Knowledge-Based Expert System for Control of Corn Crops

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Abstract. Information and communication technology in agriculture has emerged for the enhancement of agricultural and rural development through improved information and communication processes. In this context, this paper presents the design and development of a knowledge-based expert system to the control and monitoring of corn crop. The main objective of this work is to obtain a knowledge base from experts' information that helps to determine the factors (soil, diseases and pests) that should be considered for generating recommendations. The system provides a recommendation according to the problem detected and the attributes established. For this purpose, the system used a set of inference rules. The use of this system would allow farmers to obtain important benefits such as increasing the yield and productivity of their orchards, supporting inexperienced users in crop management, increasing quality in the decision making process, and reliable results.

Keywords: Expert systems · Inference rules · Knowledge-based system

1 Introduction

In recent years, microcomputers have become instruments that facilitate the development of systems to make decisions. The intelligent systems are the way to manage information that allows making decisions about problems of specific fields [1].

These expert systems have two main objectives: (1) obtain the criteria of the experts and make them more accessible and (2) improve the information about the control of the crop. Experts systems can be used when experts' knowledge about a specific problem is needed. In addition, this knowledge will be always available when requested. Furthermore, a criterion could be provided without the presence of an expert or the bibliographic material.

The aim of this study is to develop an expert system able to generate recommendations about the control of corn crops. The recommendations are based on rules for the control and monitoring of corn. This field was selected since, in Ecuador, corn crops are some of the main sources of the economy.

R. Valencia-García et al. (Eds.): CITI 2017, CCIS 749, pp. 84–95, 2017.
DOI: 10.1007/978-3-319-67283-0_7

Several expert systems have been developed to help farmers to make decisions on control of crops. These systems are oriented to different stages of corn growth such as soil preparation, planting or germination, vegetative growth, flowering, and fertilization, among others [2].

In Ecuador, maize agriculture is an important economic activity. According to a study conducted by the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries from the year 2000 to 2012, the production of soft corn increased by 68.43%. This result is mainly due to two reasons (1) the growing demand for this product and (2) corn has been considered as a staple food in the diet of the population. In the 2000 census was reported a production of 43 thousand tons, whereas in the 2012 survey (ESPAC-INEC) it increased to 73 thousand tons, which indicates an average annual growth rate of 6.93% [3].

For the development of the application proposed in this work, we consider a rule-based expert system able to generate recommendations. Therefore, two knowledge bases of the corn crop control domain were generated. The first one represents input and output variables. The second one represents the rules to be used [4].

In the domain of expert systems, several rules are activated for the same configuration of input parameters, and an output is generated for each one of the rules. These outputs cause a change in the knowledge thus activating other rules. This process is known as chaining rules. There are two specific chaining rules: forward and backward [5].

The rest of this paper is organized as follows. Section 2 presents a review of the literature concerning agriculture. Section 3 presents a knowledge-based expert system for control of corn crops. A case study is described in Sect. 4. Finally, our conclusions and future work are presented in Sect. 5.

2 Related Works

Maize is known in different ways depending on the country and culture. In America, it is known as "corn", "choclo", "elote", "jojoto", "sara" or "zara".

The growth of maize is classified into five stages: (1) germination and emergence, (2) initial vegetation, (3) vegetative growth, (4) flowering, and (5) grain filling and maturity [6].

The agricultural sector constantly undergoes changes with respect to the nutrients of the land due to climatic changes and other factors [7]. In this sense, it is important to identify the type of crop to plant according to the area and climate, among other factors. The technology plays an important role in identifying these aspects. For example, Antonopoulou et al. [8] proposed a support system for farmers to select alternative crops specifically maize, soybean, sorghum, rapeseed, and thistle.

The importance of the design of computer models based on rules is a mechanism to obtain a technical decision that considers the necessary conditions and parameters. For instance, Debaeke et al. [9] proposed a set of rules based on agronomic principles (density of plants).

Several works distinguish recommendation techniques into following four classes (1) collaborative-filtering, (2) demographic filtering, (3) knowledge-based filtering, and (4) content-based filtering [10]. Furthermore, there are different ways to infer knowledge stored in the system, such as decision trees, clustering, and rule-based. The last one is the method selected in this work [11].

Gordon [12] mentioned that rules can be stored and updated as needed. These rules are converted into a knowledge file rather than an information file since the rules would be used as the automated reasoning. A rule-based system consists of three components: (1) working memory, (2) the rule base, and (3) the inference engine. The rule base and working memory are data structures that the system uses, and the inference engine is the basic program. The advantage of this framework is the clear separation between data (knowledge about the domain) and control (how knowledge should be used) [13].

