Integrated Pest Management System Using Fuzzy Expert System

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ABSTRACT

Knowledge and information related to all aspects of crop-pest system are the foundations on which modern pest management decisions are based. The transfer of research and extension information to farmers plays the key role in the adoption of integrated Pest Management (IPM). FuzzyXPest is proposed to provide information to the farmers and researchers through the Internet using fuzzy expert system. Since rice is the main staple food of the Malaysian and Kedah is known as 'rice bowl' Malaysia, therefore this study focuses on the pest's activity in the rice fields. In FuzzyXPest, the type of pest that causes damage to the rice plant is determined by the expert system. Fuzzy Logic approach is then used to forecast the pest activity level that will determine the damages caused by the pest. As knowledge involved in determining the pest activity level is imperfect, fuzzy logic is used to cater for the uncertainty of information. The system has been verified by Malaysia Agriculture Research and Development Institute (MARDI) entomologist and the system is confirmed to benefit the researchers at MARDI and Department of Agriculture (DOA) particularly, and the farmers at large.

Keywords

Pest Management, Fuzzy Expert, Hybrid System, Rice Management, Forecasting,

1.0 INTRODUCTION

Knowledge and information related to all aspects of crop-pest system are the foundations on which modern pest management decisions are based. IPM or Integrated Pest Management is a strategy of managing pests that is designed to meet individual's production goals in the most economically and environmentally sound manner possible using a combination of control tactics. It emphasizes appropriate decision making, information intensive and depends heavily on accurate and timely information for field implementation by practitionares (Bajwa & Kogan, 2000).

Pest management in crops is a highly challenging problem and may yield losses if it is not handled properly (Saini *et al.*, 2002). Potential losses of up to 55% before harvest have been estimated, but these estimates often represent the worst case or highest levels of loss. Hence, there is a need of different technologies as well as awareness programs for effective, economical, environment friendly control of pests (Singh, 1990). The appropriate and optimal combination of control measures are required for cost effective and environment friendly control of pests (Atwal & Dhaliwal, 1997).

Due to the imperfect, vague and uncertainty involved in pest activity and damage level in rice fields, it is a difficult to measure the symptom occurrences with simply yes or no, or absence and presence notation. However, the existing expert system allows the user to answer the set of questions using the rigid crisp values (Saini, *et al.*, 2002). In crops management, it is important to estimate the damage that has been affected by pests since the degree of damage will determine the activity of pests (Atwal & Dhaliwal, 1997). Therefore, there is a need of a forecasting tool that can predict the level of pest activity so that early treatments can be applied to crops before the damage becomes worst.

Within the proliferation of internet usability, there is much effort to bring the agricultural community online in Malaysia. Focus on the Malaysian Agricultural sector was renewed following the Malaysia economic crisis in 1998 (Shariffaden, 2000). Malaysian Ministry of Agriculture has introduced the Third National Agricultura l Policy 1998-2010 (NAP3). NAP3 (1999) identified several issues and challenges to help tackle the problem of foreign food dependency. It is expected that information technology will play an important role in the acquisition and dissemination of new knowledge and technologies to motivate the involvement of youth in the agricultural sector (Deraman & Bahar, 2000).

Consequently, a new technological solution is needed to work in parallel with the government efforts to help educate and inform the farmers and smallholders.

The implementation of IPM principles and the practices in Malaysia was a gradual yet continual process. To date, the IPM approach has created measurable impacts in the various crops in Malaysia. It can be said that development and promotion of IPM rests mainly with governmental agencies like MARDI.

Pest prognosis known as FUzzyXPest is used to forecast the level of pest activity in rice fields and provide explanation facilities. The system enables the users, particularly the farmers and the MARDI representatives to forecast the cpest activity level in the rice field. It also attempts to identify the kind of rice pest that attacked crops by giving the symptoms occurred on the plant. This allows the farmers and MARDI representatives to provide the early treatment's solution before the pest activities become worst. In addition, all the information and knowledge about the pests, measurement treatment control and prevention steps will be managed in the specific knowledge base. As a result, this system allows the users (farmers, MARDI and others) to share knowledge and expertise in the area of rice crops. This system would infer a decision on the kind of pest and level of activity through the Internet. For study and reference purposes, MARDI has been chosen as case study to develop this system. This institution is one of the research institutions that contribute much in the agriculture area in this region.

