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A Fuzzy Delphi based Inference System for Detecting and Controlling Rice Weeds

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Abstract

In this research, the purpose was to design a fuzzy expert system based on fuzzy delphi method to detect and control the rice weed. The statistical population was elites and experts with regard to the science, experience and field of activity; 15 experts were selected as the sample. Two questionnaires were used to design the desired fuzzy expert: i) Fuzzy Delphi Technique Weed Detection Questionnaire, ii) Delphi Technique Weed Control Questionnaire. The design of the desired expert system was done with MATLAB software and the fuzzy logic tool box. That is, after obtaining an appropriate range of factors, through attributing the fuzzy trapezoidal membership functions to these ranges and generating the input functions, designing the rule base of this system and combining the output results of each factor, a system was designed whose input was the weed factor and the output was scores assigned to weeds. MATLAB guide was also used to design the graphical user interface. Then, for validation the designed system was tested. The answers of system and individual expert were then analyzed using paired t-test. Root Mean Square Error and Middle Absolute Value Deviation tests were used to calculate the system errors. The results were 0.12 and 0.01, respectively. This indicates that the designed fuzzy expert system has sufficient accuracy. Finally, given that all but two of the examined rules are the same as the diagnosis of an individual expert, then in 94% of the cases, the diagnosis of the system is the same as the diagnosis of an individual expert.

Keywords: Fuzzy Inference System, Fuzzy Delphi, Rice Weed, Expert System.

1 Introduction

Rice is one of the most important cereals and the staple food of over half the world's population. According to the reports about 40% of the initial calories of the world's population are provided by this plant (Bienven, 2012). About 90% of the world's rice is produced and consumed in Asia (FAO, 2014). In Iran, after the wheat, rice is the most important crop and its cultivated area is

approximately 530 thousand hectares (Rajabiān et al. 2018). Since this plant is one of the most important food crops in the world, its increasing yield can reduce the pressure on the world food production (Yu et al., 2010). Weeds are the most important factors limiting the yield in the rice production (Weerakoon et al., 2011), which leads in reducing the quantity and quality of the rice yield (Shultana et al., 2011). According to the reports, the lack of weeds' control can damage up to 90% of the rice crop (Mahzari, Omrāni and Bāghestāni, 2014). Weeds reduce the yield of the rice using the water and food and occupying part of the arable land, and they decrease its economic and nutritional value. Therefore, if they are not controlled in a timely, accurate and complete manner, they would occupy the paddy fields very quickly and they would destroy the rice (Esmā'ily kenāri et al. 2016).

Today, due to the complex problems in the agriculture and the low level of the people's literacy in the rural and agricultural society, people are forced to make their own agricultural decisions without having the sufficient knowledge. Therefore, it is tried to help the farmers to make effective and timely decisions through the expert systems. In fact, the expert systems have emerged and expanded to address the problems and limitations such as the lack of the professionals, the access problems, and the limited scope of their knowledge. The expert system is a branch of the artificial intelligence that has been proposed since the 1980s and it has quickly found a variety of applications in the decision making at different fields (Bonissone, 1983). An expert agricultural system is based on the knowledge that can be used to deal with issues such as the nutrient disorders, plant pathology and finding a suitable solution to correct the diseased plants (Khalil Moghadam and Shivandi, 2009).

The expert systems are designed to make the skills of the professionals available to the non-professionals. These programs simulate the pattern of the human thinking and practice. One of the advantages of using an expert system is its ability to reduce the information that users need to process. Other advantages include lowering the staff costs, increasing the productivity and the continuous operation. The fuzzy expert system allows for the selection of the nonlinear relationships among the criteria (inputs) and considering the selected options, in addition to the fact that the verbal variables can be numbered and analyzed. Some of the expert systems implemented in the agricultural sector are as follows:

The Soybean Diagnostic Expert System (Michalski et al, 1983), which makes decisions using two types of rules. These rules include the rules of the knowledge of the diagnostic experts, and the rules that have been adopted through the inductive learning of several hundred cases of the disease.

The COMAX cotton crop management expert system (Lemmon, 1986), for the management of the cotton crop production, which can predict the crop growth and its yield against the external variables such as the weather variables, the soil physical factors, the soil fertility, and the damages caused by the plant pests.

The UNU-AES expert system (Warkentin et al, 1990), using the inclusion of the climate, social and economic data, and improving the counseling advices could promote the cultivation in the

more diverse geographical and environmental conditions and it could address the other agricultural methods.

The ET expert system (Mohan & Arumugam, 1995), which is an advanced expert system for selecting the appropriate method of estimating the evaporation and transpiration, subject to the South Indian climatic conditions.

The weed identification system (Schulthess et al, 1996) is a rule-based system and it has a text that contains a large number of the botanical terms. In this system, the general hierarchical classification is used. To minimize the use of the technical terms, the text descriptions are replaced with the images.

In their study entitled "presenting a fuzzy decision making support system for improving the crop productivity and the efficient use of the fertilizers," Prabakaran et al. (2018) aimed at improving the crop productivity with the minimal consumption of the fertilizer through the fuzzy decision making support system. The results showed the success of the system.

