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An ontology-based knowledge management for organic and good agricultural practice agriculture: A case study of Nakhon Pathom Province, Thailand

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Abstract

In Nakhon Pathom Province, information resources for organic and Good Agricultural Practice (GAP) agriculture are not centrally organised, difficult to find and heterogeneous. This results in it being difficult to share knowledge and making it easily accessible to relevant users. Therefore, this research proposes to use the ontology-based knowledge management approach in the agricultural domain to facilitate the integration of heterogeneous data on organic and GAP agriculture in Nakhon Pathom Province. The developed ontology is served as a backbone to facilitate common understanding and knowledge sharing regarding organic and GAP agriculture to farmers, consumers and government officials in the Nakhon Pathom Provincial Agricultural Extension Office and the District Agricultural Extension Office. In addition, the ontology and its logical reasoning mechanism can increase the efficiency of information retrieval by integrating the benefits of both keyword and concept-based search.

Keywords: organic and GAP agriculture, ontology, knowledge management

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1. Introduction

Agriculture is the main occupation of Thai people. However, conventional agriculture relies heavily on using modern chemicals in every stage of the daily practice to improve yield productivity and quality, as well as to protect agricultural products from pests and diseases [1]. These chemicals cause environmental damage by placing great strain on the soil, water and atmosphere. The loss of biodiversity is another problem resulting from conventional agriculture [2]. Recently, consumers are increasingly concerned about food safety, how food is produced, and how it is handled within the supply chain. New trends of organic farming and Good Agriculture Practices (GAP) have been widely accepted among farmers, consumers and farmer authorities in Thailand, and in many other countries. As defined by the Food and Agriculture Organisation of the United Nations (FAO), *"Organic farming is environmental friendly ecosystem management in which use of all kinds of synthetic input is eliminated"* [3]. It provides long-term benefits to people and the environment, including improved soil quality, increased biodiversity, and decreased pesticide pollution and water usage. GAP is defined as a set of principles, regulations and technical recommenddations applicable to production processing and food transport, while addressing human health care, environmental protection and the improvement of worker conditions and their families [4].

The FAO leads international efforts to defeat hunger by providing information. Two of the FAO's main activities are (i) putting information within reach; and (ii) bringing knowledge to the field [5], which are the main motivations of this research. Because organic and GAP agriculture information resources are not centrally organised and difficult to find and heterogeneous, an innovative approach to manage this knowledge to enable effective knowledge sharing, and information retrieval is critically needed. In Nakhon Pathom Province, organic farming and GAP agriculture products have become economically competitive with conventional agriculture. Several farmers have switched to use these methods due to a higher demand for organically developed food products. Consumer awareness for health, in conjunction with improved environmental consciousness, has caused rising demand for organic and GAP products. This provides farmers with an opportunity to produce for the best price markets to increase their farm profitability and improve their livelihoods. Nonetheless, there are several challenges related to knowledge management of organic and GAP agriculture knowledge which needs to be tackled. These are:

i) a lack of efficiency in managing heterogeneous data on organic and GAP agriculture in Nakhon Pathom Province (e.g. certified organic and GAP agricultural products, farmers, croplands, etc.); and

ii) a lack of efficiency in the information retrieval approach that integrates the benefits of both keyword and concept-based search.

The major contribution of this work is an innovative, comprehensive ontology-based knowledge management

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model. It is aimed to address the challenges of managing the massive and heterogeneous organic and GAP agricultural data from multiple sources in Nakhon Pathom Province. The utilisation of formal and standardised models of knowledge representation and organisation is highly recommended because they can improve knowledge sharing among relevant stakeholders (e.g. farmers, consumers, government officials), enhance the efficiency of information retrieval by integrating the benefits of both keyword and concept-based search, and enable semantic interoperability of information systems.

In this paper, related works of agriculture knowledge management ontologies have been reviewed. Then we propose our conceptual framework of organic and GAP agriculture knowledge management in the foundation of ontology to represent and manage the knowledge of organic and GAP agriculture. We then discuss the results, including the evaluation of the proposed ontology. Lastly, the conclusion and future work is presented.

2. Background and Related work

2.1 Knowledge management and ontologies

Knowledge management is the process of capturing, developing, sharing and effectively using organisational knowledge [6]. It refers to a multi-disciplined approach in achieving the organisational objective by making the best use of knowledge. A successful knowledge management system can enable people to share knowledge easily and effectively.