2.0 HYBRID INTELLIGENT SYSTEM

Hybrid systems composed of Artificial Intelligence (AI) approaches have shown quite remarkable results in diagnosis (Herrmann, 1995). A fuzzy expert system is an expert system that uses fuzzy logic instead of Boolean logic and a collection of membership functions and rules that are used to reason about data. Unlike conventional expert systems, fuzzy expert systems are oriented toward numerical processing. This expert system is extended to incorporate explicit handling of imprecision in the input data and uncertainty in the embedded knowledge. The system formed the basis of the fuzzy expert system. The existent crisp rule set was used to derive the initial fuzzy rule set, and to guide the initial choice of location of membership function for each fuzzy term (Garibaldi *et al.*, 1999).

In contrast with conventional AI techniques which only deal with precision and uncertainty, the guiding principle of hybrid systems is to exploit the tolerance for imprecision, uncertainty, low solution cost, robustness, partial truth to achieve tractability, and better rapport with reality (Zadeh, 1998). In integrating hybrid approach, the complexity of its design and development increased (Watanabe *et al.*, 1994). However, although the theoretical properties of fuzzy systems have been extensively investigated, the implementation of a fuzzy expert system in practice involves a great deal of pragmatic choices. These include considerations for the type of inference methodology, rule set and fuzzy operators to determine an appropriate fuzzy model of the expertise for a particular application. Maner & Joyce (1997) have built a hybrid weather prediction system that obtained simple weather prediction rules from experts and weather almanacs, and implemented these rules in system using a fuzzy logic rule base. Sujitjorn *et al.* (1994) and Murtha (1995) separately built systems to predict fog at an airport. Hadjimichael *et al.* (1996) and Kuciauskas *et al.* (1998) together built a fuzzy system, called MEDEX, for forecasting gale force winds in the Mediterranean.

The fuzzy rule base approach to expert systems is explained by Zimmerman (1991). Kosko (1997) refers to the rule base as a "fuzzy associative memory" and describes the process of rule resolution as firing all rules partially and in parallel and take a balanced average. Following Zadeh's *principle of incompatibility*, information obtained at production system level is interpreted at society level in linguistic terms. The integrated fuzzy expert system explicitly represented both imprecision in the input data and uncertainty in the interpretive knowledge base.

Fuzzy logic lets expert system performs optimally with uncertain and unambiguous data and knowledge. With a fuzzy logic framework, one can efficiently implement linguistically expressed rules derived from expert (Hansen, 1997). Many research and development have been successfully made with this integration. Fuzzy expert-system architecture for image classification was proposed by Moraes (1998). Sugianto (1999) pointed out that the fuzzy set theory has been known to be an effective approach to cope with uncertainty or inexact statement. Such feature is useful, especially when formulated within an expert system. The hybrid can deal with fuzzy factors in load forecasting. Fuzzy ES is very effective in improving hourly load forecast accuracy. More than that it can improved accuracy using fuzzy rule-based approach. Romahi and Shen (2000) developed an evolving rule based expert system for financial forecasting.

Within the proliferation uses of Internet nowadays, there is a need to make information available every time and everywhere to be accessed by everybody. The need for web based decision support and expert systems has been felt worldwide as they are capable to provide comprehensive and up-to-date information and consultation in interactive and user-friendly manner (Coop, 2001; Grimson *et al.*, 2001). In applying Internet based applications to community development, the use of local content and culture compatibility has been very much emphasized (Baharudin, 2000; Karim, 2000). It is an essence to design the user interface that accommodates both farmer in the field and researcher (expert) in the laboratory.

