Virginia Integrated Pest Management Expert for Wheat

by

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The Virginia Integrated Pest Management Expert for Wheat was designed to combine the best available information regarding wheat pest management of disease pathogens, weeds, and insects into a decision support system that would provide potential outbreak risk and pest control information to the Comprehensive Resource Planning System (CROPS). In addition, the system stands alone as an educational tool for farmers and Extension personnel.

This is a rule-based system developed on the Microsoft Windows platform. Knowledge about crops and pest management is represented in the form of IF/THEN rules, demons, and “when-changed” methods. The inference engine analyzes specific crop system information entered by the user to determine potential risks of outbreak for wheat crop pests common to Virginia. These potential outbreak risks are presented as low, medium, and high levels of risk and are presented for each of 15 pests of wheat in Virginia.
The system was evaluated using thirty random cropping system scenarios. By comparing expert system output with output from human experts, it was shown that the expert system agreed with human expert opinions in 84 percent of the decisions made. Statistical analysis of the insect pest data showed that there was no significant statistical difference between the distribution of the human expert predictions and the expert system predictions. Statistical analysis of the disease pest data showed that there were some significant statistical differences between the distribution of the human expert predictions and the expert system predictions.
For Lisa and Lane

CALVIN AND HOBBES BY BILL WATTERTON

YOU'RE GOING TO JUGGLE EGGS?

IT'S A METAPHOR FOR LIFE, HOBBES.

EACH EGG REPRESENTS ONE OF LIFE'S CONCERNS AND THE GOAL IS TO GIVE EACH THE APPROPRIATE AMOUNT OF INDIVIDUAL ATTENTION WHILE SIMULTANEOUSLY WATCHING AND GUIDING ALL THE OTHERS.

LIFE IS ABOUT BALANCE AND STAYING QUICK AND ALERT AS EVERYTHING TRENDS TO SPIN OUT OF CONTROL.

AND SOMETIMES WE MAKE A BIG MESS OF THINGS.

BUT THE IMPORTANT THING IS PERSISTENCE.

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1. **Introduction**

Since the early 1970s, the environmental concerns of the general public regarding pesticide use in agriculture has placed considerable pressure on the United States legislature and the Virginia agricultural community to implement integrated pest management (IPM) programs to protect the environment (Laub and Ravlin 1993). In fact, on September 22, 1993, the Clinton administration made the adoption of IPM on 75 percent of the nation’s crop acres by the year 2000 a national goal (USDA 1993). Despite many IPM successes using technologies such as host plant resistance and biological control, synthetic pesticides have remained the predominant component of IPM programs through the last three decades (Allen and Rajotte 1990). Wearing (1988) has pointed out that the delay in the adoption of IPM has to do with the complexity of the programs and the considerable time and resources that must be devoted to implementation.

Despite the complexity, looking at pest management from the whole-farm level opens new avenues for pesticide and pest management (Stone and Warren 1993). By anticipating how the overall farm plan contributes to pest outbreaks, one can avoid cropping systems and practices that lead to pest management problems. To help manage the complexity of this process, a multi-objective computer decision aid was designed to help farmers generate alternative whole-farm plans that are profitable and environmentally sound (Buick et al. 1992, Stone 1995). The resulting Comprehensive Resource Planning System (CROPS) uses economic and environmental risk evaluators to estimate how well potential farm plans meet both the farmer’s goals and environmental
constraints. The research reported here describes a prototype evaluation system for CROPS that estimates the risk of pest outbreaks and the need for pest control based on planned cropping practices over time.

1.1 Preventive IPM & Decision Support Systems

There are many different definitions of IPM but the practical implementation of IPM falls into two basic categories, preventive and therapeutic. Preventive tactics strive to avoid problems before they happen and therapeutic tactics attempt to correct problems that have already occurred (Wintersteen and Higley 1993). IPM in the preventive mode requires that pest management options be considered before the crops are planted rather than waiting for the pest problems to occur. One way to implement preventive IPM is through the use of decision support systems.

A decision support system (DSS) is a computerized system for accessing and processing data and providing recommended courses of action as developed through the use of analytical methods (Ignizio 1991). In agriculture, a DSS may help farmers make tactical and strategic management decisions in areas such as cultivar selection, timing of planting and harvesting, and pest management (Plant and Stone 1991).

Because farmland is part of a larger landscape, developing sound pest management strategies should include consideration of each field as a component of the farm, and each farm as a component of a larger landscape or watershed. In other words, IPM should be part of a holistic management plan for all related resources (Bridge 1993).
One of the difficulties in implementing preventive IPM within a whole-farm planning scenario has to do with the huge number of potential farm plans that exist, each a unique combination of cropping systems and enterprise decisions. For example, on a farm with just five fields and ten possible crop rotations to choose from, there can be more than 2,000,000 possible four-year plans to consider (Buick et al. 1992). When considering multiple tillage options, planting dates, crop varieties, and fertilization schedules, the possible number of plans grows even further. This combinatorial explosion of possibilities makes it impossible to consider all possible plans, even with the fastest computers. Methods derived from operations research and artificial intelligence are needed to find good solutions quickly (Stone and Warren 1993).

1.2 The CROPS System

The CROPS system is a whole-farm planning and scheduling system that considers soil conservation, nutrient management, pest management, and economic constraints to generate farm plans (Buick et al. 1992). Each of the areas of consideration requires an automated evaluator to provide input for the process of assessing potential farm plans. This research deals specifically with the pest management aspect of this system.

The planning engine is a three-level hierarchy, and within each level are pre-planning, planning, and post-planning phases. Post-planning phases at each level facilitate detection of failure conditions (cases in which no plans can be found that meet all goals and constraints), allowing the system to return control to the user. At the third level, a two-dimensional constraint-propagation algorithm assigns crops and tillage
practices to fields to obtain a final six-year plan. The user is able to evaluate the generated plan in the final post-planning phase of CROPS. Inherent in the crop rotation plan are tillage, and recommendations for nutrient, pest management, and soil conservation strategies (Buick et al. 1992).

In level-one planning, CROPS evaluates potential multi-year crop rotations on a field by field basis. The system decides whether each rotation is acceptable based on environmental considerations or constraints. If it’s not acceptable, for example if it would result in excessive erosion, it is removed from the field’s list of potential rotations. Later, in level-three planning, whole-farm plans are made up from combinations of these acceptable rotations. In this way, plans that ultimately result from CROPS include only rotations that do not result in unacceptable risks in any of the farm’s fields (Buick et al. 1992).

To consider the potential risk of pesticide leaching and runoff resulting from a crop rotation being applied to a particular field, CROPS needs a way to predict what chemical control methods, if any, would be required in that rotation, and what environmental risks would result from those chemical controls. The first step is to determine what pests will require control.

1.3 Goal & Objectives

1.3.1 Overall Goal

The overall goal of this research was to develop a wheat pest management evaluator for the CROPS system to enable the whole-farm planning system to anticipate
and avoid pest management problems in wheat in Virginia. Since CROPS is a planning tool to be used before any crops are planted, the evaluator was not intended to give tactical pest control advice. It was, however, intended to identify pest problems likely to occur and to evaluate the economic and environmental consequences of controlling those pests.

This evaluator was built as a stand-alone system, outside the CROPS environment, for simplicity and ease of testing. An added benefit of this research, therefore, was the development of a stand-alone pest management expert system for wheat in Virginia that may prove to have an educational benefit for farmers and Extension Agents.

1.3.2 Objectives

The objectives of this research were as follows.

1. Capture pest management expertise relating to the prediction of pest problems in wheat systems in Virginia.

2. Build a knowledge base of pest control practices that have an impact on pests of wheat in Virginia, including information on their efficacy and environmental risks.

3. Build an expert system based on (1) and (2) that can predict likely pest outbreak risks for various wheat cropping system scenarios.
1.4 Justification

Since the origin of the IPM concept, the theory of pest management has revolved around integrating pesticide use with preventive management tactics. In practice, however, the emphasis has been to control or suppress pest populations with pesticides rather than to minimize the adverse effects of pest populations on human activities through preventive management tactics (Funderburk, Higley, and Buntin 1993).

The main reasons that applied IPM has concentrated so heavily on therapeutic pest control are the legacy of the pesticide era, and farmers’ not implementing preventive management strategies due to lack of knowledge (Funderburk, Higley, and Buntin 1993). The knowledge required can be extensive, because preventive pest control measures include changing cultivar selection, crop rotation, nutrient management, and tillage practices. In order to complete the integration of pesticide use with preventive tactics farmers need to adopt a total resource planning process (Stone and Warren 1993). This research provides a way to link knowledge about pest outbreaks and control with the synthetic process of whole-farm planning.

Two key challenges faced by this project were addressing the inherent uncertainty of managed ecosystems and capturing human experts’ understanding of a complex problem in a computer program (Stone and Saarenmaa 1988). How experts process information to suggest solutions or draw conclusions is often obscure. Converting expert knowledge into rules and using these rules to validate or invalidate a decision can make this process explicit (Starfield and Bleloch 1983), but the process, called knowledge engineering, remains very much an art.
When successful, decision support systems can help farmers make difficult decisions by providing valuable information in an understandable and easily accessible form (Knight and Mumford 1994). Pest management experts are often in great demand when there is a pest outbreak but they have little opportunity to provide advice for long-term strategies. The use of a planning decision support system allows this expertise to be incorporated into the decision-making process (Marshall and McCullough 1995).

The hypothesis of this research is that risks of potential pest outbreaks in Virginia winter wheat can be predicted by a decision support system with accuracy comparable to human experts in wheat pest management. By combining expert knowledge on the pest management of insects, diseases, and weeds, such a system would improve access to timely and comprehensive pest management information for wheat, and it would provide the basis for including wheat pest management goals in the whole-farm planning system, CROPS.
2. Literature Review

Research integrating IPM into farm planning systems is reviewed here, as is development of decision support systems for IPM. This chapter also provides background on the process of developing, verifying, and validating expert systems in agriculture. Because the integration of IPM into the farm planning process is a relatively unexplored research area in IPM, this chapter begins with a review of the preventive IPM literature.

2.1 Preventive IPM

*If pests are viewed as indicators of maldesigned and malfunctioning systems, the requirement is to understand the causes of pest outbreaks and to modify the design and management of systems to prevent them.* –S.B. Hill (1990)

Recall that preventive pest management and curative or therapeutic pest management are the two main strategies of IPM (Pedigo 1996). To date, research in pest control and IPM has focused mainly on the latter. Similarly, most IPM research has focused on single-event decision making, as in the case of the economic injury level or economic threshold. When decisions need to be made for multiple events, the usefulness of these tactics is greatly constrained. Ideally, farmers should plan for multiple events so pest problems can be avoided. To do this farmers should use a systems perspective when planning so that pest management is considered before pests become problems (Stone and Warren 1993).
Preventive IPM tactics have been studied as solutions to single-decision problems. For example, Speese and Sterrett (1998) showed how crop rotation reduces the cost of Colorado potato beetle control in potatoes, and Walters and Eckenrode (1996) found crop rotation was an effective method in the management of onion maggots in commercial onion production. Similarly Johnson, Hoverstad, and Greenwald (1998) determined that cultivation was instrumental in managing weeds in corn crops. Farm planning requires the integration of several tactics and strategies that together manage a suite of pests, often over many years. Given the complexity involved from the use of rotational systems and integration over many fields (Stone et al. 1992; Nevo, Oad, and Podmore 1994), this kind of holistic preventive planning probably requires computer-based systems to address the issues of knowledge integration, interpretation, and delivery in IPM (Coulson and Saunders 1987).

There has been some work in preventive IPM that attempts to incorporate single-decision strategies into systems geared toward whole-farm planning. Stone and Toman (1989) developed an integrated, farm-level expert system for cotton called COTFLEX that includes multiple rule-based modules covering a broad spectrum of problem domains. Travis et al. (1992) developed an expert system for the management of apple orchards that considers the profile of the crop, chemical management, and pest modules. Another example is the GRAPES expert system for viticulture in Pennsylvania developed by Saunders et al. (1987). The system integrates cultural methods for insect, disease, and weed control along with diagnostic techniques for grape farm management. Weisz et al. (1994) developed a knowledge-based expert system for Colorado potato beetle management. The focus of this research was to slow down the development of
insecticide resistance in this important potato pest. In field trials they had great success in both agreeing with their human expert and in controlling resistance to protect yields and profits for potato growers. An expert system tool called NERISK was developed by Messing and Croft (1990) to evaluate the effects of pesticides on beneficial organisms in various cropping systems. The versatility of this tool makes it compatible with a wide variety of systems but to integrate it with other tools could make a more useful application. Development of the CALEX expert system shell (Plant 1988) resulted in a crop production decision support system that was used for cotton and peaches. The CALEX system was designed to manage crop production and/or predict the effects of a decision upon subsequent events. Batchelor et al. (1989a) developed SMARTSOY, an expert simulation system for soybean insect pest management. Here the expert system attempting to mimic the human specialist was linked to a crop growth model to evaluate the effects of insect population on yield. Maize is a decision support system for management of field corn (Heinnemann et al. 1991). The Maize program includes production and post-harvest recommendations. Management recommendations in the production season section are primarily based on several experts' experience and knowledge. Buick, Youngman, and Stone (1993) developed VICE-Corn, an expert system that recommends insect pest management for Virginia corn production. Based on a field’s history, conditions, practices, and locality, VICE-Corn recommends a variety of sampling and control techniques.

### 2.2 Whole-farm planning

Whole-farm planning or total resource planning is a holistic or ecosystem approach to conservation planning that deals with water, air, plants, and animals and their
interactions (Bridge 1993). Over the last decade, farmers have been increasingly required to adopt and implement farm plans, e.g., the Food Security Act of 1985 and the Chesapeake Preservation Act of 1988 required farmers in the Chesapeake Bay watershed to file nutrient and pest management plans for fields located near waterways and soil management plans for fields with highly erodible soil. This has stimulated more work on the development of farm planning decision support systems and whole farm planning tools, but there are still relatively few such systems.

2.3 **Whole farm planning systems**

One solution to the problem of planning in agriculture uses the application of artificial intelligence (AI) planning methods. As described earlier, the CROPS system is a whole-farm planning and scheduling system that considers soil conservation, nutrient management, pest management, and economic constraints to generate farm plans (Buick et al. 1992).

Another example is PLANETOR (Hawkins and Nordquist 1991). This is a system that helps farmers evaluate economic and environmental tradeoffs of alternative crop and livestock production systems and practices. It was developed by the Center for Farm Financial Management at the University of Minnesota in cooperation with the USDA Farm Resource Management System Task Force. PLANETOR evaluates farm systems in a way that users can relate environmental and economic concerns relating to farm practices. In evaluations with farmers and extension specialists it was found that this system was very time consuming to use and produced unrealistic environmental risk results (Norris and Harper 1993).
2.4 Wheat crop management

Wheat crop management designed to maximize yield is a process that integrates yield-enhancing factors with yield-protecting factors. The enhancing factors include variety selection, plant nutrition, and precision planting. The protecting factors include harvest management, lodging control, disease control, insect control, and weed control (Alley et al. 1993). This research focuses on the latter three protecting factors: disease control, insect control, and weed control.

In each of these three areas of pest management, there are a variety of tactics that can be used to lessen the impact of the pests. These tactics range from preseason controls such as variety selection and crop rotation to midseason controls such as scouting and pesticide treatment. All may be necessary to achieve the highest economic benefits (Alley et al. 1993). The challenge here is that all of the components of wheat crop systems interact, and decisions affecting one variable will often affect others in the system as well. One of the most important strategy decisions is how to best utilize the variety of pest management options that are available. The goal is to maximize profits and, at the same time, not threaten ground and surface water, worker and applicator safety, and other wildlife in our environment (Stuckey et al. 1989).

Recent work in the area of wheat IPM has focused on single-decision strategies and much of the work has been done in the mid-west and western parts of the U.S. Aphids in general and the Russian wheat aphid specifically have been studied along with weed management and disease prevention. Preventive tactics investigated include establishing and enhancing populations of natural enemies (Lacey et al. 1997, Holland

In Virginia, research on weed control has looked at the effects of tillage and herbicides (Wilson et al. 1986). Maximum wheat yields were shown to be higher in conventionally tilled systems. Studies on aphids and cereal leaf beetle (Herbert et al. 1991, Herbert et al. 1999) examine the basic biology of the insects found in Virginia wheat fields and provide some preventive tactics along with traditional thresholds and scouting techniques. Recent research has revealed a previously undetermined species of aphid in Virginia small grains that is a vector for barley yellow dwarf virus (Herbert 1999a). Plant resistance to Hessian fly was investigated by Ratcliffe et al. (1997). Although there is no resistance currently to the predominant biotype “L” found in Virginia, the researchers appear hopeful that wheat cultivars may be adapted for resistance in the future. Disease pathogens have been investigated rather thoroughly for preventive tactics by Stromberg (1999). He lists a full range of preventive tactics along with reactions to various diseases by specific wheat cultivars that are grown in Virginia.

2.5 Modeling options

Ultimately, the CROPS system requires an automated evaluator for crop rotations involving wheat that can be used to determine whether a particular rotation and management system ought to be considered in a particular field, as part of an overall farm plan (Stone et al. 1992). Such an evaluator can take many forms, including a simulation model, a knowledge-based system, or a statistical discriminant analysis.
The requirements of this research include the ability to work with heuristics, to reach decisions based on incomplete information, and to search efficiently through combinatorially explosive problems. Several possible approaches to constructing a pest management evaluator were examined with these requirements in mind. Information systems such as geographic information systems, management information systems, and database systems provide information in a variety of forms, but they do not incorporate a problem-solving methodology. Likewise, simulation models can be very informative and predictive, but they lack the ability to reason (Plant and Stone 1991).

Operations research methods have the ability to analyze and find optimal solutions but they lack the ability to handle qualitative information and heuristics, and they often require simplification of their models to accommodate the solution methodology (for a good example, see Onstad and Gould [1998] analyzing scenarios for the development of insecticide resistance in European corn borers exposed to transgenic corn).

Discriminant analysis is a statistical technique used to test for mean group differences, describe overlaps among groups, and to construct classification schemes (Eisenbeis and Avery 1972). In their work with Africanized honeybees, Daly and Balling (1978) showed how discriminant analysis was able to separate Africanized bees from European bees where conventional taxonomy was unreliable. Since discriminant analysis is a classification procedure it does provide useful information. But one of the assumptions of discriminant analysis is the classification of an individual item into one of several groups is based on the distance of the item’s observation vector from the mean score vector within each of the groups (Marcoulides and Hershberger 1997). Since one
of the requirements of this project is the ability to deal with heuristics, and heuristics are not something that can be converted to a linear model, this method was rejected.