An ontology is a high-level formal specification of a knowledge domain. It is a formal and explicit specification of a shared conceptualisation [7]. Ontologies are increasingly seen as a key technology for enabling semantics-driven knowledge processing. They are used to provide a framework for sharing a precise meaning during communication. Various applications (e.g. knowledge management, e-business applications) benefit from semantically enriched information. Ontologies have been proven to be highly helpful for knowledge management, because they are applications for information retrieval, information systems and system modelling, and they are a better way to store and retrieve knowledge semantically [8]. Knowledge captured in ontologies is in a machine-readable and interpretable format. Machine-interpretable means that a computer or a software agent can make automated inferences about the relationships between concepts. Ontology reasoners have the potential to provide some additional functions including automatic classification and knowledge discovery.

In the knowledge management field, ontologies are used in several ways in both content and information staging as well as in content deployment. Ontologies are used as repositories to organise knowledge and information based on a shared common vocabulary. They facilitate access to and optimise knowledge retrieval. In addition, ontologies support mechanisms for communication and exchange of knowledge. They also enable the ability to reuse and do reasoning on existing knowledge.

2.2 Related work

Several works have been found to develop vocabularies and ontologies for the agricultural domain. AGROVOC [9] was developed by the FAO of the United Nations and is composed of topics relevant to agriculture, fisheries, forestry and the environment. AGROVOC was developed to standardise the indexing process to enhance the effectiveness of information searching. It is published in the Resource Description Framework (RDF) format as Linked Open Data (LOD), which contains links to many other LOD datasets in the LOD cloud. Thunkijjanukij and Kawtrakul [10] introduce the Thai Rice ontology aimed at being a knowledge base for the management of knowledge of Thai rice production research. The proposed ontology is also used to increase the efficiency of research information retrieval systems; however, it only focuses on rice production. Other agriculture products are not included in this work. Walisadeera et al. [11] developed an ontology regarded as a knowledge repository of agricultural information. The ontology includes information of the farming stages, varying from crop selection to the selling stage. It is also structured and specific to user context. Bansal and Malik [12] propose an ontology for the crop production cycle which is used as a building block to an ontology-driven Agriculture Information System framework. In this work, AGROVOC is used as a base vocabulary for the concepts defined in the ontology. Li et al [13] propose an ontology-based knowledge representation and implementation method to organise standard knowledge of crop cultivation effectively, so that the knowledge is shared and farmers can easily retrieve agricultural and practical technical information. The domain ontology and task ontology are combined to make an effective knowledge representation for the key control points and planting knowledge during the growth process.

According to the above-mentioned works, it is evident that several efforts have been put into the developments of agricultural ontologies. However, to the best of our knowledge, there is no work focusing on developing a knowledge base that integrates organic and GAP agricultural data which includes farmers, crops, croplands, location, activities and news coming from various data sources. As a consequence, in this study the ontology-based knowledge management for organic and GAP agriculture is proposed. The developed ontology is aimed at managing heterogeneous data on organic and GAP agriculture in Nakhon Pathom Province to facilitate effective knowledge sharing as well as enabling an information retrieval approach that integrates the benefits of both keyword and concept-based search.

2.3 Ontology development

There are a number of ontology development methodologies available in the literature, with each methodology having certain pros and cons. In this research, the methodology described in [14] has been chosen because of the high degree of formalism that it provides. The selected methodology has five processes detailed as follows.

2.3.1 Ontology purpose and scope

There are two main challenges related to knowledge management of organic and GAP agriculture knowledge in Nakhon Pathom Province which need to be tackled. First, a lack of efficiency in managing heterogeneous data on organic and GAP agriculture (e.g. certified organic and GAP agricultural products, farmers, land areas etc.) to enable effective knowledge sharing among farmers and government officials in Nakhon Pathom Province as well as with general consumers. Second, a lack of effective approach for information retrieval which integrates the benefits of both keyword and concept-based search on organic and GAP agriculture information within Nakhon Pathom Province.

Therefore, the proposed ontology is aimed at enabling knowledge management and knowledge sharing among relevant stakeholders. The knowledge of organic and GAP agriculture in Nakhon Pathom Province is captured with its structure and its classification scheme defined in the ontology. It is also used as a repository to organise knowledge based on a shared common vocabulary. It facilitates access to and optimise knowledge retrieval as well as to enable knowledge reuse.

