THESIS

ONTOLOGY DEVELOPMENT FOR AGRICULTURAL RESEARCH KNOWLEDGE MANAGEMENT: A CASE STUDY FOR THAI RICE

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This research is a pilot project aiming to develop a prototype ontology for plant production using Thai rice as a case study. It is expected that the developed ontology will be a prototype model for other efforts aimed to develop plant production ontology in the future. This rice production ontology is created from scratch using known ontological development processes, but it is the first of its kind based on a specific crop. Rice was chosen as the topic because of its importance to Thai society and the accumulated knowledge on it within Thailand. The Thai Rice Production Ontology provides an organizational framework of 2,322 concepts and 5,603 terms, in a system of hierarchical relations, together with 57 associative relations and 12 equivalence relations that allows reasoning about rice production knowledge. 2,687 terms in the ontology (about 48 percent) already exist in the Thai AGROVOC Thesaurus. Concepts and relations were formalized, then verified, and imported into the AGROVOC Concept Server Workbench. A specific Thai Agricultural Ontology Visualization tool was developed to present a graphical view of the ontology, and thus facilitate ontology editors. With this graphical facility, and with the criteria validated by experts, the ontology could be further refined. Guidelines and criteria, together with rules for maintaining the ontology, were created from the development process. The rice production ontology query expansion can improve information retrieval performance and answer questions which a retrieval system without ontology cannot. Terms in the ontology were used to query the Thai Rice Research Database (1,350 records). The efficiency of the query is measured in terms of precision and recall. The experiment was conducted using 5 competency questions, and 93 queries were also defined. Retrieval experiments were compared between conventional search and ontology search, supported with rice production ontology-based query expansion. The results showed that precision and recall rates increased averagely from 0.08 to 0.72 and 0.01 to 0.64, which means an improved efficiency of more than nine and sixty four times from the conventional search.

This study has implications for guiding the construction of other plant production ontologies for research knowledge management in Thailand. The guidelines and criteria will facilitate agricultural information specialists and agriculture domain experts to develop their own domain ontologies. Finally, the developed Thai Rice Production Ontology will be a knowledge base for rice production research knowledge management in Thailand.

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When I first started on this thesis I anticipated only the benefits of the results: the Rice Production Ontology may help to manage agricultural research knowledge in Thailand, and hopefully it will be a prototype for other ontology development in the future. At the beginning, I did not know how difficult it was, as this is a pioneer work in plant production domain, to conceptualize the research framework and to synthesize the lessons learned. Therefore, it is very obvious that this study would have never been completed without support and encouragement from the people involved.

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INTRODUCTION

Rice is the world's most common staple food. For more than half of mankind, in 118 countries, rice is the main component of their diet. The world production of rice is 605 million tons of paddy per year, equal to 403 tons of milled rice. Half of this is grown in China (30%) and India (21%). Thailand is the biggest exporter with 38% of the total worldwide rice export, Vietnam is second with 15%, then the United States with 12% and India with 10% (Dooren, 2005).

Rice is the major crop in Thailand and comprises the largest area (60 million Rai), rainfed rice farming account for about 83% of all rice production in Thailand. Rice farmers is also one of the major employer with more than 26% of the population involved in rice farming (17 million people). The export value is of rice is around 100,000 million baht. (Office of Agricultural Economics [OAE], 2008).

Because of its important, rice is considered a 'strategic resource' in Thailand has been assigned as a high priority topic in the National Research Strategic Plan for year 2008-2010 (Office of the National Research Council of Thailand [NRCT], 2008). The main research areas identified focus on production management and crop ecology without harming the environment or consumers. A large amount of research budget was spent for the major crop production researches for years.

Unfortunately, the research knowledge repositories for plant production are not well organized and utilized. This is a main obstacle for research policy administrators and researchers to make use of the previous studies. Knowledge assets are the primary factor of production in the current economy and also contends that managing information is a critical and challenging task. Knowledge assets could be a key to developing a competitive advantage of organizations. Among the advantages, knowledge management provides an opportunity for organization to develop processes that would help to prevent them from continually reinventing the wheel. Intellectual capital offers a unique competitive advantage to an organization (Drucker, 1994).

Research information is one of the critical factors for research development both in terms of research policy formulation and enhancing researchers' capabilities. Therefore all of past studies and investigation results are regarded as a valuable part of the knowledge base for research development. However, a conventional search engines cannot interpret the sense of the user's search, not all the documents that discuss the search concept can be retrieved and often the ambiguity of the query leads to the retrieval of irrelevant information. The conventional search engines that match query terms against a keyword-based index will fail to match relevant information when the keywords used in the query that are different from those used in the index, despite having the same meaning.

A number of search engines are now emerging that use techniques to apply ontology-based domain-specific knowledge to the indexing including: similarity evaluation, results expansion and query enrichment processes. Ontology has been moving from the domain of Artificial-Intelligence laboratories to the desktops of domain experts. An important role of ontologies is to serve as schemata or 'intelligent' view over information resources. Thus they can be used for indexing, querying, and reference purposes over non-ontological datasets and systems.

At present, there are research efforts to develop ontology by automatic and semi-automatic approaches, in order to decrease cost of development, given that the expert approach is costly. However, it is very difficult to automatically or semi-automatically construct ontology without an appropriate knowledge base to start from. Therefore, ontologies for plant production in Thailand, as the one generated by this study, may be a very useful resource for processing Thai agricultural knowledge base. In addition to that, it is reasonable to expect that criteria and guidelines will considerably facilitate the construction of other well-structured ontologies for a related issue in the broader domain. Objective of this theses is also the production of such criteria and guidelines.

Up until now, an ontology on a specific plant or crop has not been constructed. This research is therefore a pioneer and pilot work to develop an ontology prototype for plant production using the Thai rice production as a test case study. This prototype will be a model for other agricultural ontology development in the future and through this efficiency of agricultural knowledge management will be improved.

OBJECTIVES

1. To study and develop a prototype ontology for plant production, with Thai rice production as a case study

2. To develop criteria for rice production ontology construction

3. To apply the ontology to information retrieval mechanism, as a knowledge base for retrieving and managing knowledge, in the domain of agriculture

LITERATURE REVIEWS

This research topic focused on rice production ontology development. So emphatic reviewed literature will be divided in three parts as:

1. Rice Production

2. Classification and Nomenclature

3. Ontology and Knowledge management

Rice Production

Rice is a grass (*Gramineae* or *Poaceae*) belonging to the genus *Oryza* Linn. Of which two species are cultivated, *Oryza sativa* Linn and *Oryza glaberrima* Steud (African rice). *Oryza sativa* is widely growing in tropical and subtropical regions, either as an upland crop and, more usually, in water. Growing rice systems and crop management techniques are complex and somehow unique. In fact, they were developed to suit specific environments and socioeconomic conditions for the farmers and for that specific area (Mongkol., 1993)

Classification of rice

Rice has several classification systems, listed below, based on production area or based on rice characteristics.

Rice classified by evolution: Wild rice is rice weed, has small grain and free fall. Common rice is used for food and is an important economic crop, particular in Asia.

Rice classified by varietals based on water management: Irrigated rice is characterized by controlled water in field both dry and wet season. Rainfed rice is characterized by lack of water control, with floods and drought being the production problems. Rice yields vary depending on rainfall, cultivation practices and use of fertilizer.

Rice classified by varietals type used according to water regime: Upland rice has growing pattern as: direct seeded or broadcast seeded in non-flooded, well drained soil and sloping fields. Preparation of fields on dry land and drilled in narrow rows or broadcast. Lowland rice has growing pattern as: direct seeded or broadcast seeded in flooded, wetland and controlled water from irrigation all year.

Deepwater rice is tall 2-3 meters with rising water. Floating rice grow in very deep flooded, 5-6 meters tall with rising floodwater.

Rice classified by growing season: “In-season rice” is planted in the growing season, May-October. “Off–season rice” is planted out of the growing season, in January-April, in irrigated area.

Rice classified by photoperiod sensitivity: Photoperiod sensitive variety rice is a short-day rice and sensitive to photoperiod . This variety need short photo period (less 12 hours) to change vegetative growth to reproductive growth. The critical day length is different for each variety. Non–photoperiod sensitive variety rice is not sensitive to photoperiod. These varieties are planted all years.

Rice classified by planting method: Direct seeding rice is planted by using dry seed onto puddle soil in the field and harrow it. Indirect seeding rice is planted by pre-germinated seed planting in the field. Broadcast seeding rice is planted by broadcast seed in the field after soil is prepared.

Rice classified by harvesting period: Early variety has period of mature in range 90 – 120 days. Medium variety has period of mature in a range 130 – 160 days. Late variety has period of mature in range 180 – 210 days.

Rice classified by grain size: Short grain has grain length average 5.5 mm. Medium grain has grain length between 5.5 – 6.6 mm. Long grain has grain length between 6.61 – 7.5 mm. Extra long grain has grain length more than 7.51 mm.

Rice classified by volume of starch in grain (Shuvisitkul., 2001): Non–glutinous rice has between 15-30% amylose, does not have dextrose and clear grain color. Glutinous rice has zero or negligible amylose in the grain.

Rice growth and development

Oryza sativa contains both annual and perennial species. Perennial wild species can sometimes be troublesome weeds. The cultivated forms are generally grown as annuals and behave as such when conditions after harvest bring the plant’s life to an end by drought or cold. However, it is capable of more than annual growth and where moisture and temperature permit there is commonly a re-growth after the first harvest (Chongkid., 2004)

Cultivated rice is an annual grass with round, jointed culms, rather flat leaves and terminal panicles. The vegetative organs consist of roots, culms and leaves. A branch of the plant bearing the root, culms, leaves and a panicle. The flora organ consist of parnicle and spike. The panicle is a inflorescence on the terminal shoot.

The extent to which the panicle and a portion of the uppermost internode extend to the flag leaf sheath. The rice kernel is composed of the hull and caryopsis. The hull is comprised of sterile lemmas, rachilla, palea and lemma. The caryopsis contain the embryo and starchy and endosperm, surrounded by the seed coat and pericarp.

The life cycle of rice plant is generally 100-210 days. Cultivars with growth duration of 150-210 days are usually photoperiod sensitive and planted in the deepwater areas. Temperature and day length are the two environmental factors affecting the development of the rice plant, which can be divided into three main phases (Department of Agriculture, 1999).

1. Vegetative phase: which runs from germination to panicle initiation and consist of four stages: germination stage, seeding stage, tillering stage and stem elongation stage

2. The reproductive phase: consist of three stages: panicle grain stage, panicle develop stage, and heading/flowering stage. Flowering occur about 25 days after visual panicle initiation regardless of variety. Flowering continues successively until most spikelets in the panicle have bloomed.

3. Ripening phase: rice grain develop after pollination and fertilization. Grain development is a continuous process and the grain undergoes district change before is fully mature. Ripening involve three stages: milk grain stage, dough stage, and mature stage (De Datta, 1981).

Cultivation Process

The most suitable planting technique depends on locality, soil type, and crop ecosystem. Crops can be direct seeded or transplanted. Similarly transplanted crops can be established manually or by machine. Direct seeded crops tend to mature faster than transplanted crops but have more competition from weeds (International Rice Research Institute [IRRI], 2008).

Two methods are used for growing rice on wetland and dryland, they are broadcasting and transplanting. The methods practiced vary according to the climatic condition, soil, and availability of labor.

Broadcasting rice has become with widely used because it requires less labor. The farmer will broadcast on dry paddy or germinated seed into field after plough. In Thailand, this method is done from April or May and is divided to four types :

1. Dry seed broadcasting without narrowing: broadcasting dry seed into field

immediately (before raining season).

2. Dry seed broadcasting followed by harrowing: broadcasting dry seed into field and harrow.

3. Pre-germinated broadcasting: seed soak in the water before broadcasting into flooded soil.

4. Pre-germinated broadcasting rice: flow water into the field and plough for removed weed and broadcasting germinated seed and flow water again.

Transplanting of rice seedlings into puddled fields is widely practiced in Asia, primarily as a means of weed control. Transplanting requires less seed but much more labor, and the crop takes longer to mature due to transplanting shock. The seed growing in the nursery and transplanting in flooded, the land is ploughed. In preparing the nursery seedbed, level the surface, free of weeds, and well drained. Some form of nitrogen and phosphate fertilizer is applied to the nursery. Seeds are pre-germinated and can be broadcasted into either a flooded or wet soil surface in the nursery. Seeding rates vary depending on locality, soil type, and seed quality. Most of northeastern and southern rice growing areas in Thailand transplanted rice during the monsoonal season (De Datta, 1981).

Direct seeded crops can be established using dry seed or pre-germinated seed and seedlings. They are broadcast by hand or planted by machine. In rainfed and deepwater ecosystems, dry seed is manually broadcast onto the soil surface and then incorporated either by ploughing or by harrowing while the soil is still dry. In irrigated areas, seed is normally pre-germinated prior to broadcasting. If water in the fields is muddy following the last working, the field is allowed to dry for a time period of at least 24 hrs (preferably 48 hrs) before broadcasting commences. If water is drained from the fields after broadcasting, it is re-introduced 10 to 15 days after establishment.

Harvesting

Harvesting is the process of collecting the mature rice crop from the field. Harvesting of paddy includes cutting, stacking, handling, threshing, cleaning, and hauling of paddy. The goal of good harvesting methods is to maximize grain yield, and to minimize grain damage and quality deterioration. Harvesting can be done manually using sickles and knives, or mechanically with the use of threshers or combine harvesters. Regardless of the method, a number of guidelines should be followed that will ensure that grain quality is preserved during harvest operations and harvest losses are kept to a minimum. (IRRI, 2008)

Land preparation

Land preparation is a combination of tillage practices that places the soil in the best physical condition for plant establishment and crop growth. To attain this condition soil must be tilled to a depth so plants can develop a root system which will physically support the plant and also allow the extraction of sufficient moisture and nutrients so yield potentials can be realized, soil disturbance should be sufficient to control weeds and tillage must leave the soil surface level. Level fields improve water use efficiency and help control in crop weeds. The field also needs a drainage system that will allow the rapid removal of excess water.

Primary tillage is the first working after the last harvest and normally the most aggressive tillage operation. It is normally undertaken when the soil is wet enough to allow the field to be ploughed and strong enough to give reasonable level of traction. This can be immediately after the crop harvest or at the beginning of the next wet season. When there is sufficient power available some soil types are ploughed dry. The implement most commonly used with an animal powered system is the moldboard plough. In clay soils, the fields often have to be fully saturated before tillage can be undertaken. In lighter texture soils such as loam or sand, tillage can be undertaken at moisture levels below field capacity.

Secondary tillage is completed after primary tillage and is undertaken for reducing weed. In the animal powered system, the second working is normally undertaken with the moldboard plough when the field is fully saturated. The final workings are then completed using peg tooth harrows to puddle the soil and leave the surface level and ready for planting (IRRI, 2008).

Water management

The quality of water available for irrigation is very important for a successful rice production. Rice is a semi-aquatic plant, which has a high demand for water, particularly over the reproductive stage from panicle initiation to early grain development. The longer the crop growth period the higher will be the water requirement. A general rule is that a rice crop will need approximately 10 mm. of water per day. Therefore a crop that matures in 100 days will require approximately 1,000 mm. of water, while a crop that matures in 150 days will require 50% more.

In areas that are affected by deep water or surface flooding, later maturing crops may be necessary so that the crop is sufficiently developed and tall enough to withstand the higher levels of water (IRRI, 2008).

Seed management

High quality seed enables farmers to attain crops, which have the most economical planting rate, a minimum of replanting, uniformity in ripening, a more uniform plant stand with faster growth rate and greater resistance to stress and diseases. Seeds of high quality should be true to its kind or variety, contain a minimum of impurities and have high establishment rates in the field. The main criteria for describing seed quality can be considered under varietal purity characteristics and seed viability.

Varietal purity refers to the genetic or cultivar purity and can be described by its physical, chemical and crop attributes. The viability of the seed in the field will be determined to a large degree from its stored moisture level, Germination potential and its vigor. Moisture content has a marked influence on the life and vigor of the seed. Moisture content should be less than 14% and preferably less than 12% for extended storage times. Germination percentage expresses the proportion of the total number of seeds that are alive. It is determined through controlled tests and actual counts of the number of seeds that germinate. Many varieties have a dormancy period immediately after harvest. Stored under traditional open systems, the germination rate of most rice seed begins to deteriorate rapidly after 6 months (IRRI, 2008).

Rice breeding

Rice breeding was based on selection among farmer's varieties, which had been selected for local adaptation and preferred grain quality. The selection was limited to purification by removal of off-type in the varieties popular with farmers. The next step was mass selection in such varieties. Following that, cross fertilization for combining specific traits in different varieties was attempted. Thailand specialized early in growing varieties with high-quality, long, slender grains. These varieties still from the bulk of Thailand's exported rice. The strict demands of the export trade for high-quality grain naturally imposed some restriction on achieving other objective in breeding.

Cropping system

Thai farmers have adopted rice growing practices which are suitable to the local physical condition, particularly to the time of water supply. It can take at least five months to grow one rice crop and for broadcasting rice, it take even more than eight months. In Thailand the second crop rice is transplanted before the harvest of the first crop, the growing season of two rice crops could be shortened to within a period of eight months. It is even possible to add a third crop in the same field (Chongkid, 2004).

Diseases and control method

Rice diseases can be classified into four group: fungal diseases, bacterial diseases, viral diseases, and phytoplasma. Symtoms and controlled method are concluded as follows (IRRI, 2008) :

Fungal Diseases

1. Rice blast (caused by *Pyricularia grisea*) The fungus attacks all aboveground parts of the rice plant. Depending on the site of symptom rice blast is referred as leaf blast, collar blast, node blast and neck blast. In leaf blast, the lesions on leaf blade are elliptical or spindle shaped with brown borders and gray centers. The pathogen also causes brown lesions on the branches of panicles and on the spikelets.

Chemical control is commonly practiced. The method of application affects the efficiency as well as the economics of fungicide use. Fungicide may be applied in granular form to the seedbed, submerged in the field for leaf and neck blast control, and/or foliar spraying and dusting by ground and aerial application. Benomyl can control rice blast but it is expensive. Use the recommended N fertilizer rate and avoid excessive N rate on susceptible cultivar. Besides the resistance of rice is effective control for blast.

2. Sheath blight (caused by *Rhizoctonia solani*). The lesions are usually observed on the leaf sheaths although leaf blades may also be affected. The initial lesions are small, ellipsoid or ovoid, and greenish-gray and usually develop near the water line in lowland fields. Under favorable conditions, they enlarge and may coalesce forming bigger lesions with irregular outline and grayish-white center with dark brown borders. The presence of several large spots on a leaf sheath usually causes the death of the whole leaf.

Sheath blight is effectively controlled by fungicides. There are many agronomic practices that can effectively control the disease to certain degree. Removing, burning, or ploughing into soil the infected plant removes part of the source of inoculum. Furthermore variety resistance and biological control can control diseases too.

3. Brown spot (caused by *Cochliobolus miyabeanus*). Brown spot may be manifested as seedling blight or as a foliar and glumes disease of mature plants. On seedlings, the fungus produces small, circular, brown lesions, which may girdle the coleoptile and cause distortion of the primary and secondary leaves. In some cases, the fungus may also infect and cause a black discoloration of the roots. Infected

seedlings are stunted or killed. On the leaves of older plants, the fungus produces circular to oval lesions that have a light brown to gray center surrounded by a reddish brown margin. On moderately susceptible cultivars, the fungus produces tiny, dark specks.

This brown spot disease can be controlled by chemical seed treatment, foliar applications of fungicide, planting of resistant cultivars and by proper management of soil fertilizers, especially nitrogen fertilizer. Sowing healthy seed or treated with hot water or fungicides effectively keep the disease in check. Spraying fields with fungicide to prevent secondary infections is also practiced in many areas.

4. Leaf scald (caused by *Rhynchosporium oryzae*). Leaf scald disease exhibits a variety of symptoms. The characteristic symptoms are zonate lesions of alternating light tan and dark brown starting from the leaf edges or tips. The lesions usually occur on mature leaves, and are more or less oblong with light brown halos. Individual lesions are 1-5 cm. long, 0.5-1 cm. broad and may enlarge to as long as 25 cm. The continuous enlargement and coalescing of lesions may result in the blight of a large part of the leaf blade. The zonation on the lesions fades as they become old and affected areas dry out, giving the leaf a scalded appearance.

Disease resistance variety is used for control method. Breeding program should take advantage of their general variability and select those varieties that are resistant and less susceptible.

5. Narrow brown spot (caused by *Cercospora oryzae*). The characteristic symptoms of this disease are usually observed during the late growth stages and are characterized by the presence of short, linear, brown lesions mainly on the leaves, although it may also occur on leaf sheaths, pedicels, and glumes. A net blotch-like pattern often forms on leaf sheaths, where the cell walls turn dark brown and the intercellular areas are tan to yellow. The disease usually appears at mature crop stages. Resistant varieties provide a better means to control the disease.

6. Stem rot (caused by *Sclerotium oryzae*). The first symptoms are generally observed in the field after the mid tillering stage. Initially, the disease appears as small, blackish, irregular lesion on the outer leaf sheath near the water line. The lesion enlarges as the disease progresses with the fungus penetrating into the inner leaf sheaths. Eventually, the fungus penetrates and rots the culm while the leaf sheath is partially or entirely rotted. Infection of the culm may result in lodging, unfilled panicles, chalky grains, and in severe cases, death of the tiller. Brownish-black lesions appear and finally one or two internodes of the stem rot and collapse. Upon opening infected stem, dark grayish mycelium may be found within the hollow stem and numerous tiny, black sclerotia are embedded all over the diseased leaf sheath tissues.