Sabzi et al. (2018) implemented a fast and accurate expert system to identify the causes of weeds in potato crops using the metaheuristic algorithm. The experimental results showed that the proposed system has had a detection accuracy of 98.36%. The proposed method in this study is to use the system for the other important agricultural products at the different geographical and climatic conditions. Review of studies also shows that the various applications of the expert system have been approved and is citable with high accuracy including:

In a study, Ergun hatir (2020) determined the weathering classification of the stone cultural heritage through the analytic hierarchy process and the fuzzy inference system. Hāmedān et al. (2020) presented a fuzzy expert system for predicting the chronic kidney disease. Hosseini Galezan et al. (2020) evaluated the rainbow trout breeding status using the fuzzy inference system; Troussas et al. (2019) designed an intelligent adaptive fuzzy-based inference system for computer-assisted language learning. Vema, Sudheer, & Ghaubey (2019) used the fuzzy inference system to evaluate the suitability of the site of the water harvesting structures at the rainfed regions. In their article, Mahmoom Gonbadi, Kātebi & Donyāvi (2019) designed a two-stage fuzzy expert system to prioritize the customer needs. In all of the above-mentioned cases, the results of the system's evaluation and validation showed the high accuracy and sensitivity and the success of the system in the studied subject matter.

Given the fact that the weeds are the agricultural problems that cause damage and reduce the agricultural yields; therefore, it is necessary to use the methods that are not time-consuming and costly, lead to faster detection of weeds, and provide a way to prevent or control them. Many expert systems are presented in the form of images that are rule-based to identify the weeds. Also, they have a text that contains a large number of the botanical terms. In these systems, the general hierarchical classification has been used and to minimize the use of technical terms, the text description has been replaced by the images (Hill et al, 2014). However, about the topic of the present study, the fuzzy expert system has not been extensively designed. Therefore, considering the importance of the rice and maintaining its quality by controlling and preventing the weeds, the

present study aims to present a model based on the fuzzy expert system to diagnose and control the rice weeds. So, the objectives of the study are as follows: to study and identify the factors influential on the detection of the rice weeds, to investigate and identify the factors influential on the controlling the rice weeds, to design the rules influential on the fuzzy inference expert system, and to evaluate the expert system implemented by the fuzzy Delphi method. After obtaining the acceptable range of the factors using the fuzzy inference system, by assigning the trapezoidal membership function to these ranges, producing the input functions and designing the rule base of this system, through summing the output results of each factor, a system was designed that its input is the weed factor and its output is the scores assigned to the weeds. The MATLAB guide has also been used to design the graphical user interface.

2 The structure of the article

In this research, first the generalities and definition of the main variables of the research and the review of the related literature is presented. Then the research method and how to design a knowledge-based using the fuzzy Delphi method, as well as the graphical user interface with MATLAB software has been explained in detail. The results of the problems and the stages of obtaining the knowledge are presented in the form of images, two-dimensional and three-dimensional diagrams, and tables. Finally, the results obtained from the research findings are described.

3 Research Method

3.1 Factors influential on the detection and controlling the weed

Weed is a plant that grows unintentionally in the fields and gardens. It is an unwanted guest for the main cultivation that drastically reduces the quantity and quality and, consequently the economic value of the crop and it increases the production costs, while disrupting the crop operations. The term 'weed' is used in contrast to the plants that the farmers cultivate. Among the weeds, there are many plants that have edible or medicinal use, but because they grow unintentionally, they are not man-made, and they are considered a competitor to the cultivated crops, their loss far outweighs their benefit for the crop (Sādāty & Ebtāli, 1999).

Wheat is said to be a weed in the barley field, i.e., despite the value of wheat, it is considered as weed because it is grown into the field that its cultivation was not intended by the farmer. The farm is like a vast table prepared by a farmer to feed and cultivate his intended plants; but weeds get there in a variety of ways, consuming the owner's food and make him be starved and weak. In general, any plant that has grown unnecessarily is a weed.

In addition to being unwanted, a weed also has other characteristics, such as the ability to produce a lot of seeds and, as a result, large populations, the ability to quickly stabilize its population in earth, and the ability to retain the germination power of the buried seeds for a long time; their wide adaptability for propagation in a variety of situations; having reproductive

vegetative organs; and the ability to quickly occupy the land prepared by the farmer for cultivating and producing his own needs.

The weed classification is done based on the growing season, the duration of the growth and type of the plant, the appearance (morphology), the type of the growing site, to be native or migratory, the type of its damage to the crop, and the plant physiology of the weed.

Since the weeds are considered as one of the complementary and inseparable components of the agricultural ecosystems, so recognizing the characteristics and the spatial and temporal distribution of the biodiversity components of the agricultural ecosystems in order to protect and optimal removal of them is necessary at all levels (Kouchaki, Nasiri Mahallāti & Khiābāni, 2004).

The species composition of the weed communities is influenced by the seasonal changes, the crop cycles, and the long-term environmental fluctuations (such as the soil erosion and the climate change). The type of management such as the plowing method, the selection of the crop species, the method of the weed control and the nutrition process affect the natural colonial processes of the plant communities and the destruction patterns (Matinzāde, Alimorādi & Bahāri Kāshāni, 2012). The results of the researches have shown that the population composition of the weeds varies according to the type of the crop operation and the cultivating system at the different years (Douglas et al., 1993; Gabriel et al., 2006).

Given the fact that the weed population is influenced and changed by the managerial factors, including the nitrogen and phosphorus consumption (Mohammaddoost et al., 2005), the pesticide consumption (Li and Qiang, 2009), and the herbicides (Kuchaki, Nasiri Mahallāti and Khiābāni, 1994), it seems that the structure and function of the ecosystems would be different under the different administrations. The population composition of the weeds changes under the influence of the amount of the fertilizers as well as the type of the fertilizer composition. So, it is expected that the prevalence of certain weeds would be obvious in these ecosystems; as in the common ecosystems, under the conditions of nitrogen uptake, the population of the narrow-leaved weeds increased, but the use of phosphorus and potassium led to the superiority of the wide-leaved weeds (Mohammaddoost, Bāghestāni, & Mikhailovic, 2005).