Sarma et al. [14] presented a logical programming approach where the system integrates a structured knowledge base that contains remedies of diseases about the rice plant. Also, this database is integrated with images related to the symptoms of the disease and an interface that contains rules-based decision-making algorithms, which are validated by experts.

On the other hand, Marwaha [15] proposed the use of knowledge-based systems based on ontologies. The authors claim that these systems help to farmers to improve efficiency, crop yield, and productivity with respect to the identification of diseases, insects or pests.

In [16], the authors propose a robust and dynamic nutrient management known as SSNM (Site-specific Nutrient Management) which aims to increase yields and optimize profits while maintaining the productivity of cropping systems.

Finally, in [17], the authors present AGRIdaksh, a tool for building online experts systems. This tool enables domain experts to build agricultural expert systems for crop management with the minimal intervention of knowledge engineers and programmers.

3 Knowledge-Based Expert System for Control of Corn Crops

3.1 Modules of the Expert System

The knowledge-based expert system proposed in this work has as purpose to guide students in the best practices of control of the maize crop from the preparation of the soil to the harvest [18]. The mobile application is composed of four modules: (1) soil preparation, (2) planting or germination, (3) vegetative growth, and (4) flowering.

Figure 1 shows a scheme of the system dependent relationships [12], and the variables needed by each module to generate the recommendations. These relationships allow organizing the structure of the rules. These rules are based on the work presented in [19].

Soil Preparation. The main variables verified at this stage are (1) texture of the land, (2) date of the crop, and (3) the place to carry out the sowing. With respect to the first one it can be sandy, clayey and loamy-loamy. The system will show the features of each kind of soil to allow user to determine the correct one. Regarding the second one, the January to May months are not suitable for the crop. Finally, in the case study, it was applied in the Coast region.

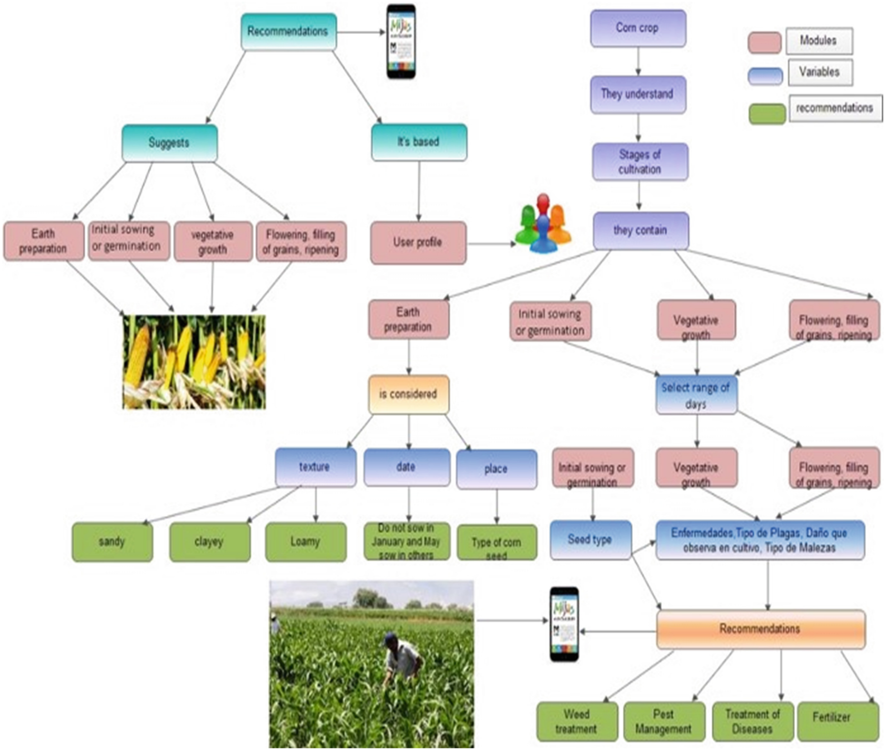

Fig. 1. Modules of the expert system for the control of corn crops.