As knowledge involved in IPM is imperfect and fuzzy logic has been successfully used for approximate reasoning in such cases, its application becomes mandatory to manage the uncertainty in the expert system (Zadeh, 1983). The development of an expert system involves the construction of a problem specific knowledge base by acquiring knowledge from experts or documented sources (Turban & Aronson, 2001). In recent years, research and development of the expert system fields of agriculture domain have been paid much attention by many countries (Saini *et al.*, 2002; Saini *et al.*, 1998; Saini *et al.*, 1997; Kasabov, 2003). The difficulty of problems confronting farmers like yield loses, soil erosion, diminishing market prices from international competition, increasing chemical pesticides costs and pest resistance and economic barriers hindering adoption of farming strategies necessitates that they become expert managers of all aspects of their farming operations.

The expert system has been developed with an objective to provide IPM decision support to the farmers through the Internet (Saini *et al.*, 2000). Pasqual & Mansfield (1988) developed an expert system prototype for identification and control of insect-pests. SOYBUG ES was developed by Beck *et al.* (1989) for insect pest management, which is meant for soybean crops grown in the US. Batchelor *et al.*, (1989) developed an expert simulation system SMARTSOY for insect pest management. SMARTSOY incorporated soybean crop growth model SOYGRO in its knowledge base. A PC based SOYPEST ES was developed for application to the Indian conditions and standard ES design (Saini *et al.*, 1997; Saini *et al.*, 1998).

3.0 FuzzyXteem SYSTEM

The development of FuzzyXPest was based on the combination of two branches of AI, known as expert system and fuzzy logic. FuzzyXPest system is a web based application that runs online and enables the users, particularly the farmers and the MARDI representative to determine the type of pest that causes damage as well as to forecast the pest activity level in the rice field.

The general architecture of the system that has been developed is illustrated in Fig. 1

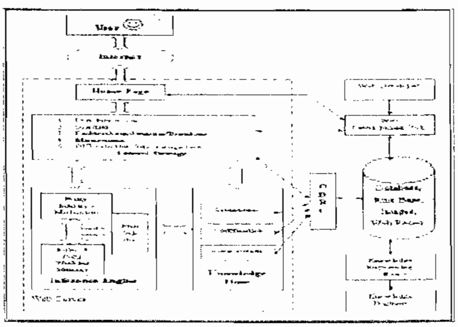


Figure 1: General architecture of FuzzyXPest System

Based on the research, pest outbreaks may yield high losses in crop production. The more damages the pest made, then the more losses will have. Since rice is the main staple food of the Malaysian and Kedah is known as 'rice bowl' Malaysia, therefore this study focuses on the pest's activity in the rice fields. Consequently, early warning system is needed to reduce the damages caused by the pests in the fields. MARDI has provides expert required for the acquisition of knowledge and pests in rice fields has been chosen as the domain of this project. Based on the research, only one attribute is used to determine the level of pest activity. In this study, the system explores the usage of other attributes to determine the level of activity. Fuzzy logic has been decided to be incorporated into the expert system as well to enhance the process of dealing with uncertainty in rules processing. Knowledge acquisition involves the process of getting and gathering information from human expert in a particular area, which is then put into the computer. In present work, knowledge has been obtained from numerous different sources such as published literature, human specialists, users and existing models. The preliminary study about the pest and its damages to the plant was conducted by reviewing and extracting knowledge from literature reference. The information gathered was converted into a form that can be processed by the computer using cognitive inference map. Published literature consists of books, pest management guides, research papers, surveys and reports, pesticides databases and news letters (Atwal & Dhaliwal, 1997; Saini, *et al.*, 1997; SOPA, 1998) provides secondary information for this project. Subsequently, an interview session has been arranged with MARDI researcher officer and entomologist expert to get detailed information and knowledge. From the observation, there is no contradiction between the knowledge from documented sources and expert because human expert refers to the same knowledge. Instead of the frequency of pest occurrence has changed. Information that has been collected are interpreted and represented to map with the system's requirement. Knowledge representation is used to illustrate the information that has been analyzed using Inference Network, Cognitive Map and Flow Chart that will make it easy to refer when developing the system. Rule base representation was also constructed where data is represented in the form of IF<antecedent> THEN <consequent> rules. The linguistic variables defined for the In fuzzification phase, FuzzyXPest variables are listed in Table 1.