As a result, various factors can provide the context for the weed growth. Through identifying these factors, it becomes possible to make a better decision to prevent and control them. Researchers have introduced some factors in the various studies. Through integrating them, six main factors were identified, which are shown in the table 1.

Table 1 Factors influential on the weed growth

	Indices	Researchers
1	Planting area	Minābāshi Moeini et al, (2010); Ya'ghoubi et al, (2010); Ya'ghoubi, (2018); Hazrati, Ya'ghoubi, & Hazrati, (2019)

2	Climate	Minābāshi Moeini et al, (2010); Ya'ghoubi et al, (2010); Kouchaki, Nasiri Mahallāti, & Khiābāni (2014); Mousavi Toghāni et al, (2017); Sa'di & Sa'eedipour et al, (2018); Mijāni et al, (2018); Ya'ghoubi et al., 66 (2018); Sabzi, Abbāspour-Gilānde, & García-Mateos, (2018)
3	Planting time	Asghari, Mohammad Sharifi, & Alizāde (2004), Bāzoobandi et al., (2010), Ya'ghoubi et al. (2010), Sabzi Abbāspour-Gilānde, & García-Mateos (2018)
4	Type of soil	Asghari Mohammad Sharifi, & Alizāde (2004), Ramezāni (2010), Khākzād et al. (2015), Ya'ghoubi et al. (2018)
5	Type of Planting	Asghari, Mohammad Sharifi, & Alizāde (2004), Minābāshi Moeini et al. (2010), Montazeri, Fallāh, & Kholdnoosh (2014), Jalili et al. (2017), Rajabiān et al. (2017), Hazrati Ya'ghoubi, & Hazrati (2018), Sabzi, Abbāspour-Gilānde, & García-Mateos, (2018).
6	Type of Fertilizer	Asghari, Mohammad Sharifi, & Alizāde (2004), Minābāshi Moeini et al. (2010), Khākzād & Valiolāhpour (2015), Mousavi Toghāni et al. (2017), Jalili & Ganj Ābādi (2017), Rajabiān et al. (2017), Ya'ghoubi et al. (2018)

3.2 Fuzzy Expert system

There are several definitions for the expert system, but here one definition is presented: The expert system is a computer-based interactive decision making tool that uses the facts and knowledge acquired from the experts to solve the problems on the difficult decision making (Chen et al., 2012).

The expert systems actually model the knowledge and reasoning of an individual expert. The individual expert's knowledge is a very specific knowledge on a problem that encompasses the facts, concepts, and relationships. Besides, the expert's reasoning is in fact the processing that he or she does on the information around a problem and knowledge to reach a conclusion. A good expert system could simulate the processes that specialists could, including designing, planning, interpreting, summarizing, generalizing, controlling, and proposing. Basically, an expert system consists of a knowledge base, the inference engine, rule setting, and the user interface. Moreover, the working memory is required to run an expert system (Basciftci & İncekara, 2011; Chang & Tseng, 2008; Babalik & Guler, 2007). There are facts at the knowledge base that have been already known. The inference engine provides an appropriate answer to the user's question through the knowledge available in the knowledge base (Basciftci & İncekara, 2011; Keleş, Keleş, & Yavuz, 2011). Significant importance of the expert systems is the availability of the knowledge and experience of an individual expert at any time and place. One of the goals of the expert systems is to improve the human-machine relationships in problem solving (Osugwu, Charles, & Okafor Eric, 2010).

There are several ways to gain knowledge from an individual expert:

- Brainstorming method: This method is used to generate many ideas on the alternative methods to solve the decision making problems.
- Knowledge Engineering Delphi Method: This method tries to create agreement among the individual experts to solve the problems
- The technique of the nominal group: The members of the group modify their ideas by studying each other's ideas and then the best idea would be selected.
- Fuzzy Delphi Method: A way to reach a consensus on the experts' opinions in which the experts present their opinions as the qualitative variables (Dalkey and Helmer, 1963).

Experts usually present the least and most possible amount of opinions. Then, the mean of the experts' opinion (the presented numbers) and the disagreement of each expert is calculated from the mean of the sum. This information is then sent to the experts to get the new opinions. Afterward, each individual expert would present a new opinion or correct his previous opinion based on the information obtained from the previous step. This process will continue until the mean of the fuzzy numbers becomes sufficiently stable. In this research, the fuzzy Delphi method has been used.

The expert system has two characteristics:

1. Frequent interaction with the user: An expert system collects data from the users and it provides the final results based on these data (Chen et al., 2012).
2. Independent and dynamic knowledge base: The major difference of an expert system from the old programs is that the knowledge is independent from the program flow. Knowledge engineer can create, modify or delete the content of the knowledge base to complement the knowledge. The content of the knowledge base could be updated without the need to recompile and redeploy the software (Ibid).

The basis of the expert system is that using the program, the facts could be given to the system and the specialized counselling could be taken (Bascitci & İncekara, 2011). Based on the purpose of the present study, the proposed expert system was designed, and its general outline has been shown in the fig. 1.