2.3.2 Knowledge acquisition and conceptualisation

Knowledge acquisition and conceptualisation is an important step in developing an ontology as a knowledge-based system. In this research study, knowledge acquisition involves various activities for data collection, including focus group, interviews and data analysis of related documents. The population consists of farmers who grow organic and GAP crops, consumers and government officials in the Nakhon Pathom Provincial Agricultural Extension Office and the District Agricultural Extension Office. The sample comprises thirty people selected from the population by a purposive selection method.

Conceptualisation is a process to build a conceptual ontological model consisting of the concepts in the domain, and the relationships between those concepts. During the conceptualisation stage, concepts derived from the knowledge acquisition stage are identified. Conceptual modelling involves defining the ontological model structure, and identifying concepts and relationships. The main key concepts and their description are as follows.

- **Practice_Type** represents the types of agricultural systems. In this study it is classified into two categories, namely, Organic and GAP.
- **Crop_Land** refers to areas of land on which crops are grown.
- **Crops** represents the concept of agricultural products. They consist of four main concepts; Fruit; Grain; Vegetable; Herb. These four agricultural product concepts are twinned with their Thai translation; ผลไม้, ธัญพืช, ผัก, สมุนไพร, respectively. These English and Thai concepts are set as equivalent classes in order to enable logical reasoning.
- **Farmer** is aimed at representing farmer information which is defined in data properties including name, address and contact information.
- **Location** is defined according to its hierarchical relations, for example province, district and sub-district.
- **Activity** represents activities relevant to organic and GAP agriculture.
- **News** represents news related to organic and GAP agriculture from various resources (e.g. newspapers, government authorities' websites etc.)

Table 1 presents the relations and their inverse relations between the identified concepts.

2.3.3 Ontology integration

In this step, relevant consensual ontologies and controlled vocabularies are reused to enrich and interlink the semantic description of the ontology instance. Friend-of-a-Friend (FOAF) vocabulary [15] is used for information describing farmers and representing relationships. For example, the names of farmers are defined in the RDF/OWL triple by using *foaf:name*. Simple Knowledge Organisation System (SKOS) [16] is used to aggregate concepts/terminologies into a single concept scheme. AGROVOC [9, 17], a multilingual agricultural thesaurus, is also used to cover the terminology of subject-fields in agriculture and related domains. The use of existing domain ontologies and controlled vocabularies is to promote the re-usability factor and enhance data interoperability [18]. In addition, it can help to find semantic similarities with other similar entities defined in different repositories.

2.3.4 Implementation

The implementation of the organic and GAP agricultural ontology was made by relying on the framework created for this research on a knowledge management. The ontology was encoded using the Web Ontology Language 2.0. The ontology editor program called Protégé was used to provide classes (concepts), class hierarchy, object properties, data type properties, axioms and individuals.

The proposed ontology has 40 classes or concepts with 28 relations and 8 equivalent relations which provide reasoning on the organic and GAP agricultural knowledge. The excerpt of the ontology class hierarchy and OWL file are shown in Figure 1.

Table 1 Examples of binary relations between the concepts

Relation name	Source concept	Target concept	Inverse relation
hasPlant	Farmer	Crops	isPlantedByFarmer
hasCropLand	Farmer	Crop_Land	hasOwner
hasSynonym	Crops	Crops	hasSynonym
hasLocation	Farmer, Crop_Land	Location	isLocationOf
consistOfDistrict	Province	District	isDistrictOf
consistOfSubdistrict	District	SubDistrict	isSubDistrictOf
isNextToSubdistrict	SubDistrict	SubDistrict	isNextToSubdistrict