The pathogens survive as sclerotia in the soil or in the straw if are not removed, burned or decomposed it become the source of inoculum. Seven days of mulching with transparent polyethylene sheets killed the fungus.

7. Sheath rot (caused by *Sarocladium oryzae*). Rotting occurs on the leaf sheath enclosing the young panicles. As the disease progresses, lesions enlarge and coalesce and may cover most of the leaf sheath. Lesions may also consist of diffuse reddish brown discoloration in the sheath. An abundant whitish powdery growth may be found inside affected sheaths; the leaf sheath may look normal from the outside. With early or severe infection, the panicle may fail to emerge completely or not at all; the young panicles remain within the sheath or only partially emerge. Panicles that have not emerged tend to rot, and florets turn red-brown to dark brown. Most grains are sterile, shriveled, partially or unfilled and discolored.

Sarocladium oryzae is seedborne and seed-transmitted. Many chemical have been evaluated for control of sheath rot; however, no field data support the use of fungicides for its management.

8. Bakanae (caused by *Fusarium moniliforme*). The classic and most conspicuous symptom of the disease is the hypertrophic effect or abnormal elongation of plant. These symptoms can even be observed from a distance. The affected plants may be several inches taller than normal plants, thin, yellowish green and may produce adventitious roots at the lower nodes of the culm. Diseased plants bear few tillers and leaves dry up quickly. The affected tillers usually die before reaching maturity; when infected plants survive, they bear empty panicles.

There are many rice cultivars resistant to bakanae. Benomyl, thiram-benomyl, and thiram-thiophanate methy wettable powders have become common as seed disinfectants.

9. False smut (caused by *Ustilaginoidea virens*). The disease occurs in the field at hard dough to mature stage of the crop. The fungus transforms individual grains of the panicle into greenish spore balls that have velvety appearance. At this stage, the surface of the ball cracks. The outermost layer of the ball is green and consists of mature spores together with the remaining fragments of mycelium. The outer soporiferous region is three-layered. The outermost layer is greenish black with powdery spores; the middle layer, orange; the innermost, yellowish.

Most cultivars appear to have good resistance to the disease. False smut is considered a minor disease, and disease control measures are normally not required. Copper foliar sprays do have activity against the fungus (Groth and Lee, 2003).

10. Dirty panicle disease**.** Many fungi infect developing grain and cause spots and discoloration on the hulls or kernels. This is a complex disorder in rice that

involves many fungi, the white-tip nematode and insect damage. High winds at the early heading stage may cause similar symptoms. Proper insect control and disease management will reduce this problem. Panicle infestations cause a uniform light to dark, reddish-brown discoloration of entire florets or hulls of developing grain. The disease can cause sterility or abortion of developing kernels.

Bacterial Diseases

1. Bacterial blight (caused by *Xanthomonas oryzae* pv. *Oryzae*). Water-soaked lesson usually starting at leaf margins, a few entimeters from the tip, and spreading towards the leaf base; affected areas increase in length and width, and become yellowish to light brown due to drying; with yellowish border between dead and green areas of the leaf. It is usually observed at maximum tillering stage and onwards. In severely diseased fields grains may also be infected. In the tropics infection may also cause withering of leaves or entire young plants and production of pale yellow leaves at a later stage of the growth.

The disease has been effectively controlled by using resistant cultivars. Various chemicals such as copper compounds as well as antibiotics have been evaluated for controlling the disease (Mew, 1991).

2. Bacterial leaf streak (caused by *Xanthomonas oryzae* pv. *Oryzicola*). First appears as short, water-soaked streaks between the veins, which become longer and translucent and turn to light brown or yellowish brown. Thus, large areas of the leaf may become dry due to numerous streaks. At the late stage the disease is indistinguishable from the bacterial leaf blight.

The disease can be adequately managed by host plant resistance. Many modern cultivars have various degree of resistance, but such cultivars have not been used sole for the purpose of controlling the disease. No other control measures are actually practiced to control the disease; however, many of the field sanitation operations, and use of clean seed should be helpful.

3. Red stripe disease (caused by *Microbacterium* sp.). Formation of lesions on leaves, initial symptom is pin-sized orange spot at any place on leaf blade, transparent stripe that advances from the spots upward to leaf tip and never downward lesions become necrotic and coalesce forming a blight appearance on the leaves. Symptoms are initial symptoms are pin-sized lesions, often yellow green to light orange. Older lesions appear as orange spots with an upward stripe, which advances towards the tip of the leaves. Lesions become necrotic and coalesce forming a blight appearance on the leaves. Lesions more common on the leaves and, less common on the sheaths. The disease usually occurs when the plants reach the reproductive stage, starting from the panicle initiation. High temperature, high

relative humidity, high leaf wetness and high nitrogen supply favor disease development.

Factors favoring disease development are high temperature and high relative humidity, high leaf wetness, high nitrogen and flowering to ripening stages of the rice crop. Controlled by chemicals benzimidazole fungicides, such as benomyl, carbendazim, and thiophanate methyl, are effective against the disease. The application of nitrogen based on the actual requirements of the crop can manage red stripe without reducing yield. Optimum seeding rate and wider plant spacing also appear to reduce the disease.

Viral Diseases

1. Tungro (caused by rice Tungro Bacillifor Virus and spherical virus). Plants affected by tungro exhibit stunting and reduced tillering. Their leaves become yellow or orange-yellow, may also have rust-colored spots. The leaf discoloration starts from the tip and may or may not extend to the lower part of the leaf blade; often only the upper portion is discolored. Young leaves may have a mottled appearance and old leaves show rusty-colored specks of various sizes. Infected plants have delayed flowering. The panicles are small and not completely exerted, and bear mostly sterile or partially-filled grains often covered with dark brown specks. Tungro are transmitted by the green leafhoppers.

The virus appears to have a wide range of hosts. These include *Leersia hexandra, Rottoellia compressa, Eleusine indica* and *Echinocloa crusgalli*. The application of insecticides at the right time would control the virus diseases through the insect vector. Spraying insecticide at the early stages of plant growth delays tungro development. Comblining chemical control and resistant varieties is perhaps most desirable for management of tungro.

2. Grassy stunt (caused by rice Grassy Stunt Virus). Plants affected by this disease, show severe stunting, excessive tillering, with short leaves that are narrow and, pale green to pale yellow in color. They may have newly-expanded leaves that maybe mottled or striped and may also have numerous small, irregular, dark brown or rust-colored spots. Brown plant hopper transmit this disease. Rice grassy stunt is effectively controlled by the resistant rice cultivars. Besides plough up and over soil can controlled virus in the field.

3. Ragged stunt (caused by Rice Ragged Stunt Virus). Affected plants show stunting that may have reduced tillering. The leaves are short, dark green, and serrated along one or both edges giving a ragged appearance. The leaf blades are often twisted form a spiral. The vein swellings appear on leaf sheaths, leaf blade and culms and nodal branches are developed at later growth stages. Brown plant hopper

transmits the disease. Disease control method are: field sanitation and apply chemical substances. Resistant varieties is the most desirable for management.

4. Gall dwarf disease (caused by Rice Gall Dwarf Virus). Rice gall dwarf disease is a severe disease. The symptoms consist of stunting of the plants, gall formation along leaf blades and sheaths, and dark green discoloration. Rice gall dwarf virus (RGDV), the causal agent of the disease, is classified as a member of the genus Phytoreovirus of the family Reoviridae. Rice gall dwarf virus (RGDV) multiplies in its leafhopper vectors, which include *Nephotettix nigropictus* and *N. cinticeps*, and is transmitted in a persistent manner to rice plants where the virus is restricted to phloem cells. Adopt resistant rice for controlling gall dwarf disease virus, Green leafhopper and burn down the straw if detected.

5. Yellow orange leaf (caused by Yellow Orange Leaf Virus). This virus is transmitted by *Nephotettix impicticeps*. The disease does not cause serious reductions of rice yield. The orange-leaf-infected rice have golden yellow to deep bright orange leaves.

Nematode Diseases

1. Ufra or stem nematode (*Ditylenchus angustus*). Affected seedlings or plants show whitish discoloration (chlorosis) at the early stage of infection. The affected plants are stunted and have deformed and twisted leaves. These plants have panicles, which are exserted, or panicles that inside the leaf sheath of the flag leaf. However, panicles that are exserted, become twisted and deformed, with unfilled grains.

Several chemicals are reported to be efficacious in controlling this disease. They include carbofuran, hexadrin and benomyl. In practice, however, farmers use little or no chemical control for the disease. Combining resistant cultivars with other measures, such as field sanitation, may effectively control the disease. Removal and destruction of the straw in infested field to reduce the amount of inoculum would be helpful.

2. White tip (*Aphelenchoides besseyi*). Affected plants shows a characteristic symptoms on leaf tips, which become chlorotic or whitened for a distance of up to 5 cm. Eventually the infected leaf becomes dry and shreds while flag leaf becomes twisted and panicles may not emerge or if emerged may have high sterility, distorted glumes, and small and distorted kernels. White-tip disease is controlled by dipping seeds in hot water (55-61 °C) for 15 minutes. Chemical treatment can also be used (De Datta,1981).

3. Root knot (*Meloidogyne graminicola*). Affected plants are stunted and become yellow in color. They have reduced tillering and their most diagnostic symptom is the presence of root galls. The disease is more serious in upland than in lowland rice. Control includes crop rotation, cultural control, burning crop debris and used resistant cultivar.

Phytoplasma Diseases

1. Orange leaf disease. Infect rice plant develop orange colored leaves, which later roll inward and desiccate. The disease plant are generally distributed sporadically in the field and the disease does not cause serious yield loss.

2. Yellow dwarf disease. This disease is found in many provinces. The caused disease was phytoplasma and transmitted by the leafhoppers *Nephotettix cincticeps*, *Nephotettix virescens* and *Nephotettix nigropictus*. The primary symptoms are yellowing of younger leaves and profuse tillering. Later the plants are stunted. The leaves appear weak and the outer ends bend down-ward. Infected plant do not die but remain small and produce no panicle (Chongkid, 2004).

Because of its small economic importance, not several chemicals are reported to be efficacious in controlling the disease. Removal host and destruction of the weed in the field to reduce the amount of inoculums would be helpful.

Nutrition deficiencies

Nutrition is the supply and absorption of those nutrient chemical elements required by an organism. There are two elements for rice: major and minor elements. All essential elements must be present in optimum amounts and in forms usable by rice plants. Nutrition deficiency and symptoms are described here below grouped by nutrient (De Datta, 1981).

1. Nitrogen gives dark green appearance to plant parts as a component of chlorophyll, promotes rapid growth or increased height and tiller number, increases size of leaves and grain increases number of spikelets per panicle, increases protein content in the grains. Deficiency of nitrogen will stunt plants with limited number of tillers, narrow and short leaves which are erect and become yellowish green as they age, old leaves become light straw colored and die.

2. Phosphorus stimulates root development and promotes earlier flowering and ripening particularly under cool climate. Promotes good grain development and gives higher food value to the rice because of phosphorus content of the grain. Deficiency of phosphorus will stunted plants with limited number of tillers. Narrow and short leaves that are erect and dirty dark green. Young leaves remain healthier

than older leaves, which turn brown and die. Radish or purplish color may develop on leaves of varieties that tend to produce anthocyanin pigment.

3. Potassium favors tillering and increases the size and weight of the grains. Increases phosphorus response. Potassium plays an important role in physiological processes in the plant including opening and closing of stomata and tolerance to unfavorable climatic conditions. Deficiency of potassium will stunt plants and tillering slightly reduced. Short, droopy and dark green leaves. Yellowing at the interveins, on lower leaves, starting from the tip and eventually drying to a light brown color. Brown spots sometimes develop on dark green leaves. Long thin panicles from. Irregular necrotic spots may develop on the panicles.

4. Calcium is a constituent of cementing material of plant cell. Calcium is a important constituent of calcium pectate, which strengthens the cell wall. Maintainer of turgidity of the cell wall. Promoter of normal root growth and development. Deficiency of calcium effected the tip of the upper growing leaves to become white, rolled and curled. In an extreame case, the plant is stunted and dies.

5. Magnesium is a constitutent of chlorophyll molecule and a component of several essential enzymes. Function of magnesium is similar to calcium. With moderate deficiency, hight and tiller number are little affected. Curly and droopy leaves due to expansion of the angle between the leaf blade and the leaf sheath. Intervenal chlorosis characterized by an orange yellow color on lower leaves.

6. Sulfer is a constituent of the amino acids cystine and methionine and the plant hormones thiamin and biotin. Sulfer ia an important factor in the functioning of many plant enzymes, enzyme activators and oxidationreduction reaction. Deficiency symptom are similar to those of nitrogen deficiency, which makes it impossible to distinguish between the two deficiencies by visual symptoms alone. Reduced plant height and tiller number. Fewer panicles, shorter panicles and reduced number of spikelets per panicle at maturity. Initially on leaf sheaths, which become yellowish, proceeding to leaf blades, with the whole plant chlorotic at the tillering stage.

Sulfer effect on grain quality of Thai jasmine rice by increasing the aroma, softness, whiteness, stickiness and glassiness of boiled milled grain (Suwanarit et al., 1997).

7. Zinc related with the production of auxin and activation of many enzymatic reactions. Close involvement in nitrogen metabolism. Deficiency symptoms are midribs of the younger leaves, especially the base become chlorotic. Brown blotches and streaks in lower leaves appear, followed by stunted growth, although tillering may continue. Reduced size of the leaf blade but with the leaf sheath little affected.

8. Iron is related to the formation of the chlorophyll. Iron is a catalyst in an organic form or combined with organic compound as a component of redoxy enzymes. Deficiency of iron will effect entire leaves as chlorotic and then whitish. The newly emerging leaf becomes chlorotic if iron supply is cut suddenly.

9. Manganese is a factor in photosynthesis and in oxidationreduction processes. Manganese is an activator of several enzymes, such as oxidase, peroxidase, dehydrogenase, decarboxylase, and kinase. Deficiency of manganese will stunted plants with normal tiller number, intraveinal chlorosis on the leaves, chlorotic streaks spreading downward from the tip to the base of the leaves, which become dark brown and necrotic. Newly emerging leaves are short, narrow and light green.

10. Boron is a catalyst in the plant system and a regulator of physiological functions such as nitrogen metabolism, metabolism and nutrient uptake, especially calcium metabolism. Deficiency of boron will reduced plant height. The tip of emerging leaves become white and rolled as in the case of calcium deficiency. The growing points may die in severe cases, but new tillers continue to be produced.

11. Molybdenum is related to reduction of nitrate to nitrite. Deficiency symptom is curl and yellow spot leaves.

12. Copper is a component of metalloenzymes and a regulator of enzymatic actions. Deficiency symptom are bluish green leaves, which become chlorotic near the tips. New leaves fail to unroll and maintain a needlelike appearance of the entire leaf or, occasionally of half the leaf, with the basal portion developing normally.

13. Chlorine is essential in photosynthesis. It deficiency symptom have not been described in rice.

14. Silicon promote translocation of phosphorus in the rice plant and retention of excessive phosphorus taken up. Makes soil phosphorus available to rice. Plants become soft and droopy if lacking of silicon.

Weed and control method

There are many kinds of weed in paddy field. Some major weeds were listed as: *Echinochloa crus-galli; Echinochloa colana; Ischaemum rugosum; Leptochloa chinensis; Monochoria vaginalis; Cyperus difformis; Cyperus iria; Marsilea crenata; Ipomoea aquatica; Melochia corchorifolia; Cyanotis axillaries; Jussiaea linifolia*; *Aeschynomene aspera; Setaria geniculata; Dactyloctenium aegyptium; Digitaria ciliaris; Cynodon dactylon; Paspalum distichum; Eleusine indica; Panicum repens; Chloris barbata; Panicum cambogiense; Trianthema portulacastrum; Corchorus aestuans; Ipomoea gracilis; Amaranthus gracilis;*

Aeschynomene aspera; Heliotropium indicum; Eclipta prostrate; Alysicarpus vaginalis (Kukhamau, 2004)

Weeds need to be controlled within the first 20-40 days to avoid yield loss. Land preparation and leveling can control weeds growth. Preventing the introduction of weeds into fields by using clean and good quality seed, keep seedling nurseries free of weeds to make sure weeds are not planted with the rice seedlings, keep irrigation channels and field bunds free of weeds to prevent weed seeds or vegetative parts entering the fields, use clean equipment to prevent field/crop contamination and rotate crops to break weed cycle. Kill weeds in fallow fields to prevent flowering, seed-set and the build-up of weed seeds in the soil. Select a weed competitive variety with early seedling vigor, and high tillering to suppress weeds. Transplanted crops tend to have fewer weeds and less yield loss than direct seeded crops. Transplant healthy, vigorous seedlings that can better compete with weeds in early stages. Maintain an adequate plant population that closes its canopy by maximum tillering to shade out weeds. Apply N fertilizer just after weeding to minimize rice-weed competition for N.

Water is the best ‘herbicide’ to control weeds. Many weeds cannot germinate or grow under flooded conditions. Maintain a 2 to 5 cm. water level in the field to minimize weed emergence and lower weed pressure. Fields should be continuously flooded from the time of transplanting to when crop canopy covers the soil completely. Good land leveling is critical to avoid high spots where weeds can become established.

Pest and control method

Pest is the most injurious factor in rice production process. The major rice pests and their control was described as follows (Rice Department, 2008**; IRRI, 2008):**

1. Rice stink bug (*Oebalus pugnax*)

Adults and nymphs have piercing-sucking mouthparts. Entry of the stylets (mouthparts for feeding) is facilitated by a salivary secretion which hardens on contact with air and remains attached to the rice grain. It is called a feeding sheath. The feeding sheath is the only external evidence that feeding by rice stink bugs has occurred on a grain. Rice stink bugs can successfully feed on kernels from shortly after fertilization until the kernel is in the soft dough stage. The stage of kernel development when fed upon determines the amount and type of damage. Attack during the early stages stops any further development of the kernel (a yield loss). Attack during kernel fill stages removes a portion or all of the kernel contents (also a yield loss). Infection by pathogens (bacteria or fungi) as well as enzymes produced by the rice stink bug cause discoloration of the kernel (a quality loss plus breakage loss). The rice industry and grain inspection services group all discolored kernels into a category called "pecky rice". Thus, rice stink bugs cause yield losses and quality losses.

Rice fields should be scouted weekly or twice weekly beginning at 75% panicle emergence and continued for 4 weeks. Avoid scouting from mid-day through late afternoon. Apply insecticide if infestation is 5 or more rice stink bugs per 10 sweeps during the first two weeks after heading; or if 10 or more per 10 sweeps is found during the third and fourth week after heading. If the number of bugs is only slightly below the threshold level or if the field is very large, increase the number of samples to improve confidence in sample estimates. Samples taken during the morning hours of 8 to 11 a.m. will improve estimates of rice stink bugs.

2. Long-horned grasshoppers (*Conocephalus fasciatus; Orchelimum vulgare*)

Adults of Conocephalus usually are about 1 inch in length and adults of Orchelimum are 1 to 2 inches in length. The body is green with brown wing covers. The antennae are longer than the body. Nymphs more than adults feed on young leaves. This is not cause economic damage. Adults and nymphs will feed on anthers of rice flowers and have been found with 'starchy materials', presumably from rice kernels, in the digestive system. Feeding on anthers and kernels is not believed to cause economic damage.

Long-horned grasshoppers can be sampled with a standard sweep net. The efficiency of a sweep net on long-horned grasshoppers is not well known because adults and nymphs drop or move deeper into the foliage when approached. No treatment thresholds are available.

3. Rice water weevil *(Lissorhoptrus oryzophilus*)

Adults feed on the leaf blade surface causing narrow longitudinal scars that parallel the midvein of the leaf. Leaf scarring can be heavy but rarely even the heaviest scarring will result in economic damage. Larvae feed in and on the roots of rice plants. Feeding reduces root volume and can result in decreased ability of plants to acquire, translocate and utilize available nutrients. Damaged plants most often will not show any symptoms unless root damage (pruning) is severe. Severely damaged plants become yellow and stunted, and will have delayed maturity and reduced yield. Occasionally root pruning will be so severe plants cannot remain anchored in the soil and when disturbed will float on the water surface.

4. Rice leafminer (*Hydrellia griseola*)

Injury is caused by leafminer larvae feeding in mines between the two epidermal layers of a leaf. The mines usually contain a swelling, which is the body of the feeding or pupating leafminer. The mined area on the leaf fades to a light green color at first, then turns yellow and may appear white with time if it dries. Because high humidity is required for hatching, leafminer infestations are usually confined to leaves lying on the water surface. The larvae are mobile and move on to new leaves after old ones are completely mined. In severe infestations, they may also mine the leaf sheath. Rice leafminers generally overwinter as adult flies, and they may begin to lay eggs on leaves of a wide range of grasses associated with aquatic habitats as early as February.

When most of the leaves of the rice plants are upright, the rice leafminer will no longer cause economic losses. Consider prevailing weather conditions in cases where the need to treat is not clear cut. Cool growing conditions may favor leafminer damage.