Planting or Germination. The system at this stage requests that the user selects between the ranges from 0 to 1 (sowing period), and from 2 to 6 (germination period). In addition, the user must enter additional variables such as seed type, type of pests, type of disease, and type of weed, among others. Regarding pests, the system will provide information about different types of pests and diseases commonly presented in the seed type. The purpose of providing this information is to make the appropriate validation of the rules and give the users the corresponding recommendations. With regards to the weeds, the system will provide a set of images to allow users to identify the correct one.

Vegetative Growth. The system at this stage requests the user to choose between the range of 7 to 48 days called the period of vegetative development. Furthermore, the user must provide additional variables such as the type of pests, damage observed in the crop, type of undergrowth, among others. The purpose of providing this information is to make the appropriate validation of the rules and give the users the corresponding recommendations related to the level of pest treatment, weed treatment, and disease.

Flowering. The system at this stage requires the user to choose between the range of 49 to 52 days, 53 to 67 days, 68 to 110 days called the development period. In addition, the user must provide additional variables such as the type of pests, damage observed in the crop, type of undergrowth. The purpose of providing this information is to make the appropriate validation of the rules and give the users the corresponding recommendations related to the level of pest treatment, weed treatment, and disease.

3.2 Inference Rules of the Mobile Application

There are different ways to represent knowledge in expert systems, one of them is the rules of inference [20]. These rules play an important role in intelligent problem-solving systems. The knowledge of a human expert is represented and stored through rules of inference. Expert systems based on rules for a specific area can detect anomalies and provide indications to develop processes according to the recommendations [21].

As can be observed in Fig. 2, the input variables are required for each module. Once the rules were evaluated by the inference engine, the reasoning control technique forward chaining was used [22]. The inference engine using the forward chaining technique searches in all rules the THEN clause equals true, this value allows generating a recommendation.

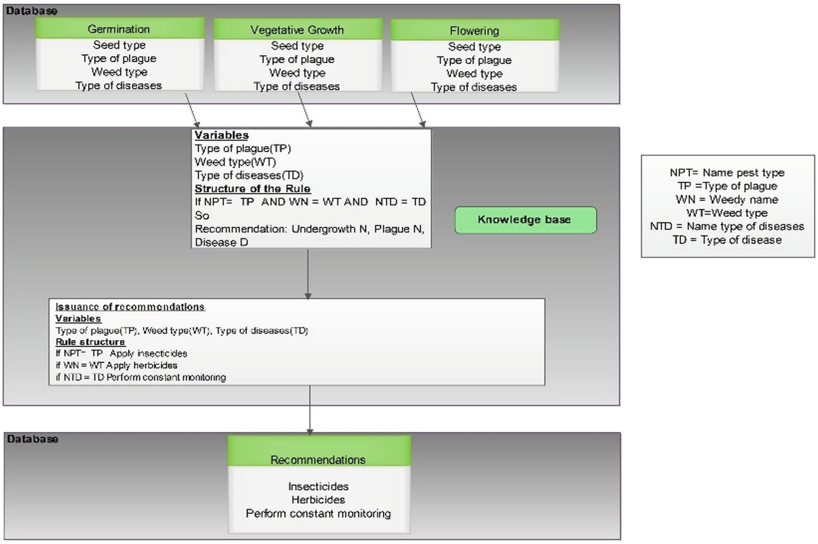

Fig. 2. Internal processing of app modules.

Table 1 shows an extract of the recommendations with respect to the different variables provided by the users according to each stage of maize cultivation.

Table 1. Recommendations for the module of vegetative growth and flowering.

Days	Seed	Pest	Undergrowth	Disease	Recommendation
2–6	Hybrid or variety	Cutting worms	jointed grass	Curvular spot	Recommendation 6, 9 and 10
7–48	Hybrid or variety	screwworm	Ipomoea	Rust	Recommendation 6, 9 and 10
49–110	Hybrid or variety	fall armyworm	Purple nutsedge	Red ribbon	Recommendation 6, 9 and 10

The description of the recommendations that the system provides for the user are the following:

- Recommendation 6.
  - Apply Insecticides.
  - Perform constant monitoring in the crop to identify damages in the crop.
  - Perform trapping to know stages and populations of the plague.
- Recommendation 7.
  - Pest detected: Diatraea spp.
  - Apply Insecticides bait.
  - Perform constant monitoring in the crop to identify damages in the crop.
  - Perform trapping to know stages and populations of the plague.
- Recommendation 8.
  - Pest detected: Spodoptera frugiperda
  - Apply Insecticides to foliage.
  - Perform constant monitoring in the crop to identify damages in the crop.
  - Perform trapping to know stages and populations of the plague.
- Recommendation 9.
  - Weed detected: Cyperus Rotundus
  - Apply herbicide.
  - The type and dose of the herbicides used will depend on the age of the crop and population of the undergrowth.
- Recommendation 10.
  - Disease detected: Spiroplasma, Phytoplasma and virus.
  - Perform constant monitoring in the crop to identify early symptoms of diseases to be able to perform an efficient control.
  - Use certified seed.
  - Use resistant hybrids.
  - Control insect vectors.

