An Ontology-Based Decision Support System for the Management of Home Gardens

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Abstract. Home gardens or family gardens are the oldest cultivation systems used in the world. The home garden has different goals which gone from leisure and recreation to self-consumption, healthy production, family savings and community integration. Home garden management has become a knowledge problem since the community needs to know what vegetables can be planted as well as the activities that must be performed according to different parameters such as illumination, harvest time, irrigation time, among others. In this sense, there is a clear need for new mechanisms in which experts' knowledge are integrated to support decision making in the context of the home garden. In this work, we present a DSS focused on the management of home gardens. This system takes advantages of semantic technologies, more specifically ontologies, to model the main activities related to the home garden management such as creation, irrigation, transplanting and harvesting. The DSS proposed was evaluated in the context of medicinal plants and vegetables obtaining encouraging results.

Keywords: Home garden · Ontologies · Support system · Agriculture

1 Introduction

Home gardens or family gardens are the oldest cultivation systems used in the world. In Latin America, there is a growing interest for this kind of systems because of the boom achieved by the agroforestry systems and the efforts of many international organizations [1]. The home garden has different goals which gone from leisure and recreation to self-consumption, healthy production, family savings and community integration.

According to the latest results of poverty, inequality and labor market from INEC, in Ecuador the 28.6% of population live in urban-rural areas where they have food, social and economic problems. This value is due to the migration of people from the countryside to the city. Due to this phenomenon, the use of home garden has increased

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significantly, thus creating a new concept of agriculture known as urban agriculture. Furthermore, according to the AEISA [2], 5 out of 10 Ecuadorians prefer the production of 100% organic products.

According to the FAO [3], it is estimated that up to 15% of world's food is produced through urban agriculture and 70% of urban households in developing countries participate in agricultural activities.

In Guayaquil, people living in the marginal urban area represent the 18% of the total population. Therefore, there have been several social assistance programs by government authorities and NGOs such as ZUMAR. This last organization is focused on the generation of family gardens through the Funding Agreement between the European Union and Guayaquil government.

All home garden programs that have been created are oriented to mitigate community problems such as malnutrition, lack of family incomes and savings, as well as to enjoy organic food and establish a relationship with nature. These efforts are disappearing due to the lack of follow-up given to the orchards after these ones have been implemented. This follow-up includes the construction of orchards, community training and technical advice.

Home garden management has become a knowledge problem since the community need to know what vegetables can be planted and the activities that must be performed according to different parameters considering the place of implementation, i.e., community need to be supported from home garden construction to the harvest time. In this sense, there is a clear need for new mechanisms in which scientific knowledge, in this case, the knowledge of management of home gardens, be integrated to support agricultural decision making [4]. Examples of this kind of tools are the decision support systems (DSS) which have been widely used in agricultural processes such as precision agriculture, climate risk analysis [5], among others. Summarizing, DSSs can support people in charge of home gardens by means of experts' knowledge.

The Semantic Web has emerged as a new approach whose main goal is to provide the information with a well-defined meaning and make it understandable not only by humans but also by computers [6]. Thanks to the Semantic Web, computers can automate, integrate and reuse high-quality information from distributed data sources. One of the pillars of the Semantic Web are the ontologies, which are defined as a formal and explicit specification of a shared conceptualization [7]. Ontologies have been successfully applied in different fields such as finances [8], cloud computing [9], and question and answering systems [10], among others.

According to the above discussed, communities interested in the implementation of home gardens need to know all tasks and criteria that must be considered for the correct management of a home garden. In this work, we present a DSS focused on the management of home gardens. This system takes advantage of semantic technologies, more specifically ontologies, to model the main activities related to the home garden management such as creation, irrigation, transplanting and harvesting. This system is based on the expertise of domain experts. In this way, when users want to create a home garden, they must provide a set of parameters through which the system suggests which activities must be performed. For this purpose, the system uses the knowledge stored in the semantic repository and a rule-based engine to infer the activities and recommendations according to the parameters provided by the users.

The rest of this paper is structured as follows. Section 2 describes research works that implement the technologies involved in this work. Section 3 describes the sociodemographic features of Guayaquil as well as its planting preferences. Section 4 presents the general architecture of the system and its components. Section 5 describes a case study for evaluating the effectiveness of the proposed method. Finally, conclusions and future work are presented.