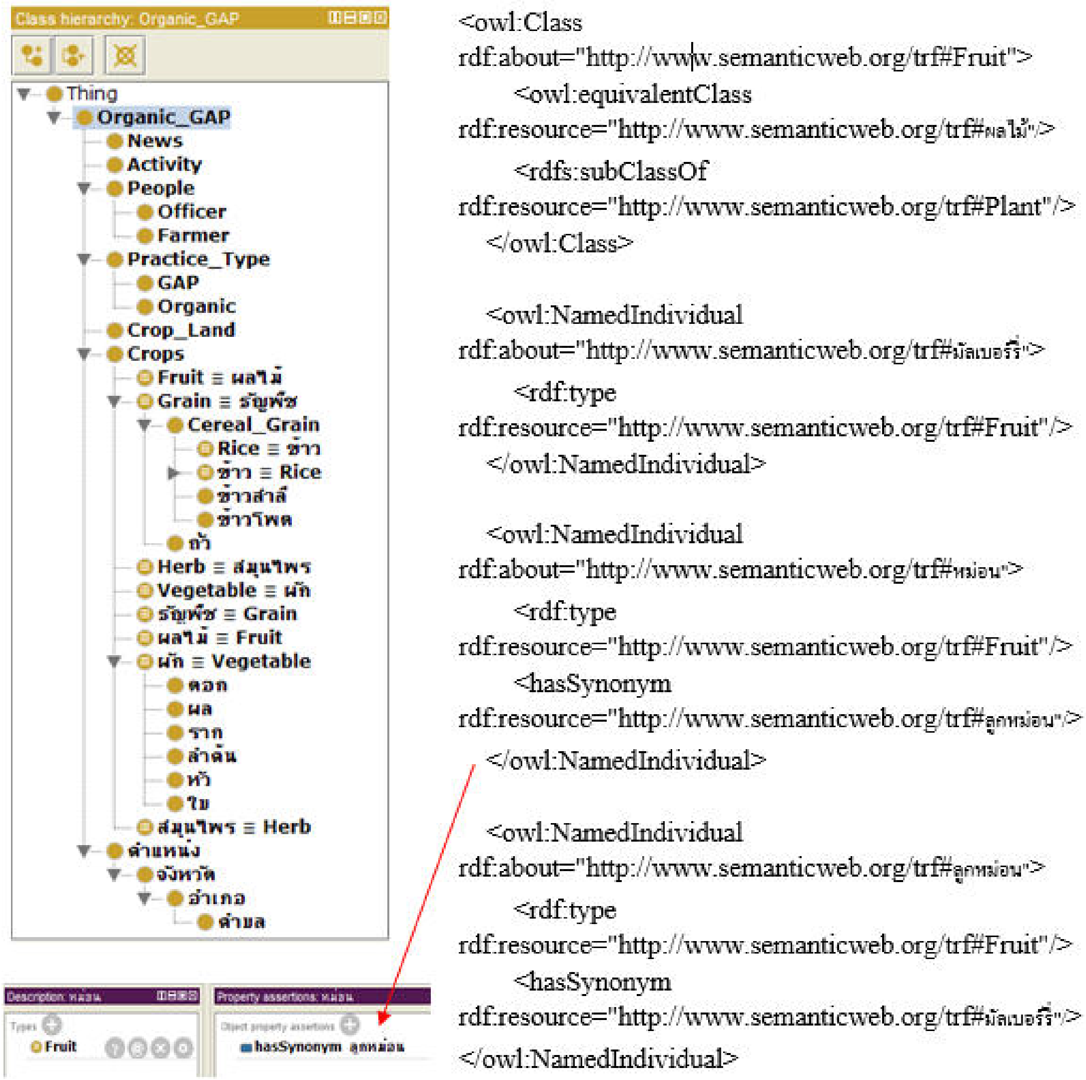

Figure 1 Excerpt of class structure represented by Protégé and OWL file

2.3.5 Evaluation

In this step the proposed ontology is verified based on consistency and conciseness by utilising automated description logic reasoners which are verification tools built in Protégé ontology editor. These reasoners include Pallet, HermiT, and FaCT++. The example of verifying consistency and conciseness of the ontology by HermiT 1.3.8 is shown in Figure 2.

```
Initializing the reasoner by performing the following steps:
        class hierarchy
        object property hierarchy
        data property hierarchy
        class assertions
        object property assertions
        same individuals
HermiT 1.3.8 classified in 180ms
```