3.3 Architecture

Figure 3 shows the architecture of the mobile application presented in this paper. The storage layer is composed of the knowledge base which contains the structure of the rules and the database which stores the information to be provided to the users. The application layer is composed of an inference engine which interacts with the

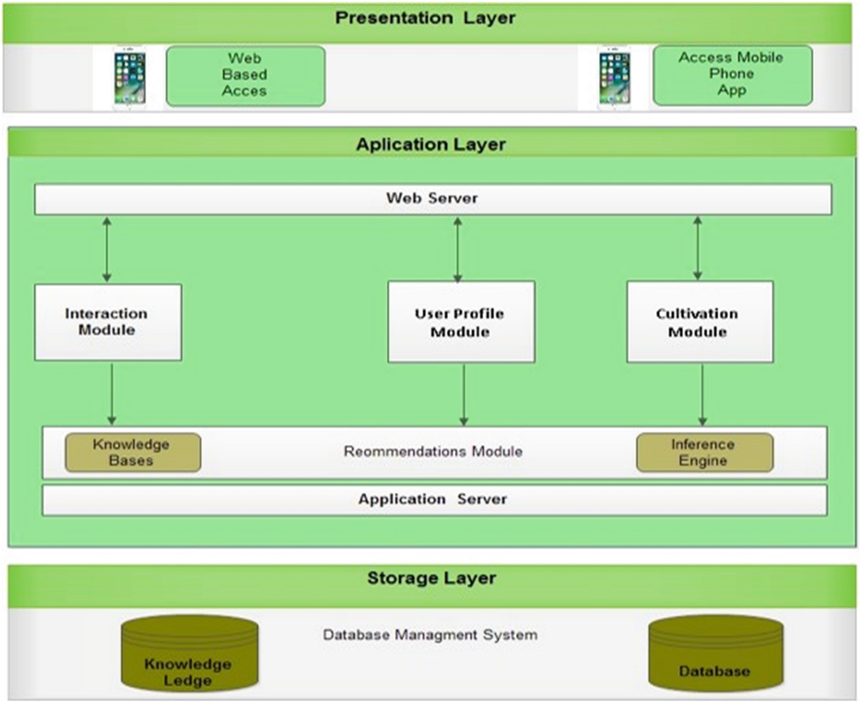

Fig. 3. Architecture of the mobile expert system

knowledge base to provide the recommendations. Finally, the presentation layer is responsible for delivering and formatting of information to the application layer for further processing or display.

4 Case Study: Mobile Application for the Control of Maize Crop

Thanks to the increasing use of the Internet in the agriculture domain, it has been possible to develop a mobile application focused on corn crops management. This application aims to be used for helping farmers to increase the yield of the crop. The present case study was carried out at the Regional Program of Teaching Naranjal of the Agrarian University of Ecuador, whose coordinates are latitude 2°40′25″ S, longitude 79°37′05″ O, and altitude of 25 m. In this place, several plots were installed to perform the different processes related to the crop management. Furthermore, to test the use of the mobile application during maize growth, the application generates a set of recommendations [23] about such agricultural processes. The recommendations provided by the application aim to help farmers to make decisions based on parameters related to each phase of the crop.

Figure 4 presents the graphical user interface of the mobile application presented in this work. To access to all functionalities provided by this application, users must perform the authentication process by using their corresponding username and password. The main interface of the applications shows a list of all phases of the crop, from which users can select one. These phases are surface preparation, planting, crop growth and flowering. Once a phase is selected, users must select the specific parameters. Finally, the system generates a set of recommendations considering the parameters selected by the users.