Knowledge-based systems have been used successfully to capture human expertise on complex problems and deliver alternatives for problem solving and decision-making (Coulson et al. 1987). An example is the COTFLEX expert system, which provides pest management advice by combining human expertise with information from simulation models (Stone et al. 1987). There are many others including one of the first expert systems developed, MYCIN: to diagnose bacterial infections of the blood (Shortliffe 1976), and LINNAEUS: an interactive taxonomy tool for classifying and identifying species of zooplankton (Estep et al. 1989). Crop systems are very complex and often cannot be described quantitatively with enough accuracy to be useful. Of the options explored, knowledge-based systems are best able to combine an explicit way of incorporating heuristics and qualitative reasoning, and handle the complexity of agricultural systems (Plant and Stone 1991).

Of the many knowledge-based systems produced, there have been a few developed with the pest management of wheat in mind. BULBFLY, an expert system for management of the wheat bulb fly in the United Kingdom (Jones et al. 1990), is designed to manage a single pest in the United Kingdom. Another program called Weed Advisor was developed to help extension workers identify and control weeds in wheat, triticale, barley, and oat crops (Pasqual 1994). SELECT is a farm planning tool developed in the United Kingdom (Morgan et al. 1989) and Caristi et al. (1987) developed EPINFORM, an expert system for predicting wheat disease epidemics. Zhang and Shroyer (1992) developed WHEATWHIZ, an expert system for wheat variety selection in Kansas.
What these systems have in common is an interest in managing wheat. What they do not do is integrate the management of insects, weeds, and diseases of wheat grown in Virginia in a preventive mode. Certainly there are lessons to be learned from these efforts to manage wheat pests in isolation or in other areas of the world. Because of differences in climate, soils, and pests present, growing wheat in Virginia is a much different process than growing wheat in the Midwest or western United States, not to mention the United Kingdom (Stromberg 1998).

2.6 Expert System Design

The process of developing and implementing an expert system is called knowledge engineering. The individual who is engaged in this process is the knowledge engineer. Once the decision has been made to use this technology there are a series of recognized processes that the knowledge engineer goes through to develop an expert system. These processes are selection of software, hardware, and implementation, knowledge acquisition, and user interface design (Nikolopoulos 1997).

2.6.1 Structure

The main components of an expert system are the knowledge base, the inference engine, and working memory. The knowledge engineer converts expert knowledge into a form that can be manipulated by computer software. This knowledge is then stored in a knowledge base. The user provides information about a specific problem via a user interface. The inference engine uses the knowledge provided to come to some conclusions and/or give advice about the specific problem (Plant and Stone 1991).
To arrive at conclusions about a problem, the inference engine must search for a solution in an efficient and effective manner. Any search will be guided by a variety of data and constraints. The search strategy that begins with data and constraints and uses them to filter a large selection down to a few choices is called forward chaining (Ignizio 1991). Here the inference engine examines a set of rules, each assertion being evaluated to determine its truth. For those rules that evaluate to true, their conclusions or consequents are added to the knowledge base. This process continues until no further consequents can be determined. Forward chaining allows the knowledge engineer to use rules to develop information from a limited set of initial data. This type of reasoning is appropriate, for example, in a monitoring situation where it is desirable to learn as much as possible about the state of a monitored system based upon the available data (Walters and Nielsen 1988).

Another search strategy called backward chaining starts with a goal and works backward to check data and constraints to determine if the goal is feasible (Ignizio 1991). In backward chaining, the inference engine identifies one or more hypotheses and begins searching for rules that contain the hypothesis as a consequent (i.e., concluding that the hypothesis is correct). For any such rule found, the inference engine tests the truth of the predicates (the if-clauses) of the rule. If the predicates are true, then the hypothesis is confirmed, and the inference engine moves on to the next hypothesis. If the truth of a predicate is unknown, the hypothesis that the unknown predicate is true is added to the inference engine’s list of hypotheses to check. This initiates a search for rules with the new hypotheses as a consequent. This process forms a chain, linking rule predicates backward to consequents. This strategy is often used in selection or classification
applications in which one item is to be selected from a fixed set of items (Walters and Nielsen 1988).

Both strategies will ultimately lead to a conclusion, but the efficiency of the search is dependent on the nature of the problem faced. A problem with few premises and many conclusions would generally be better off with a forward chaining strategy whereas a problem with many premises and few conclusions would normally do better with a backward chaining strategy. There are instances in which it would be wise to employ a combination of the two strategies (Ignizio 1991).

Expert systems can be constructed to allow the knowledge engineer to control the direction of chaining and to switch from one direction to the other by invoking methods that use the opposite chaining logic (Builders 1994). To determine when and where this is necessary, it is useful to structure the knowledge engineering process by diagramming system interdependencies, flow, and function (Plant and Stone 1991).

2.6.2 Software

There are two basic methods to build an expert system. One is to use an expert system shell and the other is to use a programming language in a programming environment.

An expert system shell can be thought of as an expert system without the knowledge base. It provides the framework and tools for building a system, and its power and utility depend on the kinds of knowledge representation and reasoning methods allowed and on the ease of use of its interface. A programming environment, on
the other hand, gives the raw materials to the developer so that a system can be custom-built from scratch to meet the developer’s specific needs and desires. The tradeoff is time for flexibility. The programming environment allows for greater flexibility since the developer has total control over the system, but the programming expertise and time required is greater (Nikolopoulos 1997).

The selection of an expert system shell or a programming environment is usually based on some sort of evaluation approach. Three such approaches are:

1. Subjective judgment by users

2. Expert observation by nonparticipants

3. Objective measurement.

Because objective measurement usually involves costly data collection and analysis, the first two methods are frequently used (Adelman and Donnell 1986).

The evaluation and selection should include four major steps:

1. Identification of required capabilities and features

2. Identification of potential shells

3. Evaluation of shells based on required capabilities and features

4. Selection of the appropriate shell.

In the end, the requirements of the specific application determine the value of the capabilities and features available (Stylianou, Madey, and Smith 1992).
At the time of this writing, there were more than 150 expert system shells available commercially for developing expert systems on personal computers (Chang, Chin, and Kartam 1992). Those used in agricultural applications include Level5 Object (Bergsma et al. 1992; Buick, Youngman, and Stone 1993) and Exsys (Linehan, Orono, and Corcoran 1994; Schmoldt and Martin 1989; Wisiol et al. 1986), among others.

2.6.3 Level5 Object

Level5 Object includes tools and a language for constructing rule-based expert systems. Control logic can be forward or backward chaining, and the knowledge engineer can use rules and methods to control the chaining strategy dynamically during a reasoning session. Level5 Object has a very powerful modeling framework based on objects and classes for encoding domain knowledge. In Level5 Object, a class defines an object’s general properties and structure. For example, the VIEW application has a class called Field, which is used to define the common properties of all the fields in a farm. Attributes are part of a class definition. They describe an object’s important features or characteristics. For example, the class, Field, includes among its attributes County, Tillage, and Previous-Crop. An instance of the class Field would contain actual data about a particular field being considered. It is this object-model that allows the grouping of similar information together and the ability to reason using second-order logic.

Procedures used to manipulate data within the Level5 Object environment include demons and “when changed” methods. A demon or a method is a series of commands, similar to macro in a spreadsheet program, that are associated with an attribute and define
the behavior of the attribute. The differences between the two are subtle and the decision to use one over the other is often a matter of personal preference (Builders 1994).

2.7 **Knowledge Acquisition**

Knowledge acquisition is the process of collecting the knowledge necessary for solving a problem and encoding it into a form that allows for efficient computer manipulation. Knowledge acquisition is comprised of two tasks: knowledge elicitation and knowledge representation. These two tasks do not necessarily occur in sequence and both usually take place throughout the development life cycle as deficiencies in the knowledge base are realized and modifications are made. In knowledge elicitation, domain knowledge is obtained through various means including interviews with experts and book and journal references. In knowledge representation, the elicited knowledge is converted to a form for efficient computer manipulation (Nikolopoulos 1997).

Knowledge in its primary form can be obtained from four sources: literature, human specialists, existing models, and examples (Sell 1985). Methods of collecting, organizing, and formalizing knowledge are many and vary widely depending on the source. When knowledge is extracted from human specialists, the acquisition process is often called knowledge elicitation. The job of knowledge elicitation from human experts can be very difficult due to the inexpressive nature of human knowledge (Schmoldt and Rauscher 1996). There is no universal agreement on which knowledge elicitation technique to use when. It is most common to start with interviews and then use other methods when considered useful. The knowledge engineer must be versatile and willing
to weigh the various methods in order to please the experts and elicit the most information (Hart 1992).

Acquisition methods or techniques are often incorporated into knowledge acquisition strategies. These strategies usually fall into one of two categories: manual or automated. Automated methods are driven by computer programs and may include machine learning or automated interviews. Manual methods may include fast prototyping, evolutionary acquisition, ad hoc methods, and expert driven strategies. Selection of a strategy by the knowledge engineer will probably depend on human and financial resources, time availability, project complexity, and familiarity with available methods (Schmoldt and Rauscher 1996).

2.8 Input/Output Interface

The input/output interface defines the way in which the expert system interacts with the user and other systems such as databases. Interfaces are usually graphical with screen displays, windowing, and mouse control. They receive input from the user and display output to the user (Nikolopoulos 1997). Some systems use natural-language front-ends that accept English-like responses but most use a graphical user interface (GUI) with a mouse device to allow the user to choose from selections in dialog boxes and menu bars. The GUI is the most natural to use, and the menus, although they restrict the values that may be specified, are more helpful to users less familiar with the domain (Schmoldt and Rauscher 1996).
2.9 Evaluation of Expert Systems

2.9.1 Definitions

The evaluation of an expert system must address the justification for the employment of an expert system and the verification and validation of the knowledge base (Ignizio 1991). Validation is often confused with verification. Validation refers to building the right system (that is, substantiating that a system performs with an acceptable level of accuracy), whereas verification refers to building the system "right" (that is, substantiating that a system correctly implements its specifications) (O'Keefe, Balci, and Smith 1987).

2.9.2 Verification

Verification of the rule base involves two categories of error checking: consistency and completeness. Within the consistency category there are five types of errors: conflict, redundancy, subsumption, unnecessary antecedents, and circularity. The completeness category consists of two error types: unreachable consequents and dead ends (Nguyen et al. 1987).

Many commercially available expert system shells have tools for catching common errors in syntax or rule redundancy. These tools are of immense value in the verification of the knowledge base (Marcot 1987).
2.9.3 Validation

Validation of the rule base involves trying to substantiate that the system performs with an acceptable level of accuracy comparable to human performance (Nikolopoulos 1997). This measurement is usually accomplished by comparing the performance of the expert system with the performance of human experts on a set of inputs from or similar to real world situations. Sources for test cases are historical files, ongoing transactions, and manual generation by the domain expert or knowledge engineer (Smith and Kandel 1993).

Since expert systems are representations of knowledge from a human expert, we cannot expect perfect performance. An acceptable performance level should be specified during development (O'Keefe, Balci, and Smith 1987). Batchelor et al. in the evaluation of SMARTSOY found that agreement with their entomologist expert 80% of the time was acceptable (Batchelor et al. 1989) and Bhogaraju concluded that a 78-80% range was acceptable in the evaluation of his case-based reasoning system using a similar domain (Bhogaraju 1996).

Measuring agreement between an expert system (ES) and an expert is often done in an *ad hoc* way, comparing the number of times the two agree versus the number of cases considered (e.g., Batchelor et al. 1989, Bhogaraju 1996). In principle, however, agreement can be represented by any measure of similarity, to distinguish cases in which the expert and ES differ but are close to agreement, from cases in which their responses are dramatically different. In cases in which the ES provides more than one response per case or consultation, multivariate distance measures can be used to compute an overall
similarity, just as they are commonly used in taxonomy to compute the similarity between operational taxonomic units (Sneath and Sokal 1973). In either case, what is needed is a matrix describing the distance between possible ES and expert responses. For example, for a system that generates pest outbreak risks, the distance matrix,

<table>
<thead>
<tr>
<th>Distance</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>4</td>
</tr>
</tbody>
</table>

would express that it is worse to under predict pest risk than to over predict.

2.10 Summary

While there are numerous examples of research involving preventive pest management, there are few whole farm planning systems that utilize preventive IPM. The development of artificial intelligence and knowledge-based systems has a relatively short history but there are some accepted methods for developing, verifying, and validating expert systems in agriculture.
3. **Capturing Pest Management Expertise**

3.1 **Materials & Methods**

Domain knowledge was obtained through individual interviews with experts in entomology, plant pathology, and weed science, reviews of published research and pest management guides, and pesticide databases. The experts interviewed were Dr. Ames Herbert, Associate Professor of Entomology, Dr. Erik L. Stromberg, Professor of Plant Pathology, and Dr. E. Scott Hagood, Professor of Weed Science, all at Virginia Tech. Initial interviews were conducted in the fall of 1993 and the spring of 1994.

The knowledge acquisition strategy used was a variation of the manual method called fast prototyping (Schmoldt and Rauscher 1996). A prototype system was developed with rudimentary knowledge of the domain. This system was the focus for further knowledge acquisition. During the iterative knowledge acquisition process it became apparent that changes to the initial system were needed and so the system evolved as new knowledge was obtained.

In the first meeting with the experts, the objectives were to communicate the purpose of this research and begin the knowledge acquisition process with an unstructured interview to elicit some basic information. Questions were prepared in advance and notes were taken at the meetings by the knowledge engineer. The experts were asked to explain the circumstances that might cause pest problems to occur. Following the first meeting, the elicited knowledge was converted to a rule-based structure.
Most of the elicited knowledge was converted to rules in the form of IF/THEN statements where satisfying the conditions of the IF clause allows the inference of conclusions in the THEN clause. For example, the following is a simple rule from the rule base.

\[
\text{IF (planting date > October 20) THEN (risk of hessian fly outbreak is low)}
\]

A more complex rule can include multiple antecedents and an ELSE clause, as in:

\[
\text{IF (Row Width OF Field IS Four AND Seed Rate OF Field < 12) OR (Row Width OF Field IS Six AND Seed Rate OF Field < 18) OR (Row Width OF Field IS Seven AND Seed Rate OF Field < 20) OR (Row Width OF Field IS Eight AND Seed Rate OF Field < 22) THEN Outbreak Risk for Seed Rate OF Cereal Leaf Beetle := 1 ELSE Outbreak Risk for Seed Rate OF Cereal Leaf Beetle := 3}
\]

The simple rule checks to see if the planting date entered by the user is later than October 20. If this is true, then the value of the attribute “risk of hessian fly outbreak” is set to “low”. This rule is examined by the inference engine during a backward chaining process to investigate the value of the consequent “risk of hessian fly outbreak”. The more complex rule checks for the combination of planting-row width and seeding rate entered by the user. This rule is also examined by the inference engine during a search for the value of “Outbreak Risk for Seed Rate OF Cereal Leaf Beetle”.

Some of the knowledge was elicited and stored in the form of data tables such as the following description of wheat cultivar reactions to various diseases (Extension 1997).
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Powdery mildew</th>
<th>Leaf rust</th>
<th>Leaf spot and glume blotch</th>
<th>Wheat spindle streak mosaic</th>
<th>Barley yellow dwarf</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFR 502W</td>
<td>MR</td>
<td>VS</td>
<td>MS</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>FFR 544W</td>
<td>MS</td>
<td>MR-MS</td>
<td>NA</td>
<td>NA</td>
<td>VS</td>
</tr>
<tr>
<td>FFR 555W</td>
<td>MS</td>
<td>S</td>
<td>MS</td>
<td>MS</td>
<td>VS</td>
</tr>
<tr>
<td>FFR 568W</td>
<td>MR-MS</td>
<td>S</td>
<td>MS-S</td>
<td>MR</td>
<td>NA</td>
</tr>
<tr>
<td>FFR 511W</td>
<td>R-MR</td>
<td>MR-MS</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Florida 302</td>
<td>MS-S</td>
<td>MR-MS</td>
<td>MS-S</td>
<td>VS</td>
<td>NA</td>
</tr>
<tr>
<td>Gore</td>
<td>MR-MS</td>
<td>MR</td>
<td>NA</td>
<td>MR</td>
<td>MR</td>
</tr>
<tr>
<td>Hunter</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>MS</td>
<td>NA</td>
</tr>
</tbody>
</table>

Level5 Object provides methods for looking up the value of a variable from a table from within a rule.

Part of the knowledge acquisition process was capturing procedural information, information about the sequences of inferences or actions taken by an expert. Encoding this kind of information can be done by writing demons and by using *when-changed* methods. These methods are also useful for adding functionality to the user interface. For example, demons and *when-changed* methods can also be used to allow the user to control the chain of events during a consulting session. For a specific example, part of the graphical interface of the system includes a histogram showing pest outbreak risk. When a user clicks on a specific bar from the histogram, a demon (Listing 1) runs, executing a structured query language (SQL) command to extract data relevant to the control of a specific pest from several pesticide databases. The demon gets the data and inserts the extracted values into a table, which is then displayed to the user. In this case,
the demon was invoked by a user action. \textit{When-changed} methods (Listing 2) are demons invoked when the value of a variable in the knowledge base is modified.

\textbf{Listing 1:} Demon to retrieve aphid control information when user clicks on the aphid bar in a pest-risk histogram.

DEMON aphid control summary

IF selected OF baraphid hr

THEN pestname := "Aphid"

AND risklevel := pestrisklevel[ 1]

!  select control table info from dBASE files

! AND EXEC i5odbc 12 SQL SELECT controls.formula,pesticid.name,pesticid.leaching,pesticid.runoff,pesticid.toxoral,pesticid.toxdermal,pesticid.birds,

pesticid.fish,pesticid.bees,pesticid.cost

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and
    controls.formula = pc.control and
    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff, ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)
Listing 2: *When-changed* method to load dBASE file of wheat varieties and their susceptibilities to certain diseases into working memory.

```
WHEN CHANGED

BEGIN

! load in the dBASE file of varieties

EXEC l5odbc 6 SQL SELECT cultivar, pm, lr, slgb, ws, byd, ta FROM variety

END SQL INTO Wheat Variety (Cultivar, PMReact, LRReact, SLGBReact, WSReact, BYDReact, TARreact)

END
```

The second meeting with the experts was designed to review the rule representation of knowledge obtained in the first meeting and to elicit changes and additions to this knowledge. These interviews were more structured and more focused than the first. Follow-up interviews were conducted as needed at irregular intervals throughout the lifecycle of the project.