2 Related Works

Home gardens are very important for community because they improve que quality of life of citizens who own it, either economically (saving, additional income), social (human-nature relation and community relation) and food (consumption of healthy and organic vegetables) [11]. To implement home gardens in cities, it is necessary to have the knowledge for managing home gardens. An innovative way to perform this task is the use of DSS's whose main goal is to provide users with tools for improving the decision-making process, thus obtaining more informed decisions [12]. DSS's have been implemented in different areas such as medical care [13] for dosing, diagnosis, preventive care and quality assurance as well as for sharing information and decisions about patients' management. In the contexts of Big Data and Cloud computing, Haluk Demirkan and Dursun Delen [14] define a list of requirements for DSS's oriented to services. Also, they propose a conceptual framework through which opportunities and challenges of service-oriented engineering are established. In the political field, Vicki L. Sauter [15] provides several examples of DSS's used in this field. For instance, the Neighbor-to-Neighbor system that helped the Obama campaign in 2008. This system includes the names and addresses of all undecided voters and the specific topics of interest for this group of citizens. By means of this tool, it is possible to identify and convince these people to vote for Obama. In the agricultural field, there are different systems for supporting different processes. For example, the DSS Vite.Net [16] is a system composed of two main parts namely, an integrated system for real-time monitoring of the components of the vineyard, and a Web-based tool for analyzing the data collected by means of advanced modeling techniques. Furthermore, DSS has also been used in the diagnosis of plant diseases. For example, in [17] authors present an Ontology-based DSS that promotes the experts' knowledge for diagnosing plant diseases.

In the context of agriculture, ontologies are used to solve interoperability and integration problems of heterogeneous data sources [18]. Several ontological models have been developed for agricultural processes such as citrus fruit production [19]. This ontology defines three decision services: fertilization, nutrient imbalance, and irrigation/drainage. In the context of plant diseases, in [20], the authors describe an expert system that diagnoses plant diseases based on a multicriteria approach. In [21], authors present and intelligent irrigation system that considers weather conditions collected by several IoT-based devices distributed along area. In the biorefinery context [22], a DSS for assessing the sustainability of biorefinery systems. Finally, in [23], the authors propose an extensible and self-adaptive DSS for the management of heterogenous data sources.

The research works above-analyzed propose DSS -based solutions to many problems from different domains. Most of them use ontologies for representing the knowledge of experts related to disease diagnosis and citrus fruit production. However, none of them is focused on the management of home gardens and family gardens. This work aims to provide a DSS for helping non-expert people interested in owning a home garden. This system has been designed to use the experience and knowledge from experts in the creation and management of home garden. All this knowledge is formalized by means of an ontology that guides processes related to the provision of place, planting of vegetables, irrigation, transplant, and harvest, based on a set of premises provided by the users. The following sections describe in detail the design of the architecture and the functionality of each of its components.

3 Socio-Demographic Characteristics of Guayaquil and Its Planting Preferences in Organic Orchards

According to the latest Population Census conducted in 2010 [24], 2,291,158 people are living in the urban area of Guayaquil. This fact makes of Guayaquil the most populated city in Ecuador. With a territorial extension of 2,493.86 Km2, Guayaquil has an urban population density of 919 inhabitants per kilometer square, 54.4% more than its population density in 2001. This increase is mainly due to the migration of Ecuadorians from the countryside to the city. These people look for better opportunities in economically attractive cities like Guayaquil.

One of the positive aspects of this migration is that now a part of the inhabitants has acquired the knowledge about a specific activity such as agriculture. Sometimes this knowledge remains latent for its use in activities of similar characteristics such as gardening, parks, among others [25].

Considering the fact above presented, the promotion of home gardens development is an important task to be considered. Unlike commercial crops that require a large area of land and a large investment in both seeds and fertilizers for their care, a home garden does not demand a large piece of land or an expensive investment for the care of the farm since they use organic natural products.

The Provincial Council of Guayas and the M.I. Municipality of Guayaquil have focused their efforts on the development of home gardens. Even, this project has obtained very positive results which are reflected in a better nutrition of the members of the family, economic saving as they produce their own food, and a better use of the leisure time in home [25].