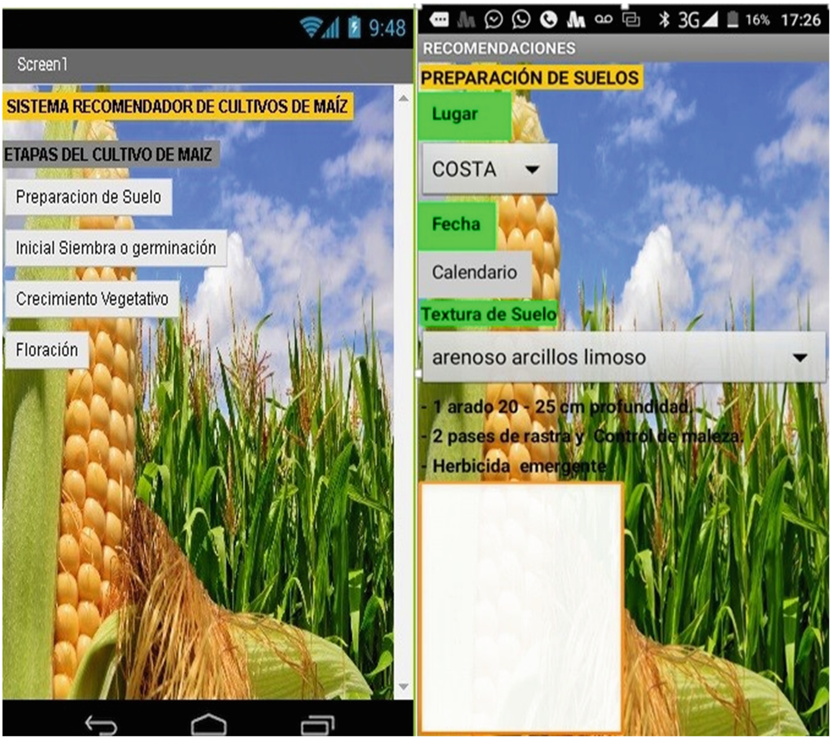

Fig. 4. Stages of corn crops. Preparation module soil with a recommendation.

4.1 Results

Once the mobile application presented in this work was used by the students from the Agricultural University of Ecuador, they were asked to answer a set of questions related to their experience using the application. Table 2 presents the questions that were used in this process.

The aspects of the system that were evaluated are: (1) quality, which refers to the objectivity of the recommendations provided by the system, (2) trust, which refers to the novelty of the recommendations, (3) utility, which refers to the reliability and effectiveness of the recommendations, and (4) satisfaction, which evaluates the users' satisfaction about the recommendations provided by the system.

Table 2. Satisfaction survey questions

Variable	Item	Question
Quality	P.1	Does the recommender system provide clear explanations of the recommendations?
Quality	P.2	Is the recommender system easy to use?
Quality	P.3	Is the system interface attractive, clear and adequate?
Trust	P.4	Did the recommendations correspond with your needs?
Trust	P.5	Were the recommendations novel and interesting?
Trust	P.6	Were the recommendations out of context?
Utility	P.7	Do you agree with the recommendations received from the system?
Utility	P.8	Are the recommendations sometimes confused?
Utility	P.9	Did the recommendations help you to improve the effective-ness in the crop?
Utility	P.10	Did the recommendations help you increasing productivity in the crop?
Satisfaction	P.11	Were the recommendations satisfactory?
Satisfaction	P.12	Would you use the system again?
Satisfaction	P.13	Would you recommend the system to farmers?

As can be seen, a total of thirteen questions were asked to the students. Some of the subjects to be evaluated through this survey are the ease of use of the application and its graphical interface. Furthermore, this survey aims to collect information about the confidence that users have about the recommendations provided by the system. The answer to the questions was based on a 4-point Likert scale where 1 indicates disagree, 2 little agree, 3 agree and 4 strongly agree.

Summarizing, the aspects that this survey aims to evaluate are the user inter-face, quality/novelty of the application, the confidence of the recommendations provided by the application, utility, and satisfaction. Table 2 presents the main subject to which the question aims to evaluate.

Table 3 shows the rating obtained by the four aspects evaluated namely, quality, confidence, utility, and satisfaction. The aspect that obtained the best results (17.67% of students agree and 57.00% of the students are strongly agreed) was the satisfaction. It means that most students have a feeling of fulfillment of de-sires and expectations about the mobile application. Regarding quality of the application, 72% of the users (30.67% - agree and 41.33% - strongly agree) think that the application is very useful for corn cultivation activities. Furthermore, the application obtained a high level of confidence about the recommendations provided by the application (15.75% - agree and 48.75 - strongly agree). With regards to the utility of the application, 64.50% of the students (15.75% - agree and 48.75% - strongly agree) think that the system provides efficient recommendations about corn crops.