Fig. 1 The Proposed Expert System

For each of the variables a specific membership function was defined. To detect the weeds of *Echinochloa crus-galli*, *Cyperus* and *Scirpus*, 6 main factor were considered which had been answered in the expert questionnaire; including the regions, type of climate, time of planting, type of planting, the effect of the type of the use of the fertilizer, the type of the soil and the parameters of each one. Due to the limitations of the paper, an example of the input and output function related to the time of planting of *Echinochloa crus-galli* weed has been presented below.

Fig. 2 The display of the input membership function related to the parameter of the appropriate time of planting for detecting *Echinochloa crus-galli* weed

Fig. 3 The display of the output membership function related to the parameters of the time of planting for detecting *Echinochloa crus-galli* weed

In the designed system, the MATLAB software guide has been used to create a graphical user interface. The guide is a set of tools that allows the designer to simply create a graphical interface aimed at increasing the interaction of the fuzzy inference system with the user.

The user interface in the fuzzy inference system first get the factors influential on the detection of weed from the user, sends the signals to the system, then the system makes the inference and presents its diagnosis as the output to the user interface. The system output is an input for the designed user interface; it captures the detected weeds and shows the proposed controlling method accordingly.

In this system, the elites consist of the rice weed experts (the faculty members of the department of the agriculture and agricultural engineers).

In the expert system of the rice weed detection and control, the users could be the students and graduates in this field and the agricultural engineers.

3.3 Knowledge base designation

In the present study, the designation of the fuzzy expert system for detecting and controlling the rice weeds has been studied. The statistical population of the respondents consisted of the elites and the experts in terms of the science and experience and their activity in the relevant field (faculty members of the department of agriculture and agricultural engineers). Also, 15 experts were selected as a sample. The demographic information consisted of the age, level of education and job experience of the elites. The results are as follows: among the total samples, the highest number, i.e., 0.87% of the respondents were in the age group of above 40 years. Also, 0.27% of the respondents had master degree and 0.73% of them hold PhD. And 0.80% of them had job experience of 20 years or more.

Two questionnaires were used to design the fuzzy expert system for detecting and controlling the weeds:

- A) The weed detecting questionnaire with fuzzy Delphi technique
- B) The weed controlling questionnaire with Delphi technique

The format of the questionnaires on detecting and controlling the rice weeds are different from each other. The use of the variables with definite values makes it difficult for the experts to comment. Therefore, it is clear that the qualitative variables give more freedom to the experts. Given the fuzzy nature of the detecting signals, the use of the qualitative variables such as "low", "medium" and "high" would partially solve the above-mentioned problems. At any phase of the fuzzy Delphi method, in the questionnaire on the signals, the three spectra are mapped into a numerical spectrum from one to ten to calculate the mean of the experts' answers. In this way, the membership function of the linguistic variables is created. The general figure of the membership functions has been specified below.

In this system, the trapezoidal functions (Fig. 4.a) have been used as input function to detect the rice weeds and the triangular functions (Fig. 4.b) have been used to analyze the outputs. The triangular and trapezoidal fuzzy numbers shown as below:

Fig. 4 Fuzzy functions of proposed inference system

(1) Trapezoidal fuzzy number

$$A \triangleq \mu_A(x) = \begin{cases} \frac{x - a_1}{b_1 - a_1} & \text{for } a_1 \leq x \leq b_1 \\ 1 & \text{for } b_1 \leq x \leq b_2 \\ \frac{x - a_2}{b_2 - a_2} & \text{for } b_2 \leq x \leq a_2 \\ 0 & \text{otherwise} \end{cases}$$

(2) The triangular fuzzy number

$$A \triangleq \mu_A(x) = \begin{cases} \frac{x - a_1}{a_M - a_1} & \text{for } a_1 \leq x \leq a_M \\ \frac{x - a_1}{a_M - a_1} & \text{for } a_m \leq x \leq a_2 \\ 0 & \text{otherwise} \end{cases}$$

For each variable in proposed system, a specific membership function has been defined.

The individuals' comments are not the same for the qualitative variables such as high or low. Since the experts have different characteristics, they have different mentalities. If the options are answered based on the different mentalities, the analysis of the variables would be worthless. However, after defining the range of the qualitative variables, the experts would answer the questions with the same mentality. Therefore, the qualitative variables are defined as the trapezoidal fuzzy numbers:

Low = (0, 0, 2, 4)

Medium= (3, 4, 6, 7)

High= (6, 8, 10, 10)

Due to the definite nature of controlling the rice weeds, the options in the relevant questionnaire are yes or no. The mean value of each factor in detecting the relevant weed is calculated according to the Equation 3 (Cheng et al., 2002):

(3)

$$A^{(i)} = (a_1^i, a_2^i, a_3^i, a_4^i), \quad i = 1, 2, 3, \dots, n$$

Designing the intended expert system was done with the MATLAB software and its fuzzy logic toolbox. After computing the acceptable range of the factors, assigning the trapezoidal fuzzy membership functions to these ranges, generating the input functions and designing the base of the rules of this system with MATLAB software, through aggregation of the output results of each factor, a system was designed that its input was the weed and its output was the scores assigned to the weeds.