5. Armyworms (*Pseudaletia unipuncta; Spodoptera praefica*)

The armyworm and the western yellowstriped armyworm, are found in rice fields in mid-summer. Spring and early summer generations are spent on other plants. When other food sources are depleted, larvae of either species may migrate into rice paddies, or adult moths may fly into the rice field to lay eggs.

Damage by armyworms is most serious during periods of stem elongation and grain formation. Larvae defoliate plants, typically by chewing angular pieces off leaves. They may also feed on the panicle near the developing kernels causing these kernels to dry before filling. This feeding causes all or parts of the panicle to turn white. If the entire panicle is white, the damage may also be due to stem rot or feeding by rats. The seriousness of armyworm injury depends on the maturity of the plant and the amount of tissue consumed. Significant yield reduction can occur if defoliation is greater than 25% at 2 to 3 weeks before heading.

6. Rice thrips (*Stenchaetothrips biformis*)

Leaves damaged have silvery streaks or yellowish patches, Translucent epidermis becomes visible on damaged area, Leaves curled from the margin to the middle, Leaf tips wither off when severely infested and Unfilled grains at panicle stage. Both the larvae and the adults of rice thrips use their rasping mouthparts or their single mandible to lacerate the plant tissues. They utilize their maxillae and mouth cone to suck the plant sap.

Flooding to submerge the infested field for 2 days as a cultural control practice is very effective against the rice thrips. There are identified cultivars with known resistance to the rice thrips. Predatory thrips, coccinellid beetles, anthocorid bugs, and staphylinid beetles are biological control agents that feed on both the larvae and adults.

7. Black bug, Malayan black bug, Japanese rice black bug (*Scotinophara coarctata; Scotinophara lurida; Scotinophara latiuscula*)

Both the adults and nymphs remove the plant sap by using its sucking mouthparts. They prefer the stem nodes because of the large sap reservoirs. Black bugs feed on the rice plant from seedling to maturity growth stages. Heavy infestation and “bugburn” is usually visible after heading or maturing. Feeding damage of black bugs causes half-filled and empty grains. Ten adults per hill can cause losses of up to 35% in some rice.

Mechanical control measures include the use of mercury bulbs as light traps for egg-laying adults. Light trapping of insects should start 5 days before and after the full moon. In the field, there are biological control agents such as small wasps that parasitize the eggs. Ground beetles, spiders, crickets, and red ants attack the eggs, nymphs, and adults. Both the eggs and the nymphs are fed-upon by coccinellid beetles. Ducks and toads also eat the nymphs and adults. There are 3 species of fungi attacking the nymphs and adults. For chemical control, foliar spraying of insecticides directed at the base of the rice plant is the most effective.

8. Cutworm (*Spodoptera litura*)

The adult insect is a moth with dark brown forewings having distinctive black spots and white and yellow wavy stripes. Its hindwings are whitish with gray margins and somewhat irridescent.

Keeping fields flooded may keep population of this pest at low levels. Biological control agents of cutworm are very abundant. For example, scelionid and braconid wasps are egg parasitods and grasshoppers are predators of the pest. Fungal and polyhedrosis viruses are pathogens that attack this insect pest. Insecticides like pyrethroids, may be needed when larval populations are extremely high. As pyrethroids can also cause secondary pests, spot spraying only at high population densities may be advisable.

9. Green leafhopper (*Nephotettix virescens; Nephotettix nigropictus; Nephotettix malayanus; Nephotettix cincticeps*)

Both nymphs and adults of the green leafhopper feed on rice by sucking the plant sap and plugging the vascular bundles with stylet sheaths. The green leafhoppers are most numerous during the tillering and panicle initiation stages of the crop. Seedling and booting stages are also susceptible. They migrate to the field soon after seedlings have emerged.They can cause indirect damage to the crop because of the virus diseases that they transmit.

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

10. Rice mealybug (*Brevennia rehi)*

The rice mealybug feeds on rice during the tillering and stem elongation stages of the rice crop. Favorable conditions that cause high populations of the pest may cause yellowing and stunting of the crop. The rice mealybug causes heavy losses to crops. High density (>100 mealybugs/hill) caused plants to wilt and die. Biological control can suppress the rice mealybugs. Small encyrtid wasps parasitize mealybugs. Spiders, chloropid fly, drosophilid, and lady beetles are predators of the mealybugs.

11. Mole cricket (*Gryllotalpa orientalis*)

Mole crickets occur in all rice environments. They are more common in non-flooded upland fields with moist soil. In flooded rice fields, mole crickets are usually seen swimming in the water. They are also found in permanent burrows or foraging-galleries in levees or field borders. The entrances to burrows in the soil are marked by heaps of soil.

The nymphs feed on roots and damage the crops in patches. There are cultural control, biological control, and resistant varieties that can be used for mole crickets. For example, cultural control includes maintaining standing water, which can help remove the eggs on the soil. The eggs can also be eliminated using bund shaving and plastering of fresh wet soil. The rice field can be flooded for 3-4 days. Levelling the field provides better water control. Construction of a raised nursery should be avoided to reduce feeding damage on seedlings. During land preparation, the nymphs and adults can be collected. Modern varieties with long and dense fibrous can tolerate damage better.

12. Brown planthopper; Whitebacked planthopper (WBPH) (*Nilaparvata lugens; Sogatella furcifera*)

Both the nymphs and adults of the brown planthopper insert their sucking mouthparts into the plant tissue to remove plant sap from phloem cells. During feeding, BPH secretes feeding sheaths into the plant tissue to form feeding tube or feeding sheaths. The removal of plant sap and the blockage of vessels by the feeding tube sheaths cause the tillers to dry and turn brown or a condition called hopperburn.

There are cultural controls and resistant varieties. For example, draining the rice field for 3-4 days is recommended during the early stage of infestation. Nitrogen application can be split to reduce BPH buildup. Synchronous planting within 3 weeks of staggering and maintaining a free-rice period could also decrease the build-up of BPH. The common parasites of the eggs are the hymenopteran wasps. Eggs are preyed upon by mirid bugs and phytoseiid mites. Both eggs and nymphs are preyed upon by mirid bugs. Nymphs and adults are eaten by general predators, particularly spiders and coccinellid beetles. Hydrophilid and dytiscid beetles, dragonflies, damselflies, and bugs such as nepid, microveliid, and mesoveliid eat adults and nymphs that fall onto the water surface. Fungal pathogens also infect brown planthoppers. BPH is a secondary problem due to insecticide spraying for leaf-feeding insects in the early crop stages. To reduce the risk of hopperburn, application of early season insecticide should be avoided.

13. Rice caseworm, case bearer (*Nymphula depunctalis*)

The rice caseworm feeds on rice during the seedling and tillering stages of the crop. Its damage usually starts in a flooded seedbed but does not occur after the maximum tillering stage. There are cultural control practices, which are available for the pest. For example, the use of correct fertilizer application, wider spacing (30×20 mm.), and early planting. Furthermore, draining the field, transplanting older seedlings, or growing a ratoon can also help control this insect. Sparse planting also reduces damage. Among the biological agents, snails are useful predators of eggs of the rice caseworm. The larvae are fed upon by the hydrophilid and dytiscid water beetles. Spiders, dragonflies, and birds eat the adults. There is a nuclear polyhedrosis virus, which is a potential control agent against the rice caseworm. Rice caseworm larvae are highly sensitive to insecticides. The use of foliar treatments of carbamate insecticides can control the insect pest. Pyrethroids should be avoided as they can cause secondary problems, such as brown planthoppers.

14. Rice field rats (*Rattus argentiventer; Rattus exulans; Rattus spp.; Rattus tanezumi*)

The feeding damage on the stem caused by the rice field rats may resemble insect damage although rat damage is usually distinguished by the clean cut at 45° of the tiller. The damage on the grains is similar to bird damage.

In lowland irrigated rice crops both the wet and dry seasons are favourable for rat reproduction and crop damage. In rainfed rice crops rodents have their greatest impact in the wet season. The availability of food, water, and shelter are factors, which provide optimum breeding conditions. The presence of grassy weeds also triggers their development. Effective management of rodents will involve strategic actions that limit population growth so that damage is kept below the threshold of economic concern of farmers. Strategic actions for management are most effective if they are developed on the basis of a sound knowledge of the ecology of the species to be controlled.

15. Rice gall midge (*Orseolia oryzae*)

Rice gall midge is found in irrigated or rainfed wetland environments during the tillering stage of the rice crop. It is also common in upland and deepwater rice. The adults are nocturnal and they are easily collected using light traps. During the dry season, the insect remains dormant in the pupa stage. They become active again when the buds start growing after the rains. The population density of the rice gall midge is favored mainly by cloudy or rainy weather, cultivation of high-tillering varieties, intensive management practices, and low parasitization.

The larva of the gall midge moves between the sheath and the stem to reach the growing point. It feeds inside the developing buds of a new tiller and release chemicals in its saliva causing the plant to grow abnormally to produce a hollow cavity or gall at the base of the tiller. The developing and feeding larva causes the gall to enlarge and elongate at the base. Gall appears within a week after larval entry. The infected tiller becomes abnormal and silvery in color.

Plowing ratoon of the previous crop and removing all off-season plant hosts can reduce infestation. Natural biological control agents such as platygasterid, eupelmid, and pteromalid wasps, which parasitize the larvae, is effective. The pupa is host to two species of eupelmid wasps. Phytoseiid mites feed upon the eggs, whereas spiders eat the adults.

16. Rice hispa (*Dicladispa armigera*)

The larvae or grubs mine or tunnel inside the leaves as leaf miners. Then the larvae feed on the green tissues using their mandibulate mouthparts. During emergence, the adult beetle cuts its way out from the leaf. The adult insects are external feeders. The rice hispa is a defoliator during the vegetative stage of the rice plant. Extensively damaged plants may be less vigorous. A cultural control method that is recommended for the rice hispa is to avoid over fertilizing the field. Close plant spacing results in greater leaf densities that can tolerate higher hispa numbers. To prevent egg laying of the pests, the shoot tips can be cut. Clipping and burying shoots in the mud can reduce grub populations.

17. Rice leaffolder, rice leaf roller, grass leaf roller (*Cnaphalocrocis medinalis; Marasmia patnalis; Marasmia exigua*)

The rice leaffolder is very common and can be found in all rice growth stages. The damage may be important when it affects more than half of the flag leaf and the next two youngest leaves in each tiller. Feeding damage of the rice leaffolders during the vegetative stage may not cause significant yield losses. Crops generally recover from these damages. Leaffolder damage at the reproductive stage may be important. Feeding damage, if it is very high, on the flag leaves may cause yield loss.

The highly visible symptoms are often the cause of farmers' early season insecticide use. Most of these insecticides have little or no economic returns. Instead, they can cause ecological disruptions in natural biological control processes, thus enhancing the development of secondary pests. The spray reduction also decreases farmers' exposure to health risk posed by pesticides.

18. Rice whorl maggot (*Hydrellia philippina*)

The larva uses its hardened mouth hooks to rasp the tissues of unopened leaves or the growing points of the developing leaves. The damage becomes visible when the leaves grow old. Mature larva prefers to feed on the developing leaves of the new developing tillers at the base of the rice plant. There is no cultural control for rice whorl maggot. Small wasps parasitized the eggs and the maggots. Dolicopodid flies prey on the eggs and ephydrid flies and spiders feed on the adults. The rice plant can compensate for the damage caused by the rice whorl maggot. Usually, the symptoms disappear during the maximum tillering stage of the crop.

19. Short-horned grasshoppers, Oriental migratory locust (*Oxya hyla intricata; Locusta migratoria manilensis)*

Both species are sometimes important pests of the rice crop. The nymphs and adults feed on the leaf by consuming large amounts of leaves. Serious damage caused by short-horned grasshoppers has been reported. Oriental migratory locust migrates in swarm and can be highly abundant. Outbreaks of the insect pest usually occur during drought.

Among the cultural control options, the following are recommended for short-horned grasshoppers: flooding the stubbles, shaving of bunds, sweeping along the bunds and adults can be picked directly from the foliage at night because they are sluggish. Short-horned grasshoppers and oriental migratory locusts are generally controlled under by natural biological control agents. Scelionid wasps parasitize the eggs of short-horned grasshopper. Nymphs and adults are hosts of parasitic flies, nematodes, and fungal pathogens. They are also infected by a certain species of an entomophthoralean fungus. Among the predators, birds, frogs, and web-spinning spiders are known. A platystomatid fly and mite prey on the eggs of oriental migratory locust. Different species of ants feed on the nymphs and adults. They are also prey to birds, bats, field rats, mice, wild pigs, dogs, millipedes, fish, amphibia, reptiles, and monkeys. A fungus also infects the insect pest. Chemical management includes the use of poison baits from salt water and rice bran. Foliar sprays can also control grashoppers in rice fields.

20. Golden apple snail, golden miracle snail, Argentine apple snail, channelled apple snail, apple snail, golden "kuhol", Miami golden snail (*Pomacea canaliculata*)

The golden apple snail has a muddy brown shell. The shell is lighter than the darker and smaller native snails. Its succulent flesh is creamy white to golden pinkish or orange-yellow. The male has a convex operculum that curves out or away from the shell, whereas the female lid curves into the shell. The eggs are bright pink or strawberry pink. With age, they lighten in color or turn light pink when about to hatch.

The golden apple snail is considered a major problem in direct-seeded rice. During dry periods or drought, the golden apple snails remain inactive in rice fields. They become active when fields are flooded. There are physical, mechanical, cultural, biological, and chemical control measures recommended against the golden apple snail. The physical control practice is to install screens with 5 mm mesh at water inlets. This can minimize the entry of snails into the rice fields and will also facilitate hand-collection. For easier drainage and collection of the golden apple snail, canalets can be constructed along bunds and inside paddies. Attractants like newspaper can be used. Depressed strips can be constructed to retain a small amount of water drainage. This method also confines the snail to limited areas, hence handpicking can be facilitated. It can be done during the final harrowing period.

21. Yellow stem borer (YSB), White stem borer (WSB), Striped stem borer (SSB), Gold-fringed stem borer, Dark-headed stem borer, Pink stem borer (*Scirpophaga incertulas; Scirpophaga innotata; Chilo suppressalis; Chilo auricilius; Chilo polychrysus; Sesamia inferens*)

The yellow stem borer is an important pest of irrigated rice. During the vegetative stage, larval feeding causes deadheart. The rice plant can compensate by growing new tillers. Stem borers can be managed using cultural control measures, biological control agents, the use of resistant varieties, and chemical control.

Cultural control measures include proper timing of planting and synchronous planting. The crops should be harvested at ground level to remove the larvae in stubble. Likewise, stubble and volunteer rice should be removed and destroyed. Plowing and flooding the field can kill larvae and pupa in the stubbles. At seedbed and transplanting, egg masses should be handpicked and destroyed. The level of irrigation water can be raised periodically to submerge the eggs deposited on the lower parts of the plant. Before transplanting, the leaf-top can be cut to reduce carry-over of eggs from the seedbed to the field. Application of nitrogen fertilizer should be split following the recommended rate and time of application.

22. Zigzag leafhopper (*Recilia dorsalis*)

In large numbers, these insects become important because they transmit viral diseases such as rice tungro, dwarf, and orange leaf viruses. They feed on the rice plant during all most all the stages of the crop particularly the vegetative stage. Zigzag leafhopper may transmit virus diseases but its low population makes the insect a minor pest of rice. There are parasites and predators that help regulate the population of this insect. Mymarid wasp and the mirid bug prey on the eggs. Dryinid wasp and pipunculid flies parasitize both the adults and the nymphs and spiders eat the adults.

23. The white-backed planthopper (*Sogatella furcifera*)

It is one of the five major rice pests. Both nymphs and adults suck the plant sap which results in leaf yellowing, reduced tillering, stunting, unfilled grains and yield loss. In young seedlings wilting and death occurs due to its attack. Severe infestation can also lead to hopperburn. Pest control has been replaced by pest management because of its adverse effect on the environment besides the development of pesticide resistance, pest resurgence and the high cost of pesticides. Because host plant resistance is a key component of pest management, studies on the preference of WBPH to different rice varieties were undertaken to obtain better understanding on insect-plant interactions during selection of their host plant.

Agricultural substance

Chemical substance which use plant production, generally can be defined in to 3 groups, they are: pesticide, fertilizer and plant growth regulator. There are many type of pesticide categorize by propose of utilized such as: rodenticide for rodent control, insecticide for insect control, fungicides (for fungus control), herbicide (for weed control), molluscicide for snails control, nematicides for nematode control, avicide for bird control.

Pesticide

Pesticide can be defined to rodenticide**,** insecticide**,** fungicides**,** acaricide, nematicide, avicide and herbicide**.** Rodenticide is a poisons for rat control. Zinc phosphide is the most deadly and the most popular because it kills very quickly. Sodium arsenate and barium carbonate have both been used for systematic destruction of rats on paddy-fields. Slow-acting poisons are anticoagulants that induce death after a rat ingests poisons for several days.

Insecticide is a pesticide which includes larvicides and ovicides used against the eggs and larvae of insects in all developmental forms. Insecticides fall under variety of classes like organophosphates, pyrethroids, neonicotinoids, biological insecticides and many more which are used against insects, pests etc. Use of insecticides is one of the major factor behind the increase in agricultural productivity. There are two type of insecticides are used: contact insecticide and systemic insecticide. Classification of insecticides by their chemical structure may categorized as: Organochlorines (DDT, perthane). Organophosphates (malathion, methy parathion, diazinon), carbamates (carbofuran, MIPC, carbaryl), formamidines, etc.

Fungicides are the chemical compounds used to preclude the spread of fungi or plants in crops and gardens which can campaign serious damage resulting in loss of yield. Sometimes, to fight with fungal infections fungicides are used. Two categories of fungicides are usually available, they are: contact fungicide: it kills fungi when sprayed on its surface, systemic fungicide: it is absorbed by the plant first and then show its effect. Chemical based fungicides are: mancozeb, tricyclazole, carbendazim, hexaconazole, metalaxyl, benomyl, difenoconazole, propiconazole, kitazin, copper oxychloride, copper hydroxide, tridemorph, propineb.

Herbicides are classified as pre-plant, pre-emergence, and post-emergence.
Pre-plant herbicides such as glyphosate are applied before the crop to kill weeds that have germinated before planting or those that were left from fallowing. Pre-emergence herbicides such as butachlor are applied after the crop has been planted and before weeds to prevent establishment of weeds right after planting emerge. Pre-

emergence herbicides are usually applied to the soil surface. Post-emergence herbicides such as 2,4-D are applied after weeds have emerged. Post-emergence herbicides not be toxic to the crop and usually need to have direct contact with the weed foliage to be effective. Since these products usually require contact with the weed, it is important to make sure that there is sufficient time after application without rainfall.

Chemical products used to control nematodes have generally fallen into two major classes, fumigants and non-fumigants or "contact nematicides", based on their chemical and physical characteristics.

An important factor to consider in the use of agrochemicals is the residual nature of the product both in terms of its subsequent effect on crops planted in that field and on the environment. Some products break down very quickly and so become essentially inert to the environment. Others remain active even into the next crop, which can cause problems if the product is not recommended for the crop.

Fertilizer

Fertilizer is a substance that contains plant nutrients that are added to the environment around a plant. Usually, fertilizer is added to soil or water, but some fertilizers can also be sprayed directly onto plant leaves, or into the air. The following are examples of different kinds of fertilizers:

1. Chemical fertilizer is defined as non-living materials of entirely moderately artificial origin. These chemical fertilizers do not replace trace mineral elements. Some examples of chemical fertilizers are ammonium nitrate, potassium sulfate, and superphosphate, or triple superphosphate.

2. Organic fertilizer is material of plant and animal origin that are applied to the soil for increasing the yields of crops. Manures and other organic sources are used to improve soil fertility and soil organic matter content and to provide micronutrients and other growth factors not normally supplied by inorganic fertilizers. Application of these materials may also enhance microbial growth and nutrient turnover in soil. Organic material or manure is normally applied uniformly across the field, two or more weeks before being incorporated into the soil during land preparation. Sometimes rice straw is directly composted in the field.

Organic waste material (OWM) is a kind of organic fertilizer which effected on rice growth, yield and nutrient uptake. The efficiency of OWM as nitrogen (N) source for lowland rice depends on the C/N ration and total N content (Panichsakpatana et al., 1991).

3. Biofertilizer is microorganisms that increase the amount of nutrients available to plants. The preparations with living or latent specific microbial strains those are associated with the cycling of nitrogen, phosphorus and carbon assisting the supply of plant nutrients such as blue green algae, rhizobium, azotobacter and mycorrhiza fungi.

Plant Production Knowledge Model

Agricultural science is the study of plant and animal production that is closely related to ecology both environmental factors such as soil, water, climate, and other livings that can affect those plant and animal. Community ecology is the study of co-existing, interdependent populations of organisms. In many cases relatively few species exert a major controlling influence on the entire community. The major interactions within the community are competition, parasitism, predation, mutualism and commensalism. Ecosystem Ecology is the community of organisms in an area and their non-living environment. The concept of communities interacting with their physical environment such as organic matter, minerals, water; and energy is the basis of ecology. It can be defined in terms of energy and matter fluxes and can be described at various scales such as crop ecology, landscape ecology or global ecology (IRRI, 2008).