Regarding the preferences of people from Guayaquil to implement a home garden, there are market research that aims to know the importance that people give to the home gardens and the benefits of their use. Figure 1 shows the results obtained from a market research about planting preferences in urban homes from Guayaquil. As can be seen in Fig. 1, 9 out of 10 homes are interested in implementing an organic orchard. With respect to their planting preferences, 6 out of 10 homes prefer planting the tomato. Other vegetables that people want to plant are radish, artichoke, pepper, red onion, chamomile, and anise.

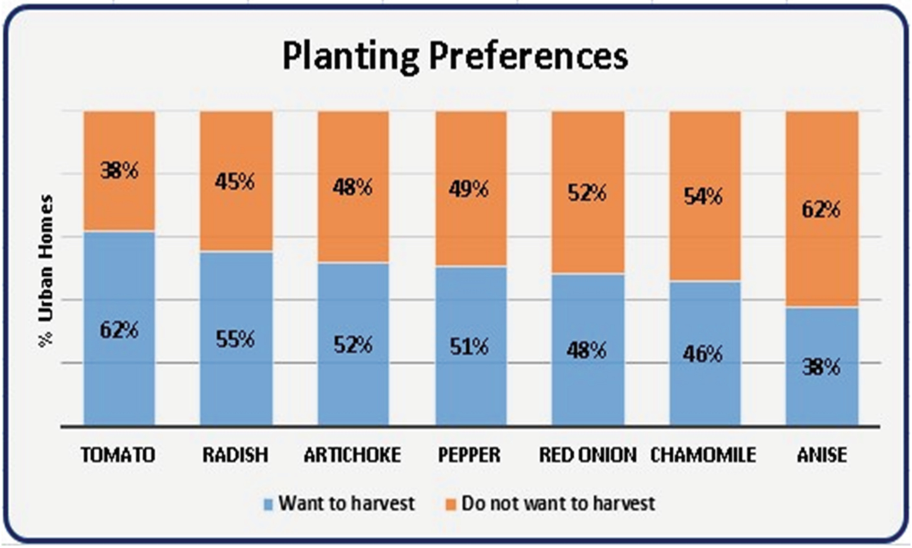

Fig. 1. Planting preferences in urban homes from Guayaquil.

Finally, it is important to emphasize the increasing availability of information technology for the benefit of the world population. In the case of Guayaquil, in 8 out of 10 homes at least one of its members has a mobile phone. On the other hand, in Guayas, 6 out of 10 people use a computer, and 6 out of 10 people have access to the Internet.

4 An Ontology-Based Decision Support System

The system proposed in this work generates recommendations about plantations in home gardens from the Coastal Region of Ecuador, based on a set of parameters provided by the user. This system is configurated for the tomato, radish, artichoke, pepper, red onion, chamomile and anise. The recommendations depend on the crop selected and the set of parameters provided. Figure 2 shows the architecture of the proposed system which consists of two main parts, a rule-based engine and the home garden ontology.

The DSS here proposed, in conjunction with the home garden ontology, aims to generate recommendations based on the experts' knowledge. In a nutshell, the system works as follows: (1) the user selects the seed to cultivate and provide a set of parameters such as quantity and space. This information is provided through a mobile application; (2) once the information has been provided, the system generates a set of recommendations based on a set of rules; (3) the system shows the user the set of recommendations which consider the soil conditions, climatic conditions, humidity, and appropriate harvest time. The next section describes the home garden ontology, which is one of the pillar of the system here proposed.