Table 1: Linguistic variables

Input	Linguistic Variable
Number Of Pest	(few, many, too_many)
Size of pest	(small, medium, big)
Damages to the plant	(low, medium, high)

Fuzzy inference rule base is the controller part of the system, and is based on truth table logic. The rule base is a collection of rules related to the fuzzy sets, the input variables, and the output variables. The fuzzy inference can be implemented in two ways using the if-then statements only or directly using Fuzzy Associative Memory (FAM). The if-then implementation is same as executed in expert system except it involves the linguistic variables. Rules are simplified in fuzzy associative memory (FAM) tables to make the system easier to evaluate each set of rules. FAM is constructed by two inputs and produced one output at each inference stage. This single inference structure is shown as Fig 2. Therefore if more than one attribute of input involved then hierarchical inference structure is needed.

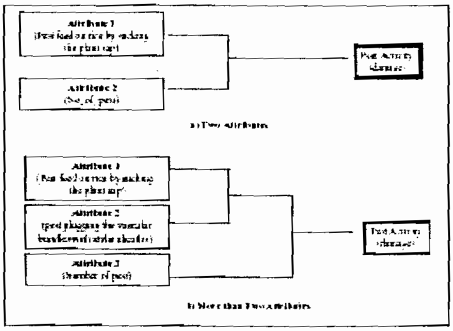


Figure 2: Single inference and Hierarchical Inference Structure

The inference process involves hierarchical decision making if more than two attributes are considered. Cordon (2002) presents a new more flexible KB structure that allows users to improve the accuracy of linguistic models without losing their interpretability: the Hierarchical Knowledge Base, which is composed of a set of layers. This results in one fuzzy subset to be assigned to each output variable for each rule. For this system, examples of the fuzzy rules constructed are listed as follows:

If attribute_1 is low and attribute_2 is few then pest_activity is low
If attribute_1 is low and attribute_2 is many then pest_activity is low
If attribute_1 is low and attribute_2 is too_many then pest_activity is medium
If attribute_1 is medium and attribute_2 is few then pest_activity is low

Defuzzification or decomposition involves finding a value that best represents the information contained in the fuzzy set. There are a number of Defuzzification methods such as Centre of Area (COA), Centre of Sums (COS) and Mean of Maxima (MOM). In MyPEST, COA method has been chosen where the crisp value u^* is taken to be the geometrical centre of the output fuzzy value $\mu_{out}(u)$, where $\mu_{out}(u)$ is formed by taking the union of all the contributions of rules whose degree of fulfillment is greater than 0 as shown in Equation (1).

$$u^* = \frac{\sum_{i=1}^{N} u_i * \mu_{OUT}(u_i)}{\sum_{i=1}^{N} \mu_{OUT}(u_i)} \quad (1)$$

4.0 RESULTS

MyPEST system is a web based application that runs online and enables the users, particularly the farmers and the MARDI representative to determine the type of pest that causes damage as well as to forecast the pest activity level in the rice field. The pest activity prognosis started by collecting information from user through system user interface. The process is divided into two phases, namely Pest Identification and Damage Forecasting.

4.1 *Pest Identification*

Several related question will be displayed and the users have to answer the questions using user input form such as slider bar, checkbox or pull down menu. To test the functionality of the knowledge base constructed with the expert system program that has been developed, a snapshot of FuzzyXPest system is shown in Fig. 3. Questions pertaining to pest's stage is first displayed on the screen.