### 3.2 Results & Discussion

Since acquisition of domain knowledge was obtained from three different experts, it was necessary to adapt to three different styles of knowledge dissemination. Varying types and degrees of processing were required for each. Some knowledge was presented
in published tables, virtually ready for translation into rules and methods. Other knowledge was presented as basic heuristic rules of thumb and required thought and discussion to unveil usable information.

The fast prototyping method of knowledge acquisition was effective in putting a system together quickly and allowing early testing of the expert system shell. In some cases, it was necessary to use many iterations of knowledge acquisition and review before a clear understanding of the heuristics was established. One unexpected finding from this process was that the experts’ opinions were dynamic. Over the course of this research, based to some extent on the iterative prototyping process itself, but also on new experiences and research, the experts occasionally changed their minds. Part of the challenge in designing the system, therefore, was implementing a flexible enough structure to allow this kind of change in expert judgement. Heuristics need to be changed to reflect growth of a body of work and the understanding of systems by the experts.

The majority of the knowledge was encoded as rules. This was the most effective way to represent the information in Level5 Object using a backward chaining system. *When-changed* methods and demons were used to load data into working memory and display results as needed. The Level5 Object representation options were satisfactory although a bit awkward to alter once established. Classes, attributes, and instances need to be deleted and recreated in order to make changes, often a very time consuming activity. The knowledge base is included in Appendix 1.
4. **VIEW: an Expert System to Predict Likely Pest Risks**

The Virginia IPM Expert System for Wheat (VIEW) is a decision support system that was designed to combine the best available information regarding wheat pest management of disease pathogens, weeds, and insects to provide potential outbreak risk and pest control information to the Comprehensive Resource Planning System (CROPS). From inputs describing where and how wheat is grown in Virginia, VIEW produces a pest risk rating, indicating the likelihood of each pest’s being enough of a problem to warrant control. The insects included are the aphid complex (including Greenbug, *Schizaphis graminum* [Rondani]; Corn Leaf Aphid, *Rhopalosiphum maidis* [Fitch]; Bird Cherry-Oat Aphid, *Rhopalosiphum padi* [Linnaeus]; English Grain Aphid, *Sitobion avenae* [Fabricius], and Rice Root Aphid, *Rhopalosiphum rufiabdominale* [Sasaki]), the True Armyworm, *Pseudaletia unipuncta* (Haworth), Cereal Leaf Beetle, *Oulema melanopus* (Linnaeus), and Hessian Fly, *Mayetiola destructor* (Say). Weeds included are Annual Ryegrass, *Lolium multiflorum*, and winter annual broadleaf weeds as a group. Pathogens incorporated include the foliar diseases, Leaf Rust, *Puccinia recondita*; Powdery Mildew *Erysiphe graminis f.sp. tritici*; Leaf and Glume Blotch *Stagonospora nodorum*; and Tan Spot *Pyrenophora tritici-repentis*. Other diseases included are the root and crown disease Take-all *Gaumannomyces graminis var. tritici*, head diseases Loose smut *Ustilago tritici* and Wheat scab *Fusarium graminearum*, and viruses Barley yellow dwarf and Wheat spindle streak.
4.1 Materials & Methods

VIEW is a primarily rule-based expert system and was developed on the Microsoft Windows platform using the Level5 Object development environment. The implementation of the VIEW system uses a primarily backward chaining logic in its inferencing. Level5 Object was chosen on the basis that it had been used successfully to develop a similar knowledge-based system (Buick, Youngman, and Stone 1993) and that it was already in-house and readily available. A user interface was created using the Level5 Object software to input information pertaining to the individual wheat crop management scenarios being analyzed.

The methods, rules, and demons were developed using the Level5 Object Methods/Rules/Demons Editor via the iterative prototyping methods for knowledge elicitation mentioned in section 3.1. Logical flowcharts or dependency networks were created based on expert interviews, and these were then translated into Level5Object code. Initially, broad factors were identified that promote pest increase or outbreak. Subsequently, situations or actions that affect these factors were identified. This process, proceeding from the end result through a logical or causal chain back to managerial, biophysical, or climatic factors, was well suited to developing a backward chaining system. When the system runs in a consulting mode, it is initialized by trying to solve for the desired end results, i.e., the outbreak risks. For example, asking for the outbreak risk for aphids would cause the system first to look back and see what factors lead to aphid outbreaks and then to check whether any of the factors is present for the entered scenario.
For each pest there were multiple factors affecting the likelihood and level of outbreak. For the insects and weeds, the factors were all weighted equally at first and then adjusted after further discussion with the experts. For the diseases, the human expert had an idea which factors were more important than others from the start. In each case the factors were weighted to more closely represent their value in the mind of the expert. The weights used for the diseases are found in Table 4.1.1 and are based on a table prepared by Stromberg et al. (1999).

### TABLE 4.1.1 EFFECTIVENESS OF MANAGEMENT ON DISEASES OF WHEAT
(Modified from Stromberg (1999))

<table>
<thead>
<tr>
<th>Diseases</th>
<th>Plow Down</th>
<th>Crop Rotation</th>
<th>Planting Date</th>
<th>Resistant Cultivars</th>
<th>Seed Fungicide</th>
<th>Seed Insecticide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powdery mildew</td>
<td>n/e</td>
<td>n/e</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>n/e</td>
</tr>
<tr>
<td>Leaf rust</td>
<td>n/e</td>
<td>n/e</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>n/e</td>
</tr>
<tr>
<td>Leaf and glume blotch</td>
<td>2</td>
<td>2</td>
<td>n/e</td>
<td>1</td>
<td>2</td>
<td>n/e</td>
</tr>
<tr>
<td>Tan spot</td>
<td>2</td>
<td>2</td>
<td>n/e</td>
<td>1</td>
<td>n/e</td>
<td>n/e</td>
</tr>
<tr>
<td>Loose smut</td>
<td>n/e</td>
<td>n/e</td>
<td>n/e</td>
<td>n/e</td>
<td>3</td>
<td>n/e</td>
</tr>
<tr>
<td>Head scab</td>
<td>3</td>
<td>3</td>
<td>n/e</td>
<td>n/e</td>
<td>n/e</td>
<td>n/e</td>
</tr>
<tr>
<td>Take-all</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>n/e</td>
<td>n/e</td>
<td>n/e</td>
</tr>
<tr>
<td>Barley yellow dwarf</td>
<td>n/e</td>
<td>n/e</td>
<td>3</td>
<td>2</td>
<td>n/e</td>
<td>3</td>
</tr>
<tr>
<td>Wheat spindle streak</td>
<td>n/e</td>
<td>n/e</td>
<td>2</td>
<td>3</td>
<td>n/e</td>
<td>n/e</td>
</tr>
</tbody>
</table>

1 = slightly effective; 2 = moderately effective; 3 = highly effective; n/e = no effect in reducing disease

Databases were used where possible to store lists of valid options for data input. This reduces the chance for errors in typing. Databases were also used to correlate information such as the relationship between a particular cultivar and its susceptibility to various diseases. Ashton-Tate dBASE III+ was chosen as the software for this data management for several reasons. Level5 Object has built in ability to make use of dBASE files; dBASE uses a relational database structure, which is an efficient way to store data about separate but related entities; and dBASE was available in-house. Entity-relationship models and data dictionaries for the databases developed and used in VIEW are presented in Appendix 2.
4.2 Program Summary

Program flow is largely predetermined (Fig. 4.2.1). The system first prompts the user for specific information about the cropping system to be analyzed through a series of seven user-input screens. These data entry screens culminate with the field data summary, a single screen that gives the user a final look at the input before submitting it to the knowledge processor (Fig. 4.2.2).

The inference engine uses the facts entered by the user in combination with rules, methods, and databases to calculate risk values for the potential outbreak of the pests. The results from the inferencing are displayed for the user in a graphical format on the Pest Outbreak Risk Summary (Fig 4.2.3) screen. From this point the user has two choices. One path displays an explanation of the pest outbreak conditions and gives fact-sheet information on pest identification, sampling procedures and decision making. A second path takes the user to the Pest Control Summary (Fig 4.2.4) screen which details the available tactical or post-emergence control options for a particular pest along with environmental toxicity data for each control option.
### FIGURE 4.2.2 FIELD DATA SUMMARY

#### Field Information

<table>
<thead>
<tr>
<th>Field</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Appomattox</td>
</tr>
<tr>
<td>Previous Spring Crop</td>
<td>Sorghum</td>
</tr>
<tr>
<td>Tillage of Previous Spring Crop</td>
<td>Minimum</td>
</tr>
<tr>
<td>Previous Fall Crop</td>
<td>Rye</td>
</tr>
<tr>
<td>Tillage of Previous Fall Crop</td>
<td>No Till</td>
</tr>
</tbody>
</table>

- Small grains grown in adjacent fields in last 12 months: TRUE
- Level of control achieved for winter annual broadleaf: Low
- Level of control achieved for annual ryegrass: Medium

#### Crop Information

<table>
<thead>
<tr>
<th>Crop</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting Date</td>
<td>November 15</td>
</tr>
<tr>
<td>Variety</td>
<td>Wakefield</td>
</tr>
<tr>
<td>Tillage</td>
<td>Conventional</td>
</tr>
<tr>
<td>Seed rate</td>
<td>19</td>
</tr>
<tr>
<td>Row width</td>
<td>Seven</td>
</tr>
<tr>
<td>Nutrient Plan</td>
<td>Soil tests</td>
</tr>
</tbody>
</table>

- Burndown for Annual Weeds: TRUE
- Plow down previous crop: TRUE

#### Field History of Pest Damage/Infestation

<table>
<thead>
<tr>
<th>Pest</th>
<th>Damage/Infestation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual broadleaf</td>
<td>Medium</td>
</tr>
<tr>
<td>Aphid</td>
<td>Medium</td>
</tr>
<tr>
<td>Armyworm</td>
<td>None</td>
</tr>
<tr>
<td>Cereal leaf beetle</td>
<td>Low</td>
</tr>
<tr>
<td>Hessian fly</td>
<td>Not Sure</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>None</td>
</tr>
<tr>
<td>Leaf rust</td>
<td>Medium</td>
</tr>
</tbody>
</table>

- Annual ryegrass: Medium
- Loose smut: Medium
- Scab: Medium
- Spindle streak: Medium
- Tan spot: Medium
- Leaf & glume blotch: Medium
- Barley yellow dwarf: Medium
- Take-all: Medium

#### Will apply seed treatments for these pests

<table>
<thead>
<tr>
<th>Pest</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aphids</td>
<td>TRUE</td>
</tr>
<tr>
<td>Hessian fly</td>
<td>TRUE</td>
</tr>
<tr>
<td>Leaf rust</td>
<td>FALSE</td>
</tr>
<tr>
<td>Loose smut</td>
<td>FALSE</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>FALSE</td>
</tr>
<tr>
<td>Scab</td>
<td>FALSE</td>
</tr>
<tr>
<td>Leaf &amp; glume blotch</td>
<td>FALSE</td>
</tr>
</tbody>
</table>
FIGURE 4.2.3 PEST OUTBREAK RISK SUMMARY
FIGURE 4.2.4 PEST CONTROL SUMMARY
4.3 Evaluation

4.3.1 Verification

The rule-base was tested for conflict, redundancy, subsumption, unnecessary antecedents, circularity, unreachable consequents, and dead-ends using the verification tools built into the Reasoning System of Level5 Object. The resulting rule-base (Appendix 1) is both consistent and complete.

4.3.2 Validation

Validation was performed to test the hypothesis that the expert system’s recommendations came from the same underlying knowledge base as that of the experts. In other words, the results of the expert system should be indistinguishable from the opinions of the experts it was meant to mimic, when applied to independent test scenarios. In this validation, 30 hypothetical test cases were created by the knowledge engineer using randomly generated values for the user input. An example test case showing all the input data is included as Appendix 3. Inputs to the system were allowed to vary independently, so to check that the resulting test cases were realistic and representative, they were reviewed by an expert who was not involved in the development of the system, Dr. Daniel E. Brann, Professor of Crop and Soil Environmental Science at Virginia Tech. He inspected parameter ranges for the test cases and his recommended changes were made.

The test cases were then submitted to the expert system and to the three experts from whom the rules had been elicited, and all output was recorded. Output from VIEW consisted of pest outbreak risk ratings of Low, Medium, or High for 15 pest species or
complexes (four insect pests, nine plant diseases, and two weed complexes). Each of the three human experts also gave values of *Low, Medium, or High* for each case and for each pest in their domain area. In addition, the entomology expert gave probability values for each of the qualitative values for each pest in each case. Also, the plant pathology expert gave eight equally probable qualitative values for each pest in each case corresponding to eight possible weather scenarios that would affect the outcome of the pest risk values. These values are discussed further in section 4.3.3. The output from the expert system was compared to that of the domain experts for accuracy using two distance measures (Table 4.3.1) and three similarity metrics.

The first distance measure arbitrarily assigns a distance measure of one to adjacent qualitative values. The second penalizes the poorest mismatches by squaring the basic distance (Table 4.3.1). The simplest similarity metric is a sum of the distances observed between human expert and expert system assessments divided by the worst possible score (i.e., the score representing complete disagreement), reported as a percentage. So, for each of the 15 pests tested, the worst score would be 60 or 120, for the basic distance or squared distance measures, respectively. The percentage similarity score for one pest would be calculated as $d_1 * 100 / 60$, or $d_2 * 100 / 120$. In the cases where the expert predicts a *Medium* risk value, the worst case score may be calculated another way. Since the value set for *Medium* risk is one, the expert system cannot be more than one off in either direction. This "context-dependent" or "corrected" metric is calculated based on the experts' answers, rather than simply on the overall possibility of error. Here the percentage similarity score for one pest would be calculated as $d_1 * 100 / (60 - x)$, where $x$ is the number of *Medium* risk values predicted by the expert. Following
Batchelor et al. (1989) and Bhogaraju (1996), an acceptable level of similarity was predetermined to be 80 percent. Values were calculated for individual pests or pest complexes and for three pest categories: insects, diseases, and weeds.

<table>
<thead>
<tr>
<th>Expert Values</th>
<th>Basic Distance</th>
<th>Squared Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Medium</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

The other similarity metrics were computed based on an explicit description of the distribution of possible responses from the human experts. That such a distribution exists is based on the assumption, verified by discussions with the experts, that assignment of a value of low, medium, or high does not completely represent their thought processes. It is more appropriate to say that the expert determines a probability of the result being low, medium, or high, and then chooses the value with the highest probability.

In the first of these two remaining metrics, the mean and variance of the sum of the log likelihoods from the expert responses were calculated to normalize the observed sum of the likelihoods of the expert system’s responses. From these likelihoods it was possible to calculate a z-statistic. Due to the central limit theorem, the distribution of the sum of thirty log likelihoods should be very close to normal (Norman and Streiner 1994). These z-values were then used to find p-values in a standard normal table. In the second metric, distributions of absolute values of distances and squares of distances were created from 10,000 random samples from the human expert response probabilities. These distributions were then used to estimate the probability of finding the expert system
responses given the hypothesis that they are based on the same (i.e., human expert) distributions. What follows is a description of the procedure used to determine the z-values from the human and expert system responses.

Recall that the null hypothesis of this research is that the expert system values are drawn from the distribution specified by the expert. To make this comparison we first need to generate a normal distribution from the human expert responses. From this distribution, a mean and standard deviation can be calculated. What remains is to calculate the standard score, which can be checked in a standard normal table for a probability that the expert system data comes from the distribution of the human expert.

Assuming each case is independent, the likelihood of the expert system getting a particular set of results under the null hypothesis is equal to the product of all the likelihoods from the 30 test cases \( L \). Equivalently, the log-likelihood of observing a particular set of results, \( \ln(L) \), is the sum of the natural logarithms of the thirty likelihoods. To make this sum of all likelihoods a useful number, we need to know the mean or expected value, \( \xi \), of \( \ln(L) \) and its variance so that we can normalize it. The expected value of the natural log of the likelihood is equal to the sum of the expected log-likelihood values for the thirty cases, \( \xi \{ \ln(L) \} = \Sigma \xi (\ln(L_i)) \). Each of these individual log-likelihood values is the sum of the log of the probabilities for Low, Medium, or High, weighted by their probabilities as given by the experts. That is,

\[
\xi(\ln(L_i)) = \ln(p(l_i))p(l_i) + \ln(p(m_i))p(m_i) + \ln(p(h_i))p(h_i)
\]
where \( p(l_i), p(m_i), \) and \( p(h_i) \) are the probabilities associated with the \textit{Low}, \textit{Medium}, or \textit{High} for each case. The variance of the log likelihood, \( \ln(L) \), is the sum of the variances of each case, \( \ln(L_i) \),

\[
\text{var}(\ln(L_i)) = \xi \left( \ln(L_i)^2 \right) - \left( \xi \ln(L_i) \right)^2
\]

calculated from the expected values for every case, \( i \), in which the first term is the weighted sum of the log of probabilities for low, medium, and high squared and the second term is the previously calculated expectation squared. A standard score or z-value is calculated by subtracting the mean of the distribution from the raw score and dividing by the standard deviation. The mean of the distribution here is the \( \xi \ln(L) \), the raw score is \( \ln(L) \), and the standard deviation is the square root of the variance:

\[
z = \frac{\ln(L) - \xi \ln(L)}{\sqrt{\text{var}[\ln(L)]}}
\]

and a z-value is calculated from which a p-value is found in a standard normal table.
With the help of Marion Reynolds and Pamela Norris of the Department of Statistics at Virginia Tech, a macro was developed using the software package Minitab to calculate all three similarity metrics. It is listed in Appendix 4.

Finally, after all the other statistical analyses were completed a post-hoc comparison, the Bonferroni method, was used for further exploration of the data in an effort to limit the overall experiment-wise error rate. With this method each comparison is tested using a significance level of $\alpha = \alpha/k$, where $k$ is the number of comparisons (Sokal and Rohlf 1995).

**4.3.3 Generating Probabilities for Low, Medium, and High Risks**

For the four insect pests evaluated, the human expert provided probabilities for each level of outbreak risk. The probability data originally contained a number of zero values. Because the logarithm of zero is undefined, to use these statistical methods, zero likelihoods needed to be replaced by a negligible but non-zero value. A value of 0.05 was chosen to substitute for these zero probabilities by statisticians Reynolds and Norris. So as not to upset the balance of the other probability values, the 0.05 values were subtracted proportionately from the nonzero values.