Figure 2 Excerpt of HerMiT 1.3.8 reasoner's logs while verifying the ontology

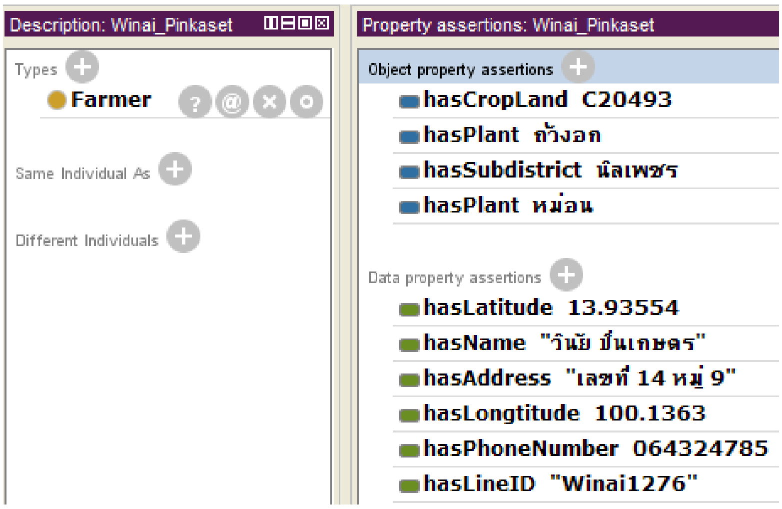

Figure 3 Hypothetical example Farmer class individual

3. Results and discussion

The proposed ontology is populated by extracting and integrating data from several sources, such as from farmers who conduct organic and GAP farming, and from government officials in the Nakhon Pathom Provincial Agricultural Extension Office and the District Agricultural Extension Office. This data is captured in the OWL ontology as individuals referred to as instances of class. Figure 3 shows a hypothetical example Farmer class individual *Winai_Pinkaset* and is populated with the farmer's information.

Figure 4 represents the instances and relationships of the Farmer class and the other related classes generated by the OntoGraf plug-in. From Figure 4 it can be seen that various data regarding organic and GAP agriculture in Nakhon Pathom Province from heterogeneous sources have been integrated into the knowledge base. Therefore, it can enable the use of a common vocabulary supported by the proposed ontology and the management of knowledge, as well as the reusability of knowledge represented.

In terms of information retrieval performance, in the conventional or keyword-based method the query is based on the search term. Therefore, a user needs to cover all the possible search terms in a query as shown in Figure 5, resulting in inflexibility and poor performance. Another challenge is regarding the term-mismatch problem, which can occur when a user enters a search term that does not match with the words stored in the database (e.g. 'mulberry' versus 'mulberries'). The main advantage of using an ontology-based approach over the conventional approach is its ability to perform concept-based knowledge queries. With the semantic querying method provided by the ontology, a user can make a query based on the concept of the search term (Figure 5). Therefore, the results are more accurate and relevant.

Figure 6 shows the results of concept-based querying of instances of the concept 'หม่อน'. All instances that have the same synonyms as 'หม่อน' are returned, namely, Mulberry, Mulberries, ลูกหม่อน, มัลเบอร์รี่.

Figure 7 demonstrates the usage scenario of the developed ontology to answer the competency question; "Who are the farmers growing organic or GAP Mulberry?" It can be seen from Figure 4 that in the knowledge base, the instance *Winai_Pinkaset* has a relation to *hasPlant* หม่อน. However, the query question uses the term 'Mulberry'. In the conventional querying approach, there will be no result returned. Nonetheless, with the concept-based and logical reasoning provided by the ontology, the result is returned as *Winai_Pinkaset.* As a consequence, it can be concluded that the