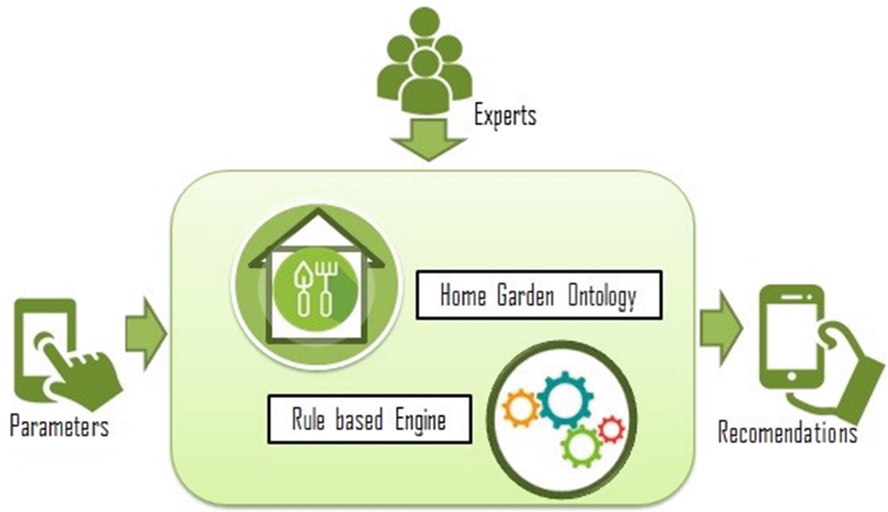

Fig. 2. Overall architecture guided by ontologies.

4.1 Home Garden Ontology

As has been mentioned, the system here proposed is based on an ontology that describes the home garden domain through concepts such as irrigation, pesticides, climatic conditions, among others. Figure 3 shows an extract of the ontology proposed in this work. This ontology has been created by using OWL and Protégé 4.3.

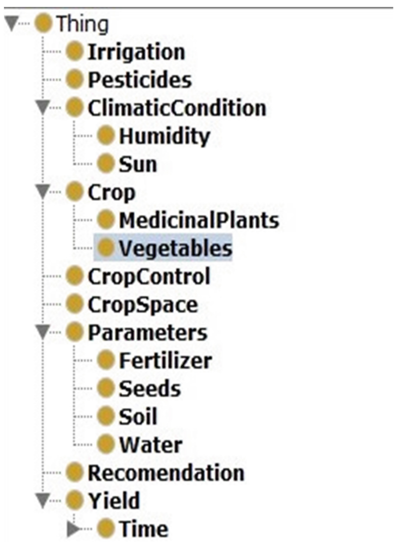

Fig. 3. Home Garden Ontology.

Types

The home garden ontology defines nine types namely, irrigation, pesticide, climatic condition, crop, crop control, crop space, parameter, recommendation and harvest time. All these types are defined as disjoint types; however, the types recommendation, climatic conditions and parameter share criteria of several entities or instances. This ontology has been created based on the cultivate preferences of a group of users. However, this ontology can evolve by including more types of crops such as vegetables, fruits and medicinal plants.

The types defined by the ontology allow classifying the preferred crops for home gardens implementation. In this way, the class *Crop* has two subtypes, *MedicinalPlant* and *Vegetables*. The first subclass represents crops such as anis and chamomile. Meanwhile, the second subclass represents crops such as tomato, radish, artichoke, pepper and onion.

Regarding the class *parameter*, it refers to those parameters provided by the user such as seed and quantity. The class *recommendation* covers all those recommendations about crop control, pesticide control, harvest time and crop recommendations. Also, it is important to consider the climatic conditions such as humidity, sun, and water, among others.

Finally, it must be remarked that the home garden ontology describes such domain based on the knowledge and expertise of domain experts, to provide user appropriate recommendations.

Properties

The home garden ontology defines a set of properties that allow the system to generate a set of recommendations about care and control crop according to the parameters provided by the user. These properties represent the existing relationship between the domain types. All types are related to the Crop class due to factors such as irrigation, pesticides, climatic conditions, crop control, crop space, parameters, recommendations and harvest time depend on the crop the user want to plant. The properties described by the home garden ontology are presented in Fig. 4.

Fig. 4. Properties of the Home Garden Ontology.

- *isParameterOf.* It defines the input parameters such as crop and quantity. For instance, for the Tomato, it must be provided the amount of seed and the area (square meter) on which will be cultivated.
- *isCropSpaceOf.* It is used to define the recommended area of cultivation according to the chosen crop. For example, the cultivation of radish or pepper requires an area of one square meter.

- *hasRecommendation*. It uses a set of relations among the types defined by the ontology since the recommendations depends on the irrigation, pesticides, climatic conditions and the way crops are controlled.

The properties above have their corresponding inverse properties that allow establishing relations among entities. In this way, the property *isParameterOf* is the inverse property of *hasParameter*, the property *isCropSpaceOf* is the inverse property of *hasCropSpace*, and *hasRecommendation* is the inverse property of *isRecommendationOf*.