For the nine disease pathogens evaluated, the human expert provided predictions for eight different weather scenarios. Because weather is fairly unpredictable, these eight weather scenarios were weighted equally. The number of qualitative prediction levels of low, medium, and high were summed for each case and divided by eight, the number of weather conditions. A set of probability values was thereby obtained for the disease data. For example, if the eight predictions for powdery mildew for case 1 are 4(low),
3 (medium), and 1 (high), then the probability values for low, medium, and high would be 
low = 4/8 = 0.5, medium = 3/8 = 0.375, and high = 1/8 = 0.125. The same value of 0.05 
was chosen to substitute for the zero probability values in the disease data as well.

4.4 Results

The results of the comparison of the human expert predictions with the expert 
system predictions are reported in Table 4.4.1. In addition, a detailed breakdown of the 
responses for each pest is provided in Appendix 5.

| Pest Type | Pest Name          | Percent Agreement | z-statistic | Distance | (Distance)² | Corrected p-value | | | |
|-----------|--------------------|-------------------|-------------|----------|-------------|-------------------| | | |
| Insect    | Aphid              | 95                | 95          | 95       | 0.334       | 0.9089            | 0.9175   | |
|           | Armyworm           | 98                | 98          | 98       | 0.065       | 0.982             | 0.982    | |
|           | Cereal leaf beetle | 93                | 93          | 91       | 0.317       | 0.9311            | 0.9374   | |
|           | Hessian fly        | 93                | 93          | 93       | 0.411       | 0.8359            | 0.8703   | |
|           | All Insects        | 95                | 95          | 94       | n/a         | n/a               | n/a      | |
| Disease   | Powdery mildew     | 78                | 75          | 70       | 0.01        | 0.2017            | 0.215    | |
|           | Leaf rust          | 57                | 50          | 50       | 0           | 0                 | 0.0001   | |
|           | Tan spot           | 92                | 88          | 84       | 0.25        | 0.8756            | 0.1868   | |
|           | Loose smut         | 97                | 97          | 94       | 0.224       | 0.9523            | 0.9523   | |
|           | Spindle Streak     | 72                | 68          | 60       | 0           | 0.098             | 0.0238   | |
|           | Take all           | 77                | 77          | 64       | 0           | 0.0838            | 0.0013   | |
|           | Scab               | 73                | 70          | 50       | 0.046       | 0.0148            | 0        | |
|           | Leaf & glume       | 90                | 90          | 82       | 0.504       | 0.9122            | 0.4984   | |
|           | Barley yellow dwarf| 83                | 83          | 69       | 0.006       | 0.8192            | 0.1174   | |
|           | All Diseases       | 80                | 78          | 68       | n/a         | n/a               | n/a      | |
| Weeds     | Annual Ryegrass    | 85                | 85          | 82       | n/a         | n/a               | n/a      | |
|           | Annual Broadleaf   | 72                | 72          | 67       | n/a         | n/a               | n/a      | |
|           | All Weeds          | 79                | 79          | 75       | n/a         | n/a               | n/a      | |
| Overall   |                    | 84                | 82          | 77       | n/a         | n/a               | n/a      | |

The probabilities of observing given distances or greater based on 10,000 samples 
from the distribution of responses provided by the experts for insects and diseases are
displayed in Figure 4.4.2. The distances from the expert system are marked with a red vertical line.
The p-value for a given observed distance can be taken directly from the graph as the y-value for any observed distance found on the x-axis.
The results of the percent agreement comparison show that the expert system agreed with the experts overall 84, 82, and 77 percent of the time for the basic distance, squared distance, and corrected distance, respectively. This exceeds or is close to the 80 percent threshold set as satisfactory at the beginning of the project. When broken into disease, weed, and insect pest groups, the expert system was slightly unsatisfactory with the disease (80%) and weed (79%) groups and well above satisfactory with the insect (95%) group. At the final level of comparison with individual pests, the expert system met or exceeded the satisfactory threshold in nine out of 15 pests in both the basic distance and the squared distance and eight out of 15 in the corrected distance. Five out of six that rated unsatisfactory were within eight percent of the threshold on the basic distance measure. Only one pest performance was far off the mark at 57 percent agreement. For the corrected distance measure the number of unsatisfactory performances increased to seven with two pest performances far off the mark at 50 percent agreement and the other five falling in the 60 to 70 percent agreement range.

According to the statistical analysis, none of the expert system results for the insect pests were significantly different from those of the experts at an alpha error rate of 0.05; however, the expert system results for six of the nine diseases were significantly different (Table 4.4.1). The absolute distance method showed no significant difference with 11 of the 13 pests and the distance-squared method showed no significant difference with nine of the 13 pests. As a group, the insect pest recommendations of the expert system were not significantly different from those of the expert at an alpha error rate of 0.05. In the 30 cases involving armyworm, the expert systems matched the expert’s assessments so well that the null hypothesis was nearly rejected (p < 0.1) as being too
similar to have come from the expert’s distribution. The expert system responses for
diseases as a group were not significantly different for three, five, and seven of the nine
disease pests for the z-statistic, distance squared, and absolute distance tests, respectively,
at an alpha error rate of 0.05.

Using Bonferroni’s method to ensure a procedure-wise error rate of 0.05, the nine
disease comparisons ought to be done at a significance level of $\alpha = 0.05/9 = 0.006$. Even
with the correction, expert system results for four of the nine diseases were significantly
different from the expert’s conclusions based on the z-statistic. Looking only at the
distance measures, the expert system gave significantly different results only for leaf rust
and scab, and for leaf rust only when using the absolute distance measure. Using this
same correction method for the insects, a significance level of $\alpha = 0.05/4 = 0.0125$ was
used for the four insect comparisons. With the correction, expert system results for all
four of the insects were not significantly different from the expert’s conclusions based on
the z-statistic. Thus it may be stated that the expert system responses for the insect data
are within the range of the distributions of the human expert and the expert system
responses for the disease data are not consistently within the range of the distributions of
the human expert.

4.5 Discussion

It is interesting that the several methods of evaluation used to validate this expert
system gave different results for several pests. The case of the armyworm already
mentioned points out that likelihood estimates can reject a system for being too good a
match, but there is also the case of barley yellow dwarf which satisfied the distance
percentage requirements but was significantly different from the expert according to the z-statistic. One drawback to using just distance measures is that they do not take into account the direction of the distance. An expert system that consistently estimated risk as higher than the expert’s judgement would be indistinguishable from one that misses sometimes high and sometimes low.

With hindsight, it would have been useful as well to generate probability distributions for the likelihood of seeing a given number of cases over-predicted and under-predicted. Choosing a statistical test is not an exact science. This aspect of evaluating agricultural expert systems clearly could benefit from further investigation.

4.6 Conclusions

The results show it is possible to simulate the expertise of integrated pest management with a reasonable degree of accuracy. Combining the expertise of three specialists to cover the areas of insect, disease, and weed pest management makes this an efficient method for synthesizing a variety of pest management information. It is only with this gathering of disciplines that it will be possible to make holistic choices about pest management in our diverse ecosystems.

This expert system, as a standalone decision support tool, needs more testing before it can be used in the field. While the insect component has reached an acceptable level of performance and is ready for further implementation, in the weed and especially the disease prediction components more work is needed. One area that needs more attention is the consideration of weather as a factor in disease outbreaks. In this research all weather events were given equal chances of occurring throughout the state. By
incorporating historical weather patterns in to the knowledge base there may be a way to weight weather events by region or by county. Although this system has shown that it agrees with the experts in the majority of cases, it has not been tested sufficiently by the target users, the agricultural Extension Agents and farmers in the field.

To be included as an evaluator in the CROPS environment, the knowledge base must now be converted to the language of that system. This may be a future project for the Information Systems and Insect Studies Laboratory at Virginia Tech where the CROPS system was developed.

In conclusion, it has been shown that preventive IPM can be implemented through whole-farm planning. More specifically, crop-specific decision support systems help facilitate preventive IPM.
5. References


Bhogaraju, Prabhakar V. V. 1996. A Case-Based Reasoner for Evaluating Crop Rotations in Whole-Farm Planning, Entomology, Virginia Polytechnic Institute & State University, Blacksburg.


Wisiol, Karin, Meeta Patel, Gary E. Pepper, and James R. Wilcox. 1986. SOYSEED: soybean variety choice. Urbanna, IL: USDA/ARS.


6. Appendix 1. Knowledge Base

6.1 Field Rules

RULE Planting Date in October

IF Planting Month OF Field IS October

THEN Planting Date OF Field := 273 + Planting Day OF Field

RULE Planting Date in November

IF Planting Month OF Field IS November

THEN Planting Date OF Field := 304 + Planting Day OF Field

RULE Planting Date in December

IF Planting Month OF Field IS December

THEN Planting Date OF Field := 334 + Planting Day OF Field

RULE Planting Date Risk for BRH Medium

IF BlueRidge OF Virginia County = 1
AND Planting Date OF Field > 281

AND Planting Date OF Field < 290

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 3.5

AND Outbreak Risk for Planting Date OF Leaf Rust := 2

AND Outbreak Risk for Planting Date OF Weeds := 2

AND Outbreak Risk for Planting Date OF Tan Spot := 2

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 3.5

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 2

AND Outbreak Risk for Planting Date OF Take All := 2

RULE Planting Date Risk for BRH Late

IF BlueRidge OF Virginia County = 1

AND Planting Date OF Field > 289

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 6

AND Outbreak Risk for Planting Date OF Leaf Rust := 3

AND Outbreak Risk for Planting Date OF Weeds := 1

AND Outbreak Risk for Planting Date OF Tan Spot := 3
AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 6

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 1

AND Outbreak Risk for Planting Date OF Take All := 3

RULE Planting Date Risk for BRH Early

IF BlueRidge OF Virginia County = 1

AND Planting Date OF Field < 282

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 1

AND Outbreak Risk for Planting Date OF Leaf Rust := 1

AND Outbreak Risk for Planting Date OF Weeds := 3

AND Outbreak Risk for Planting Date OF Tan Spot := 1

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 1

AND Outbreak Risk for Planting Date OF Take All := 1

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 3

RULE Planting Date Risk for Piedmont Medium

IF EastShore OF Virginia County = 0
AND Coastal OF Virginia County = 0

AND BlueRidge OF Virginia County = 0

AND Planting Date OF Field > 284

AND Planting Date OF Field < 296

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 3.5

AND Outbreak Risk for Planting Date OF Leaf Rust := 2

AND Outbreak Risk for Planting Date OF Weeds := 2

AND Outbreak Risk for Planting Date OF Tan Spot := 2

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 3.5

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 2

AND Outbreak Risk for Planting Date OF Take All := 2

RULE Planting Date Risk for Piedmont Late

IF EastShore OF Virginia County = 0

AND Coastal OF Virginia County = 0

AND BlueRidge OF Virginia County = 0

AND Planting Date OF Field > 295
THEN Outbreak Risk for Planting Date OF Powdery Mildew := 6

AND Outbreak Risk for Planting Date OF Leaf Rust := 3

AND Outbreak Risk for Planting Date OF Weeds := 1

AND Outbreak Risk for Planting Date OF Tan Spot := 3

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 6

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 1

AND Outbreak Risk for Planting Date OF Take All := 3

RULE Planting Date Risk for Piedmont Early

IF EastShore OF Virginia County = 0

AND Coastal OF Virginia County = 0

AND BlueRidge OF Virginia County = 0

AND Planting Date OF Field < 285

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 1

AND Outbreak Risk for Planting Date OF Leaf Rust := 1

AND Outbreak Risk for Planting Date OF Weeds := 3

AND Outbreak Risk for Planting Date OF Tan Spot := 1
AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 1

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 3

AND Outbreak Risk for Planting Date OF Take All := 1

RULE Planting Date Risk for EAST Medium

IF EastShore OF Virginia County = 1 OR Coastal OF Virginia County = 1
AND Planting Date OF Field > 305
AND Planting Date OF Field < 313
THEN Outbreak Risk for Planting Date OF Powdery Mildew := 3.5
AND Outbreak Risk for Planting Date OF Leaf Rust := 2
AND Outbreak Risk for Planting Date OF Weeds := 2
AND Outbreak Risk for Planting Date OF Tan Spot := 2
AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 3.5
AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 2
AND Outbreak Risk for Planting Date OF Take All := 2

RULE Planting Date Risk for EAST Late
IF EastShore OF Virginia County = 1 OR Coastal OF Virginia County = 1

AND Planting Date OF Field > 312

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 6

AND Outbreak Risk for Planting Date OF Leaf Rust := 3

AND Outbreak Risk for Planting Date OF Weeds := 1

AND Outbreak Risk for Planting Date OF Tan Spot := 3

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 6

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 1

AND Outbreak Risk for Planting Date OF Take All := 3

RULE Planting Date Risk for EAST Early

IF EastShore OF Virginia County = 1 OR Coastal OF Virginia County = 1

AND Planting Date OF Field < 306

THEN Outbreak Risk for Planting Date OF Powdery Mildew := 1

AND Outbreak Risk for Planting Date OF Leaf Rust := 1

AND Outbreak Risk for Planting Date OF Weeds := 3

AND Outbreak Risk for Planting Date OF Tan Spot := 1
AND Outbreak Risk for Planting Date OF Wheat Spindle Streak := 1

AND Outbreak Risk for Planting Date OF Cereal Leaf Beetle := 3

AND Outbreak Risk for Planting Date OF Take All := 1

RULE Tillage Risk Conventional

IF Tillage Type OF Field IS Conventional

THEN Outbreak Risk for Tillage OF Aphid := 3

AND Outbreak Risk for Tillage OF Barley Yellow Dwarf := 3

AND Outbreak Risk for Tillage OF Hessian Fly := 3

AND Outbreak Risk for Tillage OF Winter annual broadleaf := 3

RULE Tillage Risk Minimum

IF Tillage Type OF Field IS Minimum

THEN Outbreak Risk for Tillage OF Aphid := 2

AND Outbreak Risk for Tillage OF Barley Yellow Dwarf := 2

AND Outbreak Risk for Tillage OF Hessian Fly := 2

AND Outbreak Risk for Tillage OF Winter annual broadleaf := 2
RULE Tillage Risk No Till

IF Tillage Type OF Field IS No Till

THEN Outbreak Risk for Tillage OF Aphid := 1

AND Outbreak Risk for Tillage OF Barley Yellow Dwarf := 1

AND Outbreak Risk for Tillage OF Hessian Fly := 1

AND Outbreak Risk for Tillage OF Winter annual broadleaf := 1

RULE Seed Rate Risk

IF (Row Width OF Field IS Four AND Seed Rate OF Field < 12)

OR (Row Width OF Field IS Six AND Seed Rate OF Field < 18)

OR (Row Width OF Field IS Seven AND Seed Rate OF Field < 20)

OR (Row Width OF Field IS Eight AND Seed Rate OF Field < 22)

THEN Outbreak Risk for Seed Rate OF Cereal Leaf Beetle := 1

AND Outbreak Risk for Seed Rate OF Weeds := 1

ELSE Outbreak Risk for Seed Rate OF Cereal Leaf Beetle := 3

AND Outbreak Risk for Seed Rate OF Weeds := 3
RULE Region BRH

IF BlueRidge OF Virginia County = 1

THEN Region OF Virginia County := "Blue Ridge Highlands"

RULE Region PM

IF BlueRidge OF Virginia County = 0

AND Coastal OF Virginia County = 0

AND EastShore OF Virginia County = 0

THEN Region OF Virginia County := "Piedmont"

RULE Region ES

IF Coastal OF Virginia County = 1

OR EastShore OF Virginia County = 1

THEN Region OF Virginia County := "Tidewater"

RULE Crop Rotation Risk
IF name OF Fall Crop = "Wheat"

THEN Outbreak Risk for Crop Rotation OF Septoria Leaf & Glume Blotch := 1

AND Outbreak Risk for Crop Rotation OF Hessian Fly := 1

AND Outbreak Risk for Crop Rotation OF Wheat Spindle Streak := 1

AND Outbreak Risk for Crop Rotation OF Tan Spot := 1

AND Outbreak Risk for Crop Rotation OF Scab := 1

AND Outbreak Risk for Crop Rotation OF Take All := 1

ELSE Outbreak Risk for Crop Rotation OF Septoria Leaf & Glume Blotch := 6

AND Outbreak Risk for Crop Rotation OF Hessian Fly := 3

AND Outbreak Risk for Crop Rotation OF Wheat Spindle Streak := 6

AND Outbreak Risk for Crop Rotation OF Tan Spot := 6

AND Outbreak Risk for Crop Rotation OF Scab := 9

AND Outbreak Risk for Crop Rotation OF Take All := 9

RULE Planting Date for Aphid & BYD & HF Early

IF Planting Date OF Field < 293

THEN Outbreak Risk for Planting Date OF Aphid := 1
AND Outbreak Risk for Planting Date OF Barley Yellow Dwarf := 1
AND Outbreak Risk for Planting Date OF Hessian Fly := 1

RULE Planting Date for Aphid & BYD & HF Late

IF Planting Date OF Field > 311

THEN Outbreak Risk for Planting Date OF Aphid := 3
AND Outbreak Risk for Planting Date OF Barley Yellow Dwarf := 9
AND Outbreak Risk for Planting Date OF Hessian Fly := 3

RULE Planting Date for Aphid & BYD & HF Medium

IF Planting Date OF Field >= 293
AND Planting Date OF Field < 312

THEN Outbreak Risk for Planting Date OF Aphid := 2
AND Outbreak Risk for Planting Date OF Barley Yellow Dwarf := 5
AND Outbreak Risk for Planting Date OF Hessian Fly := 2

RULE Plow Down Risk High
IF Plow Down OF Field = FALSE

THEN Outbreak Risk for Plow Down OF Septoria Leaf & Glume Blotch := 1

AND Outbreak Risk for Plow Down OF Hessian Fly := 1

AND Outbreak Risk for Plow Down OF Tan Spot := 1

AND Outbreak Risk for Plow Down OF Scab := 1

AND Outbreak Risk for Plow Down OF Take All := 1

RULE Plow Down Risk Low

IF Plow Down OF Field = TRUE

THEN Outbreak Risk for Plow Down OF Septoria Leaf & Glume Blotch := 6

AND Outbreak Risk for Plow Down OF Hessian Fly := 3

AND Outbreak Risk for Plow Down OF Tan Spot := 6

AND Outbreak Risk for Plow Down OF Scab := 9

AND Outbreak Risk for Plow Down OF Take All := 6

RULE Risk of Adjacent Grains

IF Adjacent Grains OF Field = TRUE
THEN Outbreak Risk for Adjacent Grains OF Hessian Fly := 1
ELSE Outbreak Risk for Adjacent Grains OF Hessian Fly := 3