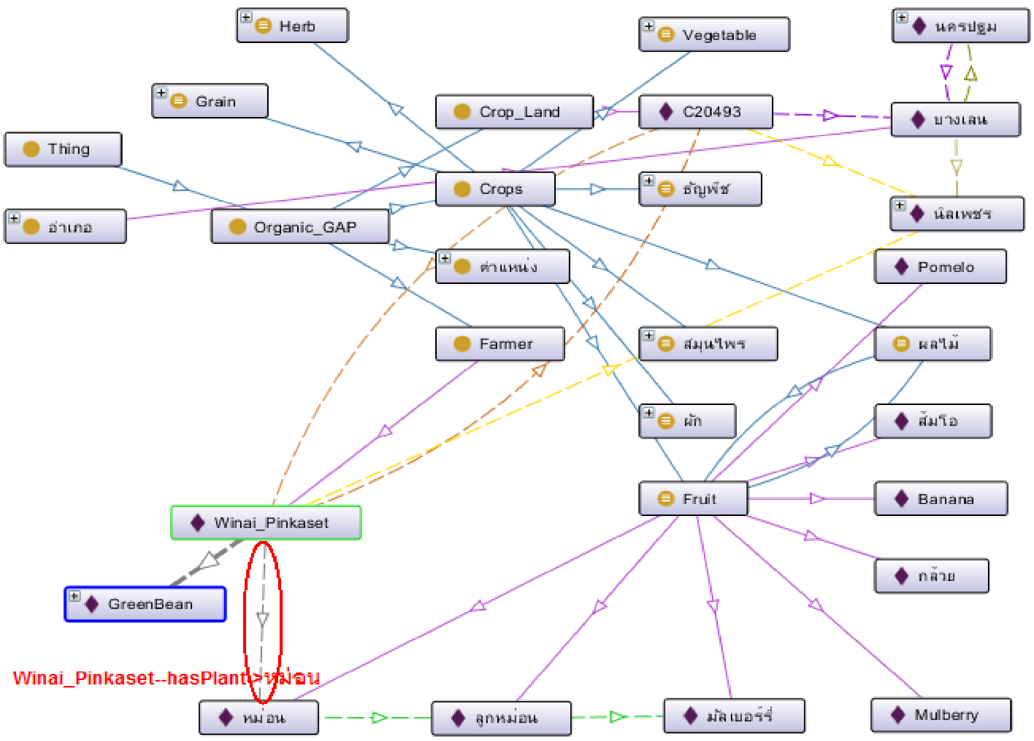

Figure 4 Visualisation of the instances and relationships between the Farmer class and other related classes

Query by conventional method (keyword-based):
Query term a = (หม่อน or ลูกหม่อน or มัลเบอร์รี่ or Mulberry or Mulberries)
Query by the proposed ontology (concept-based method):
Query term b = [concept หม่อน]

Figure 5 Difference between queries undertaken by the conventional and the concept-based method

developed organic and GAP agriculture ontology can facilitate query processing based on the semantic concept and relationship. It helps to obtain the required information based on concepts as well as search terms.

Ontology Evaluation

Precision and recall are the most widely used metrics to evaluate the effectiveness of information retrieval by using the ontology [19]. Precision measures the number of correctly identified items as a percentage of the number of items identified. The calculation is made by dividing true positives by true positives plus the false positives (Equation 1). The higher the Precision rate can ensure that what has been identified is correct. Recall measures the number of correctly identified items as a percentage of the total of correct items. The calculation is made by dividing true positives by true positives plus false negatives (Equation 2). The higher the Recall rate can ensure not missing correct items [20].

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{1}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{2}$$

Where TP = True positive, FN = False negative, FP = False positive, TN = True negative

The F-measure is frequently used along with Precision and Recall [21] and is regarded as a weighted average of the two. In this work, the weight is set to 0.5 meaning that Precision and Recall are considered equally important. F-measure is formally defined as:

$$\text{F - measure} = \frac{\text{P} * \text{R}}{0.5 * (P + R)} \tag{3}$$

Where P = Precision, R = Recall

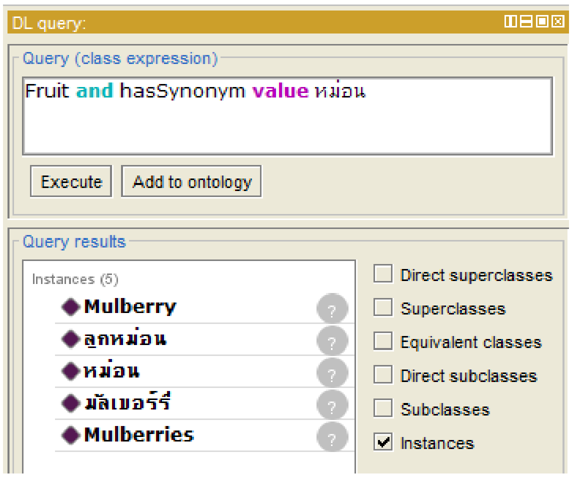

Figure 6 Results of concept-based querying of instances of the concept 'หม่อน'