On the individual plant scale, genetic and environmental factors combine to affect plant physiology in such processes as energy fixation and metabolism, water and nutrient uptake, and carbohydrate partitioning. However, growers manage entire populations of plants rather than individuals, and cultural practices on the field scale affect physiological processes at the plant level. To understand whole-plant processes that affect crop yield, consider plant growth and development as the integration of the flow of energy, water, and nutrients through the plant, Beverly *et al.* (1993) described the whole plant model about physiological responses to environmental effects as follows:

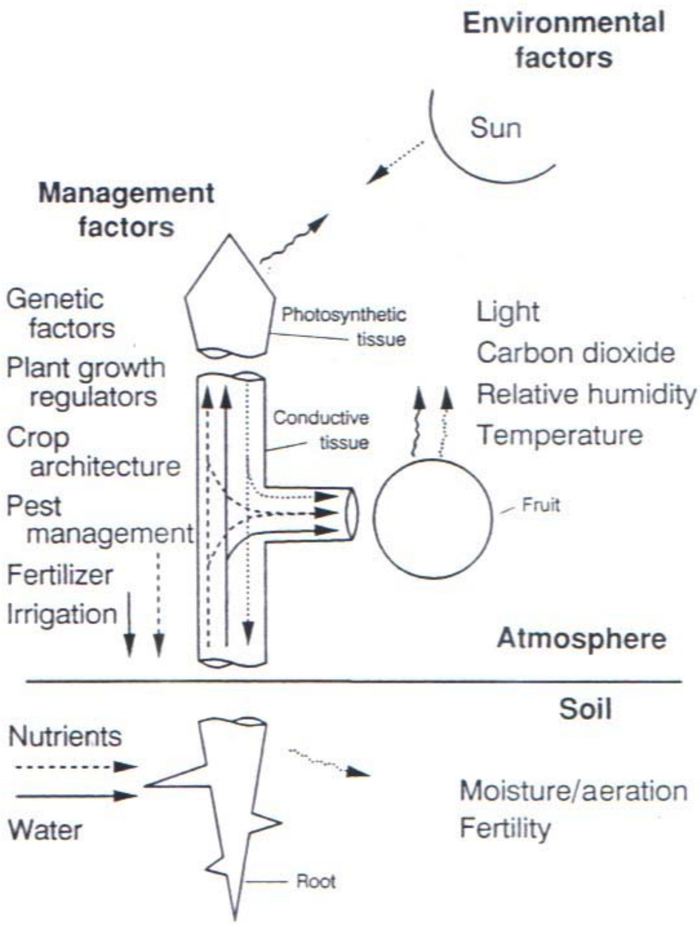


Figure 1 Whole plant model and flow of energy, water and nutrient

Note: Flows of energy (…..), water (__), and nutrients (-----) through the environment and plant. Management factors are designed to optimize yield and quality within constraints imposed by environmental conditions.

Source: Beverly *et al.* (1993)

Energy, water and nutrient movements through the plant are relatively simple and generally unidirectional prior to the formation of storage organs. Energy is fixed by the plant through photosynthesis, then is transported in the form of photosynthates (sugars or organic acids) down the phloem to the roots. Energy exits the plant from all tissues in the form of heat of respiration. Water and nutrients flow through the soil and are taken up by roots, then transported through the xylem primarily to the leaves. In leaves, nutrients are incorporated into structural organs, remain in the cytoplasm, or accumulate in the vacuole, whereas water is lost by transpiration.

Environmental factors affecting energy, water, and nutrient flows within the plant include atmospheric and soil factors. Atmospheric environmental conditions include solar radiation, carbon dioxide concentration, relative humidity, and temperature, which are virtually unmanageable in field production.

Temperature factor affects rice development. Rice is adaptable to areas with abundant sunshine and average temperature above 20°C – 38 °C. Temperature below 15 °C retard seedling development, delay transplanting, slow tiller formation, delay reproductive growth and consequently reduce grain yields. The lower temperature limits for germination are difficult to estimate and vary with variety. Optimum germination is in the range of 18°C - 33°C, germination is arrested at 50°C. A temperature variation during each crop season and changes from season are complex and affect plant growth and maturity in different way (Luh, 1991).

Day length is a major factor influencing the development of rice plant, especially its flowering characteristics. Average solar energy for rice flowering is 350 $cal/cm^2/day$. Photoperiod that are longer or shorter than the optimum delay the flowering of photoperiod sensitive variety.

Water is the most important factor influencing the distribution of rice. The major benefits from flooded soil are the enhance availability of nutrients, especially N, P, enhanced nitrogen fixation and less competition from weeds. On the other hand over flooded cause of rice elongation, tall weak and low yield. Furthermore a lack of water affect to rice growth and competition from weeds (Luh, 1991).

Soil factors include soil physical conditions, which determine water and oxygen supply to roots, and soil fertility, which determines the supply of nutrients to roots. The soil environment is more manageable than the atmospheric environment, albeit indirectly. The environmental conditions establish constraints within which growers must operate. The soils on which rice growth are as vary as a climatic regime to which the crop is exposed: texture ranges from sand to clay, pH from 3 to 10, organic matter content from 1 to 50%, salt content from 0 to 1% and sufficient nutrient. Fertilizer used for soil improvement such as acid or basic soil. The same time a rich soil affect to vegetative growth more than reproductive growth (De Datta, 1981).

Crop nutrients are the elements, or simple inorganic compounds, necessary, for growth of plant and not synthesize during the normal metabolic processes. Essential elements for rice are 17 elements as follows C, H, O, N, P, K, S, Ca, Mg, Zn, Fe, Cu, Mo, B, Mn, Cl and Ni. All Essential element must be present in optimum amounts and in forms usable by rice plants. When planted in the same area longtime, because rice uptake mineral (the lacking nutrient) to plant growth development. Cultural practices, ecological conditions, varieties, different latitudes or different regions, make different in nutrient uptake patterns (Attanandana and Prateep, 2008; Osotsapar, 2003)

Fertilizer application, either directly onto the plant or to the soil, is the most direct cultural intervention when nutrient deficiencies threaten to limit crop yield or quality. Applying fertilizer increase the supply of nutrients in the soil, but chemical transformation and soil condition affect root uptake of those nutrients. Climate effects, nutrient interactions, physical and chemical process in the soil complicate the issue of nutrient availability and uptake.

Genetic management for quality production includes both farmer selection from available cultivars and the development of new cultivars with desirable characteristics through traditional plant breeding or biotechnology. The challenge is to find cultivars that satisfy the need of the farmer for profitability and the demand of the consumer for quality at purchase and at consumption.

Whereas plants integrate their individual environmental conditions into physiological responses as dictated by their particular genetic codes, farmers must manage entire population of plants. Field-scale management requires the integration of production management, information and uncertainty regarding legal, socioeconomic, environmental and biological factors that affect yield quality, and profitability. Cause of the unmanageable environmental factors, farmers attempt to optimize yield and quality indirectly through genetic management, cultural practice, pest management, and soil management. Temperature regimes can be managed passively to a certain extent by varying planting dates to alter the temperature conditions to which crops are exposed (Smittle, 1986). As relative humidity cannot be controlled in the field, the most direct method to address water flow in plants is to increase the availability of water in the root zone by irrigation. Thus, it is important to realize that farmers use only indirect interventions in attempts to optimize the quality of physilological and cultural effects. Example of consideration affecting crop production management decision on a field scale was described in the table following.

Table 1 Environmental and biological factors affecting crop production management on a field scale

Decision domain	Considerations: Environmental	Considerations: Biological
Crop and cultivar selection	Temperature extremes: length of growing season; soil conditions	Crop adaptation; pest resistance
Land preparation	Risk of erosion; risk of decline in soil productivity	Soil biology
Crop establishment timing and method	Soil temperature and moisture; soil strength	Germination; emergence; growth rate
Irrigation management	Temperature; humidity; rainfall amount and distribution; light intensity; soil moisture; soil characteristics	Water required by crop; water available to crop; crop water use efficiency
Fertility management	Soil chemical conditions; soil moisture and aeration; soil temperature	Soil nutrient transformations; plant nutrient uptake; growth rate; crop residue contribution to subsequent crops
Pest management	Temperature; humidity; rainfall	Weed; insect and disease populations; population of pest predators or parasites
Harvest timing and method	Temperature; rainfall; light intensity; humidity	Rate of maturation; risk of loss due to over maturity or pest damage

Source: Beverly *et al.* (1993)

Classification and Nomenclature

Biological taxonomic classification

In biological taxonomy, a kingdom is a taxonomic rank in either (historically) the highest rank, or (in the new three-domain system) the rank below domain. Each kingdom is divided into smaller groups called phyla (or "divisions"). Currently, many textbooks from the United States use a system of six kingdoms (Animalia, Plantae, Fungi, Protista, Archaea, and Eubacteria), while British and Australian textbooks describe five kingdoms (Animalia, Plantae, Fungi, Protista, and Prokaryota or Monera). The classifications of taxonomy are life, domain, kingdom, phylum, class, order, family, genus, and species (Cavalier-Smith, 1998).

Carolus Linnaeus distinguished two kingdoms of living things: Animalia for animals and Vegetabilia for plants (Linnaeus also treated minerals, placing them in a third kingdom, Mineralia). Linnaeus divided each kingdom into classes, later grouped into phyla for animals and divisions for plants.

Carl Woese divided the prokaryotes (Kingdom Monera) into two kingdoms, called Eubacteria and Archaebacteria. Carl Woese attempted to establish a Three Primary Kingdom (or Urkingdom) system in which Plants, Animals, Protista, and Fungi were lumped into one primary kingdom of all eukaryotes. The Eubacteria and Archaebacteria made up the other two urkingdoms. The initial use of "Six Kingdom Systems" represents a blending of the classic Five Kingdom system and Woese's Three Kingdom system. Such Six Kingdom systems have become standard in many works. Each kingdoms was described as follows *(*Woese *et al.*, 1990):

Bacteria are a large group of unicellular microorganisms. Typically a few micrometres in length, bacteria have a wide range of shapes, ranging from spheres to rods and spirals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a milliliter of fresh water; in all, there are approximately five nonillion bacteria on earth, forming much of the world's biomass. Bacteria are vital in recycling nutrients, with many important steps in nutrient cycles depending on these organisms, such as the fixation of nitrogen from the atmosphere and putrefaction. However, most bacteria have not been characterized, and only about half of the phyla of bacteria have species that can be cultured in the laboratory.

Once regarded as plants constituting the class Schizomycetes, bacteria are now classified as prokaryotes. Unlike cells of animals and other eukaryotes, bacterial cells do not contain a fully differentiated nucleus and rarely harbour membrane-bound organelles. Although the term bacteria traditionally included all prokaryotes, the scientific classification changed after the discovery in the 1990s that prokaryotic life consists of two very different groups of organisms that evolved independently from an ancient common ancestor. These evolutionary domains are called Bacteria and Archaea.

Animals are a major group of multicellular, eukaryotic organisms of the kingdom Animalia or Metazoa. Their body plan eventually becomes fixed as they develop, although some undergo a process of metamorphosis later on in their life. Most animals are motile, meaning they can move spontaneously and independently. Animals are also heterotrophs, meaning they must ingest other organisms for sustenance.

Plants are living organisms belonging to the kingdom Plantae. They include familiar organisms such as trees, herbs, bushes, grasses, vines, ferns, mosses, and green algae. About 350,000 species of plants, defined as seed plants, bryophytes, ferns and fern allies, are estimated to exist currently. As of 2004, some 287,655 species had been identified, of which 258,650 are flowering and 18,000 bryophytes. Green plants, sometimes called metaphytes or viridiplantae, obtain most of their energy from sunlight via a process called photosynthesis.

Fungi were previously included in the plant kingdom, but are now seen to be more closely related to animals. Unlike embryophytes and algae which are generally photosynthetic, fungi are often saprotrophs: obtaining food by breaking down and absorbing surrounding materials. Most fungi are formed by microscopic structures called hyphae, which may or may not be divided into cells but contain eukaryotic nuclei. Fruiting bodies, of which mushrooms are most familiar, are the reproductive structures of fungi.

Virus classification involves naming and placing viruses into a taxonomic system. Virus classification is based mainly on phenotypic characteristics, including morphology, nucleic acid type, mode of replication, host organisms, and the type of disease they cause. Like the relatively consistent classification systems seen for cellular organisms, virus classification is the subject of ongoing debate and proposals. This is largely due to the pseudo-living nature of viruses, which are not yet definitively living or non-living. As such, they do not fit neatly into the established biological classification system in place for cellular organisms, such as plants and animals. Accompanying this broad method of classification are specific naming conventions and further classification guidelines set out by the International Committee on Taxonomy of Viruses.

Soil Taxonomy

Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.

Standard rounding conventions should be used to determine numerical values. Soil colors (hue, value, and chroma) are used in many of the criteria that follow. Soil colors typically change value and some change hue and chroma, depending on the water state. In many of the criteria of the keys, the water state is specified. If no water state is specified, the soil is considered to meet the criterion if it does so when moist or dry or both moist and dry.

Soil Categories

Soil Taxonomy has six categories. These are, from top to bottom, order, suborder, great group, subgroup, family and series. Ten classes are in the order level. Criteria used to differentiate orders are highly generalized and based more or less on the kinds and degrees of soil-forming processes. Mostly these criteria include properties that reflect major differences in the genesis of soils **(**USDA, 2006).

A soil suborder category is a subdivision of an order within which genetic homogeneity is emphasized. Soil characteristics used to distinguish suborders within an order vary from order to order. The great group category is a subdivision of a suborder. They are distinguished one from another by kind and sequence of soil horizons. All soils belonging to one of the suborders of Aridisols have argillic horizons. They also may have additional diagnostic horizons such as a petrocalcic as well as several others. Great group categories are divided into three kinds of subgroups: typic, intergrade and extragrade. A typic subgroup represents the basic concept of the great group from which it derives. An intergrade subgroup contains soils of one great group, but have some properties characteristic of soils in another great group or class. Extragrade subgroup soils have aberrant properties that do not intergrade to any known soil. A soil family category is a group of soils within a subgroup that has similar physical and chemical properties that affect response to management and manipulation. The principal characteristics used to differentiate soil families are texture, mineralogy and temperature. Family textural classes, in general, distinguish between clayey, loamy and sandy soils. For some soils the criteria also specify the amount of silt, sand and coarse fragments such as gravel, cobbles and rocks.

Soil Nomenclature

The soil nomenclature was developed so that each class had a name that was recorded to help memory, and that would connote some properties of the soils of each class. The name also places a class in the system so that a person can recognize both the category of the class and the classes of the higher categories to which it belongs. Soil series are abstract names sometimes taken from some local geographic feature near the site where the series was first established. Examples include the Gila, Graham, Mohave, Tubac and Moenkopie series. Other names are variants of these place names and still others simply are coined **(**USDA, 2006).

Soil Series in Thailand

Thai soils were classified into 9 within 12 orders such as : soil orders Ultisols, Inceptisols, Alfisols, Entisols, Mollisols , Vertisols, Spodosols, Oxisols and Histosols. In addition soil series in Thailand were defined to 239 series in 62 groups (Land Development Department. 2008).

Agricultural subject classification

The United Nations Food and Agriculture Organization (FAO) has developed a classification and scope of agricultural information called the AGRIS/CARIS Subject Categorization Scheme. This is used as a standard for analyzing and classifying information related with plant production, animal production, veterinary, fishery, forestry, soil science and natural resource, food science, agricultural economics, agricultural engineering. There are a total of 17 main categories and 115 sub-categories. As for plant production subject, the classification can be categorized into three main categories and 27 sub-categories, as follows: (FAO, 1998)

Table 2 AGRIS/CARIS Subject Categorization Scheme related with plant production

Code	Subject Categories	Code	Subject Categories
F	**Plant Science and Production**	**H**	**Plant Protection**
F01	Crop husbandry	H01	Protection of plants - General aspects
F02	Plant propagation	H10	Pests of plants
F03	Seed production	H20	Plant diseases
F04	Fertilizing	H50	Miscellaneous plant disorders
F06	Irrigation	H60	Weeds
F07	Soil cultivation	**P**	**Natural Resources, Environment**
F08	Cropping patterns and systems	P30	Soil science and management
F30	Plant genetics and breeding	P31	Soil surveys and mapping
F40	Plant ecology	P32	Soil classification and genesis
F50	Plant structure	P33	Soil chemistry and physics
F60	Plant physiology, biochemistry	P34	Soil biology
F61	Plant physiology - Nutrition	P35	Soil fertility
F62	Plant physiology - Growth and development	P36	Soil erosion, conservation, reclamation
F63	Plant physiology - Reproduction		
F70	Plant taxonomy and geography		

Ontology and Knowledge Management

Ontology Definition

Ontology in Philosophy is a branch of metaphysics that deals with reality itself, as apart from the subjective impressions and thoughts of the person who experiences it." (Harriman, 2007)

In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members). The definitions of the representational primitives include information about their meaning and constraints on their logically consistent application (Gruber, 2007). An ontology is an explicit specification of a conceptualization, where "a conceptualization" is an abstract, simplified view of the world that we with to represent for some purpose (Gruber, 1992).

Concept is something formed in the mind; a thought or notion. Ogden and Richards (1923) said that the three components for communication are concept, symbol, and thing, as indicated by the "Meaning Triangle" below:

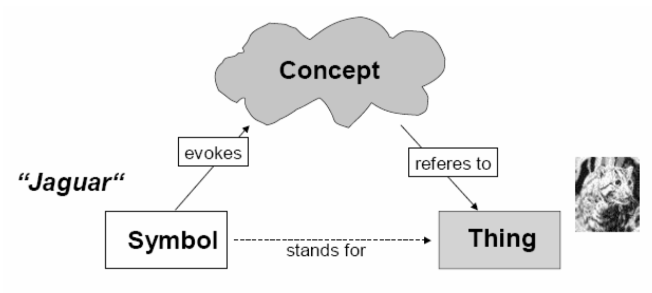


Figure 2 Meaning Triangle of Communication

Source: Odgen and Richards (1923)

An ontology is a medium of human expression. All forms of knowledge representation including ontologies are both mediums of expression for human beings and ways for us to communicate with machines in order to tell them about the world. (see figure below):

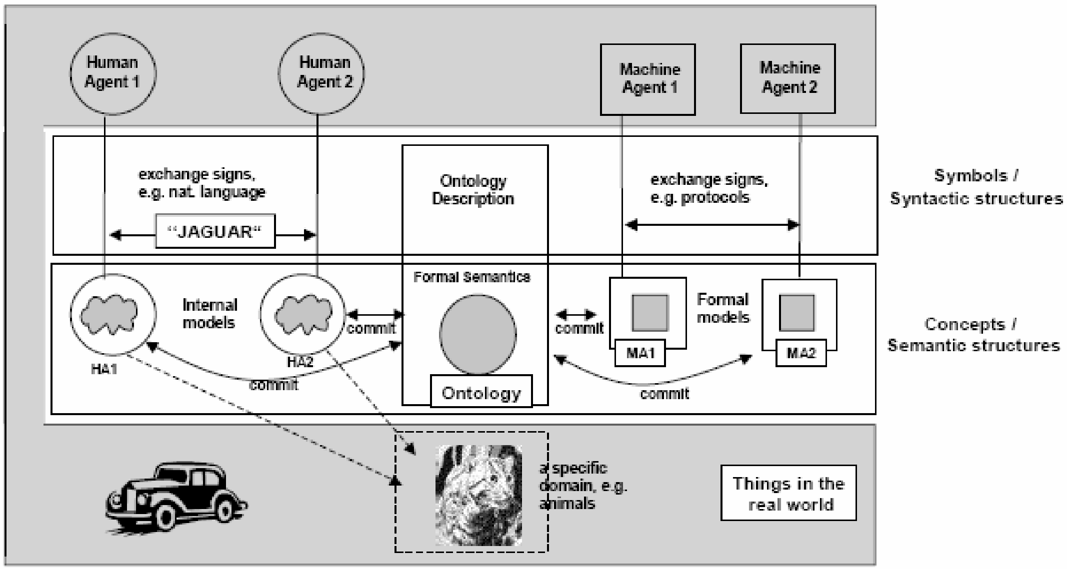


Figure 3 Human and Machine Communication

Source: Maedche (2001)

Ontologies are generally organized in hierarchical structures: a set of concepts (or the terms used to represent them) describing a domain can be used as a skeleton foundation for a knowledge base. Ontologies provide an organizational framework for the concepts, organized in a system of hierarchical and associative relations that allows reasoning about that knowledge (In this work the word "concept" refers to the ontological meaning as presented in part of ontology definition. The word "term" ("symbols") is actually used to indicate the linguistic representation of the concepts. However, sometimes these two expressions may be used interchangeably).

Ontologies can also be considered as conceptual schemata, intended to represent knowledge in the most formal and reusable way. Formal ontologies are represented in logical formalisms, such as Web Ontology Language (OWL) (Dean *et al.*, 2004), which allow automatic inferencing over them and over other datasets aligned to them.

In the context of database systems, ontology can be viewed as a level of abstraction of data models, analogous to hierarchical and relational models, but intended for modeling knowledge about individuals, their attributes, and their relationships to other individuals. Ontologies are typically specified in languages that allow abstraction away from data structures and implementation strategies; in practice, the languages of ontologies are closer in expressive power to first-order logic than languages used to model databases. For this reason, ontologies are said to be at the "semantic" level, whereas database schema are models of data at the "logical" or "physical" level. Due to their independence from lower level data models, ontologies are used for integrating heterogeneous databases, enabling interoperability among disparate systems, and specifying interfaces to independent, knowledge-based services (Gruber, 2007).