RULE Seed Insecticide

IF Seed Treatment OF Aphid = TRUE

OR Seed Treatment OF Hessian Fly = TRUE

THEN Outbreak Risk for Seed Insecticide OF Aphid := 5
AND Outbreak Risk for Seed Insecticide OF Hessian Fly := 5
AND Outbreak Risk for Seed Insecticide OF Barley Yellow Dwarf := 9
ELSE Outbreak Risk for Seed Insecticide OF Aphid := 1
AND Outbreak Risk for Seed Insecticide OF Hessian Fly := 1
AND Outbreak Risk for Seed Insecticide OF Barley Yellow Dwarf := 1

RULE Seed Fungicide for LR

IF Seed Treatment OF Leaf Rust = TRUE

THEN Outbreak Risk for Seed Fungicide OF Leaf Rust := 3
ELSE Outbreak Risk for Seed Fungicide OF Leaf Rust := 1
RULE Seed Fungicide for LS

IF Seed Treatment OF Loose Smut = TRUE

THEN Outbreak Risk for Seed Fungicide OF Loose Smut := 9

ELSE Outbreak Risk for Seed Fungicide OF Loose Smut := 1

RULE Seed Fungicide for PM

IF Seed Treatment OF Powdery Mildew = TRUE

THEN Outbreak Risk for Seed Fungicide OF Powdery Mildew := 9

ELSE Outbreak Risk for Seed Fungicide OF Powdery Mildew := 1

RULE Seed Quality Risk

IF Disease Free Seed OF Field = TRUE

THEN Outbreak Risk for Seed Quality OF Septoria Leaf & Glume Blotch := 6

AND Outbreak Risk for Seed Quality OF Loose Smut := 9

ELSE Outbreak Risk for Seed Quality OF Septoria Leaf & Glume Blotch := 1

AND Outbreak Risk for Seed Quality OF Loose Smut := 1
6.2 \textit{Insect Rules}

RULE Evaluate Risk of Aphid

IF Outbreak Risk \text{ OF Aphid IS High OR Outbreak Risk \text{ OF Aphid IS Medium}

OR

Outbreak Risk \text{ OF Aphid IS Low

THEN Evaluate Risk of Outbreak for Aphid := TRUE

RULE Armyworm Risk High

IF Outbreak Risk Total \text{ OF Armyworm} \leq 3

THEN Outbreak Risk \text{ OF Armyworm IS High

AND Evaluate Risk of Outbreak for Armyworm := TRUE

AND Bar Right Loc[ 2] \text{ OF Insect Risk Graph} := 410

AND Bar Colors[ 2] \text{ OF Insect Risk Graph} := \text{SETCOLOR( 255, 0, 0)}

AND pestrisklevel[ 2] := "High"

RULE Armyworm Risk Low
IF Outbreak Risk Total OF Armyworm > 6
AND Outbreak Risk Total OF Armyworm < 99
THEN Outbreak Risk OF Armyworm IS Low
AND Evaluate Risk of Outbreak for Armyworm := TRUE
AND Bar Colors[ 2] OF Insect Risk Graph := SETCOLOR( 0, 0, 255)
AND pestrisklevel[ 2] := "Low"

RULE Armyworm Risk Medium

IF Outbreak Risk Total OF Armyworm > 3
AND Outbreak Risk Total OF Armyworm <= 6
THEN Outbreak Risk OF Armyworm IS Medium
AND Evaluate Risk of Outbreak for Armyworm := TRUE
AND Bar Colors[ 2] OF Insect Risk Graph := SETCOLOR( 255, 255, 0)
AND pestrisklevel[ 2] := "Medium"
RULE CLB Risk Low

IF Outbreak Risk Total OF Cereal Leaf Beetle > 6

THEN Outbreak Risk OF Cereal Leaf Beetle IS Low

AND Evaluate Risk of Outbreak for Cereal Leaf Beetle := TRUE


AND Bar Colors[ 3] OF Insect Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 3] := "Low"

RULE CLB Risk High

IF Outbreak Risk Total OF Cereal Leaf Beetle <= 3

THEN Outbreak Risk OF Cereal Leaf Beetle IS High

AND Evaluate Risk of Outbreak for Cereal Leaf Beetle := TRUE


AND Bar Colors[ 3] OF Insect Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 3] := "High"

RULE CLB Risk Medium
IF Outbreak Risk Total OF Cereal Leaf Beetle > 3

AND Outbreak Risk Total OF Cereal Leaf Beetle <= 6

THEN Outbreak Risk OF Cereal Leaf Beetle IS Medium

AND Evaluate Risk of Outbreak for Cereal Leaf Beetle := TRUE


AND Bar Colors[ 3] OF Insect Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 3] := "Medium"

RULE CLB Risk Not Available

IF Outbreak Risk Total OF Cereal Leaf Beetle > 98

THEN Outbreak Risk OF Cereal Leaf Beetle IS Not Available

AND Evaluate Risk of Outbreak for Cereal Leaf Beetle := TRUE


AND Bar Colors[ 3] OF Insect Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[ 3] := "Not Available"

RULE HF Risk Not Available
IF Outbreak Risk Total OF Hessian Fly > 98

THEN Outbreak Risk OF Hessian Fly IS Not Available

AND Evaluate Risk of Outbreak for Hessian Fly := TRUE


AND Bar Colors[ 4] OF Insect Risk Graph := SETCOLOR( 0, 255, 0)


RULE Aphid Risk High

IF Outbreak Risk Total OF Aphid <= 3

THEN Outbreak Risk OF Aphid IS High

AND Bar Right Loc[ 1] OF Insect Risk Graph := 410

AND Bar Colors[ 1] OF Insect Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 1] := "High"

RULE Aphid Risk Low

IF Outbreak Risk Total OF Aphid > 6

AND Outbreak Risk Total OF Aphid < 99
THEN Outbreak Risk OF Aphid IS Low


AND Bar Colors[ 1] OF Insect Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 1] := "Low"

RULE Aphid Risk Medium

IF Outbreak Risk Total OF Aphid > 3

AND Outbreak Risk Total OF Aphid <= 6

THEN Outbreak Risk OF Aphid IS Medium

AND Bar Right Loc[ 1] OF Insect Risk Graph := 380

AND Bar Colors[ 1] OF Insect Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 1] := "Medium"

RULE Aphid Risk Not Available

IF Outbreak Risk Total OF Aphid > 98

THEN Outbreak Risk OF Aphid IS Not Available

AND Bar Right Loc[ 1] OF Insect Risk Graph := 410
RULE HF Risk High

IF Outbreak Risk Total OF Hessian Fly <= 5

THEN Outbreak Risk OF Hessian Fly IS High


AND Bar Colors[ 4] OF Insect Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 4] := "High"

RULE HF Risk Low

IF Outbreak Risk Total OF Hessian Fly > 10

AND Outbreak Risk Total OF Hessian Fly < 99

THEN Outbreak Risk OF Hessian Fly IS Low


AND Bar Colors[ 4] OF Insect Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 4] := "Low"
RULE HF Risk Medium

IF Outbreak Risk Total OF Hessian Fly > 5
AND Outbreak Risk Total OF Hessian Fly <= 10
THEN Outbreak Risk OF Hessian Fly IS Medium

AND Bar Colors[ 4] OF Insect Risk Graph := SETCOLOR( 255, 255, 0)

RULE Armyworm Risk Not Available

IF Outbreak Risk Total OF Armyworm > 98
THEN Outbreak Risk OF Armyworm IS Not Available

AND Bar Colors[ 2] OF Insect Risk Graph := SETCOLOR( 0, 255, 0)

RULE Aphid and BYD Link
IF Outbreak Risk Total OF Aphid > Outbreak Risk Total OF Barley Yellow Dwarf

THEN Corrected Risk Total OF Barley Yellow Dwarf := Outbreak Risk Total OF Aphid

ELSE Corrected Risk Total OF Barley Yellow Dwarf := Outbreak Risk Total OF Barley Yellow Dwarf

RULE History of Aphid Damage High

IF Field History of Damage OF Aphid IS High

THEN Outbreak Risk for Field History OF Aphid := 1

RULE History of Aphid Damage Low

IF Field History of Damage OF Aphid IS Low

OR Field History of Damage OF Aphid IS None

THEN Outbreak Risk for Field History OF Aphid := 3

RULE History of Aphid Damage Medium
IF Field History of Damage OF Aphid IS Medium

OR Field History of Damage OF Aphid IS Not Sure

THEN Outbreak Risk for Field History OF Aphid := 2

RULE History of Armyworm Damage High

IF Field History of Damage OF Armyworm IS High

THEN Outbreak Risk for Field History OF Armyworm := 1

RULE History of Armyworm Damage Low

IF Field History of Damage OF Armyworm IS Low

OR Field History of Damage OF Armyworm IS None

THEN Outbreak Risk for Field History OF Armyworm := 7

RULE History of Armyworm Damage Medium

IF Field History of Damage OF Armyworm IS Medium

OR Field History of Damage OF Armyworm IS Not Sure

THEN Outbreak Risk for Field History OF Armyworm := 4
RULE History of CLB Damage High

IF Field History of Damage OF Cereal Leaf Beetle IS High

THEN Outbreak Risk for Field History OF Cereal Leaf Beetle := 1

RULE History of CLB Damage Low

IF Field History of Damage OF Cereal Leaf Beetle IS Low

OR Field History of Damage OF Cereal Leaf Beetle IS None

THEN Outbreak Risk for Field History OF Cereal Leaf Beetle := 3

RULE History of CLB Damage Medium

IF Field History of Damage OF Cereal Leaf Beetle IS Medium

OR Field History of Damage OF Cereal Leaf Beetle IS Not Sure

THEN Outbreak Risk for Field History OF Cereal Leaf Beetle := 2

RULE Location Risk for Armyworm

IF EastShore OF Virginia County = 1 OR Coastal OF Virginia County = 1
THEN Outbreak Risk for Location OF Armyworm := 3
ELSE Outbreak Risk for Location OF Armyworm := 6

RULE Outbreak Risk Total of Aphid

IF Outbreak Risk for Planting Date OF Aphid > 0
AND Outbreak Risk for Seed Insecticide OF Aphid > 0
AND Outbreak Risk for Field History OF Aphid > 0
THEN Outbreak Risk Total OF Aphid := Outbreak Risk for Planting Date OF Aphid + Outbreak Risk for Seed Insecticide OF Aphid + Outbreak Risk for Field History OF Aphid
ELSE Outbreak Risk Total OF Aphid := 99

RULE Outbreak Risk Total of Armyworm

IF Outbreak Risk for Field History OF Armyworm >= 0
AND Outbreak Risk for Location OF Armyworm >= 0
THEN Outbreak Risk Total OF Armyworm := Outbreak Risk for Field History OF Armyworm + Outbreak Risk for Location OF Armyworm
ELSE Outbreak Risk Total OF Armyworm := 99

RULE Outbreak Risk Total of CLB

IF Outbreak Risk for Planting Date OF Cereal Leaf Beetle > 0

AND Outbreak Risk for Field History OF Cereal Leaf Beetle > 0

AND Outbreak Risk for Seed Rate OF Cereal Leaf Beetle > 0

THEN Outbreak Risk Total OF Cereal Leaf Beetle := Outbreak Risk for Planting Date OF Cereal Leaf Beetle + Outbreak Risk for Field History OF Cereal Leaf Beetle + Outbreak Risk for Seed Rate OF Cereal Leaf Beetle

ELSE Outbreak Risk Total OF Cereal Leaf Beetle := 99

RULE Outbreak Risk Total of HF

IF Outbreak Risk for Planting Date OF Hessian Fly > 0

AND Outbreak Risk for Tillage OF Hessian Fly > 0

AND Outbreak Risk for Crop Rotation OF Hessian Fly > 0

AND Outbreak Risk for Seed Insecticide OF Hessian Fly > 0

AND Outbreak Risk for Adjacent Grains OF Hessian Fly > 0
THEN Outbreak Risk Total OF Hessian Fly := Outbreak Risk for Planting Date
OF
Hessian Fly + Outbreak Risk for Tillage OF Hessian Fly + Outbreak Risk for Crop Rotation OF Hessian Fly + Outbreak Risk for Seed Insecticide OF Hessian Fly + Outbreak Risk for Adjacent Grains OF Hessian Fly
ELSE Outbreak Risk Total OF Hessian Fly := 99

6.3 Weed Rules

RULE Ryegrass Risk Not Available

IF Outbreak Risk Total OF Annual ryegrass > 98

THEN Outbreak Risk OF Annual ryegrass IS Not Available

AND Evaluate Risk of Outbreak for Annual Ryegrass := TRUE


AND Bar Colors[ 1] OF Weed Risk Graph := SETCOLOR( 0, 255, 0)


RULE Ryegrass Risk Medium
IF Outbreak Risk Total OF Annual ryegrass > 3

AND Outbreak Risk Total OF Annual ryegrass < 6

THEN Outbreak Risk OF Annual ryegrass IS Medium

AND Evaluate Risk of Outbreak for Annual Ryegrass := TRUE


AND Bar Colors[ 1] OF Weed Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 5] := "Medium"

RULE Ryegrass Risk Low

IF Outbreak Risk Total OF Annual ryegrass > 5

AND Outbreak Risk Total OF Annual ryegrass < 99

THEN Outbreak Risk OF Annual ryegrass IS Low

AND Evaluate Risk of Outbreak for Annual Ryegrass := TRUE


AND Bar Colors[ 1] OF Weed Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 5] := "Low"
RULE Ryegrass Risk High

IF Outbreak Risk Total OF Annual ryegrass < 4

THEN Outbreak Risk OF Annual ryegrass IS High

AND Evaluate Risk of Outbreak for Annual Ryegrass := TRUE


AND Bar Colors[ 1] OF Weed Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 5] := "High"

RULE Winter annual broadleaf Risk High

IF Outbreak Risk Total OF Winter annual broadleaf < 7

THEN Outbreak Risk OF Winter annual broadleaf IS High

AND Evaluate Risk of Outbreak for Winter Annual Broadleaf := TRUE


AND Bar Colors[ 2] OF Weed Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 6] := "High"

RULE Winter annual broadleaf Risk Medium
IF Outbreak Risk Total OF Winter annual broadleaf < 11

AND Outbreak Risk Total OF Winter annual broadleaf > 6

THEN Outbreak Risk OF Winter annual broadleaf IS Medium

AND Evaluate Risk of Outbreak for Winter Annual Broadleaf := TRUE


AND Bar Colors[ 2] OF Weed Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 6] := "Medium"

RULE Winter annual broadleaf Risk Low

IF Outbreak Risk Total OF Winter annual broadleaf > 10

THEN Outbreak Risk OF Winter annual broadleaf IS Low

AND Evaluate Risk of Outbreak for Winter Annual Broadleaf := TRUE


AND Bar Colors[ 2] OF Weed Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 6] := "Low"

RULE Winter annual broadleaf Risk Not Available
IF Outbreak Risk Total OF Winter annual broadleaf > 98

THEN Outbreak Risk OF Winter annual broadleaf IS Not Available

AND Evaluate Risk of Outbreak for Winter Annual Broadleaf := TRUE


AND Bar Colors[ 2] OF Weed Risk Graph := SETCOLOR( 0, 255, 0)


RULE Outbreak Risk Total of AR

IF Outbreak Risk for Field History OF Annual ryegrass > 0

AND Outbreak Risk for Level of Control OF Annual ryegrass > 0

THEN Outbreak Risk Total OF Annual ryegrass := (Outbreak Risk for Field History OF Annual ryegrass + Outbreak Risk for Level of Control OF Annual ryegrass)

RULE Outbreak Risk Total of WAB

IF Outbreak Risk for Burndown OF Winter annual broadleaf > 0

AND Outbreak Risk for Tillage OF Winter annual broadleaf > 0
AND Outbreak Risk for Field History OF Winter annual broadleaf > 0

AND Outbreak Risk for Level of Control OF Winter annual broadleaf > 0

THEN Outbreak Risk Total OF Winter annual broadleaf := (Outbreak Risk for Burndown OF Winter annual broadleaf + Outbreak Risk for Tillage OF Winter annual broadleaf + Outbreak Risk for Field History OF Winter annual broadleaf + Outbreak Risk for Level of Control OF Winter annual broadleaf)

RULE History of Annual Ryegrass Infestation High

IF Field History of Damage OF Annual ryegrass IS High

THEN Outbreak Risk for Field History OF Annual ryegrass := 1

RULE History of Annual Ryegrass Infestation Medium

IF Field History of Damage OF Annual ryegrass IS Medium

THEN Outbreak Risk for Field History OF Annual ryegrass := 2

RULE History of Annual Ryegrass Infestation Low

IF Field History of Damage OF Annual ryegrass IS Low
THEN Outbreak Risk for Field History OF Annual ryegrass := 3

RULE History of Annual Ryegrass Infestation None
IF Field History of Damage OF Annual ryegrass IS None
THEN Outbreak Risk for Field History OF Annual ryegrass := 4

RULE History of Winter Annual Broadleaf Infestation High
IF Field History of Damage OF Winter annual broadleaf IS High
THEN Outbreak Risk for Field History OF Winter annual broadleaf := 1

RULE History of Winter Annual Broadleaf Infestation Medium
IF Field History of Damage OF Winter annual broadleaf IS Medium
THEN Outbreak Risk for Field History OF Winter annual broadleaf := 2

RULE History of Winter Annual Broadleaf Infestation Low
IF Field History of Damage OF Winter annual broadleaf IS Low
THEN Outbreak Risk for Field History OF Winter annual broadleaf := 3
RULE History of Winter Annual Broadleaf Infestation None

IF Field History of Damage OF Winter annual broadleaf IS None

THEN Outbreak Risk for Field History OF Winter annual broadleaf := 4

RULE Level of Annual Ryegrass Control High

IF Level of Control Achieved OF Annual ryegrass IS High

THEN Outbreak Risk for Level of Control OF Annual ryegrass := 3

RULE Level of Annual Ryegrass Control Medium

IF Level of Control Achieved OF Annual ryegrass IS Medium

THEN Outbreak Risk for Level of Control OF Annual ryegrass := 2

RULE Level of Annual Ryegrass Control Low

IF Level of Control Achieved OF Annual ryegrass IS Low

THEN Outbreak Risk for Level of Control OF Annual ryegrass := 1
RULE Level of Annual Ryegrass Control None Applied