Individuals

The home garden ontology defines the types MedicinalPlants and Vegetables to classify the cultivation preferences of people from the Coastal Region of Ecuador. The type MedicinalPlants groups crops such as anise and chamomile. Meanwhile, the class Vegetables groups crops such as tomato, radish, artichoke, pepper and red onion. Furthermore, climatic conditions such as humidity and sunlight have been considered by this ontology. Finally, each crop has a set of recommendations about the crops control and harvest time. These recommendations are related to the crop by means of the properties described in the previous section.

Finally, it is worth mentioning that a semantic knowledge base based on descriptive logic has two fundamental elements clearly defined: TBox (terminological axioms) which contains the schema that defines the domain through concepts, relations and constraints; and the ABox (assertions) which contains all instances of the domain.

4.2 Rule-Based Engine

The rules definition process involved the participation of domain experts who were asked to express their knowledge and experiences regarding the parameters to be considered during home garden implementation, as well as the recommendations to follow for controlling and harvesting home gardens.

The recommendations provided by the experts were analyzed according to the space and distance used to plant the seeds, the way and frequency of irrigation, the recommended doses of pesticides, crop control, the appropriate harvest time and the climatic conditions of the Coastal Region of Ecuador.

The input parameters that must be provided by the user are the product to grow, quantity of seeds to be cultivated, the space (square meters) that he/she owns for the crop, and the season (winter or summer). Based on such parameters, the system provides recommendations about the distance between seeds, harvest time, the yield to be obtained from the crop, frequency of irrigation, time of exposure to the sun and amount of nutrients to add to the crop.

Once this information was obtained, a set of inference rules were established. For this purpose, the SWRL [26] language was used. The set of rules created from the experts' knowledge are used to obtain recommendations according to the type of crop. The inference process emphasizes the type of crop (vegetables or medicinal plants) because they share some recommendation criteria.

Table 1 presents a set of recommendations provided by the system. For example, when the user provides the input parameters Tomato, as seed, and 3 m^2, as the space to be cultivated, the system generates next recommendations: a distance between seeds of 1 m, a yield of 8–10 tomatoes, and that the harvest time must be every 90 days.

Table 1. Home Garden recommendations

Input data		Recommendations		
Seed	Space	Distance between seeds	Yield	Harvest time
Tomato	3 m^2	1 m	8–10	90 days
Onion	3 m^2	1 m	4–6	Only one
Radish	3 m^2	1 m	2–3	Only one

5 Evaluation

5.1 Method

We perform an evaluation process to validate the coherence and correctness of the recommendations provided by the system. This process required the participation of 50 urban farmers from Guayaquil. These people are immersed in a program of home gardening promoted by the Municipality of Guayaquil. Table 2 shows the type of crops considered by this program. These farmers cultivated medicinal plants such as chamomile and anise, and vegetables such as tomatoes, radishes, artichokes, peppers and red onions. Each participant provided different sets of conditions and parameters concerning their home garden. Some of these parameters are the type of crop, seed quantity, area for cultivation, and climatic conditions.

Table 2. Types of plants grown by urban farmers

Plant	Total of home gardens
Medicinal plant	30
Vegetables	53
Total	83

For the purposes of this evaluation, the type of plants grown by urban farmers was divided into two main groups:

- Medicinal plants. These plants are used for health problems. They offer economic benefits since they do not need a large area and do not require a big investment. The medicinal plants considered in this evaluation were chamomile and anise.
- Vegetables. These plants are used for a balanced diet. This evaluation considers vegetables from the Coast Region of Ecuador namely tomatoes, radishes, artichokes, peppers, and red onions.

Once all sets of parameters were provided by the farmers, these were provided as input to the system proposed. Then, the DSS generates a set of recommendations for the maintenance of the home garden as well as about the harvest time and yield of the harvest. The recommendations provided by the system were compared to the maintenance tasks, harvest time and yield previously known. Finally, the results were evaluated by using the metrics of precision, recall, and their harmonic mean F-measure whose formulas are shown below.

$$recall = \frac{TP}{TP + FN} \tag{1}$$

$$precision = \frac{TP}{TP + FP} \tag{2}$$

$$F1 = 2 * \frac{precision * recall}{precision + recall} \tag{3}$$

The TP (True Positives) refers to those recommendations provided by the system that match those ones established by the experts. The FP (False Positives) are the set of recommendations obtained by the system but they do not match with those ones established by the experts. Finally, FN (False Negatives) are the set of recommendations provided by the system that were related to another type of planting, that is, those sets of recommendation that was not related to the correct plant. The F1 metric corresponds to the weighted average of the precision and recall obtained by the system. Next section discusses the results of this evaluation.