Types of Ontology

Ontologies are typically classified depending on the generality of the conceptualization behind them, their coverage, and intended purpose (Davies *et al.*, 2006) :

1. Upper-level ontologies represent a general model of the world, suitable for large variety of tasks, domains, and application areas.

2. Domain ontologies represent a conceptualization of a specific domain, for example road-construction or medicine.

3. Application and task ontologies are such suitable for specific ranges of application and tasks.

Guarino (1998) classified typed of ontologies according to their level of dependence on a particular task or point of view, as follows:

1. Top-level ontologies describe very general concept and provide general notions under which all root-concepts in existing ontologies should be linked.

2. Domain ontologies provide vocabularies about concepts within a domain and their relationship, activities, theories and elementary principles.

3. Task ontologies describes the vocabulary and the structure of the knowledge related to a generic task or activity.

4. Application ontologies contain all of the definitions needed to model the knowledge required for a particular application.

Mizoguchi *et al.* (1995) proposed four kinds of ontologies as follows:

1. Content ontologies for reusing knowledge which include domain ontologies, task ontologies, and general or common ontologies.

1.1 Domain ontologies, subdivided into: Object ontologies, Activity ontologies, and Field ontologies.

1.2 Task ontologies, subdivided into: Generic Nouns ontologies, Generic Verbs ontologies, Generic Adjectives ontologies.

1.3 General / Common ontologies, which contains generic elements such as: Things, Events, Time, Space, Causality, Behavior, Function, etc.

2. Communication ontologies ("tell & ask") for sharing knowledge.

3. Indexing ontologies for retrieval.

4. Meta-ontologies or knowledge representation ontology.

Lassila and McGuinness (2001) classified ontology according to the richness of its internal structure. They point out the following categories of ontological systems: controlled vocabularies, glossaries, thesauri, informal is-a hierarchies, formal is-a hierarchies, formal is-a hierarchies which contains instances, frames, value restriction, and general logical constraints.

van Heijst *et al.* (1997) identified types of ontologies base on subject of the conceptualization, as follows:

1. Knowledge Representation (KR) ontologies, capture the representation primitives used to formalize knowledge under a given knowledge representation paradigm.

2. General or Common Ontologies, used to represent reusable common sense knowledge across domain.

Example of Domain Ontology

The Rice ontology (RO) developed in Japan, is an ontology specialized for genome informatics of rice and has been developed as biological domain ontology, applies to all organisms useful to exchange genome informatics. It is necessary to provide the common controlled vocabulary for researchers interested in the field. In the biological domain ontology, gene, gene product, and biological process were connected for covering knowledge of molecular genetics and genome informatics (Takeya *et al.*, 2003)

The Plant Ontology (PO) developed by Jaiswal and others, contains the controlled vocabulary, available in ontology format, to the flowering plant for use in the annotation of gene and phenotype expression datasets. The ontology describes morphological and anatomical landmarks that define various stages of a plant's life cycle (growth stages) and plant structures (developmental stages) such as: vegetative stage, reproductive stage, germination, etc. The controlled vocabularies are used to generically describe plant anatomy, morphology, growth and developmental stages and annotate various datasets from plant genomics and genetics. The PO is constructed by integrating basic terms from three species-specific ontologies that had previously been developed for rice, maize and Arabidopsi and extended introducing terms required by the families Solanaceae and Fabaceae. The vocabularies represent common concepts in plant biology and offer a unifying language that serves as a foundation for describing spatial and temporal aspects of flowering plant biology in a comparative context (Jaiswal *et al*., 2005).

The *Zea mays* ontology is a sample of plant ontology. It presents plant structure, included anatomy and morphology of maize. It comprises also international botanical terms, references, synonyms, and phylogenetic information and is open-source. The arrangement of controlled vocabulary terms reflected current understanding of the biological relationships between the associated plant parts at the organelle, cell, tissue and organ level. The Zea mays ontology can be accessed via the Plant Ontology website (Vincent *et al.*, 2003).

The Crop Wild Relatives Ontology (CWR) is part of an international project, which involves both FAO and Bioversity International and other national stakeholders. The starting point for the CWR ontology was a larger set of 11,407 terms that were extracted from on-line sources (glossaries, dictionaries, pdf-publications and thematic web-pages). Terms with high relevance were grouped into themes, roughly corresponding to AGROVOC (top level) categories, or indicative of the thematic sources from which the terms were collected (biological, geographical on-line dictionaries etc), with an attempt to balance the number of terms between the groups. For the import into the ontology structure, the themes were converted to namespaces in order to preserve the grouping and allow manipulation within ontology client tools on terms based on namespaces. Before the import, the namespaces were slightly modified and adapted to some other existing ontologies. Definition of vertical and horizontal relationships between the concepts was performed. Terms were also linked to sources (URIS) through Dublin Core extensions of the ontology structure (Hulden, 2007)

Components of an ontology

Gruber (1993) identified five kinds of ontology components: classes, relations, functions, formal axioms and instances.

1. Classes represent concepts, which can be considered generic entities in the broad sense.

2. Relations represent a type of association between concepts of the domain.

3. Functions are a special case of relations.

4. Formal axioms serve to model sentences that are always true. They are normally used to represent knowledge that cannot be formally defined by other ontology components.

5. Instances are used to represent elements or individuals in an ontology.

An ontology can be characterized as comprising of four tuples (Davies *et al*., 2006):

O= <C,R,I,A.>

C is a set of classes representing concepts we wish to reason about in the given domain, such as: invoices, payments, products, prices, etc.

R is a set of relations holding between those classes , such as: relation ‘ProductHasPrice’

I is a set of instances, where each instance can be an instance of one or more classes and can be linked to other instances by relations, such as: product A isA Product; product B hasPrice 170 baht

A is set of axioms, such as: if a product has a price greater than 200 baht, shipping is free.

Noy and McGuinness (2001) described an ontology as a formal explicit description of concepts in a domain of discourse, and can include:

Classes (formal representation of concepts) are the focus of most ontologies. Classes describe concepts in the domain, properties of each concept describing various features and attributes of the concept. For example, a class of wines represents all wines. Specific wines are instances of this class. The Bordeaux wine in the glass in front of you while you read this document is an instance of the class of Bordeaux wines. A class can have subclasses that represent concepts that are more specific than the superclass. For example, the class of all wines can be divided into red, white, and rosé wines. Alternatively, we can divide a class of all wines into sparkling and nonsparkling wines.

Slots (sometimes called roles or properties) and restrictions on slots is facets (sometimes called role restrictions), describe properties of classes and instances: Château Lafite Rothschild Pauillac wine has a full body; it is produced by the Château Lafite Rothschild winery. Two slots described the wine in this example: the slot body with the value full and the slot maker with the value Château Lafite Rothschild winery. At the class level, instances of the class Wine will have slots describing their flavor, body, sugar level, the maker of the wine and so on.

All instances of the class Wine, and its subclass Pauillac, have a slot maker the value of which is an instance of the class Winery. All instances of the class Winery have a slot produces that refers to all wines (instances of the class Wine and its subclasses) that the winery produces.

Taxonomies are used to organize classes and instances in the ontology. Hierarchical and associative relationships are relationships between concepts. A relation represents the dependency between concepts in the domain. Relations in an ontology can be organized in relation taxonomies according to a specialization relationship called Subrelation-Of.

Soergel *et al*. (2004) developed an inventory of specific relationship types with well-defined semantics for the agricultural domain and explore the rules-as-you-go approach to streamlining the reengineering process. Examples of concept relationships are indicated below:

X, Y are concepts

Isa

X <includesSpecific> Y / Y <*isa*> X
X <*inheritsTo*> Y / Y <*inheritsFrom*> X

Holonymy / meronymy *(the generic whole-part relationship)*

X <*containsSubstance*> Y / Y <*substanceContainedIn*> X
X <*hasIngredient*> Y / Y <*ingredientOf*> X
X <*madeFrom*> *Y / Y* <*usedToMake*> *X*
X <*yieldsPortion*> Y / Y <*portionOf*> X
X <*spatiallyIncludes*> Y / Y <*spatiallyIncludedIn*> X
X <*hasComponent*> Y / Y <*componentOf*> X
X <*includesSubprocess*> Y / Y <*subprocessOf*> X
X <*hasMember*> Y / Y <*memberOf*> X

Further relationships examples (some from Schmitz-Esser 1999)

X <*causes*> Y / Y <*causedBy*> X
X <*instrumentFor*> Y / Y <*performedByInstrument*> X
X <*processFor*> Y / Y <*usesProcess*> X
X <*beneficialFor*> Y / Y <*benefitsFrom*> X

X <*treatmentFor*> Y / Y <*treatedWith*> X
X <*harmfulFor*> Y / Y <*harmedBy*> X
X <*hasPest*> Y / Y <*afflicts*> X
X <*growsIn*> Y / Y <*growthEnvironmentFor*> X
X <*hasProperty*> Y / Y <*propertyOf*> X
X <*hasSymptom*> Y / Y <*indicates*> X
X <*similarTo*> Y / Y <*similarTo*> X
X <*oppositeTo*> Y / Y <*oppositeTo*> X
X <*hasPhase*> Y / Y <*phase*Of> X
X <*growsIn*> Y / Y <*EnvironmentForGrowing*> X
X <*ingests*> Y / Y <*ingestedBy*> Y

The Food and Agriculture Organization (FAO) created a Concept Server (CS) using the AGROVOC thesaurus as a starting point for the conceptual knowledge base. The current term-based AGROVOC system was restructured to a concept-based system. The traditional thesaurus relationships are over generalized and refined. Here below a number of basic relationships used in the CS (FAO, 2008; http://www.fao.org/aims/cs_relationships.htm)

Table 3 Term level relationship

Thesaurus Relationship	Relationship Description
used for	X <used_for> Y. A preferred term X should be used instead of a non-preferred term Y. E.g. "foods" <used_for> "food products".
used for+	X <used_for+> Y, Z <used_for+> Y. X is used in combination with another term Z instead of the non-preferred term Y. E.g. "foods" <used for+> "food conservation", "preservation" <used for+> "food conservation".
use	Y <use> X. Describes the link between descriptor (or preferred) X and the non-descriptor (or non-preferred) Y. Use this relationship only for this purpose. E.g. "food products" <use> "foods".
related term	X <related_term> Y. Used for expressing relations between X and Y not covered by BT/NT.
acronym	Y <acronym> X. Y has acronym X. X can be a series of initial letters or parts of words and can be a pronounceable name. E.g. "Food and Agriculture Organization" <acronym> "FAO";
acronym of	X <acronym_of> Y. X is an acronym of Y. X can be a series of initial letters or parts of words and may be a pronounceable name. E.g. "FAO" <acronym_of> "Food and Agriculture Organization";

Table 3 (Continued)

Terms Relationship	Relationship Description
translation	X <translation> Y . Word X has the same meaning as Y in another language. E.g. "vache" (FR) <translation> "cow" (EN); "cow" (EN) <translation> "vache" (FR);
synonym	X <synonym> Y. A word X that means the same or nearly the same as another word Y. E.g. "bucket" <synonym> "pail"; "pail" <synonym> "bucket".
spelling variant	X <spelling_variant> Y. A variation in the way in which a word is spelt. E.g. "organisation" <spelling_variant> "organization"; "organization" <spelling_variant> "organisation";
scientific taxonomic name of	X <scientific_taxonomic_name_of> Y. X is used in the domain of science or in the practice of classification for Y. E.g. "Saintpaulia" <scientific_taxonomic_name_of> "African violet";
scientific taxonomic name	Y <scientific_taxonomic_name> X. Y is represented in the domain of science or in the practice of classification by a name X. E.g. "African violet" <scientific_taxonomic_name> "Saintpaulia";
abbreviation of	X <abbreviation_of> Y. A letter or group of letters X taken from one or more words and employed to represent Y for the sake of brevity. E.g. "Corp." <abbreviation_of> "Corporation"; "e.g." <abbreviation_of> "exempli gratia".
abbreviation	Y <abbreviation> X. A fully-spelled out term or name Y has shortened form X consisting of a letter or group of letters taken from one or more words employed to represent them for the sake of brevity. E.g. "Corp." <abbreviation> "Corporation"; "e.g." <abbreviation> "exempli gratia".

Table 4 Concept level relationship

Relationship	Relationship Description
scope note reference	X <scope_note_reference> Y. The scope notes for the term X contains information on the term Y. E.g.: "foods" <scope_note_reference> "feeds".
is referenced in scope note	Y <referenced_in_scope_note> X. Term Y is contained in the scope explanatory notes for the term X. E.g., "feeds" <referenced_in_scope note> "foods".
broader term	X <broader_term> Y. X is in some sense more specific than Y. X is the most general term that is more specific than Y. E.g. "soups" <broader_term> "foods";
narrower term	Y <narrower_term> X . Y is in some sense more general than X. Y is the most specific term that is more general than X. E.g. "foods" <narrower_term> "soups".
subclass of	Y <subclass_of> X. Y has all the features of X plus additional ones which make it more specific than X. E.g. { cow's milk } <subclass_of> { milk }.
superclass of	X <superclass_of> Y. X is more general than Y in the sense that X is characterized by having a subset of the features of Y. E.g. { milk } <superclass_of> { cow's milk }.
part of	Y <part_of> X. Part Y is a constituent of entity X. Use this relationship when none of the other partitivity relations (<component>, <composed_of>, <portion>, <member>, <includes_subprocess>) apply. E.g. in a plant ontology: {PlantPart} <part_of> {taxon}
part	X <part> Y. A composite entity X that can be identified as having one or more parts Y. Use this relationship when none of the other partitivity relations (<component>, <composed_of>, <portion>, <member>, <includes_subprocess>) apply.
used as	X <used_as> Y. Thus far, restricted to plant domain, i.e., {Taxon} <used_as> {use}, and for uses of chemicals i.e., {chemical substance} <used_as> {use}. E.g.: “apple” <used_as> “fruit”; “alcohol” <used_as> “cleaner”; “ddt” <used_as> “pesticide”.
Is use of	Y <is_use_of> X. For use within the plant domain, {Use} <is_use_of> {Taxon}, And for chemical substances {use} <is_use_of> {chemical substance}. E.g.: “fruit” <is_use_of> “apple”; “cleaner” <is_use_of> “alcohol”; “pesticide” <is_use_of> “ddt”;
pest of	X <pest_of> Y. An organism X causes harm to organism Y. E.g. “Bactrocera dorsalis” <pest_of> “Litchi chinensis”;

Table 4 (Continued)

Relationship	Relationship Description
pest	Y <pest> X. An organism Y can be harmed by organism X. E.g. “Litchi chinensis” <pest> “Bactrocera dorsalis”;
grows in	X <grows_in> Y. A taxon X grows in an environment Y. Use this in the plant domain (e.g. fungi). E.g. “jasmine rice” <grows_in> “isarn region”; “rice” <grows_in> “moist soil”.
Growth environment for	Y <growth_environment_for> X. An environment Y favorable to cultivating a taxon X. This is used as the inverse relationship of <grows_in>. Use this in a plant and related domain (e.g. fungi). E.g. “isarn region” <growth_environment_for> “jasmine rice”; “moist soil” <growth_environment_for> “rice”.
Afflicted by	Y <afflicted_by> X. The health of organism Y is adversely affected by disease X. E.g. “cows” <afflicted_by> “BSE”;
afflicts	X <afflicts> Y. Disease X adversely affects the health of organism Y. E.g. “BSE” <afflicts> “cows”;
beneficial for	X <beneficial_for> Y. Agent X acts in a way that produces some condition Y that is advantageous to some beneficiary. E.g. “biological control arthropods” <beneficial_for> “biological control”; “pest control” <beneficial_for> “plant health”.
Benefits from	Y <benefits_from> X. A condition Y that is advantageous to some beneficiary is produced by the actions of an agent X. E.g. “biological control” <benefits_from> “biological control arthropods”; “plant health” <benefits_from> “pest control”.
portion of	Y <portion_of> X. Relation between a mass X and a piece Y taken from the mass. E.g. “cutting” <portion_of> “plant”; “chicken skin” <portion_of> “chicken”; “a slice” <portion_of> “a loaf of bread”;
portion	X <portion> Y. A mass X from which a piece Y can be taken. E.g. “plant” <portion> “cutting”; “chicken” <portion> “chicken skin”; “a loaf of bread” <portion> “a slice”.
Composed of	X <composed_of> Y. A relation in which X composed of Y holds is one where Y consists of the material or substance of which X is made. This relation also subsumes <ingredient_of> and <substance_of> relations. E.g. “blood” <composed_of> “blood gas”, “blood lipid”, “blood protein”.
Compose	Y <composes> X. A relation in which Y composes X holds is one where Y consists of the material or substance of which X is made. This relation also subsumes <ingredient_of> and <substance_of> relations. E.g. “blood gas”, “blood lipid”, “blood protein” <composes> “blood.”

Table 4 (Continued)

Relationship	Relationship Description
Spatially includes	X <spatially_includes> Y. Part X is an inalienable part of Y. E.g. “Africa” <spatially_includes> “Congo”; “Asia” <spatially_includes> “Southeast Asia”; “arm” <spatially_includes> “hand”.
Spatially included in	Y <spatially_included_in> X. Part X is an inalienable part of Y. E.g. “Congo” <spatially_included_in> “Africa”; “Southeast Asia” <spatially_included_in> “Asia”; “hand” <spatially_included_in> “arm”.
Member of	X <member_of> Y. A social or political unit (group or individual) X belongs to a social or political group Y. E.g. “cow” <member_of> “herd”; “Algeria”, “Benin”, “Burkina Faso”, etc. <member_of> “Francophone Africa”.
Member	Y <member> X. A social or political group Y consists of one or more subsidiary social or political units (group or individual) X. E.g. “herd” <member> “cow”; “Francophone Africa” <member> “Algeria”, “Benin”, “Burkina Faso”, etc..
caused by	Y <caused_by> X. A result Y occurs because of an agent X (animate or inanimate). E.g.: “BSE” <caused_by> “prions”; “water erosion” <caused_by> “water”;
causes	X <causes> Y. Agent X (animate or inanimate) brings about a result Y. Examples: “prions” <causes> “BSE”; “water” <causes> “water erosion”;
includes subprocess	X <includes_subprocess> Y. Process X naturally or conventionally id realized through one or more processes Y. Equivalent to <stage_of>. E.g. “milk production” <includes_subprocess> “pasteurization”.
Subprocess of	Y <subprocess_of> X. Y is one of one or more processes naturally or conventionally associated with the realization of process X. E.g. “pasteurization” <subprocess_of> “milk production”.
Derived from	X <derived_from> Y. A substance or product X obtained exclusively from source Y without any additional substance or product. E.g. “cow milk” <derived_from> “cow”; “plant oil” <derived_from> “plant”; “olive wood” <derived_from> “olive tree”; “chicken meat” <derived_from> “chicken”.

Table 4 (Continued)

Relationship	Relationship Description
Source	Y <source> X. A source Y from which a substance or product X is exclusively obtained, without any additional substance or product. E.g. “cow” <source> “cow milk”; “plant” <source> “plant oil”; “olive tree” <source> “olive wood”; “chicken” <source> “chicken meat”.
Used to make	Y <used_to_make> X. A substance or a product Y from which a product X can be mainly (in terms of importance) obtained. E.g. “cow milk” <used_to_make> “cheddar cheese”; “hops” <used_to_make> “beer” (see <composed_of>)
made from	X <made_from> Y. A product X obtained mainly (in terms of importance) from a substance or a product Y. E.g. “cheddar cheese” <made_from> “cow milk”; “beer” <made_from> “hops” (see <composed_of>)
affected_by	Y <affected_by> X. An object Y changes state because of an action of an agent X. E.g. “bacteria” <affected_by> “sterilization”; “pest” <affected_by> “pest control”; “agriculture” <affected_by> “pollution of agriculture”.
Affects	X <affects> Y. Agent X acts on object Y in a way that Y changes state. E.g. “sterilization” <affects> “bacteria”; “pest control” <affects> “pest”; “pollution of agriculture” <affects> “agriculture”.
Component of	X <component_of> Y. An object X that is a part of a whole Y and has also an existence independently from Y. E.g. “engine part” <component_of> “engine”; “leaf” <component_of> “tree”; “chromosome” <component_of> “cell”; but NOT “blood cell” <component_of> “blood”.
Component	Y <component> X. An object X that is a part of a whole Y and has also an existence independently from Y. E.g. “engine” <component> “engine part”; “tree” <component> “leaf”; “cell” <component> “chromosome”; but NOT “blood” <component> “blood cell” (see <component>.)
process for	X <process_for> Y. One or more actions, activities, methods X that produce a change or development Y. E.g.: “sterilization” <process_for> “fruit cleaning”.
Uses process	Y <uses_process> X. One or more actions, activities, methods X that produce a change or development Y. E.g.: “fruit cleaning” <uses_process> “sterilization”.