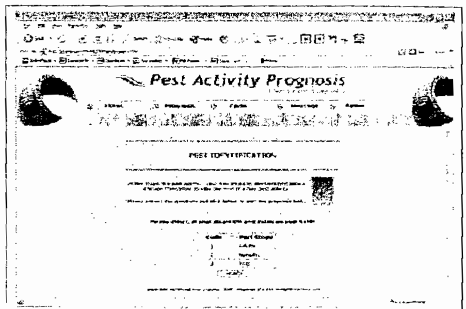


Figure 3: MyPEST User Interface for Pest Identification

In this phase, system will ask several general and specific questions to the user in order to identify the name of active pest in the rice fields. The question is related with the appearance and signs of pest such as colour, shape and its stage.

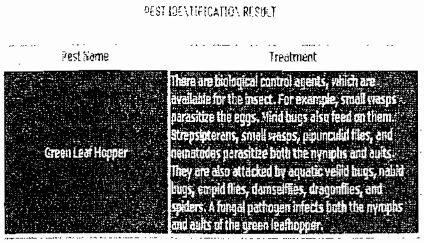
No.	Question	Answer	Why Ask?
1	Is adult in appearance of slender and green?	Yes	WHY
2	Is there a large butterflies with patterns of eye spots on the wings?	No	WHY
3	Is adult color brownish black with yellowish brown body?	No	WHY
4	Is there any borers observed at the plants?	No	WHY
5	Is there any bugs with slender and brown green appearance?	No	WHY

No.	Question	Answer	Why Ask?
1	Is adult's head rounded or pointed with or without black bands?	Yes	WHY
2	Can you find a pair of black spots that is either present or absent on the forewings?	Yes	WHY

Figure 4: Questions for Pest Identification

The information gathered is then used by the system to infer the conclusion.

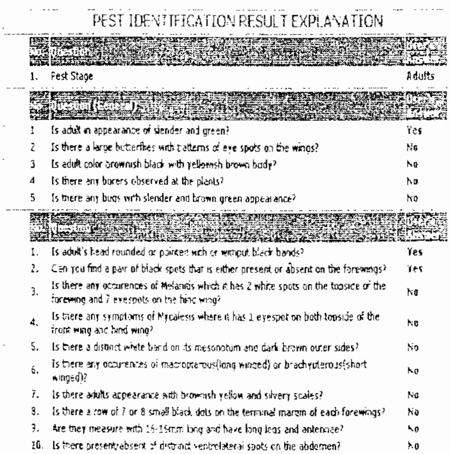
With reference to Fig. 3, user has given answers to the related questions and system will invoke the knowledge base to find the conclusion based on the given answer. Based on the user's answer, the identified pest is known as 'Green Leaf Hopper' and appropriate treatment solution is given. Fig. 4 displays the result for Pest Identification phase while Fig. 5 shows the explanation facility.



PEST IDENTIFICATION RESULT

Pest Name	Treatment
Green Leaf Hopper	There are biological control agents, which are available for the insect. For example, small wasps parasitize the eggs. Mirid bugs also feed on them. Strepsipterans, small wasps, pipunculid flies, and nematodes parasitize both the nymphs and aults. They are also attacked by aquatic veliid bugs, nabid bugs, empid flies, damselflies, dragonflies, and spiders. A fungal pathogen infects both the nymphs and aults of the green leafhopper.

Figure 4: Pest Identification's Result



PEST IDENTIFICATION RESULT EXPLANATION

1.	Pest Stage	Adults
1	Is adult in appearance of slender and green?	Yes
2	Is there a large butterflies with patterns of eye spots on the wings?	No
3	Is adult color brownish black with yellowish brown body?	No
4	Is there any borers observed at the plants?	No
5	Is there any bugs with slender and brown green appearance?	No
1.	Is adult's head rounded or pointed with or without black bands?	Yes
2.	Can you find a pair of black spots that is either present or absent on the forewings?	Yes
3.	Is there any occurences of Melanitis which it has 2 white spots on the topside of the forewing and 7 eyespots on the hind wing?	No
4.	Is there any symptoms of Mycalesis where it has 1 eyespot on both topside of the front wing and hind wing?	No
5.	Is there a distinct white band on its mesonotum and dark brown outer sides?	No
6.	Is there any occurences of macropterous(long winged) or brachypterous(short winged)?	No
7.	Is there adults appearance with brownish yellow and silvery scales?	No
8.	Is there a row of 7 or 8 small black dots on the terminal margin of each forewings?	No
9.	Are they measure with 16-15mm long and have long legs and antennae?	No
10.	Is there present/absent of distinct ventrolateral spots on the abdomen?	No