IF Level of Control Achieved OF Annual ryegrass IS None Applied

THEN Outbreak Risk for Level of Control OF Annual ryegrass := 2

RULE Level of WAB Control High

IF Level of Control Achieved OF Winter annual broadleaf IS High

THEN Outbreak Risk for Level of Control OF Winter annual broadleaf := 3

RULE Level of WAB Control Medium

IF Level of Control Achieved OF Winter annual broadleaf IS Medium

THEN Outbreak Risk for Level of Control OF Winter annual broadleaf := 2

RULE Level of WAB Control Low

IF Level of Control Achieved OF Winter annual broadleaf IS Low

THEN Outbreak Risk for Level of Control OF Winter annual broadleaf := 1

RULE Level of WAB Control None Applied
IF Level of Control Achieved OF Winter annual broadleaf IS None Applied

THEN Outbreak Risk for Level of Control OF Winter annual broadleaf := 2

RULE Burndown of WAB

IF Burndown OF Winter annual broadleaf = TRUE

THEN Outbreak Risk for Burndown OF Winter annual broadleaf := 3

ELSE Outbreak Risk for Burndown OF Winter annual broadleaf := 1

6.4 Disease Rules

RULE PM Risk High

IF Outbreak Risk Total OF Powdery Mildew <= 3

THEN Outbreak Risk OF Powdery Mildew IS High

AND Evaluate Risk of Outbreak for Powdery Mildew := TRUE


AND Bar Colors[ 1] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 7] := "High"
RULE PM Risk Not Available

IF Outbreak Risk Total OF Powdery Mildew > 98

THEN Outbreak Risk OF Powdery Mildew IS Not Available

AND Evaluate Risk of Outbreak for Powdery Mildew := TRUE


AND Bar Colors[ 1] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[ 7] := "Not Available"

RULE PM Risk Low

IF Outbreak Risk Total OF Powdery Mildew > 6

AND Outbreak Risk Total OF Powdery Mildew < 99

THEN Outbreak Risk OF Powdery Mildew IS Low

AND Evaluate Risk of Outbreak for Powdery Mildew := TRUE


AND Bar Colors[ 1] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 7] := "Low"
RULE PM Risk Medium

IF Outbreak Risk Total OF Powdery Mildew > 3

AND Outbreak Risk Total OF Powdery Mildew <= 6

THEN Outbreak Risk OF Powdery Mildew IS Medium

AND Evaluate Risk of Outbreak for Powdery Mildew := TRUE


AND Bar Colors[ 1] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 7] := "Medium"

RULE LR Risk High

IF Outbreak Risk Total OF Leaf Rust <= 3

THEN Outbreak Risk OF Leaf Rust IS High

AND Evaluate Risk of Outbreak for Leaf Rust := TRUE


AND Bar Colors[ 2] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 8] := "High"
RULE LR Risk Medium

IF Outbreak Risk Total OF Leaf Rust > 3

AND Outbreak Risk Total OF Leaf Rust <= 6

THEN Outbreak Risk OF Leaf Rust IS Medium

AND Evaluate Risk of Outbreak for Leaf Rust := TRUE


AND Bar Colors[ 2] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 8] := "Medium"

RULE LR Risk Low

IF Outbreak Risk Total OF Leaf Rust > 6

AND Outbreak Risk Total OF Leaf Rust < 99

THEN Outbreak Risk OF Leaf Rust IS Low

AND Evaluate Risk of Outbreak for Leaf Rust := TRUE


AND Bar Colors[ 2] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 8] := "Low"
RULE LR Risk Not Available

IF Outbreak Risk Total OF Leaf Rust > 98

THEN Outbreak Risk OF Leaf Rust IS Not Available

AND Evaluate Risk of Outbreak for Leaf Rust := TRUE


AND Bar Colors[ 2] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[ 8] := "Not Available"

RULE SLGB Risk High

IF Outbreak Risk Total OF Septoria Leaf & Glume Blotch <= 3

THEN Outbreak Risk OF Septoria Leaf & Glume Blotch IS High

AND Evaluate Risk of Outbreak for SLGB := TRUE


RULE SLGB Risk Low

IF Outbreak Risk Total OF Septoria Leaf & Glume Blotch > 6
AND Outbreak Risk Total OF Septoria Leaf & Glume Blotch < 99
THEN Outbreak Risk OF Septoria Leaf & Glume Blotch IS Low
AND Evaluate Risk of Outbreak for SLGB := TRUE
AND Bar Colors[ 3] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)
AND pestrisklevel[ 9] := "Low"

RULE SLGB Risk Not Available

IF Outbreak Risk Total OF Septoria Leaf & Glume Blotch > 98
THEN Outbreak Risk OF Septoria Leaf & Glume Blotch IS Not Available

AND Evaluate Risk of Outbreak for SLGB := TRUE


AND Bar Colors[3] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[9] := "Not Available"

RULE SLGB Risk Medium

IF Outbreak Risk Total OF Septoria Leaf & Glume Blotch > 3

AND Outbreak Risk Total OF Septoria Leaf & Glume Blotch <= 6

THEN Outbreak Risk OF Septoria Leaf & Glume Blotch IS Medium

AND Evaluate Risk of Outbreak for SLGB := TRUE


AND Bar Colors[ 3] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

AND pestsrisklevel[ 9] := "Medium"

RULE TS Risk High

IF Outbreak Risk Total OF Tan Spot < 4

THEN Outbreak Risk OF Tan Spot IS High

AND Evaluate Risk of Outbreak for Tan Spot := TRUE


AND Bar Colors[ 4] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestsrisklevel[ 10] := "High"

RULE TS Risk Low

IF Outbreak Risk Total OF Tan Spot > 6
AND Outbreak Risk Total OF Tan Spot < 99

THEN Outbreak Risk OF Tan Spot IS Low

AND Evaluate Risk of Outbreak for Tan Spot := TRUE


AND Bar Colors[ 4] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 10] := "Low"

RULE TS Risk Medium

IF Outbreak Risk Total OF Tan Spot > 3

AND Outbreak Risk Total OF Tan Spot < 7

THEN Outbreak Risk OF Tan Spot IS Medium

AND Evaluate Risk of Outbreak for Tan Spot := TRUE


AND Bar Colors[ 4] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 10] := "Medium"

RULE TS Risk Not Available

IF Outbreak Risk Total OF Tan Spot > 98

THEN Outbreak Risk OF Tan Spot IS Not Available

AND Evaluate Risk of Outbreak for Tan Spot := TRUE


AND Bar Colors[ 4] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[ 10] := "Not Available"

RULE LS Risk High

110
IF Outbreak Risk Total OF Loose Smut <= 3

THEN Outbreak Risk OF Loose Smut IS High

AND Evaluate Risk of Outbreak for Loose Smut := TRUE


AND Bar Colors[ 5] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)


RULE LS Risk Low

IF Outbreak Risk Total OF Loose Smut > 6

AND Outbreak Risk Total OF Loose Smut < 99

THEN Outbreak Risk OF Loose Smut IS Low

AND Evaluate Risk of Outbreak for Loose Smut := TRUE


AND Bar Colors[ 5] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)


RULE LS Risk Medium
IF Outbreak Risk Total OF Loose Smut > 3
AND Outbreak Risk Total OF Loose Smut <= 6
THEN Outbreak Risk OF Loose Smut IS Low
AND Evaluate Risk of Outbreak for Loose Smut := TRUE
AND Bar Colors[ 5] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

RULE LS Risk Not Available
IF Outbreak Risk Total OF Loose Smut > 98
THEN Outbreak Risk OF Loose Smut IS Not Available
AND Evaluate Risk of Outbreak for Loose Smut := TRUE
AND Bar Colors[ 5] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

RULE Scab Risk High
IF Outbreak Risk Total OF Scab < 4

THEN Outbreak Risk OF Scab IS High

AND Evaluate Risk of Outbreak for Scab := TRUE


AND Bar Colors[ 6] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 12] := "High"

RULE Scab Risk Low

IF Outbreak Risk Total OF Scab > 6

AND Outbreak Risk Total OF Scab < 99

THEN Outbreak Risk OF Scab IS Low

AND Evaluate Risk of Outbreak for Scab := TRUE


AND Bar Colors[ 6] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 12] := "Low"

RULE Scab Risk Medium
IF Outbreak Risk Total OF Scab > 3
AND Outbreak Risk Total OF Scab <= 6
THEN Outbreak Risk OF Scab IS Medium
AND Evaluate Risk of Outbreak for Scab := TRUE
AND Bar Colors[6] OF Pathogen Risk Graph := SETCOLOR(255, 255, 0)
AND pestrisklevel[12] := "Medium"

RULE Scab Risk Not Available

IF Outbreak Risk Total OF Scab > 98
THEN Outbreak Risk OF Scab IS Not Available
AND Evaluate Risk of Outbreak for Scab := TRUE
AND Bar Colors[6] OF Pathogen Risk Graph := SETCOLOR(0, 255, 0)
AND pestrisklevel[12] := "Not Available"

RULE TA Risk High
IF Outbreak Risk Total OF Take All < 4

THEN Outbreak Risk OF Take All IS High

AND Evaluate Risk of Outbreak for Take All := TRUE

AND Bar Left Loc[ 7] OF Pathogen Risk Graph := 320


AND Bar Top Loc[ 7] OF Pathogen Risk Graph := 240


AND Bar Colors[ 7] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[ 13] := "High"

RULE TA Risk Low

IF Outbreak Risk Total OF Take All > 6

AND Outbreak Risk Total OF Take All < 99

THEN Outbreak Risk OF Take All IS Low

AND Evaluate Risk of Outbreak for Take All := TRUE

AND Bar Left Loc[ 7] OF Pathogen Risk Graph := 320

AND Bar Top Loc[7] OF Pathogen Risk Graph := 240


AND Bar Colors[7] OF Pathogen Risk Graph := SETCOLOR(0, 0, 255)

AND pestrisklevel[13] := "Low"

RULE TA Risk Medium

IF Outbreak Risk Total OF Take All > 3

AND Outbreak Risk Total OF Take All < 7

THEN Outbreak Risk OF Take All IS Medium

AND Evaluate Risk of Outbreak for Take All := TRUE

AND Bar Left Loc[7] OF Pathogen Risk Graph := 320


AND Bar Top Loc[7] OF Pathogen Risk Graph := 240


AND Bar Colors[7] OF Pathogen Risk Graph := SETCOLOR(255, 255, 0)

AND pestrisklevel[13] := "Medium"
RULE TA Risk Not Available

IF Outbreak Risk Total OF Take All > 98

THEN Outbreak Risk OF Take All IS Not Available

AND Evaluate Risk of Outbreak for Take All := TRUE

AND Bar Left Loc[ 7] OF Pathogen Risk Graph := 320


AND Bar Top Loc[ 7] OF Pathogen Risk Graph := 240


AND Bar Colors[ 7] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)


RULE BYD Risk High

IF Corrected Risk Total OF Barley Yellow Dwarf < 4

THEN Outbreak Risk OF Barley Yellow Dwarf IS High

AND Evaluate Risk of Outbreak for Barley Yellow Dwarf := TRUE


AND Bar Colors[ 8] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)
RULE BYD Risk Low

IF Corrected Risk Total OF Barley Yellow Dwarf > 6

AND Corrected Risk Total OF Barley Yellow Dwarf < 99

THEN Outbreak Risk OF Barley Yellow Dwarf IS Low

AND Evaluate Risk of Outbreak for Barley Yellow Dwarf := TRUE


AND Bar Colors[ 8] OF Pathogen Risk Graph := SETCOLOR( 0, 0, 255)

AND pestrisklevel[ 14] := "Low"

RULE BYD Risk Medium

IF Corrected Risk Total OF Barley Yellow Dwarf > 3

AND Corrected Risk Total OF Barley Yellow Dwarf < 7

THEN Outbreak Risk OF Barley Yellow Dwarf IS Medium

AND Evaluate Risk of Outbreak for Barley Yellow Dwarf := TRUE


AND pestrisklevel[ 14] := "High"
AND Bar Colors[ 8] OF Pathogen Risk Graph := SETCOLOR( 255, 255, 0)

AND pestrisklevel[ 14] := "Medium"

RULE BYD Risk Not Available

IF Corrected Risk Total OF Barley Yellow Dwarf > 98

THEN Outbreak Risk OF Barley Yellow Dwarf IS Not Available

AND Evaluate Risk of Outbreak for Barley Yellow Dwarf := TRUE


AND Bar Colors[ 8] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)

AND pestrisklevel[ 14] := "Not Available"

RULE WSS Risk Not Available

IF Outbreak Risk Total OF Wheat Spindle Streak > 98

THEN Outbreak Risk OF Wheat Spindle Streak IS Not Available

AND Evaluate Risk of Outbreak for Wheat Spindle Streak := TRUE


AND Bar Colors[ 9] OF Pathogen Risk Graph := SETCOLOR( 0, 255, 0)
AND pestrisklevel[15] := "Not Available"

RULE WSS Risk Medium

IF Outbreak Risk Total OF Wheat Spindle Streak > 4

AND Outbreak Risk Total OF Wheat Spindle Streak < 9

THEN Outbreak Risk OF Wheat Spindle Streak IS Medium

AND Evaluate Risk of Outbreak for Wheat Spindle Streak := TRUE


AND Bar Colors[9] OF Pathogen Risk Graph := SETCOLOR(255, 255, 0)

AND pestrisklevel[15] := "Medium"

RULE WSS Risk Low

IF Outbreak Risk Total OF Wheat Spindle Streak > 8

AND Outbreak Risk Total OF Wheat Spindle Streak < 99

THEN Outbreak Risk OF Wheat Spindle Streak IS Low

AND Evaluate Risk of Outbreak for Wheat Spindle Streak := TRUE

RULE WSS Risk High

IF Outbreak Risk Total OF Wheat Spindle Streak < 5

THEN Outbreak Risk OF Wheat Spindle Streak IS High

AND Evaluate Risk of Outbreak for Wheat Spindle Streak := TRUE


AND Bar Colors[9] OF Pathogen Risk Graph := SETCOLOR( 255, 0, 0)

AND pestrisklevel[15] := "High"

RULE BYDReaction 1

IF BYDReact OF Wheat Variety = "VS"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 1

RULE BYDReaction 2

IF BYDReact OF Wheat Variety = "S"
THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 1.83

RULE BYDReaction 3

IF BYDReact OF Wheat Variety = "MS-S"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 2.67

RULE BYDReaction 4

IF BYDReact OF Wheat Variety = "MS"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 3.5

RULE BYDReaction 5

IF BYDReact OF Wheat Variety = "MR-MS"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 4.33

RULE BYDReaction 6

IF BYDReact OF Wheat Variety = "MR"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 5.15
RULE BYDReaction 7

IF BYDReact OF Wheat Variety = "R"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 6

RULE BYDReaction 8

IF BYDReact OF Wheat Variety = "NA"

THEN Outbreak Risk for Cultivar OF Barley Yellow Dwarf := 99

RULE LRReaction 1

IF LRReact OF Wheat Variety = "VS"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 1

RULE LRReaction 2

IF LRReact OF Wheat Variety = "S"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 2.33
RULE LRReaction 3

IF LRReact OF Wheat Variety = "MS-S"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 3.67

RULE LRReaction 4

IF LRReact OF Wheat Variety = "MS"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 5

RULE LRReaction 5

IF LRReact OF Wheat Variety = "MR-MS"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 6.33

RULE LRReaction 6

IF LRReact OF Wheat Variety = "MR"

THEN Outbreak Risk for Cultivar OF Leaf Rust := 7.67

RULE LRReaction 7
IF LRReact OF Wheat Variety = "R"
THEN Outbreak Risk for Cultivar OF Leaf Rust := 9

RULE LRReaction 8

IF LRReact OF Wheat Variety = "NA"
THEN Outbreak Risk for Cultivar OF Leaf Rust := 99

RULE Outbreak Risk Total of BYD

IF Outbreak Risk for Cultivar OF Barley Yellow Dwarf > 0
AND Outbreak Risk for Planting Date OF Barley Yellow Dwarf > 0
AND Outbreak Risk for Seed Insecticide OF Barley Yellow Dwarf > 0
THEN Outbreak Risk Total OF Barley Yellow Dwarf := (Outbreak Risk for Cultivar OF Barley Yellow Dwarf + Outbreak Risk for Planting Date OF Barley Yellow Dwarf + Outbreak Risk for Seed Insecticide OF Barley Yellow Dwarf) / 3
ELSE Outbreak Risk Total OF Barley Yellow Dwarf := 99

RULE Outbreak Risk Total of LR
IF Outbreak Risk for Cultivar OF Leaf Rust $\geq 0$

AND Outbreak Risk for Planting Date OF Leaf Rust $\geq 0$

AND Outbreak Risk for Seed Fungicide OF Leaf Rust $\geq 0$

THEN Outbreak Risk Total OF Leaf Rust := (Outbreak Risk for Cultivar OF Leaf Rust + Outbreak Risk for Planting Date OF Leaf Rust + Outbreak Risk for Seed Fungicide OF Leaf Rust) / 3

ELSE Outbreak Risk Total OF Leaf Rust := 99

RULE Outbreak Risk Total of LS

IF Outbreak Risk for Seed Fungicide OF Loose Smut > 0

AND Outbreak Risk for Seed Quality OF Loose Smut > 0

THEN Outbreak Risk Total OF Loose Smut := (Outbreak Risk for Seed Fungicide OF Loose Smut + Outbreak Risk for Seed Quality OF Loose Smut) / 2

ELSE Outbreak Risk Total OF Loose Smut := 99

RULE Outbreak Risk Total of PM
IF Outbreak Risk for Cultivar OF Powdery Mildew $\geq 0$

AND Outbreak Risk for Planting Date OF Powdery Mildew $\geq 0$

AND Outbreak Risk for Seed Fungicide OF Powdery Mildew $\geq 0$

THEN Outbreak Risk Total OF Powdery Mildew $:= (\text{Outbreak Risk for Cultivar OF Powdery Mildew} + \text{Outbreak Risk for Planting Date OF Powdery Mildew} + \text{Outbreak Risk for Seed Fungicide OF Powdery Mildew}) / 3$

ELSE Outbreak Risk Total OF Powdery Mildew $:= 99$

RULE Outbreak Risk Total of Scab

IF Outbreak Risk for Crop Rotation OF Scab $\geq 0$

AND Outbreak Risk for Plow Down OF Scab $\geq 0$

THEN Outbreak Risk Total OF Scab $:= (\text{Outbreak Risk for Crop Rotation OF Scab} + \text{Outbreak Risk for Plow Down OF Scab}) / 2$