Table 4 (Continued)

Relationship	Relationship Description
Has symptom	X <has_symptom> Y. A disease X presents disease characteristic Y in an organism. E.g. “BSE” <has_symptom> “anorexia”;
indicates	Y <indicates> X. A disease characteristic Y in an organism indicates disease X. E.g. “anorexia” <indicates> “BSE”.
performed by means of	Y <performed_by_means_of> X. An object or process X mainly used to perform a process Y. See also <used_as>. E.g. "curry paste grinding" <performed_by_means_of> "curry paste grinding machine"; "weapon" <means_for> "killing"; "fishing pole" <means_for> "fishing".
means for	X <means_for> Y. An object or process X mainly used to perform a process Y. See also <used_as>. E.g. "curry paste grinding" <performed_with_instrument> "curry paste grinding machine"; "weapon" <instrument_for> "killing"; "fishing pole" <instrument_for> "fishing".
stage	X <stage> Y.

Slaughter and Soergel (2003) examined the semantic relationships in consumers’ health-related questions, physician-provided answers, and between questions and answers with the purpose of supporting the design of health consumer question-answering systems. The information present in the text was expressed using a pilot ontology that was based on the semantic relationships from the Unified Medical Language System (UMLS) Semantic Network. The extracted semantic relationships were represented as a set of instances as follows:

0 associated_with
1 . topologically_related_to
1.1 .. part_of
1.1.1 ... consists_of
1.1.2 ... contained_in
1.1.3 ... ingredient_of
1.1.4 ... component_of
1.2 .. connected_to
1.2.1 ... branch_of
1.2.2 ... interconnected_with
1.2.3 ... tributary_of
1.3 .. location_of
1.3.1 ... adjacent_to
1.3.2 ... surrounds
1.3.3 ... traverses
2 . functionally_related_to
2.1 .. affects
2.1.1 ... absorbs
2.1.2 ... delays (also 3.5)
2.1.3 ... complicates
2.1.4 ... disrupts
2.1.5 ... facilitates
2.1.6 ... increases
2.1.7 ... decreases
2.1.8 ... interacts_with
2.1.9 ... manages
2.1.10 ... prevents
2.1.11 ... treats
2.2 .. brings_about
2.3 .. performs
2.3.1 ... carries_out
2.3.2 ... exhibits
2.3.3 ... practices
2.4 .. occurs_in
2.5 .. process_of
2.6 .. uses
3 . temporally_related_to
3.1 .. co-occurs_with
3.2 .. precedes
3.3 .. age_of
3.4 .. cyclic_frequency_of
3.5 .. delays (also 2.1.2)
3.6 .. duration_of
3.7 .. time_position_of
4 . conceptually_related_to
4.1 .. analyzes
4.1.1 ... assesses_effect_of
4.1.2 ... diagnoses
4.1.3 ... measures
4.1.4 ... evaluation_of
4.1.5 ... degree_of
4.1.6 ... measurement_of
4.1.7 ... compared_to
4.1.7.1 ... . equivalent
4.1.7.2 ... . similar_to
4.1.7.3 ... . different_from
4.2 .. property_of
4.3 .. requires
4.4 .. derivative_of
4.5 .. developmental_form_of
4.6 .. method_of
4.7 .. issue_in
5 isa
Additional Relations:
definition_of
same_concept_same_term
same_concept_diff_term
has_family_relationship
relation_x

Figure 4 Pilot ontology of semantic relationships based on the UMLS Semantic Network

Ontology construction

Noy and McGuinness (2001) described the reasons to develop ontologies and how to develop them. An ontology, between other characteristics, defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them. Reasons that justify people to develop an ontology are: 1) To share common understanding of the structure of information among people or software agents. 2) To enable reuse of domain knowledge. 3) To make domain assumptions explicit. 4) To separate domain knowledge from the operational knowledge, and 5) To analyze domain knowledge.

Fundamental rules referred to design ontology are:

a. There is no one correct way to model a domain ontology. There are always viable alternatives. The best solution almost always depends on the application that you have in mind and the extensions that you anticipate.

b. Ontology development is necessarily an iterative process.

c. Concepts in the ontology should be close to objects (physical or logical) and relationships in your domain of interest. These are most likely to be nouns (objects) or verbs (relationships) in sentences that describe your domain.

Noy and McGuinness (2001) proposed seven steps to develop ontology:

Step 1. Determine the domain and scope of the ontology
Step 2. Consider reusing existing ontologies
Step 3. Enumerate important terms in the ontology
Step 4. Define the classes and the class hierarchy
Step 5. Define the properties of classes—slots
Step 6. Define the facets of the slots
Step 7. Create instances

There are several approaches in defining the classes and the class hierarchy of an ontology. Uschold and Gruninger (1996) proposed the following technique to structure ontology concepts:

1. Top-down development process starts with the definition of the most general concepts in the domain and subsequent specialization of the concepts.

2. Bottom-up development process starts with the definition of the most specific classes, the leaves of the hierarchy, with subsequent grouping of these classes into more general concepts.

3. Combination development process is a combination of the top-down and bottom up approaches by defining the more salient concepts first and then generalize and specialize them appropriately.

Ontology building is a process that aims at producing an ontology. The usually accepted stages through which an ontology is built are specification, conceptualization, formalization, implementation, and maintenance. Pinto and Martins (2004) proposed activities to be performed in the ontology development stages including:

1. Specification: Identify the purpose and scope of the ontology. The purpose is obtained by answering the question "Why is the ontology being built?" and the scope is obtained by answering the question "What are its intended uses and end users?"

2. Knowledge acquisition: Acquire knowledge about the subject either by using elicitation techniques on domain experts or by referring to relevant bibliography. Several techniques can be used to acquire knowledge, such as brainstorming, interviews, questionnaires, text analysis, and inductive techniques.

3. Conceptualization: Describe, in a conceptual model, the ontology to be built, so that it meets the specification found in the previous step. Different methodologies propose the use of different conceptual models, from informal sketchy models like mind maps™ used in to semi-formal models like the binary relations diagram or concept dictionary proposed in. The conceptual model of an ontology consists of concepts in the domain and relationships among those concepts. Relationships enhance stronger connections between groups of concepts. These groups of highly connected concepts usually correspond to different modules (sub-ontologies) into which the domain can be decomposed.

4. Formalization: Transform the conceptual description into a formal model, that is, the description of the domain found in the previous step is written in a more formal form, although not yet its final form. Concepts are usually defined through axioms that restrict the possible interpretations for the meaning of those concepts. Concepts are usually hierarchically organized through a structuring relation, such as is-a (class-superclass, instance-class) or part-of.

5. Implementation: Implement the formalized ontology in a knowledge representation language. For that, one commits to a representation ontology, chooses

a representation language and writes the formal model in the representation language using the representation ontology.

6. Evaluation: Technically judge the quality of the ontology.

7. Documentation: Report what was done, how it was done and why it was done. Documentation associated with the terms represented in the ontology is particularly important, not only to improve its clarity, but also to facilitate maintenance, use and reuse.

8. Maintenance: Update and correct the implemented ontology.

To construct an ontology, there are three basic approaches, namely;

1. Manually-driven by domain-experts: This approach relies totally on experts of the field. The experts will set the rules and concepts and sort of relationships about words and their relationship based upon experts' knowledge and experience of the knowledge domain.

2. Automatic approach: This approach will construct ontology by using a computer program, whereas the program will be produced according to rules and conditions laid out by developer with the help of experts and the computer.

3. Semi-automatic approach: This approach also uses computer program but the ontology builder will have product's accuracy and rules verified and confirmed by expert who created the rules. Semi-automatic processing of complex data is becoming possible to extract hidden and useful pieces of knowledge which can be further used for different purpose.

In automatic ontology construction process, term can be extracted by computer by the Annotation process which comprising Word segmentation process, Part-of-speech tagging (POS tagging), Name entity extraction process, Word formation recognition and Elementary Discourse Unit Segmentation (EDU segmentation) (Kawtrakul et al., 2004) applied together with Lexico-syntactic process (Imsombut, 2007).

Sini and Yadav (2009) propose guidelines for defining concepts and relationship. They propose to identify the key concepts that apply to the domain. Capitalize the concepts (e.g. "Manure"). Do not enter spaces in concept or instances names (e.g. "Rice_crop"). Organize map hierarchically: general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. Label concepts or instances in general with one word; sometimes multiple words if this can help clarifying the meaning of the concept (e.g. "Carbamate_fungicide" and/or "Carbamate_insecticide", "Rice_virus_diseases" and/or "Potato_virus_diseases"); avoid "sentences" unless strictly needed or unless cannot be modelled differently; use English only. Use symbols as literals for concepts or instances (e.g. "P" hasChemicalSymbol for "Phosphorus"). Use singular. All relationship names should be written starting with lower case and capitalizing other words, without any space. E.g. "isPerformedByMeansOf". Connect two or more concepts or instances using linking words or phrases to form a meaningful statement (e.g. "Field_preparation" "usesProcess" "Harrowing"). Every concept could be related to every other concept: choose to identify the most prominent and most useful cross-links.

Constructing ontology by automatic and semi-automatic approach can be done by many means, for example, from non-structured documents, from Thesaurus, and from dictionary (Imsombut, 2007).

AGROVOC is a comprehensive multilingual agricultural thesaurus that is developed with the cooperation of FAO and member countries. It is used for indexing data in agricultural information systems and is continually being improved and updated. The first version of AGROVOC was produced in 1982. It was distributed to all AGRIS (International Information System for Agricultural Science and Technology) Resource Centre worldwide, to be used as a reference for indexing (FAO, 1999). The Thai National AGRIS Centre has developed a Thai version of AGROVOC by using English AGROVOC as source (Thunkijjanukij *et al.*, 2005; 2006). Some limitations of AGROVOC were found during the process of developing the Thai AGROVOC, such as incorrect term meaning, terms inconsistency and some mistake of terms hierarchy. Approaches to refine AGROVOC were suggested (Thunkijjanukij, 2005).

AGROVOC thesaurus is now being re-modeled using OWL (the Web Ontology Language), into a more semantically structured system called the Concept Server. AGROVOC has been represented initially in a MySQL database, organizing concepts with URIs, relationships in a concept-to-concept table, and it has then been converted in OWL using the OWL AGROVOC Model (Liang *et al.,* 2006). In this model it can represent more knowledge including more specific relationships and detailed terminology which can be exploited for providing better services. The AGROVOC Concept Server Workbench tool (FAO, 2008; http://www.fao.org/aims/agrovoccs.jsp) is used to maintain concepts and relations of the AGROVOC Concept Server.

Soergel *et al.* (2004) used the AGROVOC thesaurus as a case study for exploring the reengineering of a traditional thesaurus into a fully-fledged ontology and summarized limitations of the existing thesaurus as follows:

1. Lack of conceptual abstraction: thesauri are collections of terms (generic or domain specific), ordered in a poly-hierarchic lattice structure or a mono-hierarchic tree structure and interlinked with some very broad and basic relationships. The distinction between a concept (meaning) and its lexicalizations (words) is not made consistently, if at all, in such a system, and as such it does not reflect the ways humans understand the world in terms of meaning and language.

2. Limited semantic coverage: most thesauri do not differentiate concepts into types (such as living organism, substance, or process) and have a very limited set of relationships between concepts, distinguishing only between hierarchical relationships, i.e. NT/BT, and associative relationships, i.e. RT. These very rudimentary relationships are not powerful enough to guide a user in meaningful information discovery on the Web or to support inference. They do not reflect the conceptual relationships that people know and that can be used by a system to suggest concepts for expanding the query or making it more specific. The concept relations provided by most thesauri force all relations into the two broad categories, hierarchical and associative. Too often the semantic relationships captured in this way are ambiguous and poorly defined. The generalization/specialization relations defined in most thesauri are not adequately developed to be of use for semantic description and discovery of Web resources. Thus there is a need for a richer and more powerful set of relationships.

3. Lack of consistency: since the relationships in thesauri lack precise semantics, they are applied inconsistently, both creating ambiguity in the interpretation of the relationships and resulting in an overall internal semantic structure that is irregular and unpredictable. Many of the NT/BT hierarchical relationships could be resolved to the nonhierarchical RT relationship, and vice versa.

4. Limited automated processing: traditionally thesauri were designed for indexing and query formulation by people and not for automated processing. The ambiguous semantics that characterizes many thesauri makes them unsuitable for automated processing.

Imsombut (2007) has done research on Building Automatic Thai ontology from document repositories, thesauri and dictionaries. She found that there are two critical problems if to build an ontology from thesaurus. Firstly, there are incorrectly-defined relationships, for instance, Blood NT Blood cells (Blood cells is narrower term of Blood) of which correct relation would be composed of relationship not general-specific. The other is that the identified relationship is too general, for example, Mutton RT Sheep (Mutton is related term of Sheep) of which the appropriate relation would be “production of” relationship.

Criteria for building ontology

The Delphi Technique originally developed by the RAND Corporation for technological forecasting in 1960s, and was later enhanced by U.S. government for group decision-making (Cline, 2000). The Delphi technique is becoming increasingly popular. Modification to the classic version of the Delphi is increasing. The popularization of Delphi technique has not led to a uniform application of the original ideas. Many differing forms now exist. These include, the ‘modified Delphi’ (McKenna, 1994), the ‘policy Delphi’ (Crisp *et al.*, 1997) and the ‘real-time Delphi’ (Beretta, 1996).

Typically a Delphi study involves a series of rounds of data gathering in which respondents offer and then refine their views on defined issues in an interactive process. Most studies start with the selection of a panel of experts in the area under investigation. There are usually three Delphi rounds in which the experts are invited to put forward opinions, indicate the extent of their agreement or disagreement with the opinions that have been expressed, and then re-score their agreement or disagreement in the light of group responses. Operationalizing such a framework is not straightforward. Many researches are attracted to the Delphi technique because it reserves interpretative aspects of qualitative research, but also because they wish to analyze aggregate data through a series of statistical operations.

The classical Delphi, begins with an open-ended set of questions that generates ideas and allows participants complete freedom in their responses in round one. Participants are encouraged to donate as many opinions as possible so as to maximize the chance of covering the most important opinions and issues. However, this can generate large amounts of data, so many researchers have limited the number of opinions a participant can contribute. Several participants are likely to raise the same issue using different terms. Duffield (1993) and Jerkins & Smith (1994) revised this approach by providing pre-existing information for ranking or response in round one.

Hasson *et al.* (2000) propose guidelines for the Delphi technique and summarized as a check list shown below:

1. Clarify the research problem, remember the Delphi technique is a group facilitation technique and as such only lends itself to group involvement.

2. Identify the resources available and skills of the researcher in analysis, administration and relationship building.

3. Understand the technique's process and decide upon which medium to use (electronic or written communication).

4. Decide on the structure of the initial round (either qualitative or quantitative) and the number of rounds to employ.

5. Determine the criteria and the definition of 'expert' and the meaning of 'consensus' in relation to the studies aims.

6. Give careful thought to, the criteria employed, the justification of a participant as an 'expert', the use of non-probability sampling techniques, either purpose or criterion methods.

7. Give attention to issues which guide data collection: the discovery of opinions, the process of determining the most important issues referring to the design of the initial round, and the management of opinions, analysis and handling of both qualitative and quantitative data.

8. Consider how to present the final results in either graphical and/or statistical representations with an explanation of how the reader should interpret the results, and how to digest the findings in relation to the emphasis being placed upon them.

9. Finally, address issues of ethical responsibility, anonymity, reliability, and validity issues in an ongoing manner throughout the data collection process.

Ontology as a tool for knowledge management

In the current economy, knowledge has become a key success factor. Acknowledging the importance of knowledge, Drucker (1994) argues that compared to previous economic development periods, knowledge assets are the primary factor of production in the current economy. He also contends that managing information is a critical and challenging task and in many organizations could be a key to developing a competitive advantage. Among the advantages, knowledge management provides an opportunity for the organization to develop processes to learn from previous mistakes and allows for more efficiently by not continually reinventing the wheel. Intellectual capital offers a unique competitive advantage to an organization.

Data, Information and Knowledge are often used in a similar vein. Data are facts, specifically numerical facts collected together for reference or information. According to Ellis (2003), the distinction is that data are the facts, which are organized into information. When information was used by someone to solve a problem, information in turn becomes personal knowledge. When we convert it to explicit knowledge, it becomes an intellectual asset that can be shared.

Knowledge is derived from thinking, and it is a combination of information, experience and insight. Deriving knowledge from information requires human judgment, and is based on context and experience. Information establishes itself in the sphere of common understanding whereas knowledge is derived form information and is subjective in nature, and this knowledge is intimately linked to the individual or the group of individuals generating it (Baumard, 1999).

Allee (1997) suggests that data float in a large sea of information, and data becomes information through linking and organizing with other data. Information become knowledge when it is analyzed, linked to other information, and compared to what is already known.

In a report, “Knowledge Management Research Report 2000,” (KPMG, 1999), which summarized the results based on a survey of 423 organizations in Europe and the US (101 US organizations), with revenues exceeding $347 million a year, 81% mentioned that they had or were considering knowledge management. The survey findings also revealed some important problems: Nearly two-thirds (65%) of organizations with a KM program complained of information overload – an overwhelming collection of information for information’s sake that can be difficult and laborious to use.

Managing information is a critical and challenging task of knowledge management. But there are many limitation of current search technology, as follows (Davies *et al*., 2006) :

1. Query construction. In general, when specifying a search, users enter a small number of terms in the query. Yet the query describes the information need, and is commonly based on the words that people expect to occur in the types of document they seek. This gives rise to a fundamental problem, in that not all documents will use the same words to refer to the same concept. Therefore, not all the documents that discuss the concept will be retrieved by a simple keyword-based search. Furthermore, query terms may of course have multiple meanings (query term polysemy). As conventional search engines cannot interpret the sense of the user’s search, the ambiguity of the query leads to the retrieval of irrelevant information.

2. Lack of semantics. Converse to the problem of polysemy, is the fact that conventional search engines that match query terms against a keyword-based index will fail to match relevant information when the keywords used in the query are different from those used in the index, despite having the same meaning (index term synonymy). Although this problem can be overcome to some extent through thesaurus-base expansion of the query, the resultant increased level of document recall may result in the search engine returning too many results for the user to be able to process realistically.

3. Lack of context. Many search engines fail to take into consideration aspects of the user's context to help disambiguate their queries.

4. Presentation of results. The results returned from a conventional search engine are usually presented to the user as a simple ranked list. The sheer number of results returned from a basic keyword search means that results navigation can be difficult and time consuming. Generally, the user has to make a decision on whether to view the target page based upon information contained in a brief result fragment. A survey of user behavior on BT's intranet suggests that most users will not view beyond the 10^{th} result in a list of retrieved documents . Only 17% of searches resulted in a user viewing more than the first page of results.

Soergel *et al.* (2004) studied in reengineering thesaurus into an ontology and suggested that ontologies should be multilingual, domain-specific, and cross disciplinary at the same time to facilitate information categorization, integration and retrieval. For maximum application potential they should be developed in a non-proprietary, application-independent, and machine-process able format to ensure interoperability among different systems. Ontology is an effective tool and expected potential benefits in the future knowledge organization systems (KOSs) include:

1. Unique identifiers and formal semantics: the explicit definition of concepts and relations in an ontology allows a unique identifier to be assigned to each concept. As each concept and relation is explicitly defined as a unique entity, the ontology lends itself to semantic formalization.

2. Internal consistency: another benefit of explicit semantics is the achievement of internal structural consistency in the expression of knowledge due to the possibility of applying integrity constraints.

3. Interoperability: clear semantics enables interoperability among different KOSs since corresponding concepts within different KOSs would have the same unique identifier, irrespective of the actual lexicalizations used to express those concepts. Semantic interoperability promotes sharing and reuse of knowledge.

4. Greater information integration: interoperability among different KOSs makes it possible for machines to recognize and analyze intended meaning of terms from disparate vocabularies. This is possible by using structured meta-information and formal knowledge description such as agreed-upon metadata schemas, controlled domain vocabularies, and taxonomies. The ability to integrate terminologies from different sources maximizes the value of investment made in the ontology.

5. Inference capability: new KOSs have the potential for expressing knowledge beyond what is present in the structure of the system. Unlike traditional KOSs where

both concepts and relations are underspecified and very few, if any, axiomatic rules exist, the facts (concepts and relations) and rules that can be derived from an ontology have the expressive capabilities that allow for reasoning.

6. Automated information processing: new KOSs create improved potential to discover relevant information from different sources by exploring patterns and filtering information using conceptual connections represented in the ontology. This enables question-answering from one or more databases or, using natural language processing from text.

7. Natural language processing (NLP) support: offers the possibility of providing a direct reply to a search question that is expressed in natural language, using the enhanced relationships and semantics in an ontology, instead of only returning a list of relevant documents.

8. Search query understanding: using NLP and semantic processing, a system can understand a query posed in natural language, determine the concepts involved and, where useful, create a boolean query.

9. Concept-based search: an ontology can provide context-aware search capabilities specific to the area of interest.

10. Integrated information search/browse support: text mining on the Web (Web mining) through meaning-oriented access, dynamic organization of information with the possibility for cross-domain links are feasible with emerging KOSs.

11. Search query expansion: the enhancement, extension, and disambiguation of user query terms become possible with the addition of enriched domain-specific and context-specific information.

A number of search engines are now emerging that use techniques to apply ontology-based domain-specific knowledge to the indexing, similarity evaluation, results augmentation and query enrichment processes.

In addition to a conventional index, the system contains a domain-specific knowledge base. This knowledge base consists of a model of the domain, with instance nodes pointing to web resources, each node having additional data in the form of linked properties as specified in the domain model (ontology).