Figure 5: Pest Identification's Explanation

4.2 *Damage Forecasting*

The occurences of pest in rice field and crops production may affect the field yields. Pest management is needed where, losses are much higher, resulting in to complete damage. These pests attack the crop from the time of sowing through to harvest and beyond, often causing significant economic losses. Therefore a forecasting system is intend to facilitates the warning system so farmers can make early treatment to avoid high losses resulting from complete damage.

After the first level output are successfully generated from pest identification phase, the next level of pest activity forecasting asked only related questions to the pest identified. Output from this second level is the level of pest activity and represented in terms of percentage of (0.0 to 1.0).

In the Damage Forecasting phase, the Fuzzification will be invoked where the real value given by user will be transformed into linguistic labels of *low*, *medium* and *high*. While, for number of pest, it has also three linguistic labels: *few*, *many* and *too_many*.

For signs of damage to the plants, the number of signs depends on the pest identified. Each pest commonly has different signs of damages. Table 2 shows the linguistic variables for damage forecasting module.

Table 2: Liguistic variables for Damage Forecasting Module

Input	Linguistic Variable
Number Of Pest	(few, many, too_many)
Size of pest	(small, medium, big)
Damages to the plant	(low, medium, high)

The linguistic variables used for output variable (level of pest activity) are *low*, *medium* and *high*. The output produced at this stage is converted into real value through Defuzzification phase. Commonly, the crisp value used is using the simple rigid form that is either *yes* or *no* values. However, the damage system does not always hundred percent (100%) guarantees the identification of the pests. The damage occurs may be at early stage and involves 25% and so forth. Furthermore, partial truth values of symptoms supporting the existence of pests that may strengthen the confidence in pest identification.

Fuzzy logic approach was introduced to deal with the incomplete or imprecise data. In these cases facts are not exactly '*yes*' or '*no*' and such facts have to be suitably structured and represented for their use in the knowledge base rules. Such fuzzy rules have been represented as given below.

IF crop stem bores visible are 'high'
THEN Pest stem fly is 'highly active'

The damage level is ranged from 0.1 to 1.0 which also matches to the commonsense and user perception. Later, these values of the level of percentage damage perception are internally converted into rule membership values (0.0 to 1.0).

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If more than one attributes are considered in forecasting the level of pest activity, hierarchical fuzzy inference structure will be invoked. The process is the same as single inference structure except that the inference process is divided into several stages.

For illustration purposes, only two attributes are used and executed using single inference structure. The information used for generating the first test case is shown in Table

Table 3: Test Case

Attributes	Value
1. Does pest feed on rice by sucking the plant sap	0.3
2. How many numbers of pests occur in the paddy plot?	14

From the user interface, a user needs to select the appropriate signs of damages that occur on his fields by ticking the check box to determine the occurrences of the damages and later slides the slider bar to indicate the value of damages that has been affected by pest (see Fig. 6).

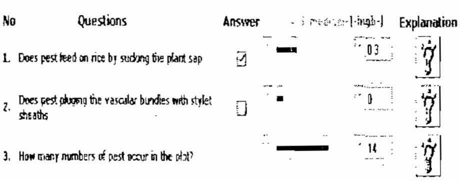

Figure 6: Consultation Interface

If two attributes are considered for predicting the pest level activity, single fuzzy inference structure will be chosen for forecasting computation (see Fig. 7).