ELSE Outbreak Risk Total OF Scab $:= 99$

RULE Outbreak Risk Total of SLGB

IF Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch $\geq 0$
AND Outbreak Risk for Crop Rotation OF Septoria Leaf & Glume Blotch >= 0
AND Outbreak Risk for Plow Down OF Septoria Leaf & Glume Blotch >= 0
AND Outbreak Risk for Seed Fungicide OF Septoria Leaf & Glume Blotch >= 0
AND Outbreak Risk for Seed Rate OF Septoria Leaf & Glume Blotch >= 0
AND Outbreak Risk for Seed Quality OF Septoria Leaf & Glume Blotch > 0

THEN Outbreak Risk Total OF Septoria Leaf & Glume Blotch := (Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch + Outbreak Risk for Crop Rotation OF Septoria Leaf & Glume Blotch + Outbreak Risk for Plow Down OF Septoria Leaf & Glume Blotch + Outbreak Risk for Seed Fungicide OF Septoria Leaf & Glume Blotch + Outbreak Risk for Seed Rate OF Septoria Leaf & Glume Blotch + Outbreak Risk for Seed Quality OF Septoria Leaf & Glume Blotch) / 6

ELSE Outbreak Risk Total OF Septoria Leaf & Glume Blotch := 99

RULE Outbreak Risk Total of TA

IF Outbreak Risk for Crop Rotation OF Take All >= 0
AND Outbreak Risk for Plow Down OF Take All >= 0

AND Outbreak Risk for Planting Date OF Take All >= 0

THEN Outbreak Risk Total OF Take All := (Outbreak Risk for Crop Rotation OF Take All + Outbreak Risk for Plow Down OF Take All + Outbreak Risk for Planting Date OF Take All) / 3

ELSE Outbreak Risk Total OF Take All := 99

RULE Outbreak Risk Total of TS

IF Outbreak Risk for Crop Rotation OF Tan Spot >= 0

AND Outbreak Risk for Plow Down OF Tan Spot >= 0

AND Outbreak Risk for Planting Date OF Tan Spot >= 0

THEN Outbreak Risk Total OF Tan Spot := (Outbreak Risk for Crop Rotation OF Tan Spot + Outbreak Risk for Plow Down OF Tan Spot + Outbreak Risk for Planting Date OF Tan Spot) / 3

ELSE Outbreak Risk Total OF Tan Spot := 99

RULE Outbreak Risk Total of WSS
IF Outbreak Risk for Cultivar OF Wheat Spindle Streak \( \geq 0 \)

AND Outbreak Risk for Planting Date OF Wheat Spindle Streak \( \geq 0 \)

THEN Outbreak Risk Total OF Wheat Spindle Streak := \( \frac{\text{Outbreak Risk for Cultivar OF Wheat Spindle Streak} + \text{Outbreak Risk for Planting Date OF Wheat Spindle Streak}}{2} \)

ELSE Outbreak Risk Total OF Wheat Spindle Streak := 99

RULE PMReaction 1

IF PMReact OF Wheat Variety = "VS"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 1

RULE PMReaction 2

IF PMReact OF Wheat Variety = "S"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 2.33

RULE PMReaction 3

IF PMReact OF Wheat Variety = "MS-S"
THEN Outbreak Risk for Cultivar OF Powdery Mildew := 3.67

RULE PMReaction 4

IF PMReact OF Wheat Variety = "MS"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 5

RULE PMReaction 5

IF PMReact OF Wheat Variety = "MR-MS"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 6.33

RULE PMReaction 6

IF PMReact OF Wheat Variety = "MR"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 7.67

RULE PMReaction 7

IF PMReact OF Wheat Variety = "R"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 9
RULE PMReaction 8

IF PMReact OF Wheat Variety = "NA"

THEN Outbreak Risk for Cultivar OF Powdery Mildew := 99

RULE SLGBReaction 1

IF SLGBReact OF Wheat Variety = "VS"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 1

RULE SLGBReaction 2

IF SLGBReact OF Wheat Variety = "S"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 1.33

RULE SLGBReaction 3

IF SLGBReact OF Wheat Variety = "MS-S"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 1.67
RULE SLGBReaction 4

IF SLGBReact OF Wheat Variety = "MS"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 2

RULE SLGBReaction 5

IF SLGBReact OF Wheat Variety = "MR-MS"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 2.33

RULE SLGBReaction 6

IF SLGBReact OF Wheat Variety = "MR"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 2.67

RULE SLGBReaction 7

IF SLGBReact OF Wheat Variety = "R"

THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 3
IF SLGBReact OF Wheat Variety = "NA"
THEN Outbreak Risk for Cultivar OF Septoria Leaf & Glume Blotch := 99

RULE WSSReaction 1
IF WSReact OF Wheat Variety = "VS"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 1

RULE WSSReaction 2
IF WSReact OF Wheat Variety = "S"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 2.33

RULE WSSReaction 3
IF WSReact OF Wheat Variety = "MS-S"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 3.67

RULE WSSReaction 4
IF WSReact OF Wheat Variety = "MS"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 5

RULE WSSReaction 5
IF WSReact OF Wheat Variety = "MR-MS"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 6.33

RULE WSSReaction 6
IF WSReact OF Wheat Variety = "MR"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 7.67

RULE WSSReaction 7
IF WSReact OF Wheat Variety = "R"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 9

RULE WSSReaction 8
IF WSReact OF Wheat Variety = "NA"
THEN Outbreak Risk for Cultivar OF Wheat Spindle Streak := 99
6.5 Demons

DEMON aphid control summary

IF selected OF baraphid hr

THEN pestname := "Aphid"

AND risklevel := pestrisklevel[1]

AND text OF pest control textbox := recommendation[1]

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.leaching,pesticid.runoff,pesticid.toxoral,pesticid.toxdermal,
pesticid.birds,pesticid.fish,pesticid.bees,pesticid.cost

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and
pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

**DEMON armyworm control summary**

IF selected OF bararmyworm

THEN pestname := "Armyworm"

AND risklevel := pestrisklevel[ 2]

AND text OF pest control textbox := recommendation[ 2]

!

! select control table info from dbase files

!

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,

pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,

pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid
WHERE pesticid.name = cp.pesticide and
    cp.control = controls.formula and
    controls.formula = pc.control and
    pc.pest = :pestname
ORDER BY controls.formula
END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
    ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMON hessian fly control summary

IF selected OF hessian fly hr
THEN pestname := 'Hessian fly'
AND risklevel := pestrisklevel[ 4]
AND text OF pest control textbox := recommendation[ 4]

! select control table info from dbase files

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticide.class, pesticide.leaching, pesticide.runoff, pesticide.oralld50, pesticide.toxoral,
pesticide.toxdermal, pesticide.birds, pesticide.fish, pesticide.bees

FROM pc, controls, cp, pesticide

WHERE pesticide.name = cp.pesticide and
    cp.control = controls.formula and
    controls.formula = pc.control and
    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMON clb control summary

IF selected OF barclb hr

THEN pestname := "Cereal leaf beetle"

AND risklevel := pestrisklevel[3]

AND text OF pest control textbox := recommendation[3]
! select control table info from dbase files

! 

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

cp.control = controls.formula and

controls.formula = pc.control and

pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,

ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)


DEMON weed control summary

IF selected OF barweed hyperregion

THEN pestname := "Weeds"
AND risklevel := pestrisklevel[5]

AND text OF pest control textbox := recommendation[5]

!

! select control table info from dbase files

!

AND EXEC l5odbc 12 SQL SELECT controls.formula, pesticid.name, pesticid.class, pesticid.leaching, pesticid.runoff, pesticid.oralld50, pesticid.toxoral, pesticid.toxdermal, pesticid.birds, pesticid.fish, pesticid.bees

FROM pc, controls, cp, pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and

    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,

ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)
DEMON pm control summary

IF selected OF barpm hyperregion

THEN pestname := "Powdery mildew"

AND risklevel := pestrisklevel[ 6]

AND text OF pest control textbox := recommendation[ 6]

! select control table info from dbase files

! AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and

    pc.pest = :pestname

ORDER BY controls.formula

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END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff, ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

**DEMON lr control summary**

IF selected OF barlr hyperregion

THEN pestname := "Leaf rust"

AND risklevel := pestrisklevel[7]

AND text OF pest control textbox := recommendation[7]

!

! select control table info from dbase files

!

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name, pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral, pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees FROM pc,controls,cp,pesticid WHERE pesticid.name = cp.pesticide and cp.control = controls.formula and
controls.formula = pc.control and

pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff, ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMON slgb control summary

IF selected OF barslgb hyperregion

THEN pestname := "Septoria leaf & glume blotch"

AND pestnickname := "Slgb"

AND risklevel := pestrisklevel[ 8]

AND text OF pest control textbox := recommendation[ 8]

! select control table info from dbase files

! EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and

    pc.pest = :pestnickname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff, ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMOn ts control summary

IF selected OF barts hyperregion

THEN pestname := "Tan spot"

AND risklevel := pestrisklevel[ 9]

AND text OF pest control textbox := recommendation[ 9]

!

! select control table info from dbase files
AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees
FROM pc,controls,cp,pesticid
WHERE pesticid.name = cp.pesticide and
    cp.control = controls.formula and
    controls.formula = pc.control and
    pc.pest = :pestname
ORDER BY controls.formula
END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMON is control summary

IF selected OF barls hyperregion
THEN pestname := "Loose smut"
AND risklevel := pestrisklevel[ 10]
AND text OF pest control textbox := recommendation[10]

!

! select control table info from dbase files

!

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and
    cp.control = controls.formula and
    controls.formula = pc.control and
    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMON scab control summary
IF selected OF barscab hyperregion

THEN pestname := "Scab"


! select control table info from dbase files

!  select control table info from dbase files

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid(bees

FROM pc,controls,cp,pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and

    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMOn ta control summary

IF selected OF barta hyperregion

THEN pestname := "Take-all"

AND risklevel := pestrisklevel[ 12]

AND text OF pest control textbox := recommendation[ 12]

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees
FROM pc,controls,cp,pesticid
WHERE pesticid.name = cp.pesticide and

cp.control = controls.formula and

controls.formula = pc.control and
pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMOM byd control summary

IF selected OF barbyd hyperregion

THEN pestname := "Barley yellow dwarf"

AND risklevel := pestrisklevel[ 13]

AND text OF pest control textbox := recommendation[ 13]

!

! select control table info from dbase files

! AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class,pesticid.leaching,pesticid.runoff,pesticid.oralld50,pesticid.toxoral,
pesticid.toxdermal,pesticid.birds,pesticid.fish,pesticid.bees

FROM pc,controls,cp,pesticid
WHERE pesticid.name = cp.pesticide and
    cp.control = controls.formula and
controls.formula = pc.control and
pc.pest = :pestname
ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff,
ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

DEMEN wss control summary

IF selected OF barwss hyperregion
THEN pestname := "Wheat spindle streak"
AND risklevel := pestrisklevel[ 14]
AND text OF pest control textbox := recommendation[ 14]

! select control table info from dbase files

AND EXEC l5odbc 12 SQL SELECT controls.formula,pesticid.name,
pesticid.class, pesticid.leaching, pesticid.runoff, pesticid.oralld50, pesticid.toxoral, pesticid.toxdermal, pesticid.birds, pesticid.fish, pesticid.bees

FROM pc, controls, cp, pesticid

WHERE pesticid.name = cp.pesticide and

    cp.control = controls.formula and

    controls.formula = pc.control and

    pc.pest = :pestname

ORDER BY controls.formula

END SQL INTO ControlTable (ControlName, PesticideName, Leaching, Runoff, ToxOral, ToxDermal, ToxBirds, ToxFish, ToxBees, Cost)

6.6 Methods

ATTRIBUTE load county names and crop names SIMPLE

WHEN CHANGED

BEGIN

!

! attached to start pushbutton
! load in the dBASE file of county names into the Virginia County class

EXEC l5odbc 1 SQL SELECT county_cod, county_nam, coastal, brh, es, nv
FROM Counties

END SQL INTO Virginia County (Code, Name, Coastal, BlueRidge, East Shore, Northern)

! load crop names from dBASE file

EXEC l5odbc 2 SQL SELECT * FROM scrops END SQL INTO Spring Crop
EXEC l5odbc 14 SQL SELECT * FROM fcrops END SQL INTO Fall Crop

output OF main window := Field Information

END

ATTRIBUTE load varieties SIMPLE
WHEN CHANGED

BEGIN

!

! load in the dBASE file of varieties

!

EXEC l5odbc 6 SQL SELECT cultivar, pm, lr, slgb, ws, byd, ta FROM variety

END SQL INTO Wheat Variety (Cultivar, PMReact, LRReact, SLGBReact, WSReact, BYDReact, TARReact)

END

ATTRIBUTE load pesticides SIMPLE

WHEN CHANGED

BEGIN

!

! load pesticide data from dBASE file into pesticide object

!
EXEC l5odbc 5 SQL SELECT * FROM pesticides END SQL INTO

Pesticides

END

ATTRIBUTE Evaluate Risk of Outbreak for Powdery Mildew

SIMPLE

WHEN CHANGED

BEGIN

location OF barPM := SETRECT( 320, 180, Bar Right Loc[ 1] OF Pathogen Risk Graph, 200)

fill color OF barPM := Bar Colors[ 1] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Leaf Rust SIMPLE

WHEN CHANGED

BEGIN

fill color OF barLR := Bar Colors[ 2] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for SLGB SIMPLE

WHEN CHANGED

BEGIN


Risk Graph, 240)

fill color OF barSLGB := Bar Colors[ 3] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Tan Spot SIMPLE
WHEN CHANGED

BEGIN


fill color OF barTS := Bar Colors[ 4] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Loose Smut SIMPLE

WHEN CHANGED

BEGIN


fill color OF barLS := Bar Colors[ 5] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT
ATTRIBUTE Evaluate Risk of Outbreak for Scab SIMPLE

WHEN CHANGED

BEGIN


fill color OF barSCAB := Bar Colors[6] OF Pathogen Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Take All SIMPLE

WHEN CHANGED

BEGIN


fill color OF barTA := Bar Colors[7] OF Pathogen Risk Graph

END
ATTRIBUTE Evaluate Risk of Outbreak for Barley Yellow Dwarf

SIMPLE

WHEN CHANGED

BEGIN

location OF barBYD := SETRECT( 320, 320, Bar Right Loc[ 8] OF Pathogen Risk Graph, 340)

fill color OF barBYD := Bar Colors[ 8] OF Pathogen Risk Graph

END

ATTRIBUTE Evaluate Risk of Outbreak for Wheat Spindle Streak

SIMPLE

WHEN CHANGED

BEGIN


fill color OF barWSS := Bar Colors[ 9] OF Pathogen Risk Graph

END
ATTRIBUTE Evaluate Risk of Outbreak for Weeds SIMPLE

WHEN CHANGED

BEGIN


fill color OF barBL := Bar Colors[ 2] OF Weed Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Armyworm SIMPLE

WHEN CHANGED

BEGIN
ATTRIBUTE Evaluate Risk of Outbreak for Cereal Leaf Beetle

SIMPLE

WHEN CHANGED

BEGIN

location OF barCLB := SETRECT( 320, 100, Bar Right Loc[ 3] OF Insect Risk Graph, 120)

fill color OF barCLB := Bar Colors[ 3] OF Insect Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT
ATTRIBUTE Evaluate Risk of Outbreak for Hessian Fly SIMPLE

WHEN CHANGED

BEGIN

location OF barHF := SETRECT(320, 120, Bar Right Loc[4] OF Insect Risk Graph, 140)

fill color OF barHF := Bar Colors[4] OF Insect Risk Graph

END

SEARCH ORDER CONTEXT RULES DEFAULT

ATTRIBUTE Evaluate Risk of Outbreak for Annual Ryegrass

SIMPLE

WHEN CHANGED

BEGIN


fill color OF barAR := Bar Colors[1] OF Weed Risk Graph

END
ATTRIBUTE Evaluate Risk of Outbreak for Winter Annual Broadleaf

SIMPLE
7. Appendix 2. Databases

The database information is presented as data models, expressed as entity-relationship models, and data dictionaries. The entities are the tables and the relationships are the 1-1 and 1-many relationships between the tables. The data dictionaries describe each table’s fields, including the type of data, any constraints, and include a basic text description. Primary keys are in bold type and foreign keys are underlined.

7.1 Reactions

7.1.1 Entity-Relationship Model

Since this entity is not related to another entity, there is no entity-relationship model for this database.

7.1.2 Data Dictionary

DESCRIPTION: Name of wheat cultivar. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: CULTIVAR

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 20
DOMAIN: Acceptable values are found in the Pest Management Guide.

REVISED: 1999

DESCRIPTION: Wheat cultivar reaction to powdery mildew. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: PM

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 6

DOMAIN: VS = Very Susceptible; S = Susceptible; MS = Moderately Susceptible; MR = Moderately Resistant; R = Resistant; NA = Data not available, or combinations of two consecutive reactions, such as MR-MS, excluding NA.

REVISED: 1999

DESCRIPTION: Wheat cultivar reaction to leaf rust. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: LR

TIME-VARIANT: Yes
STORAGE TYPE: Character

WIDTH: 6

DOMAIN: VS = Very Susceptible; S = Susceptible; MS = Moderately Susceptible; MR = Moderately Resistant; R = Resistant; NA = Data not available, or combinations of two consecutive reactions, such as MR-MS, excluding NA.

REVISED: 1999

DESCRIPTION: Wheat cultivar reaction to leaf and glume blotch. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: SLGB

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 6

DOMAIN: VS = Very Susceptible; S = Susceptible; MS = Moderately Susceptible; MR = Moderately Resistant; R = Resistant; NA = Data not available, or combinations of two consecutive reactions, such as MR-MS, excluding NA.

REVISED: 1999
DESCRIPTION: Wheat cultivar reaction to wheat spindle streak. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: WS

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 6

DOMAIN: VS = Very Susceptible; S = Susceptible; MS = Moderately Susceptible; MR = Moderately Resistant; R = Resistant; NA = Data not available, or combinations of two consecutive reactions, such as MR-MS, excluding NA.

REVISED: 1999

DESCRIPTION: Wheat cultivar reaction to barley yellow dwarf virus. The data is populated from a table of wheat cultivars that is revised annually and published in the Virginia Cooperative Extension Pest Management Guide for Field Crops.