Muenpai (2005) proposed ontology-based query expansion to improve information retrieval performance. The experiment was conducted using 40 word and phrase queries on 100 documents. Retrieval experiments comparing between word-based representation and the frequency tuned noun phrase variant and name entity representation supported with ontology-based query expansion showed precision 103% which increased averagely from 0.344 to 0.699 without any recall degradation (at recall 0.94). Processing time increased 5.2 times from 3.1 seconds to 16.1 seconds per document when integrating with natural language processing. Storage increased 1.62 times from 1Mb to 1.7Mb when term variants were added.

Ontologies are extremely important tools for the organization and contextualization of knowledge, particularly in well-bounded contexts, such as scientific research, or within individual organizations. Ontologies have become the knowledge representation medium of choice in recent years for a range of computer science specialties including the Semantic Web and bioinformatics (Brewster and O'Harab, 2007).

Ontologies are used for organizing knowledge in a structured way in many areas- from philosophy to Knowledge Management and the Semantic Web. We usually refer to an ontology as a graph/network structure consisting from:

1. A set of concepts (vertices in a graph)

2. A set of relationships connecting concept (directed edges in a graph)

3. One set of instances assigned to a particular concepts (data records assigned to concepts or relation)

An Ontology or knowledge representation is a fragmentary theory of intelligent reasoning: The way a knowledge representation is conceived reflects a particular insight or understanding of how people reason. "Represent knowledge" where knowledge was taken to mean knowledge of the world. Since knowledge equated with facts, knowledge representation was largely seen as the task of managing collections of facts about the world.

Formal knowledge representation (KR) is about building models of the world, of a particular domain or a problem, which allow for automatic reasoning and interpretation. Such formal models are called ontologies and can be used to provide formal semantics (ie. Machine-interpretable meaning) to any sort of information: databases, catalogs, documents, webpages, etc. The association of information with such formal models makes the information much amenable to machine processing and interpretation.

Ontology is recently one of the hot issues in research community. We can categorize those researchers into groups according to their issues of interest, namely

Information retrieval, Digital Library, Semantic web, e-Commerce, Natural language processing, Knowledge engineering, and Knowledge management (Maedche, 2001).

At present, there is increasing evidence of ontology being utilized as a search engine on the web page. Their objective is mainly to make searching on the web page substantially more efficient, especially with regard to finding the right web page, than searching with usual keywords (Komut, 2004).

As information retrieval is a main task to be performed with ontology, Information Retrieval System (IR) has objective to retrieve document queried by users. The main functions of the system are Document Operations, Index or Document Representation, Query Operations, Query Representation, and Searching by Similarity Computation. The outcome of the system comprises list of documents ranked by its degree of connection with the querying words. The efficiency of the query would be measured in terms of its precision and recall rate (Asawanopakiat, 2004).

In information retrieval contexts, precision and recall are defined in terms of a set of retrieved documents (e.g. the list of documents produced by a web search engine for a query) and a set of relevant documents (e.g. the list of all documents on the internet that are relevant for a certain topic). Precision can be seen as a measure of exactness or fidelity, whereas recall is a measure of completeness. In an information retrieval scenario, precision is defined as the number of relevant documents retrieved by a search divided by the total number of documents retrieved by that search, and recall is defined as the number of relevant documents retrieved by a search divided by the total number of existing relevant documents (which should have been retrieved). A perfect precision score of 1.0 means that every result retrieved by a search was relevant whereas a perfect recall score of 1.0 means that all relevant documents were retrieved by the search.

Accordingly, ontology plays a critical role in knowledge creation process and knowledge management process. In other words, ontology is a representative of knowledge therefore it can also be a basis for recording and retrieving knowledge. As a transfer of knowledge from someone to another requires either socialization or combination process, there is therefore a need for some kind of media or tools for doing the transfer. In addition, if that knowledge sharing is to be most efficient it is essential that the people in that respective community share some basic understanding as to the concepts and tools that represent the knowledge. Ontology as a knowledge representative is such a tool. It helps make knowledge retrieval process more intelligent.

Having reviewed the literatures, it can be concluded that ontology is a representative for specific knowledge domain, hence the necessity to bring in experts in that respective domain. However, as the cost of constructing ontology via expert is especially high in terms of both time and expenses, the automatic and semi-automatic approaches become far more attractive. Nevertheless expertise from expert is still needed if we are to build a well-structure ontology that can accurately represent knowledge.

Criteria and guideline for constructing ontology and rules for semi-automatic maintenance are also another approach that has incorporated expert's knowledge into the construction process. As such there is no need for experts every time we construct an ontology. Instead, any researcher or information specialist can apply those created criteria and guidelines when they are going to build up another ontology. Unfortunately, most research works on ontology construction are carried out by computer scientists, very few are domain specific and none of plant production ontology has ever been constructed. So, this research aiming to construct prototype ontology on rice production must be a real challenge. It is expected that the criteria, guideline and rules created in this study can be applied to construct the other kind of plant production ontology and enhance the knowledge management system in Thai agricultural research community, especially in terms of knowledge sharing and knowledge retrieval.

MATERIALS AND METHODS

An ontology is a formal and explicit description of concepts. It is a collection of concepts, lexicalizations in several languages, and relationships between them. Developing and ontology is a complex task that requires a high degree of analytical and abstract thinking.

Ontology can be created by reusing existing ones or building new ones from scratch. There are three approaches for ontology construction, namely: automatic approach, semi-automatic approach, and manually-driven by domain-experts approach. In each of these approaches we can find some pros and cons.

This research is based upon a case of a rice production ontology development. The selected approach was manually-driven by domain-experts and the ontology was created from scratch. The methodology consists of three parts:

1. Ontology Development Process. The rice production ontology development process was divided in to five steps, which are: specification, knowledge acquisition, conceptualization, formalization, and implementation.

2. Ontology Evaluation Process. A procedure detailing how to evaluate the developed ontology. There are two approaches: validated by experts and evaluated by users. The evaluation by users will allow to judge the usefulness of the ontology to query a search system based on the competency questions defined by users, and measuring results in term of precision and recall.

3. Ontology Criteria Development Process. This procedure involved documentary research and experts consultation to validate the criteria which have been identified from the developed ontology process. The Delphi Technique was the research technique used to reach consensus on the desirability criteria without face-to-face contact with the selected experts.

The conceptual framework for the development of a rice production ontology is presented in the figure below:

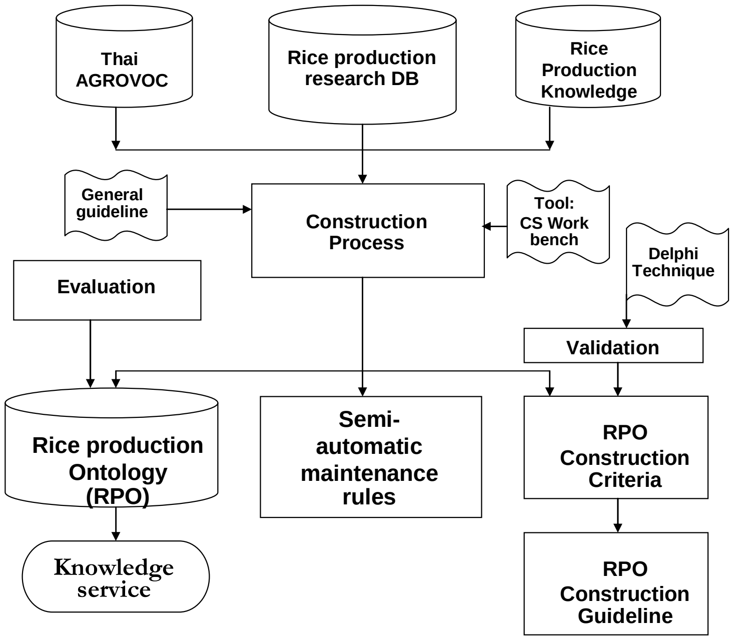


Figure 5 Conceptual Framework of Rice Production Ontology Development

Materials

Knowledge resources

All of the knowledge resources used for developing the rice production ontology can be described as follows:

1. Domain specific experts.

27 experts specialized in the subject of Rice Production and Agricultural Science were invited to validate the created criteria and verify the developed ontology.

2. Domain specific knowledge materials (Appendix E).

2.1 Rice production and related subject textbooks.

2.2 Rice and agricultural dictionary.

2.3 Thai AGROVOC Thesaurus (http://pikul.lib.ku.ac.th).

2.4 AGRIS/CARIS Subject categorization schemes.

2.5 Rice production website.

2.6 Thai Rice Research Database (http://pikul.lib.ku.ac.th/rice1).

2.7 General ontology construction guideline.

2.8 Related relationship schemes.

3. Tools and Applications.

3.1. FAO AGROVOC Concept Server Workbench tool (http://www.fao.org/aims/agrovoccs.jsp).

3.2. Touch Graph.

3.3. Thai Agricultural Visualization Tool.

3.4. CmapTools version 4.08 COE (http://cmap.ihmc.us/).

3.5. Mind Manager version X5.

3.6. MySQL database management for Thai Rice Research Database.

4. Equipment.

4.1 Computer servers.

4.2 Computer for processing.

Methods

Ontology Development Process

The research task for the construction of the rice production ontology is divided into five stages: 1) Ontology specification; 2) Knowledge acquisition; 3) Conceptualization; 4) Formalization and 5) Implementation.

1. Ontology specification

In this stage domain and scope of the ontology are clearly defined. The rice production ontology was started by defining its domain and scope. The easiest way to do this is by sketching two kind of questions, “basic questions” (Noy and McGuinness, 2001) and “competency questions” (Gruninger and Fox, 1995). The basic questions clarifies the purpose of the ontology and limit the scope of the model. The competency questions are list of questions that a knowledge base based on the ontology should be able to answer. These competency questions are just a sample and do not need to be exhaustive. The answers to these questions may be changed during the ontology design process.

The ontology basic questions were created by following the Stanford University ontology guidelines “Ontology Development 101” by Noy and McGuinness (2001)

A list of basic questions may be:

a) What is the domain that the ontology will cover?

b) For what we are going to use the ontology?

c) For what types of questions the information in the ontology should provide answers?

d) Who will use and maintain the ontology?

The list of competency questions was collected by interviewing rice researchers and research project managers in the Rice Department, Ministry of Agriculture and Cooperatives, in a meeting held on the 23rd of August 2007. The five competency questions, included:

a) Jasmine rice is the most popular rice variety of Thailand. How many Jasmine rice researches literature is defined by each subjects from well know classification schemes?

b) How many researches focus on rice biological control organism?

c) What is the most popular rice disease research in Thailand?

d) How many rice research papers contain chemical fertilizer and organic fertilizer?

e) How many research papers concern rice pest control, divided by type of pest, namely "field pest" and "stored product pest"?

The domain and scope of the ontology will be determined from the answers to the basic questions and the competency questions. The answers are focused on the research objective and usability of the ontology.

Answers of basic questions are:

a) What is the domain that the ontology will cover?
The ontology will cover rice production from cultivation to harvesting. So the scope is not to cover post harvesting and rice processing and is not related with economy, marketing, farm machinery and other un-related scope of subject.

b) For what we are going to use the ontology?
The purpose of the ontology is mainly increasing information retrieval efficiency for research knowledge.

c) For what types of questions the information in the ontology should provide answers?
The ontology should facilitate and improve search results on research literature.

d) Who will use and maintain the ontology?
Senior researchers and research project managers will use the ontology. Agricultural information specialists in the knowledge service organization and Agricultural Science faculty members will maintain the ontology.

Judging from the list of competency questions, the ontology should include information on rice variety and properties, rice pest, biological control organism, rice diseases and pathogen, pest management, soil, fertilizer and other rice related subjects. The five competency questions raised by rice research administrators were analysed as follows:

a) Jasmine rice is the most popular rice variety of Thailand. How many Jasmine rice researches literature is defined by each subjects from well know classification schemes?

Related information: Jasmine rice in the whole process of rice production, from planting to harvesting.

b) How many researches focus on rice biological control organism?
Related information: Natural enemies of rice pests.

c) What is the rice disease research in Thailand?
Related information: Numbers of researches related to rice diseases define by diseases name.

d) How many rice research papers contain chemical fertilizer and organic fertilizer?
Related information: Research related to rice and chemical fertilizer and organic fertilizer.

e) How many research papers concern rice pest control, divided by type of pest, namely “field pest” and “stored product pest?
Related information: Research related to rice and pest management or pest control of all kind of pest before harvesting (in rice field) and after harvesting (store product).

2. Knowledge acquisition

The approach of this research is to create an ontology from scratch by consulting domain-experts and referring to relevant rice production knowledge. The methodology to use for this approach is a combination of text analysis and expert approach. Steps of knowledge acquisition are described as follows:

2.1. Knowledge capture

The first step is to extract as much as possible plant production based knowledge from the literature. Collect and review related knowledge resources and categorize them systematically. The categories should cover all topics related with rice production from the starting process of cultivation to harvesting, included rice pest protection, and rice breeding. Since rice production is related to many disciplines, there is a need to collect knowledge comprehensively from multiple resources. Domain specific knowledge is captured from both the explicit knowledge (knowledge that can be written down, shared with others and stored in a database, such as: reports, procedures, instructions), and tacit knowledge (knowledge that resides inside people, such as: experiences, intuition, insights) coming from the experts. Some techniques are used to acquire knowledge from experts as interviews, discussions, etc.

Knowledge resources which are used in this research can be defined in five groups as follows:

a) Domain specific experts

27 experts in 11 key disciplines have been consulted. They are experts in subjects such as crop production, plant physiology, plant taxonomy, plant ecology, seed production, plant breeding, pathology, entomology, weed science, soil science, and soil taxonomy.

b) Domain specific information

This research is based upon a case of a rice production ontology development. Information related with rice production are: rice cultivation, soil cultivation, rice fertilizing, irrigation, rice harvesting, rice physiology, rice anatomy, rice pest and protection, rice disease/disorder and control, rice weed and control, rice breeding, rice variety and property, rice ecology, plant taxonomy, soil classification and biological classification.

Rice production resources which are selected for this research are 65 text books, 17 related websites and one agricultural thesaurus (Appendix E).

c) Ontology construction guidelines and criteria

This research is a pioneer research on developing plant production ontology by using rice as a case study. Specific plant production ontology guidelines and criteria do not really exists yet. This research starts by applying general ontology guidelines and plant production knowledge to sketch an ontology conceptual model for rice plant production, and then create guideline and criteria for this specific subject. Guidelines and criteria to be referenced for this research are: “Ontologies: How can they be built” (Pinto and Martins, 2004); “Ontology Development 101: A Guide to Creating Your First Ontology” (Noy and McGuinness, 2001), and “Ontologies: Principles, Methods and Applications” (Uschold and Gruninger, 1996).

d) Relationships guidelines and repositories

Existing relationships and refinement guidelines: AGROVOC CS Workbench assigned relationships (http://www.fao.org/aims/agrovoccs.jsp); AGROVOC refinement assigned relationships (Soergel *et al*., 2004) and Thai AGROVOC refinement guidelines (Thunkijjanukij, 2005).

e) Related thesaurus and dictionary

Terms and descriptions from thesaurus and dictionaries have been collected. Most of terms representing concept of rice production process were mainly collected from the Thai AGROVOC Thesaurus (Thunkijjanukij *et al.*, 2005; http://pikul.lib.ku.ac.th). Subject name entity for representing concepts were reviewed and collected also from the Thai AGROVOC Thesaurus, text books and many related dictionaries (see Appendix E).

2.2. Knowledge analysis and summarization

This step involved the study all of the previous knowledge sources, which has been summarized and organized in structural form. A final revision has confirmed the data structure by expert. Rice production knowledge were analysed and summarized as follows:

Rice production knowledge summarization

As rice production is related to many factors, reviewing all emphatic literatures, knowledge about rice production was analyzed and summarized. Since there are various subjects an enormous related content was collected and summarized. The tables below show examples of those summaries.

Table 5 Rice production related factors

Rice individual	Biological factor	Environmental factor	Management factor	Management process
Rice morphology	Weed	Soil	Fertilizer	Rice cultivation
Rice physiology	Pest insect and animal	Nutrient	Pesticide	Rice genetic and breeding
	Disease	Light	Other substance	Rice protection and control
	Natural enemy	Humidity		Rice fertilizing
	Soil microorganism	Soil moisture		Rice irrigation
		Water		Rice cropping system
		Temperature		Soil preparation
		Atmosphere		

Table 6 Rice taxonomy summary

Common name	Local name	Family	Genus	Specific epithet	Scientific name	Cultivar
rice	ข้าว	*Poaceae*	*Oryza*	*sativa*	*Oryza sativa*	detail of rice cultivar in table 7

Table 7 Rice cultivar summary defined by composition, cultivation ecology and photoperiod sensitivity (example of five cultivars)

Rice certified cultivar (English name)	Rice certified cultivar (Thai name)	Type defined by starch composition	Type defined by cultivation ecology	Photoperiod sensitivity
Khao Dawk Mali 105	ขาวดอกมะลิ 105	aromatic non-glutinous rice	lowland rice	Yes
RD 6	กข 6	glutinous rice	lowland rice	Yes
Khao Jow Hawm Khlong Luang 1	ข้าวเจ้าหอมคลองหลวง 1	non-glutinous rice	lowland rice	No
Khao Jow Hawm Phitsanulok 1	ข้าวเจ้าหอมพิษณุโลก 1	non-glutinous rice	lowland rice	Yes
Khao Jow Hawm Suphan Buri	ข้าวเจ้าหอมสุพรรณบุรี	non-glutinous rice	lowland rice	No

Table 8 Rice cultivar summary defined by diseases resistant, disease susceptible, pest resistant and pest susceptible properties (example of five rice cultivars)

Rice certified cultivar (English name)	**Diseases resistant**	**Diseases susceptibility**	**Pest resistant**	**Pest susceptibility**
Khao Dawk Mali 105	-	yellow orange leaf, bacterial leaf blight, blast, ragged stunt	-	*Nilarparvata lugens*, *Nephotettix apicalis*, *Nephotettix malayanus*, *Nephotettix nigropictus*, *Nephotettix virescens*, *Scirpophaga incertulas*, *Chilo supressalis*, *Chilo polychrysus*, *Sesamia inferens*
RD 6	brown spot	bacterial leaf blight, blast	*Meloidogyne graminicola*	*Nilarparvata lugens*, *Orseolia oryzae*
Khao Jow Hawm Khlong Luang 1	blast, bacterial leaf blight	-	*Sogatella furcifera*, *Sogatella kolophon*, *Sogatella vibix*, *Sogatodes pusanus*	*Nilarparvata lugens*, *Nephotettix apicalis*, *Nephotettix malayanus*, *Nephotettix nigropictus*, *Nephotettix virescens*
Khao Jow Hawm Phitsanulok 1	blast, bacterial leaf blight, ragged stunt	yellow orange leaf		*Nilarparvata lugens*, *Nephotettix apicalis*, *Nephotettix malayanus*, *Nephotettix nigropictus*, *Nephotettix virescens*
RD 6	brown spot	bacterial leaf blight, blast	*Meloidogyne graminicola*	*Nilarparvata lugens*, *Orseolia oryzae*

Table 9 Weed taxonomy summary (example of five weed species)

Common name	Local name	Family	Genus	Specific epithet	Scientific name
red rice, brown-beard rice, brownbeard rice, common wild rice, perennial wild red rice	หญ้าข้าวผี	*Poaceae* (synonym : *Gramineae*)	*Oryza*	*rufipogon*	*Oryza rufipogon*
horse purslane	ผักเบี้ยหิน	*Aizoaceae*	*Trianthema*	*portulacastrum*	*Trianthema portulacastrum*
slender amaranth	ผักโขมไร้หนาม	*Amaranthaceae*	*Amaranthus*	*viridis*	*Amaranthus viridis*
indian heliotrope	ผักงวงช้าง	*Boraginaceae*	*Heliotropium*	*indicum*	*Heliotropium indicum*
spreading dayflower	ผักปราบนา	*Commelinaceae*	*Cyanotis*	*axillaris*	*Cyanotis axillaris*

Table 10 Weed characteristic properties summary (example of five weed species)

Scientific name	Habit	Plant type	Plant life cycle	Reproductive organ	Growth environment	Spread environment
Oryza rufipogon	Grass	narrow leaf	annual	seed	paddy field	dry seed broadcasting
Trianthema portulacastrum	Herb	broad leaf	annual	seed	paddy field	dry seed broadcasting
Amaranthus viridis	Herb	broad leaf	annual	seed	paddy field	dry seed broadcasting
Heliotropium indicum	Herb	broad leaf	annual	seed	paddy field	dry seed broadcasting
Cyanotis axillaris	Herb	broad leaf	annual	seed or stem	wet soils or marshyland	rainfed rice

Table 11 Weed control method and chemical control substance summary (example of five weed species)

Scientific name	Control method	Chemical control substance
Oryza rufipogon	Using clean rice seed and free from wild rice seeds. Crop rotation and hand weeding.	Use molinate combined with continuous flooding.
Trianthema portulacastrum; Amaranthus viridis; Heliotropium indicum; Cyanotis axillaris	Use cultural practices to control weeds. Repeat tillage as adequate. Reduce weed entry into fields by use clean and good quality seed; use clean equipment to prevent field/crop contamination and rotate crops to break weed cycles.	Spray 2,4-D, 2,4-D/ioxynil, 2,4-D /propanil before tillering

Table 12 Pathogen taxonomy summary (example of five pathogen species)

Kingdom/ Domain	Class	Order	Family	Genus	Specific epithet	Scientific name
Fungi	*Deutero mycetes*	*Moniliales*	*Dematiaceae*	*Pyricul aria*	*grisea*	*Pyricularia grisea; Pyricularia oryzae*
Fungi	*Deutero mycetes*	*Moniliales*	*Dematiaceae*	*Helmin thospor ium*	*oryzae*	*Helminthos porium oryzae; Cochiobolu s miyabeanu s*
Fungi	*Basidiom ycete*	*Ceratobasi diales*	*Ceratobasidi aceae*	*Thanat ephoru s*	*cucumeri s*	*Thanateph orus cucumeris; Rhizoctoni a solani*
Bacteria	*Gamma Proteoba cteria*	*Xanthomon adales*	*Xanthomona daceae*	*Xantho monas*	*oryzae* pv. *oryzae*	*Xanthomon as oryzae* pv. *oryzae*
Virus			*Caulimovirid ae*	Tungro virus	RiceYell ow Orange Leaf Virus	

Table 13 Diseases name and pathogen name summary (example of five diseases)

Pathogen name	Disease (English name)	Disease (Thai name)
Pyricularia grisea; Pyricularia oryzae	blast	โรคไหม้
Helminthosporium oryzae; Cochiobolus miyabeanus	brown spot	โรคใบจุดสีน้ำตาล
Thanatephorus cucumeris; Rhizoctonia solani	sheath blight	โรคกาบใบแห้ง
Xanthomonas oryzae pv. oryzae	bacterial leaf blight	โรคขอบใบแห้ง
yellow orange leaf virus	yellow orange leaf	โรคใบสีส้ม

Table 14 Diseases control, epidemiology and ecological factor defined by disease name (example of five diseases)

Disease	Epidemiology	Ecological factor	Protection and control
blast	Pathogen disperse with wind, water and plant in June - August.	High Relative humidity, temperatur 27-30 °C , rice density and high nitrogen fertilizer	Rice disease resistant, seed treatment by fungicide : kazumin
brown spot	Over season spore on plant or seeds	High relative humidity, temperatur 23.5 °C	Crop rotation, weed control, tillage, seed treatment.
sheath blight	Over wintering and planting season	Excess nitrogen causing rice weak to diseaes	Husk burning, weed control, incorporate residue, disease resistant variety, chemical control: validacin, benlate or hinasan
bacterial leaf blight	Rainstorms and typhoons speed the spread of disease. Irrigation water also carries the pathogen from field to field.	High temperature (30 degree C) favors development of the disease. Lesion enlarged and leaves died faster at higher temperatures, high rate of nitrogen fertilizer increase the incidence of disease.	Disease resistant varieties, chemical control avoid to apply nitrogen in fertilized soil.
yellow orange leaf	Insect vector and host plant in field in June - August	Temperature at 28-29 C, high density of insect vectors	Resistant varieties against tungro virus disease (RD1, RD3), plowing and harrowing the field to destroy stubbles right after harvest in order to eradicate other tungro hosts are also advisable.