The proposed system's knowledge base is a fuzzy knowledge base that is responsible for supporting the factors influential on the existence and detection of the weeds. The knowledge is

stored at the knowledge base of the system as the rules. The reason for this choice is the closeness of the nature of the identified knowledge with the format of the rules. With regard to the inference method at the knowledge base of the system, the type of the fuzzy inference must be specified to complete the fuzzy system. In this system, the relationship among Mamdani inference, the maximal aggregation operator, Yi maximum, the minimum requirement and the defuzzification of the center of gravity have been used. At the knowledge base, the relation <IF <FP1> THEN <FP2> was interpreted as the fuzzy relation

$$[\mu_{FP1}(x), \mu_{FP2}(y)] \rightarrow \min[\mu_{FP1}(x), \mu_{FP2}(y)] \rightarrow \mu_{QZ}(x, y) = \max$$

with the Mamdani argument.

The working memory in this system is the rules that are activated in the system, according to the signals given to it during the inference process. Through entering more information by the user, the rules required for inference making are extracted from among them, and the system offers its own detection.

After aggregating the comments of the experts, the results were written as the rule. The "And" operator has been used for writing the rules. Considering the required conditional statement to define a rule, after analyzing the rice weed detection questionnaire based on the experts' comments, the rules have been defined, so that the system could infer based on them and it could offer the desired output that is as follows:

If (north is high) and (late is high) and (mild is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (north is high) and (late is high) and (warm is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (south is high) and (late is high) and (warm is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (south is high) and (late is high) and (mild is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (east is high) and (late is high) and (mild is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (east is high) and (late is high) and (warm is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (west is high) and (late is high) and (warm is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (west is high) and (late is high) and (mild is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (center is high) and (late is high) and (mild is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (center is high) and (late is high) and (warm is high) and (clay is high) and (direct is high) and (nitrogen is high) then (echinochloacrusgalli is high) (1)

If (proper is medium) and (sand is medium) and (transplanting is medium) and (phosphor.potassium is medium) then (echinochloacrusgalli is medium) (1)

If (early is low) and (cold is low) then (echinochloacrusgalli is low) (1)

If (proper is medium) and (loamy is medium) and (transplanting is medium) and (phosphor.potassium is medium) then (echinochloacrusgalli is medium) (1)

If (north is high) and (late is high) and (mild is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (north is high) and (late is high) and (warm is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (south is high) and (late is high) and (warm is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (south is high) and (late is high) and (mild is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (center is high) and (late is high) and (mild is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (center is high) and (late is high) and (warm is high) and (loamy is high) and (direct is high) and (nitrogen is high) then (cyperusrotunclus is high) (1)

If (west is medium) and (proper is medium) and (clay is medium) and (transplanting is medium) and (phosphor.potassium is medium) then (cyperusrotunclus is medium) (1)

If (west is medium) and (proper is medium) and (sand is medium) and (transplanting is medium) and (phosphor.potassium is medium) then (cyperusrotunclus is medium) (1)

If (east is low) and (early is low) and (cold is low) then (cyperusrotunclus is low) (1)

If (south is high) and (late is high) and (warm is high) and (sand is high) and (transplanting is high) and (phosphor.potassium is high) then (scirpus is high) (1)

If (south is high) and (late is high) and (warm is high) and (sand is high) and (transplanting is high) and (nitrogen is high) then (scirpus is high) (1)

If (south is high) and (late is high) and (mild is high) and (sand is high) and (transplanting is high) and (nitrogen is high) then (scirpus is high) (1)

If (south is high) and (late is high) and (mild is high) and (sand is high) and (transplanting is high) and (phosphor. potassium is high) then (scirpus is high) (1)

If (north is medium) and (early is medium) and (loamy is medium) and (direct is medium) then (scirpus is medium) (1)

If (north is medium) and (early is medium) and (clay is medium) and (direct is medium) then (scirpus is medium) (1)

If (center is medium) and (early is medium) and (clay is medium) and (direct is medium) then (scirpus is medium) (1)

If (center is medium) and (early is medium) and (loamy is medium) and (direct is medium) then (scirpus is medium) (1)

If (east is low) and (proper is low) and (cold is low) then (scirpus is low) (1)

If (west is low) and (proper is low) and (cold is low) then (scirpus is low) (1)

The fuzzy functions derived from the analysis of the experts' responses on detecting *Echinochloa crus-galli* weed have been offered in the figures 5, 6, and 7.

Fig. 5 The combinations of the fuzzy functions of the variables in the fuzzy rules of *Echinochloa crus-galli* weed detection and controlling system

Fig. 6 The combination of the fuzzy functions of the variables in the fuzzy rules of Cyperus weeds detection and controlling system

Fig.7 The combination of the fuzzy functions of the variables in the fuzzy rules of Scirpus weeds detection and controlling system

MATLAB software's GUIDE is a set of tools that allows the designer to easily create a graphical user interface with the aim of interacting between the fuzzy expert system and the user. The graphical user interface is a graphical marker of one or more windows. The user interface of an expert system must have high exchange power, so that the structure of the information exchange could be done in the form of a conversation between an applicant and an individual expert. Since the graphical interface must have an intelligible and predictable behavior, that is the user knows what will happen in return for performing a specific action, therefore the current user interface was set up in a way that would be presented in the form of the three- and two-dimensional charts and it would be easier to understand and also it would be shapelier. It is also possible for the user to see the amount of change in the weed abundance by changing the various parameters, and finally, the ways to control it to be shown. Fig. 5 shows the user environment of the fuzzy expert system of the rice weed detection and control.

Fig. 8 The display of the graphical user interface environment of the rice weeds detection and control of the fuzzy expert system

Below, the different parts of the user environment, shown in Fig. 8, have been explained:

- 1- FIS files are called by pressing the Load Data button
- 2- In the Type of Plat section, the type of chart is selected (two or three dimensional).