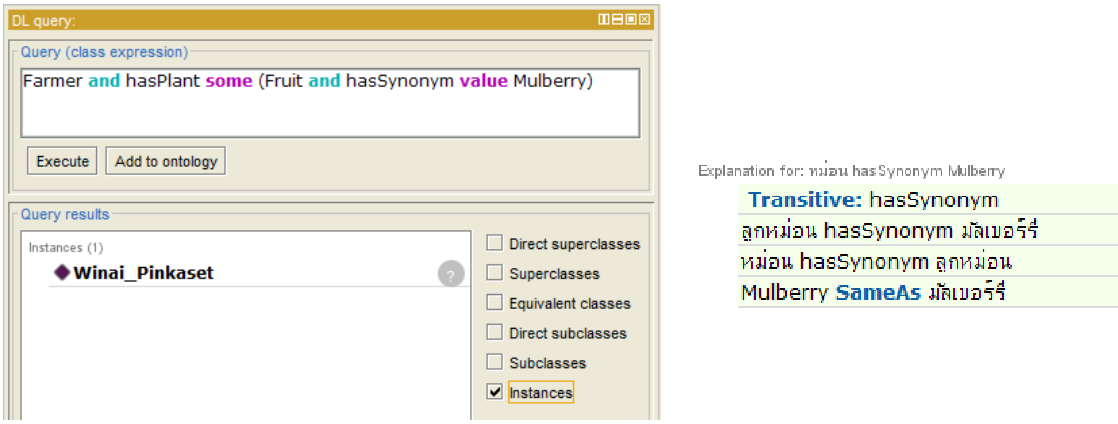

Figure 7 Results of the competency question and its explanation

The experiment was conducted by domain experts to evaluate the ontology retrieval effectiveness using the search terms. In this experiment, the data was extracted from farmers who conduct organic and GAP farming, and from the Nakhon Pathom Provincial Agri-cultural Extension Office and the District Agricultural Extension Office documents in a three-year period, and then captured in the developed ontology. Table 2 presents the number of instances populated for the main ontology classes.

Five test cases were elaborated to evaluate the performance of the developed ontology. These test cases express the following major aspects of the proposed model that were tested:

1) The test case that explores organic and GAP agricultural product terminology;
2) The test case regarding certified farmers who grow organic and GAP agricultural products in Nakhon Pathom Province;
3) The test case that explores the spatial information of organic and GAP farms in Nakhon Pathom Province;
4) The test case that explores news related to organic and GAP agricultural products; and
5) The test case that explores activities relevant to organic and GAP agricultural products.

The results of the retrieval performance evaluation had an average of precision of 92.85%, an average recall of 89.64%, and an average F-measure at a 0.5 weighting of 91.21%. As a result, it can be concluded that the developed ontology for organic and GAP agriculture in Nakhon Pathom Province can facilitate query process-sing based on semantic concept and relationship. It is helpful to obtain the required information not only by being based on search terms but also based on concepts. Therefore, the resulting efficiency of information retrieval has been increased.

Table 2 Number of instances populated for the main ontology classes

Class	Number of instances	Class	Number of instances
Farmer	169	District	7
Crops	48	SubDistrict	54
CropLand	217	News	61
Province	1	Activity	52

4. Conclusion and Future work

In this paper, the ontology for organic and GAP agriculture in Nakhon Pathom Province has been developed. In terms of a theoretical perspective, it is a significant contribution to the body of knowledge in the domain of agriculture knowledge management. Regarding a practical perspective, the proposed ontology facilitates a common understanding of the organic and GAP agricultural knowledge to consumers, farmers and government officials in the Nakhon Pathom Provincial Agricultural Extension Office and the District Agricultural Extension Office. The main benefits are that it can facilitate the integration of heterogeneous organic and GAP agricultural data from various sources; improve the understanding of organic and GAP agricultural knowledge by enabling the same concept to be representted in various phrases; and it can also improve the efficiency of information retrieval by integrating the benefits of both keyword and concept-based searches.

Nevertheless, the current approaches for organic and GAP agriculture information retrieval on the proposed ontology knowledge base is intended to be used by experienced users. As a consequence, future work will investigate the implementation of an intelligent knowledge management application based on the underlying knowledge representation of the proposed ontology. This work will be aimed at helping users easily query the organic and GAP agricultural knowledge which is captured in the ontology based on natural language input. Put differently, the application will enable its users to start their search by formulating a question in natural language so that they can retrieve the desired information.

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