5.2 Discussion

The evaluation results obtained by the system for medicinal plants cultivation are shown in Table 3. The system obtained an average precision score of 0.7965, and average recall score of 0.9183, and an average F-measure score of 0.8474. The system obtained the best results when recommendations about illumination that need the plants are provided. Meanwhile, the aspect with the lowest precision (0.6316) is the distance that must exist between the plants cultivated.

Table 3. Evaluation results for medicinal plants

	TP	FN	FP	Precision	Recall	F-measure
Distance	12	5	7	0,631578947	0,705882353	0,666667
Irrigation time	13	2	2	0,866666667	0,866666667	0,866667
Illumination	26	0	0	1	1	1
Nutrients	15	1	2	0,882352941	0,9375	0,909091
Performance	12	0	7	0,631578947	1	0,774194
Harvest time	23	0	7	0,766666667	1	0,867925
Average				0,796474028	0,918341503	0,84742

The evaluation results obtained by the system for vegetable cultivation are shown in Table 4. In this case, the system obtained better results than with medicinal plants. More specifically, the system obtained scores of 0.8598, 0.9716 and 0.90988 for the precision, recall, and F-measure, respectively. In this context, the aspect for which better results were obtained is the irrigation time with a score of 0.9167. Meanwhile, the lowest score was obtained for the aspect of illumination with a score of 0.8301.

Table 4. Evaluation results

Plant	TP	FN	FP	Precision	Recall	F-measure
Distance	33	0	0	1	1	1
Irrigation time	44	3	4	0,916666667	0,936170213	0,926316
Illumination	44	0	9	0,830188679	1	0,907216
Nutrients	40	3	6	0,869565217	0,930232558	0,898876
Performance	26	1	7	0,787878788	0,962962963	0,866667
Harvest time	40	0	13	0,754716981	1	0,860215
Average				0,859836055	0,971560956	0,90988

The evaluation results obtained by the system are good for both medicinal plants and vegetables. In Tables 3 and 4 we can observe that there is no a big difference among the results obtained in both scenarios. We attribute these differences to two main facts: (1) some plants were cultivated in winter, and the climate in this season varies widely, hence, urban farmers make certain changes in the cultivation process; and (2) some medicinal plants and vegetables share several parameters; therefore, it was difficult to provide the specific recommendation when more than 3 parameters were the same for a medicinal plant and a vegetable.

Sometimes, urban farmers provided parameter related to the season (winter or summer), e.g., they provide the parameter rainy, very rainy or wet. These values are not considered by the system. Hence, it is necessary to extend the ontology by adding new parameters as well as jargon used in the domain of home gardens. Furthermore, it would be important to integrate a broader set of properties that allow the system to provide the correct recommendations when two or more parameters are common between different plants. Finally, it is necessary to generate more rules to improve the effectiveness of the system.

6 Conclusions and Future Work

In response to the requirements of food, leisure and social welfare in big cities, the creation of home gardens is proposed. To help this task, in this work we present a DSS that aims to provide urban farmers support for decision making. Thanks to this system, these farmers have access to experts' knowledge in the form of recommendations about the general implementation process of a home garden including harvest time and yield. In this system, ontologies and semantic reasoning play a fundamental role.

The main goal of this project is to make this type of technology accessible to urban farmers to reduce the rate of premature abandonment of their home garden project. The system here proposed obtained encouraging results with an average F-measure of 0.8787 for the cultivation of medicinal plants and vegetables.

As future work, authors plan to generate new rules and recommendations, as well as to extend the knowledge described by the ontology. Furthermore, the authors are considering the possibility of covering a new set of crops such as fruits. The ontology proposed in this work could be extended by including new seeds that can be planted in home gardens. Furthermore, it will be necessary to include information concerning their harvest time, yield and distance between seeds. For this purpose, a bigger group of experts will be involved. Also, it is important to integrate a mechanism that allows users to share information and experiences through a social network or a messaging service, thus improving the teamwork for solving specific problems. Finally, authors plan to extend the ontology by integrating the knowledge concerning control of pests and insects that affect home gardens.

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