As it was explained above, the two-dimensional chart shows the relationships among the variables with the weed detection, and the three-dimensional chart shows the effect of change in the weed abundance, identified by changing each parameter□

- 3- Given the fact that a three-dimensional chart requires two axes X and Y and the type of parameters must be selected, through the selection of each parameter, in the next menu (4), its subset is selected, for example when Time is selected, the three main inputs related to the Time in the bottom menu are shown, allowing the user to select three options, i.e., late, proper or early. Or, if the Soil option is selected, the options related to the soil type in the bottom menu are shown.

In the Result section, also, the type of weed is selected, and through the selection of each weed, its image is displayed on the right side. And by pressing the button, the chart is shown (7).

5- Through the selection of the Display the Dealing Method button, the type of weed control, selected based on the opinion of the experts will be displayed in another window in the form of a chart and the percentage. Fig. 9 shows this page.

Fig. 9 The second window environment of the graphical user interface related to the rice weed control

Then, in order to validate, the designed system was tested. The answers of the system and the expert were analyzed using the paired samples t-test in the SPSS software.

Two tests, i.e., MAD and RMSE were used to calculate the errors of system. The results of these errors could be a good criterion to measure the accuracy of the expert system in detecting the disturbances. It is worth mentioning that the criterion for measuring the error in this system is comparing the results of the detection of the expert system with the results of the detection of the individual expert.

4 Findings

4.1 The mean of the experts' opinions

The questionnaire was designed based on the extracted factors and defining the linguistic variables. The experts were asked to select the amount of each of the factors and parameters in the detection of weeds as low, medium and high options. Then, the mean of the answers to the rice weed detection questionnaire was calculated by the formula 3, which has been shown in Table 2.

Table 2 The mean of experts' viewpoints on the rice weed detection questionnaire

		Echinochloa crus-galli	Cyperus rotundus	Scirpus
		The mean of the experts' opinions	The mean of the experts' opinions	The mean of the experts' opinions
the planting area	North	[6, 8, 10, 10]	[6, 8, 10, 10]	[3.6, 4.8, 6.8, 7.6]
	South	[6, 8, 10, 10]	[6, 8, 10, 10]	[6, 8, 10, 10]
	East	[6, 8, 10, 10]	[0.2, 0.3, 2.3, 4.2]	[0.2, 0.3, 2.3, 4.2]
	West	[6, 8, 10, 10]	[2.6, 3.5, 5.5, 6.6]	[0.2, 0.3, 2.3, 4.2]
	Center	[6, 8, 10, 10]	[6, 8, 10, 10]	[3.6, 4.8, 6.8, 7.6]
planting time	Proper	[2.6, 3.5, 5.5, 6.6]	[2.6, 3.5, 5.5, 6.6]	[0.2, 0.3, 2.3, 4.2]
	Early	[0.2, 0.3, 2.3, 4.2]	[0.2, 0.3, 2.3, 4.2]	[2.6, 3.5, 5.5, 6.6]
	Late	[6, 8, 10, 10]	[6, 8, 10, 10]	[6, 8, 10, 10]
Climate	Temperate	[6, 8, 10, 10]	[6, 8, 10, 10]	[6, 8, 10, 10]
	Warm	[6, 8, 10, 10]	[6, 8, 10, 10]	[6, 8, 10, 10]
	Cold	[0.2, 0.3, 1.1, 2.3]	[0.2, 0.3, 1.1, 2.3]	[0.2, 0.3, 1.1, 2.3]
type of soil	Sandy	[3.2, 4.3, 6.3, 7.2]	[3.2, 4.3, 6.3, 7.2]	[6, 8, 10, 10]
	Loam	[3.2, 4.3, 6.3, 7.2]	[6, 8, 10, 10]	[3.2, 4.3, 6.3, 7.2]
	Clay	[6, 8, 10, 10]	[3.2, 4.3, 6.3, 7.2]	[3.2, 4.3, 6.3, 7.2]
Type of planting	Treasury (transplanting)	[3.6, 4.8, 6.8, 7.6]	[3.6, 4.8, 6.8, 7.6]	[6, 8, 10, 10]
	Direct (Sowing)	[6, 8, 10, 10]	[6, 8, 10, 10]	[3.6, 4.8, 6.8, 7.6]
the effect of the type of used fertilizer	Phosphorus and potassium	[3.6, 4.8, 6.8, 7.6]	[3.2, 4.3, 6.3, 7.2]	[5.8, 7.7, 9.7, 9.8]
	With nitrogen	[6, 8, 10, 10]	[6, 8, 10, 10]	[5.8, 7.7, 9.7, 9.8]

4.3 Designing the expert system for the rice weed detection and control

4.3.1 The relationship between the input and output parameters of Echinochloa crus-galli weed

Using the Surfview command in the MATLAB's Fis environment, you can see the relationship between the output and inputs of the designed fuzzy system with the two- and three-dimensional charts.

Echinochloa crus-galli's two-dimensional chart showed that: the late planting time, the clay, the direct planting and the effect of using the nitrogen fertilizer on the agricultural land are directly related to the growth and abundance of the weed. Therefore, based on the conditions of the mentioned cases, it could be recognized that there is a high probability of Echinochloa crus-galli weed. Below is an example of the two and three-dimensional charts. Chart 1 shows the relationship between the direct planting and the weed detection:

Chart 1 The relationship between the direct planting and Echinochloa crus-galli weed detection

Fig. 10 The relationship between the early planting time and the northern planting area despite the existence of Echinochloa crus-galli weed

According to the three-dimensional chart 2, it could be said that in the northern areas of the country, where there is high abundance of Echinochloa crus-galli, with early planting, this weed would be minimized.