The tabulation of the survey data was expressed as a central tendency (mode). The mode is the value that occurs most often in the distribution of data. The mode was used to determine the scores corresponding to each category. The mode of this survey is presented in Table 4.

Table 3. Evaluation results of the recommender system.

	Disagree	%	Little agree	%	Agree	%	Strongly agree	%	Total
Quality	1,33	0,02	1,67	0,02	30,67	0,41	41,33	0,55	75
Trust	12,67	0,17	3,00	0,04	21,67	0,29	37,67	0,50	75
Utility	7,75	0,10	2,75	0,04	15,75	0,21	48,75	0,65	75
Satisfaction	0,00	0,00	0,33	0,00	17,67	0,24	57,00	0,76	75
Average	5,43	0,07	1,93	0,02	21,44	0,28	46,18	0,61	75

Table 4. Results obtained in the user evaluation

Category	Score (mode)
Quality	4.0
Trust	4.0
Utility	4.0
Satisfaction	4.0
General	4.0

For the confidence category, the same number of scores was obtained with a value of 4. Therefore, a score of 4 was assigned to this category. This score corresponds to the arithmetic mean of the three values. This score demonstrates that the level of confidence of users correspond to strongly agree.

The scores assigned by the users who completed the survey cover a range of 1 to 4 point to express: strongly agree (4), agree (3), little agree (2) and disagree (1). Considering this scale, the scores of 1 and 2 can be considered as negative scores and the scores of 3 and 4 as positive scores.

An analysis of the results obtained by the survey shows that users have a high degree of satisfaction (4.0 points) about the application. Furthermore, these users are highly agreed (4.0 points) with the utility and quality of the recommendations provide by the system.

Regarding the confidence that the users shown about the recommendations provided by the system, it obtained a score of 4.0.

With regards to the quality, utility, and satisfaction about the application and the recommendations provided by it, the users shown to highly agree with these subjects.

A combined analysis of the scores assigned by the users to the different sub-jects places the recommendation system with an average score of 4 points, ac-cording to the histogram of mode corresponding to the general evaluation.

5 Conclusions and Future Work

The knowledge-based expert system proposed in this work was used by students from the Agricultural University of Ecuador during the whole course of cultivation. More specifically, they used this system for the control of corn crops. To store and represent the experts' knowledge, several rules were implemented. These rules allowed generating recommendations for the different phases of corn cultivation.

The interaction between rules as well as the relative independence of the different pieces of knowledge are some advantages of the rule-based approach followed in this work. In many systems, it cannot be assumed that rules do not inter-act among them, because when this interaction is ignored it could lead to unexpected results that would undermine system recommendations.

Some tasks that can be easily defined in terms of procedural representations are not very easy to define by means of rules. The rule-based approach is very useful because it provides a thorough analysis about the solution of human problems. However, there are systems where the use of rules is tedious.

The system here proposed was designed to generate recommendations oriented to the different phases of corn cultivation, using the rules. More specifically, these recommendations are oriented to students for corn cultivation and for determining the problems that affect their crops.

There are no methodologies for implementing rule-based systems. These systems are implemented based on intuition, experience, trial and errors. Our system has been implemented following the expertise and knowledge of experts on crop control and management. Furthermore, this system is based on pictures taken on crop from the Cantón Naranjal, Ecuador. Despite the features provided by our proposal, it has a main disadvantage, which refers to the fact that it is mainly oriented to corn crops management. In this sense, as future work we plan to include new types of crops in order to allow a bigger group of farmers to take advantage of this technology.

The students involved in this work are satisfied with the use of the system. Also, they consider that the system can be qualified as a tool that contributes to decision-making in the corn cultivation processes. The system here proposed represents a technological tool that allows people to learn about the monitorization of crops as well as the pests and weeds that affect them.

The inference process performed by this system is based on first-order logic, where each variable takes values within limited intervals which are defined by facts. In this sense, the authors plan to implement fuzzy sets [22]. This approach has been applied in Asthma as well as different processes in medicine. The authors think that this approach must be applied in agriculture as an efficient mechanism for the control and management of maize crops and other short-cycle and perennial crops.

The simplicity of the rules used in this system leads to the disadvantage that all they have the same level. Therefore, it is necessary to have rules at different levels, working with a hierarchy. However, this change will demand the system to be consistent with this hierarchy. It is worth mentioning that the needs of farmers can change continuously, and users have long-term information needs. Therefore, instead of providing a query, users could directly collect information from weather stations.

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