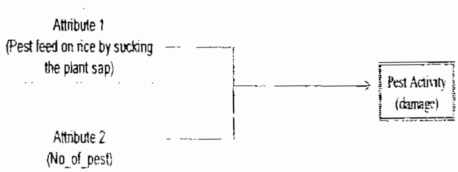

Figure 7: Inference Structure with Two Attributes

In fuzzy inference stage, Fuzzy Associative Memory (FAM) was constructed using AND operator. Therefore the minimum value from the two inputs will be considered as confidence value for fuzzy output variable. The value of μ_i is taken from the FAM table while value of μ_{out} is calculated using Equation (1) yields 0.47.

The results inferred by FuzzyXPest are the identified pest and the level of pest activity in the rice fields as illustrated in Fig 8. In addition, the treatment solution is also provided so that early treatment can be applied before the pest activities become worst. The information and knowledge about the pests, measurement of treatment control and prevention steps is managed in the specific knowledge base. As a result, the proposed system allows the users (farmers, MARDI and others) to share knowledge and expertise in the area of rice crops.

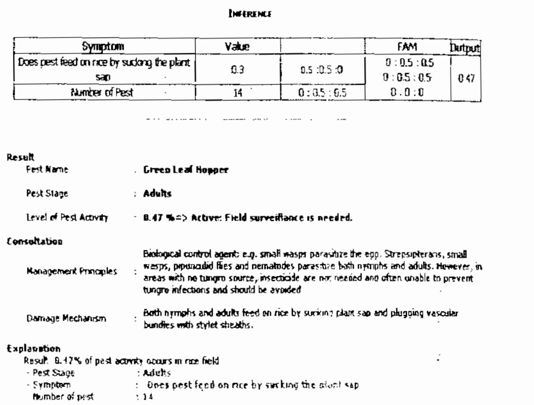

Figure 8: Test Case Inference Result

Based on the current practice on determining the pest activity forecasting only involves one attributes that is the number of pest. Therefore singleton function was involved where the decision is either normal or critical. On the other hand, the rest of forecasting lies on the expert knowledge. It is also assumed that the farmers knew the type of pest exists on the fields. In this study, the forecasting process using more than one attributes was explored. From the findings, if more than one attributes involved, the less rigid 3-dimensional decision graph was produced. The identification for the type of pest is also involved in the first phase of this system which is followed by the forecasting activity based on the identified pest. For testing purposes, MARDI representative was involved to verify the correct information coded and the correct result evaluated from FuzzyXPest. Although fuzzy logic eases the mapping problem, more programming effort was involved. To this end, fuzzy technique has definitely eases the mapping process. As a result it produces more meaningful information to the user as well as improving the efficiency of handling uncertainty.

5.0 CONCLUSION

This study focuses on the software development using hybrid AI technology and the employment of fuzzy expert system in agriculture domain typically in Malaysia. Therefore it emphasize on data acquisition and mapping of uncertainty into fuzzy values, which consists of labels and confidence values. This involves the determination of membership function graph that requires the knowledge from agriculture organization representative. This mapping process is very crucial in this study since if incorrect membership function graph was chosen, the final value yields from the fuzzy logic system is also incorrect. FuzzyXPest system has been verified by MARDI entomologist and the system is confirmed to benefit the researchers at MARDI and DOA particularly, and the farmers at large. FuzzyXPest offers computerized fuzzy expert system in dealing with uncertainty information in a way to identify the kind of pests attack on the rice plant derived from the symptoms given by the farmers. The system helps the user by managing the consultation session in order to forecast the pest activity. A set of questions will be asked through graphical user interface and helps user diagnose their given symptom to infer such a conclusion. The consultation performed by the expert system also involved fuzzy logic when dealing with the natural and uncertainty data. The project can be a beginning to the development of many other fuzzy expert systems in any other domains. This system can be further enhanced by applying agent in order to increase explanation facilities. For the forecasting tasks, if more historical data can be captured, it is beneficial to integrate neural network and fuzzy logic

For this reason and based on work that has been carried out by Saini, *et al.* (2002) for Web Based Fuzzy Expert System for Integrated Pest Management in Soybean (SOYPEST), this study explores the prediction of pest activity based on a few selected attributes.

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