Cyperus rotundus two-dimensional charts showed that the late planting, the loam soil and the direct planting are directly related to the growth and abundance of weeds. Therefore, based on the conditions of the mentioned cases, it could be recognized that the possibility of the existence of Cyperus rotundus weed is high. Chart 2 shows the relationship between loam soil and Cyperus rotundus weed detection. Fig. 4 shows the relationship between loam soil and Cyperus rotundus weed detection.

Chart 2 The relationship between loam soil and Cyperus rotundus weed detection

Fig. 11 The relationship between loam soil and the type of the treasury planting despite the existence of Cyperus rotundus weed

According to the three-dimensional Fig, 11, it could be said that in the conditions of the treasury planting and the loam soil, the possibility of the existence of Cyperus rotundus weed is very high.

Scirpus's two-dimensional chart showed that the southern area, the late planting, the sandy soil and the treasury planting are directly related to the growth and abundance of the weed. Therefore, based on the conditions of the mentioned cases, it could be recognized that the probability of the existence of Scirpus weed is high. Chart 3 shows the relationship between the southern area of the country and the Scirpus weed detection.

Chart 3 The relationship between the southern area of the country and the Scirpus weed detection

Fig. 12 The relationship between the proper planting time and the transplanting planting despite the existence of Scirpus weed

Considering the three-dimensional fig. 12, it could be said that in the case of the transplanting and the proper time of the planting, the possibility of Scirpus weed would be minimized.

4.3.2 Validating the model

In order to validate the model, the accuracy of the outputs of the system was surveyed. First, the normality of the data was examined using the "Kolmogorov–Smirnov" test. If the normality of the data was confirmed, then the parametric paired comparison test would be used. Here, the normality of the data was confirmed, the paired comparison test was run and the T-test was performed on the experts' opinions. Table 3 shows the output of the paired t-test in the SPSS software.

Table 3 The results of the paired samples test

paired differences			
0.95 confidence interval			

Parameters		Mean	Standard deviation	Mean standard error	Low	High	t	df	Significance level
Pair 1	The system detection and the expert detection	0.078	0.294	0.078	-0.070	0.203	1.002	29	0.309

As it could be observed the lower limit of the confidence interval is negative and the upper limit is positive, so it could be concluded that there is no significant difference between the means. In other words, there was no significant difference between the two variables of the system detection and the expert one.

4.3.3 Calculating the system error

In order to calculate the system error, MAD and RMSE tests were used, and the results are presented in the Table 4.

Table 4 The system error measurement results

The title of exam	The obtained value
RMSE	0.12
MAD	0.01

As the numerical value of RMSE and MAD shows, the fuzzy expert system designed in this study has sufficient accuracy in replacing with an individual expert.

Finally, considering that all but the two of the examined rules are the same with the detection of an expert, it could be concluded that in 94% of the cases, the detection of the system is the same as the detection of the expert.

5 Conclusion

The dependency of the human life to the agricultural products to supply the food is undeniable. Therefore, it is important to pay attention and do research on the agriculture in order to provide human nutrition. To meet the growing need for the food security of the human society, the agricultural science requires the efforts to establish the lasting relationships with the experts, and

the expert system in the agriculture is a tool in achieving this goal. The aim of this study was to design a fuzzy expert system for detecting and controlling the rice weed.

Parameters were first identified by the theoretical studies; each of which had been dealt sporadically on a case. Then, the expert was asked to determine the accuracy of the proposed criteria and at his or her discretion, he/she may add, delete, or modify a parameter. Finally, 5 parameters were confirmed including the planting area (north, south, east, west, and the center of the country), the time of planting (proper, early and late), the climate (temperate, warm and cold), the type of soil (sand, loam and clay), type of planting (direct and treasury) and the effect of the type of the used fertilizer (phosphorus and potassium fertilizer and nitrogen fertilizer) in determining the type of the weed studied in this study (*Echinochloa crus-galli*, *Cyperus rotundus*, *Scirpus*). This became as a rule and it was approved by the experts with 94% validity.

Regarding the *Echinochloa crus-galli* weed, it was found that it is abundant in all parts of the country, with the late *planting period*, in temperate and warm climates, in clay, in direct *planting* and in the areas where the nitrogen fertilizers are used.

In the case of *Cyperus rotundus* weed, it has been identified that it is abundant in the northern, southern and central areas of the country, with the late *planting* time, in the temperate climate, in loamy soil, in direct the and in areas where nitrogen fertilizers are used.

In the case of *Scirpus* weed, it is very abundant in the southern areas of the country, with late planting, in temperate and warm climates, in sandy soil, with treasury *planting*, and in the areas where nitrogen, phosphorus and potassium fertilizers are used.