COLUMN-NAME: BYD

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 6
7.1.3 Description

This data file is a representation of the table titled “Wheat cultivars and their disease reactions” found in the Virginia Cooperative Extension Pest Management Guide for Field Crops. It is indexed by wheat cultivar and lists reactions to five diseases endemic to Virginia. These diseases are powdery mildew, leaf rust, leaf and glume
blotch, wheat spindle streak mosaic, and barley yellow dwarf virus. The disease reactions are categorized in one of six ways: very susceptible, susceptible, moderately susceptible, moderately resistant, resistant, and data not available. The list of cultivars included is changed annually when the Pest Management Guides are revised by Erik Stromberg, Professor of Plant Pathology at Virginia Tech.

7.2 Counties

7.2.1 Entity-Relationship Model

Since this entity is not related to another entity, there is no entity-relationship model for this database.

7.2.2 Data Dictionary

DESCRIPTION: Numeric key assigned to each county.

COLUMN-NAME: COUNTY_COD

TIME-VARIANT: No

STORAGE TYPE: Numeric

WIDTH: 5

DOMAIN: 1 through 199.

REVISED: 1999

DESCRIPTION: Name assigned to each county.

COLUMN-NAME: COUNTY_NAM
TIME-VARIANT: No

STORAGE TYPE: Character

WIDTH: 20

DOMAIN: Names of counties in Virginia.

REVISED: 1999

DESCRIPTION: Code used to designate if the county is in the coastal region of the state of Virginia.

COLUMN-NAME: COASTAL

TIME-VARIANT: No

STORAGE TYPE: Logical

WIDTH: 1

DOMAIN: 0 or 1

REVISED: 1999

DESCRIPTION: Code used to designate if the county is in the Blue Ridge highlands region of the state of Virginia.

COLUMN-NAME: BRH

TIME-VARIANT: No
STORAGE TYPE: Logical

WIDTH: 1

DOMAIN: 0 or 1

REVISED: 1999

DESCRIPTION: Code used to designate if the county is in the eastern shore region of the state of Virginia.

COLUMN-NAME: ES

TIME-VARIANT: No

STORAGE TYPE: Logical

WIDTH: 1

DOMAIN: 0 or 1

REVISED: 1999

DESCRIPTION: Code used to designate if the county is in the New River Valley region of the state of Virginia.

COLUMN-NAME: NV

TIME-VARIANT: No

STORAGE TYPE: Logical
7.2.3 Description

This data file contains a list of the counties in Virginia and a field to indicate their position in one of the three regions in Virginia. These regions are Coastal/Eastern Shore, Piedmont, and Blue Ridge Highlands. Each of these regions has characteristic weather patterns and geographies. As a result, the pest problems will sometimes differ as well.

7.3 Pesticide, CP, and PC

7.3.1 Entity-Relationship Model

There are two entity sets, *pesticide* and *pc*. Since there may be more than one chemical active ingredient included in a pesticide brand, the binary relationship *cp* is defined to denote the association between pesticide brand names listed in *pc* and the chemicals contained within those brands.

7.3.2 Data Dictionary for Pesticide

DESCRIPTION: Chemical name of active ingredient.

COLUMN-NAME: **NAME**

TIME-VARIANT: Yes

STORAGE TYPE: Character
WIDTH: 20

DOMAIN: Chemical names of pesticide active ingredients.

REVISED: 1999

DESCRIPTION: Leaching index.

COLUMN-NAME: LEACHING

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 2

DOMAIN: L = large, M = medium, S = small, XS = extra small.

REVISED: 1999

DESCRIPTION: Runoff index.

COLUMN-NAME: RUNOFF

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 2

DOMAIN: L = large, M = medium, S = small, XS = extra small.

REVISED: 1999
DESCRIPTION: Oral toxicity to mammals.

COLUMN-NAME: TOXORAL

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 10

DOMAIN: High, Moderate, Low.

REVISED: 1999

DESCRIPTION: Dermal toxicity to mammals.

COLUMN-NAME: TOXDERMAL

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 10

DOMAIN: High, Moderate, Low.

REVISED: 1999

DESCRIPTION: Toxicity to birds.

COLUMN-NAME: BIRDS

TIME-VARIANT: Yes
<table>
<thead>
<tr>
<th>STORAGE TYPE</th>
<th>Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH</td>
<td>10</td>
</tr>
<tr>
<td>DOMAIN</td>
<td>High, Moderate, Low</td>
</tr>
<tr>
<td>REVISED</td>
<td>1999</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>Toxicity to fish.</td>
</tr>
<tr>
<td>COLUMN-NAME</td>
<td>FISH</td>
</tr>
<tr>
<td>TIME-VARIANT</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STORAGE TYPE</th>
<th>Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH</td>
<td>10</td>
</tr>
<tr>
<td>DOMAIN</td>
<td>High, Moderate, Low</td>
</tr>
<tr>
<td>REVISED</td>
<td>1999</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>Toxicity to bees.</td>
</tr>
<tr>
<td>COLUMN-NAME</td>
<td>BEES</td>
</tr>
<tr>
<td>TIME-VARIANT</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STORAGE TYPE</th>
<th>Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH</td>
<td>10</td>
</tr>
<tr>
<td>DOMAIN</td>
<td>High, Moderate, Low, Nontoxic</td>
</tr>
</tbody>
</table>
REVISED: 1999

DESCRIPTION: Cost per acre to purchase pesticide.

COLUMN-NAME: COST

TIME-VARIANT: Yes

STORAGE TYPE: Numeric

WIDTH: 6

DOMAIN: Dollar amount.

REVISED: 1999

7.3.3 Data Dictionary for PC

DESCRIPTION: Common names of pests of wheat.

COLUMN-NAME: PEST

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 20

DOMAIN: Pest common names.

REVISED: 1999

DESCRIPTION: Names of pesticide brands.
7.3.4 Data Dictionary for CP

DESCRIPTION: Names of pesticide brands.

COLUMN-NAME: CONTROL

TIME-VARIANT: Yes

STORAGE TYPE: Character

WIDTH: 20

DOMAIN: Names of pesticide brands.

REVISED: 1999

DESCRIPTION: Names of pesticide active ingredients.

COLUMN-NAME: PESTICIDE

TIME-VARIANT: Yes
7.3.5 Description

Pesticide names, their risk of leaching or runoff, and their toxicity to mammals, birds, fish, and bees are stored in this database. This information is displayed at the user’s request when information about control options for specific pests is selected from the Pest Outbreak Summary screen. The information in this file is taken from the Virginia Cooperative Extension Pest Management Guide for Field Crops and should be updated annually as is the case for the Pest Management Guide.
### Appendix 3. Example Test Case

<table>
<thead>
<tr>
<th>Field Information</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Mecklenburg</td>
</tr>
<tr>
<td>Previous Spring Crop</td>
<td>Sorghum</td>
</tr>
<tr>
<td>Tillage of Previous Spring Crop</td>
<td>Minimum</td>
</tr>
<tr>
<td>Previous Fall Crop</td>
<td>Rye</td>
</tr>
<tr>
<td>Tillage of Previous Fall Crop</td>
<td>No Till</td>
</tr>
<tr>
<td>Small Grains in Adjacent Fields Previously</td>
<td>No</td>
</tr>
<tr>
<td>Level of Control Achieved for Winter Annual Weeds</td>
<td>High</td>
</tr>
<tr>
<td>Level of Control Achieved for Annual Ryegrass</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Field History of Pest Damage/Infestation**

<table>
<thead>
<tr>
<th>Pest</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter Annual Weeds</td>
<td>Medium</td>
</tr>
<tr>
<td>Aphid</td>
<td>Low</td>
</tr>
<tr>
<td>Armyworm</td>
<td>High</td>
</tr>
<tr>
<td>Plant Disease</td>
<td>Severity</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Cereal leaf beetle</td>
<td>Medium</td>
</tr>
<tr>
<td>Hessian fly</td>
<td>Not Sure</td>
</tr>
<tr>
<td>Powdery Mildew</td>
<td>Low</td>
</tr>
<tr>
<td>Leaf rust</td>
<td>High</td>
</tr>
<tr>
<td>Annual Ryegrass</td>
<td>Medium</td>
</tr>
<tr>
<td>Loose Smut</td>
<td>Not Sure</td>
</tr>
<tr>
<td>Scab</td>
<td>Not Sure</td>
</tr>
<tr>
<td>Spindle streak</td>
<td>High</td>
</tr>
<tr>
<td>Tan spot</td>
<td>High</td>
</tr>
<tr>
<td>Leaf &amp; glume blotch</td>
<td>High</td>
</tr>
<tr>
<td>Barley yellow dwarf</td>
<td>None</td>
</tr>
<tr>
<td>Take-all</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Crop Information**

<table>
<thead>
<tr>
<th>Information</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting Date</td>
<td>December 19</td>
</tr>
<tr>
<td>Variety</td>
<td>Pioneer 2551</td>
</tr>
<tr>
<td>Tillage</td>
<td>Minimum</td>
</tr>
<tr>
<td>Seed rate</td>
<td>20</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Row width</td>
<td>Seven</td>
</tr>
<tr>
<td>Nutrient plan</td>
<td>Nutrient Management Plan</td>
</tr>
<tr>
<td>Burndown for Annual Weeds</td>
<td>Yes</td>
</tr>
<tr>
<td>Plow down previous crop</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Seed treatments for following pests**

<table>
<thead>
<tr>
<th>Pest</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aphids</td>
<td>True</td>
</tr>
<tr>
<td>Hessain fly</td>
<td>True</td>
</tr>
<tr>
<td>Leaf rust</td>
<td>False</td>
</tr>
<tr>
<td>Loose smut</td>
<td>False</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>False</td>
</tr>
<tr>
<td>Scab</td>
<td>False</td>
</tr>
<tr>
<td>Leaf &amp; glume blotch</td>
<td>False</td>
</tr>
</tbody>
</table>

# EXPERT2.mac This macro does the computations for the comparison of
the expert system with the expert, where the expert
gives the probabilities for LOW, MEDIUM, and HIGH and
calculates the distribution of the distance measure

MACRO
EXPERT2 CHR CCR CLP CMP CHP

# This identifies our columns
# CHR Human Status L M or H (1 2 or 3)
# CCR Expert System L M H (1, 2 or 3)
# CLP CMP CHP are the probabilities designated to Low Medium or High

MCONSTANT N I ELL VLL LL ZSTAT K
MCONSTANT BASEE NSIM SCORE ASCORE STAT ASTAT
MCOLUMN CHR CCR CLP CMP CHP
MCOLUMN CELL CELL2 CVLL CL CLL
MCOLUMN
MCOLUMN CVALUE CPROB.1-CPROB.30
MCOLUMN CSR CSRS CSCORE CASCORE CSTAT CASTAT CDIFF CZSTAT
MMATRIX MP MPT

# These just set up information for use in determining likelihood functions

#**********************************************************************
# Find the mean and variance of the likelihood
#**********************************************************************

LET CELL = (LOGE(CLP)*CLP) + (LOGE(CMP)*CMP) + (LOGE(CHP)*CHP)
LET CELL2= ((LOGE(CLP)**2)*CLP) + ((LOGE(CMP)**2)*CMP) +
((LOGE(CHP)**2)*CHP)
LET CVLL = CELL2 - (CELL**2)
# This converts probabilities to Log Likelihood Functions
# CVLL is the variance of the function

LET ELL = SUM(CELL)
LET VLL = SUM(CVLL)

# ELL This is the sum of the log likelihood relationships
# VLL This is the sum of the variances

#**********************************************************************
# Calculate the statistics for the computer ratings
#**********************************************************************

LET BASEE = 230661361
BASE = BASEE
# This is a random number generator for use in simulations

# Change probabilities to rows

COPY CLP CMP CHP MP
TRANSPOSE MP MPT
COPY MPT CPROB.1-CPROB.30

SET CVALUE
  1:3/1
END

# Simulate ratings

LET NSIM = 1000
DO K = 1:NSIM
  DO I = 1:30
    RANDOM 1 CSRS;
    DISCRETE CVALUE CPROB.I.
    LET CSR(I) = CSRS(1)
  # Calculate scores for the simulated ratings
  IF CHR(I) = 1
    IF CSR(I) = 1
      LET CSCORE(I) = 0
    ELSEIF CSR(I) = 2
      LET CSCORE(I) = 1
    ELSE
      LET CSCORE(I) = 2
    ENDIF
  ELSEIF CHR(I) = 2
    IF CSR(I) = 1
      LET CSCORE(I) = -1
    ELSEIF CSR(I) = 2
      LET CSCORE(I) = 0
    ELSE
      LET CSCORE(I) = 1
    ENDIF
  ELSE
    IF CSR(I) = 1
      LET CSCORE(I) = -2
    ELSEIF CSR(I) = 2
      LET CSCORE(I) = -1
    ELSE
      LET CSCORE(I) = 0
    ENDIF
  ENDIF

# Find the log likelihood statistic for the simulated ratings

IF (CSR(I) = 1)
LET CL(I) = CLP(I)
ELSEIF (CSR(I) = 2)
   LET CL(I) = CMP(I)
ELSE
   LET CL(I) = CHP(I)
ENDIF
ENDDO

LET CASCORE = ABSOLUTE(CSCORE)

LET CSTAT(K) = SUM(CSCORE)
LET CASTAT(K) = SUM(CASCORE)

LET CLL = LOGE(CL)
LET LL = SUM(CLL)
LET CZSTAT(K) = (LL - ELL)/SQRT(VLL)
ENDDO

TALLY CSTAT CASTAT;
   COUNTS;
   PERCENT.

HISTOGRAM CZSTAT

******************************************************************************
# Calculate the statistics for the computer ratings
******************************************************************************

# Find the score for the computer ratings

DO I = 1:30

IF CHR(I) = 1
   IF CCR(I) = 1
      LET CSCORE(I) = 0
   ELSEIF CCR(I) = 2
      LET CSCORE(I) = 1
   ELSE
      LET CSCORE(I) = 2
   ENDIF
ELSEIF CHR(I) = 2
   IF CCR(I) = 1
      LET CSCORE(I) = -1
   ELSEIF CCR(I) = 2
      LET CSCORE(I) = 0
   ELSE
      LET CSCORE(I) = 2
   ENDIF
ELSE
   IF CCR(I) = 1
      LET CSCORE(I) = -2
   ELSEIF CCR(I) = 2
      LET CSCORE(I) = -1
   ELSE
      LET CSCORE(I) = 0
   ENDIF
# Find the log likelihood statistic for the computer ratings

IF (CCR(I) = 1)
   LET CL(I) = CLP(I)
ELSEIF (CCR(I) = 2)
   LET CL(I) = CMP(I)
ELSE
   LET CL(I) = CHP(I)
ENDIF
ENDDO

LET CASCORE = ABSOLUTE(CSCORE)

LET STAT = SUM(CSCORE)
LET ASTAT = SUM(CASCORE)

LET CDIFF = CCR - CHR

LET CLL = LOGE(CL)
LET LL = SUM(CL)
LET ZSTAT = (LL - ELL)/SQRT(VLL)

# Print the statistics for the computer ratings
PRINT STAT ASTAT ZSTAT

ENDMACRO
10. Appendix 5. Response Comparison Matrices

In the table below, the diagonal where the human and computer agree is lined with zeros. Where the distance between the predictions is positive, the expert system is predicting a higher outbreak risk than the human expert. Where the distance between the predictions is negative, the human is predicting a higher outbreak risk than the computer. Considering the sign of the distance will show these tendencies and allow for generalizations about the bias of the expert system versus the human experts. The absolute value and distance squared tests will ignore the sign and show how the expert system performs without regard to which direction the differences occur.

TABLE 10.1 DETAIL OF COMPARISON FORMAT EXAMPLE

<table>
<thead>
<tr>
<th>Pest Name</th>
<th>Expert</th>
<th>H</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
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</tbody>
</table>
### TABLE 10.2 DETAIL OF COMPARISON FOR INSECTS

<table>
<thead>
<tr>
<th></th>
<th>Expert</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Armyworm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>2</td>
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</tr>
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<td></td>
<td></td>
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<td>HF</td>
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<td></td>
</tr>
<tr>
<td>System</td>
<td>H</td>
<td>M</td>
</tr>
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<td>4</td>
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</tr>
<tr>
<td>Aphids</td>
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<td></td>
</tr>
<tr>
<td>System</td>
<td>H</td>
<td>M</td>
</tr>
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<td>M</td>
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<td></td>
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<td>0</td>
</tr>
<tr>
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<tr>
<td></td>
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</tbody>
</table>

### TABLE 10.3 DETAIL OF COMPARISON FOR WEEDS

<table>
<thead>
<tr>
<th></th>
<th>Expert</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Ryegrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>3</td>
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<tr>
<td></td>
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<td>7</td>
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</tr>
<tr>
<td>WABL</td>
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</tr>
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<td>3</td>
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</tbody>
</table>
### TABLE 10.4 DETAIL OF COMPARISON FOR DISEASES

<table>
<thead>
<tr>
<th>Disease</th>
<th>Expert</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. mildew</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
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<td>0</td>
</tr>
<tr>
<td>M</td>
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<td>12</td>
</tr>
<tr>
<td>L</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Leaf rust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
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<tr>
<td>M</td>
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<td>6</td>
</tr>
<tr>
<td>L</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leaf/glume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
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<td>2</td>
</tr>
<tr>
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<td>24</td>
</tr>
<tr>
<td>L</td>
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<tr>
<td>Tan spot</td>
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<td></td>
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<td>Expert</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>L</td>
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<td>0</td>
</tr>
<tr>
<td>Loose smut</td>
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<td></td>
</tr>
<tr>
<td>Expert</td>
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<td>L</td>
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<tr>
<td>Take all</td>
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</tr>
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<td>Expert</td>
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</tr>
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</tr>
<tr>
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<td>0</td>
<td>3</td>
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<td>13</td>
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<tr>
<td>L</td>
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<td>1</td>
</tr>
</tbody>
</table>
11. Vita

Name          Peter Lane Warren

Birthplace    Bryn Mawr, Pennsylvania, August 4 or 5, 1960

Education     B.A., Mathematics, University of Richmond, Virginia 1982
                Conestoga Senior High School, Berwyn, Pennsylvania 1978

                Through Whole-farm Planning. Paper read at the Fourth National
                Conference on Pesticides, at Blacksburg, Virginia.

Presentations Virginia IPM Expert for Wheat. Presented at the Entomological Society of
                America annual meeting in Dallas, Texas, 1994.