts to naturally resistant weed species will be a bigger problem than evolution of resistance.
4.  Where crop rotation is practiced, herbicide-resistant crops can become weeds in a crop rotation system if the second crop is an herbicide-resistant crop engineered to be resistant to the same herbicide to which the original crop was resistant.
5.  An herbicide-resistant transgene in a crop can greatly increase the chance of survival of interspecies crosses by eliminating competition of other herbicide susceptible weeds (Duke, 1999).

#### Status of resistance

The introgression of herbicide resistance from conventionally bred crops into weeds was first documented in 1970. Since then this phenomenon has been increasing exponentially (see Figure 1). Biotypes of 172 weed species have exhibited herbicide resistance to 17 classes of herbicide chemicals. Consequently a number of herbicides have lost their agronomic usefulness (binas.unido.org/xdtree/index, 2005), over half of them from one class, the triazines. (Lebaron, 1991). Weeds resistant to various herbicide families such as phenoxy, benzonitriles, ureas and bipyridyliums have been reported. Weeds such as kochia, Russian thistle, common waterhemp, palmer amaranth, common cocklebur, shattercane and common sunflower

ave developed resistance to ALS inhibitors such as midazolinones and sulfonylureas. (Peterson, 1998).

It is thought that resistance did not develop in plants as early as in insects or fungi due to fundamental differences in the life cycles and genetics of plants, insects and fungi. Delay in appearance of resistant weeds is attributed to the slower generation time of plants, incomplete selection pressure from most herbicides, soil seed reserves and the plasticity of weedy plants. These factors keep susceptible individuals in a population and thus delay resistance development. See Prather et al. (2000) for a list of the most common mechanisms of action or target sites of herbicides, the chemical classes and the number of species with biotypes resistant to each herbicide class (Prather et al., 2000). From the above information one can recognize herbicide resistance as a significant threat to weed control. So why is it an environmental concern? If one follows the argument that the use of glyphosate as an herbicide instead of other traditional herbicides is environmentally beneficial, then the loss of glyphosate as an effective weed control agent will mean a return to traditional herbicides that are relatively more harmful to the environment.

Genetic engineering has been increasingly used in order to express resistance to new classes of herbicides that are specific to a particular crop, while also having low or no ecotoxicity. Examples of such herbicides include glyphosate and phosphinothricin (binas.unido.org/xdtree/index). Note that in the above figure the glycine family of herbicides has the lowest number of resistant species. This is an important consideration regarding the potential longevity of the transgenic herbicide tolerant crops.

There are several factors including herbicide characteristics, weed control practices and production practices that may increase the probability of selection for resistance development. The herbicide factors include a long soil residual activity, a single target site and specific mode of action and a high effective mortality rate for a wide range of weed species. Herbicides that possess prolonged soil residual activity exert selection pressure for a longer time period, as the herbicide will kill most susceptible individuals that germinate over a growing season. Any herbicide that possesses a single target site controlled by a few genes is more likely to encounter plants with mutations for resistance as compared to a herbicide that possesses several modes of action. A high effective kill rate then depletes susceptible genes from the population. Thus the end result is a rapid resistance development among the population of progeny of a few initial resistant plants (Prather et al., 2000).

Continuous planting of the same crop within and between growing seasons reduces the options of rotation to herbicides with different target sites. The limited number of herbicides registered for the many minor crops is a factor restricting the grower's ability to rotate among compounds with differing sites of action. The result is often the continuous use of one or a few herbicides and thus the probability of resistance development occurring increases. Exclusive use of herbicides for weed control can select for resistance when there are other control practices such as tillage or hand hoeing that may be used to control herbicide-resistant weeds. Generally, non-chemical methods will not select between susceptible and resistant individuals, and thus should be used wherever possible. Resistance development is also more likely in lower-value solid-seeded crops on large acreage, as cultivation and hand-weeding may not be feasible. Growers using large areas tend to rely heavily on herbicides for weed control. Furthermore a large acreage farm contains a greater overall number of individual weeds that may contain a resistance trait (Prather et al., 2000).

The concern over whether or not the introduction of transgenic crops resistant to glyphosate will lead to resistance is based on the assumption that the cultivation of such crops will lead to a significant increase in the use of the glyphosate herbicide. The projected increase of glyphosate use is not considered significant for this to occur (Monsanto Company, 2002a). However, there are examples where increased use of glyphosate has increased selection pressure, which has

Approximately 50% weed control failure is observed for a particular species. If resistant weed patches can be identified early management practices can be employed that prevent their spread. In the case of weed escapes appearing in patterns such as distinct strips, or if several species usually controlled by the particular herbicide appear in these strips then the problem is probably associated with a calibration or application error. In the case of patches made up of only one escaped species and showing no distinctive pattern, there may be an herbicide-resistant population problem (Prather et al., 2000). It is important to note that herbicide-resistant weeds had become an issue long before transgenic herbicide-tolerant crops were developed.

Roundup Ready herbicide is a code group G herbicide regarding resistance management. A weed population may have individuals naturally resistant to Roundup Ready herbicide and other code group G herbicides. If such herbicides are used repeatedly, through selection of resistance, resistant Roundup Ready herbicide, or other code group G herbicides. In order to delay resistance development:

1.  Avoid the exclusive and repeated use of herbicides from the same herbicide code group. The user should alternate or tank mix with registered products from different herbicide code groups.
2.  The user should integrate other control methods into the weed control programme such as chemical, cultural and biological controls (Monsanto, 2005a).

Aware of RR Maize resistance monitoring? No

Monitoring for herbicide resistance

Farmers should monitor weeds in the field after herbicide applications checking for resistance.

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