Therefore, the obtained results and rules confirmed and reinforced the results of the Minābāshi Moeini et al., (2010), Ya'ghoubi et al., (2018), Hazrati, Ya'ghoubi, & Asghari (2019) on the effect of the planting area on the abundance of the rice weed. Kouchaki, Nasiri Mahallāti, M., & Khiābāni (2014), Mousavi Toghāni et al., (2017), Sa'di & Sa'eedipour (2018), Mijāni et al., (2018), Ya'ghoubi et al., (2018), Sabzi et al., (2018) on the effectiveness of the type of the climate on the existence and abundance of the rice weed; Asghari et al., (2004), Bāzoobandi et al., (2009), Ramezāni (2009), Ya'ghoubi et al. (2009), Sabzi, Abbāspour-Gilānde, & García-Mateos (2018) on the effectiveness of the planting time and the type of soil on the existence and abundance of the rice weed; Minābāshi Mo'ini et al., (2010), Montazeri, Fallāh, & Kholdnoosh (2014), Jalili & Ganj Ābādi (2017), Rajabiān et al., (2017), Hazrati, Ya'ghoubi & Asghari (2016) on the effectiveness of the planting type on the existence and abundance of the rice weeds; and the effect of the fertilizer type on the cultivated land ((Asghari, Mohammad Sharifi, & Alizāde (2004), Minābāshi Mo'ini et al., (2010), Khākzād & Valiolāhpor (2015), Mousavi Toghāni et al., (2017), Jalili, & Ganj Ābādi (2017), Rajabiān et al., (2017), Ya'ghoubi et al., (2018)).

By distributing the weed control questionnaire among the experts, the best weed control factors for each weed were identified. Drowning, transplanting, weeding out, and the use of pesticides were unanimously chosen by the experts as the controlling method of all three weeds of *Echinochloa crus-galli*, *Cyperus rotundus* and *Scirpus*.

In addition to the above-mentioned factors, the use of the natural enemies was recognized as suitable for the *Cyperus rotundus* weed. Based on the results obtained from the experts'

viewpoints, it could be said that the best method of controlling *Echinochloa crus-galli*, *Cyperus rotundus* and *Scirpus* weeds is the integrative method.

Moreover, in the section on the explanation of the questionnaire, some of the experts discussed some points on controlling the rice weed:

- In the transplanting, the best type of controlling would be weeding out
- Observing the proper distance in rice cultivation is effective on the weeds' population
- In the rice drowning cultivation, maintaining the water height around 10 cm during the first 10-15 days of transplanting is important and necessary for the management of the rice weeds. Another point that the experts of the rice research institute indicated in the weed control questionnaire as the additional explanation was to pay attention to the prevention. In fact, they believed that the first way to control the weeds was prevention, and this was a good sign of the experts' attention that the prevention should be strengthened as much as possible so that there is no need to control. Among the prevention strategies were land leveling, irrigation management and border coverage.

Also, what can be deduced from the detection questionnaire could pave the way for controlling these weeds, as using this questionnaire, the factors most influential on the weed detection are identified. Some factors are uncontrollable; however, some factors are under the control of the farmer. They play an important role in reducing the abundance of the weeds, and with new alternatives they can minimize the existence of the weed factor.

For example, the researcher found that by changing the time and type of planting, the possibility of the existence of the weeds could be reduced; the direct planting has a great impact on the weed growth, so the farmer could control this factor by replacing it with the treasury planting method.

Given the high validity of the expert system (0.94), the results of the research indicated the success of the fuzzy expert system in detecting and controlling the rice weeds, such as the soybean disease detection expert system Michelsky et al., (1983), COMAX cotton crop management by Lemmon (1986), the advising on cultivation in the more diverse geographical and environmental conditions by UNU-AES Warkentin et al., (1990), the ET expert system for selecting the appropriate method of estimating the evaporation and transpiration, under the climatic conditions of South India by Mohan & Arumugam (1995), the weed detection system of Schulthess et al., (1996), Prabakaran, Vaithiyanathan, & Ganesan (2018) and Sabzi, Abbāspour-Gilānde, & García-Mateos (2018). So, it could be concluded that the fuzzy expert system has been approved in the various agricultural applications with a high level of accuracy.

Therefore, the fuzzy expert system has acceptable accuracy in detecting the rice weed and it was successful. The findings of the present study were in line with Ergun hatir (2020), Hāmedān et al., (2020), Hosseini Galezan et al., (2020), Troussas, ChrysaPadi & Virvou (2019), Vama, Sudheer, & Ghaubey (2019) and Mahmoom Gonbadi, Kātebi, & Donyāvi (2019). All of them emphasized on the successful performance of the fuzzy expert system in detection and they considered it as valid and usable.

In order to make the best use of the research results, it is recommended that:

- An application to be designed and written based on this finding, so that the results could be easily seen in an environment other than the MATLAB. For example, in Windows or Android environment and any widely used operating system that is easily accessible. In this way, the results could be used by everybody.
- Due to the identification of the weed detection and control methods, preventive measures could be implemented to curb the cases that are under the control of the farmer in order to achieve a decent result.

Two related topics are recommended to the eager researchers:

- 1) Investigating the present study on the detection and control of the other rice weeds
- 2) To study the other factors and variables as a predictor variable of the rice weed detection.

Compliance with Ethical Standards

We (all authors) include information regarding sources of funding, potential conflicts of interest (financial or non-financial), informed consent to ensure objectivity and transparency of research entitled ***"A Fuzzy Delphi based Inference System for Detecting and Controlling Rice Weeds"*** (Manuscript No: SOCO-D-21-00424). We certify that all accepted principles of ethical and professional conduct have been followed.

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Najmeh Fatahi: Literature review, Data Collection, FIS design, FIS implementation, Writing manuscript.

Adeleh Asemi: Problem statement, Research Methodology, FIS design, guidance of Najmeh for her duties, Editing.

Hamid Tahaei: Data Collection, interface programming, FIS testing and improvement.

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