Table 15 Agricultural substance type defined by type of pesticide, fertilizer and plant growth substance

Pesticide	**Fertilizer**			**Plant growth substance**
acaricide	inorganic fertilizer	organic fertilizers	biofertilizer	auxins
avicide	-compound fertilizer	-green manures		cytokinins
herbicide	--nitrogen phosphorus fertilizer	-farm manure		dormancy breaker
insecticide	--nitrogen potassium fertilizer	-compost		ethephon
molluscicide	--NPK fertilizer			germination inhibitor
nematicide	--phosphorus potassium fertilizer			gibberellic acid
rodenticide	-single fertilizer			growth inhibitors
pesticide synergist	--calcium fertilizer			growth retardant
fungicide	--magnesium fertilizer			plant growth stimulant
bactericide	--micronutrient fertilizer			
biopesticide	--nitrogen fertilizer			
-botanical pesticide	--phosphate fertilizer			
-microbial pesticides	--potassium fertilizer			

3. Conceptualization

This is the stage in which the conceptual model of the ontology will be built following the specifications elaborated in the previous step. The conceptual model of an ontology consists of concepts in the domain and relationships among those concepts. Conceptual modeling involve the following processes:

3.1 Define the model structure

As ontology is a data model that represents a set of concepts within a domain and the relationships between those concepts. So the main components of ontology are concepts and relations. Concepts can be organized with a class hierarchy, including superclasses and subclasses concept. Relationships between concepts can be grouped in two main groups: hierarchical relationships and associative relationships. Hierarchical relationship identifies the hierarchy between superclasses, subclasses. Associative relationship connects concepts which are not in the same hierarchy. A generic ontology structure model can be represented as indicated by the pictures below:

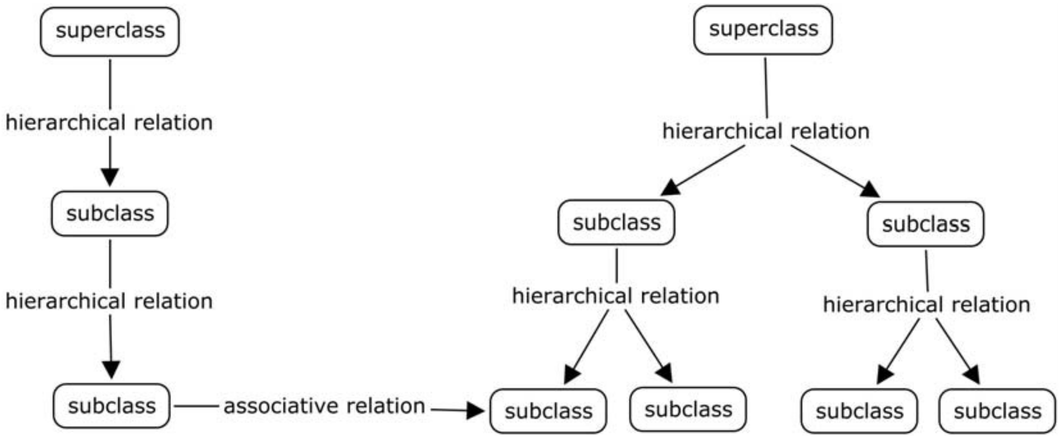


Figure 6 Ontology structure model

3.2 Identify concepts

There are several possible approaches in developing a class hierarchy (Uschold and Gruninger, 1996). Both the top-down and bottom-up approaches are used in this research as follows:

a) List all possible concepts from the previous rice production knowledge summary. Then, divide the concepts into two groups: top level concepts and bottom level concepts.

b) Use the top-down approach to indentify the hierarchical structure. Identify all of the top level concepts as superclasses. Verify that top level concepts cover all categories of rice production: rice anatomy, rice physiology, environmental factor, management factor, management process (Table 5) and then define subclass concept. For any concept that is not included into these categories, define the most general concept in the domain for that category and subsequently specialize this concept with subclasses.

c) Use bottom-up approach. Identify bottom level concepts, most of them are object entity such as: rice species or cultivar, weed species, pest species, biological control organism species, pathogen species, host species, pesticide substance. After identify the bottom level concepts then define upper-class concepts until reach the most top-level concept.

d) Use the middle-out approach (Uschold and Gruninger, 1996) when a concept can have both top and down levels.

Remind that each concept is unique in the same ontology and there is no single correct class hierarchy for any given domain. The hierarchy depends on the possible uses of the ontology and the level of the detail that is necessary for the application (Noy and McGuinness, 2001) .

3.3 Identify relationships

a) For hierarchical relationships, there is only one relation namely “hasSubclass”. Define this relation between all of the hierarchical concepts.

b) Assign associative relationship by identify verbs related between concepts and assign relation name by forming a meaningful statement. The most common way to label relationship is with role names. Conventionally, and based on good standardization practices, relationships names should be selected from the existing ontology relationship lists. New relationships can be assigned when there are not existing or more specify relation is needed.

c) Create associative relationships between concepts in different hierarchies which are related.

d) Assign inverse relation if necessary to present information in both direction.

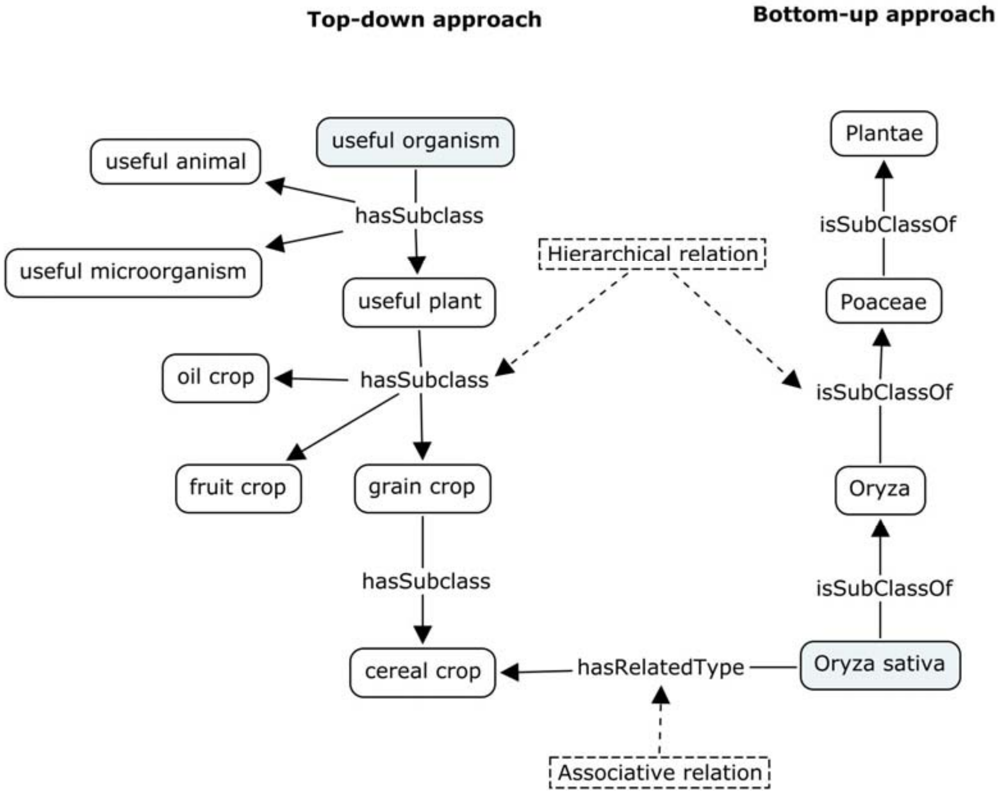


Figure 7 Identify concept by top-down and bottom-up approach

3.4 Create informal draft models by using the previous summarized knowledge. Knowledge modeling tools as MindManager (ver. X5) and CmapTools (ver. 4.08 COE) were used for sketching ontology model in this research.

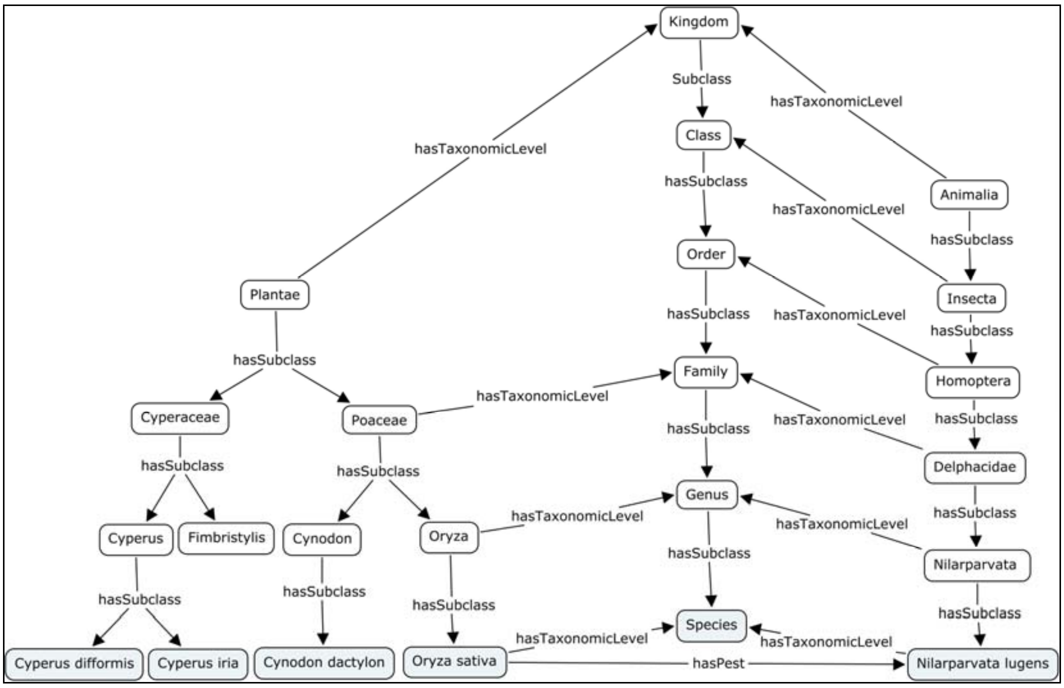


Figure 8 Concept and relationship of rice and pest insect

4. Formalization

This stage is used to transform the conceptual model into a formal model. The rice ontology conceptual model from the previous step is written in a more formal form. Concepts are usually represented by term and hierarchically organized through structural relations.

The steps to convert a conceptual model to a formal form are:

4.1 All the concepts and relationships defined in the previous conceptual model should be listed in a data sheet.

4.2 Define term representing the concepts

"Concept" is a an idea that can be represented with many words and in many languages;

"Term" is a simple word or compound form, symbol or formula that designates a particular concept within a given subject field.

“Preferred term” is a term which is selected to represent the concept.

“Synonym” (non-preferred term) is a term in the same concept (same meaning) which is not selected to be preferred term.

One concept may have many terms. To avoid ambiguities, terms have to be arranged and formalized as follows:

a) List all terms of each concepts from the conceptual model.

b) Select preferred term as a concept representative. Non-preferred terms will be assigned as synonym. Use Thai AGROVOC thesaurus and follow the criteria for term selecting and refinement (Thunkijjanukij, 2005) as a guideline. These criteria will be described in rice production ontology construction guideline (Appendix D)

c) Synonym can be defined at a term level or at a string level, for example: acronym, abbreviation term, spelling variant term, plural or singular, common name, local name, scientific name, chemical symbol, chemical formula, trade name, translated term, etc.

4.3 Define terminology relationships

All relationships names should be written starting with lower case and capitalizing other words, without any space (Sini and Yadav, 2009). There are three types of terminology relationships which are:

a) Concept to term relationship namely “hasLexicallization”. This is the relationship between concept and the selected preferred term. For example: concept[rice] hasLexicalization term[*Oryza sativa*]

b) Term to term relationships. All of these relations are used for preferred term and it’s synonyms which are difference terms, such as: hasAcronym, hasAbbreviation, hasSpellingVariant, hasPural or hasSingular, hasCommonName, hasLocalName, hasScientificName, hasTradeName, hasChemicalSymbol, hasChemicalFormula, hasTranslation, hasSynonym. For example: term[rice] hasPural term[rices], term[sulphur] hasSpellingVariant term[sulfer], term[*Oryza sativa*] hasCommonName term[rice].

c) Concept to concept relationship. These relations connect concepts (represented by the preferred term) in a different position in the hierarchy, such as: hasPest, hasDisease, hasPathogen, hasRelatedType, etc.

4.4 Define concept properties, for example : status, scope notes or definitions.

A data type property can be used to link a concept or an instance to a specific value. The data connected to the concept or the instance through this relationship can be a specified data type.

The level of concepts may not provide enough information to answer the competency questions. In the summary table of rice variety knowledge, we found a lot of properties which should be defined: seed size, seed color, dormancy period, yield, etc. For each concept, we have to decide which properties should be defined. Unforutnately, the AGROVOC CS Workbench tool has not design function for entry this kind of properties yet. These properties can be completed in the system later.

4.5 This stage involve filling the datasheet to formalize rice production concepts. Datasheets were designed to facilitate new ontology editors, especially for the domain experts to transform the conceptual model to a formal model. Three kind of datasheets were designed: datasheet for concept lexicalization (Table 16), datasheet for formalizing concept and hierarchical relationship (Table 17) and datasheet for formalizing concept and associative relationship (Table 18). Some example of the data samples and datasheets are presented below:

Table 16 Datasheet for formalizing term lexicallization

Conceptual object	Concept representative (preferred term)	Status (top concept or subclass)	Synonym											Properties			
			Acro	**Abbr**	**Spel**	**Pural**	**Tran**	**Comn**	**Local**	**Symb**	**Form**	**Trade**	**other**	**Scope**	**Desc**	**Subj**	**other**
concept rice (plant)	Oryza sativa	subclass	-	-	-	-	-	rice	ข้าว	-	-	-	-	-	-	-	-
concept sulphur element	sulphur	subclass	-	-	sulfer	-	กำมะถัน	-	-	S	-	-	-	-	-	-	-

Note:

Acro	:	hasAcronym	Comn	:	CommonName	Trade	:	TradeName
Abbr	:	Abbreviation	Local	:	LocalName	Scope	:	Scope note
Spel	:	Spelling Variant	Symb	:	ChemicalSymbol	Desc	:	Description
Tran	:	Translation	Form	:	ChemicalFormula	Subj	:	Subject code

Table 17 Datasheet for formalizing concept and hierarchical relationship

Concept and Hierarchical relationship		
Subjdect concept	**relation**	**Object concept**
Plantae	hasSubclass	*Poaceae*
Poaceae	hasSubclass	*Oryza*
Oryza	hasSubclass	*Oryza sativa*
Oryza sativar	hasSubclass	Pathum Thani 1

Table 18 Datasheet for formalizing concept and associative relationship

Concept and Associative relationship		
Subjdect concept	**relation**	**Object concept**
Plantae	hasTaxonomicLevel	Kingdoms
Poaceae	hasTaxonomicLevel	Family
Oryza	hasTaxonomicLevel	Genus
Oryza sativar	hasTaxonomicLevel	Species
Oryza sativar	hasWeed	*Oryza rufipogon*
Oryza sativar	hasPest	*Dicladispa armigera*
Pathum Thani 1	hasTaxonomicLevel	Cultivar
Pathum Thani 1	resistanceTo	bacterial leaf blight
Pathum Thani 1	susceptibilityTo	yellow orange leaf

5. Implementation

This research implement the formalized rice production ontology by using the FAO AGROVOC Concept Server Workbench Tool (AGROVOC CS WB) (http://www.fao.org/aims/ agrovoccs.jsp) for a knowledge representation in form of OWL DL.

The AGROVOC CS WB provides a web-based integrated environment for the development and management of agricultural concepts. The workbench allows multiple distributed users to accomplish a range of tasks covering every stage of terminology development (for example, create a corpus and using it, create concepts, edit existing concepts or terms, etc.), and it allows for language-specific conceptualizations of the domain . It also contains a set of administrative modules to manage the users, access rights and the data validation workflow (proposal, revision, validation, publishing and deprecation). Since the AGROVOC CS WB doesn't have ontology visualization tool and editor for moving hierarchical concept in the same tree (Concept Tree Editor), the visualization tool and the Concept Tree Editor were developed for the purpose of facilitating ontology construction in this research.

Concepts and relations were formalized and verified in form of datasheet table (XLS format). A converting application was develop by the NAiST Laboratory, Department of Computer Engineering, Kasetsart University, to transfer data from Excel datasheet to the AGROVOC CS WB format.

The approach of this research is to construct the ontology from scratch consulting domain experts, Numerous terms have been collected and combined with each other through relationships. As this task resolve to be complicated, a datasheet has been found, since this is the most simple and easy way to work with subject experts. After the data import into the AGROVOC CS WB, visualizing the hierarchy and the concept graph can help to clarify the whole ontological structure. With this technique, the domain specific experts can edit and re-define the ontology comprehensively.

Ontology visualization in AGROVOC CS WB is an added-on module which is developed for visualize the Thai rice production ontology. The “Thai Agricultural Ontology Visualization Tool” is developed from the open sources “Touch Graph” (http://sourceforge.net/projects/touchgraph) by the Thai National AGRIS Centre in consultation with the NAiST Laboratory. The tool was modified to visualize concepts and relations in Thai and English languages. This tool was designed to expand or hide each concepts or relations in order to focus the view on desired elements. Moreover, query expansion to retrieve information from Thai Rice Research Database, and Thai WebAGRIS Database, was also developed. However, the application development and implementation process are beyond of this study.

The AGROVOC CS WB set up six roles for different users: Guests, Terminologists, Ontology editors, Validators, Publishers, and Super Users. The steps planned with the CS for the creation of concepts and relations can be, for example, summarized as follows:

a) Create a new concept

b) View and Edit the selected concept

c) Create and Edit term

d) Create and Edit concept definition

e) Create and Edit concept scope note

f) Create relationship between concepts (Associative relationship)

g) Create relationship between terms (relationship between synonym terms in the same concept)

Ontology Evaluation Process

The quality of the rice production ontology is judge by two methods:

1. Validation by experts. The domain specific experts verify the ontology and correct if needed. This is the step of evaluation in term of theoretical correctness of concepts, terms, and relationships relevant to rice production.

2. Evaluation by users. This evaluation judge how good the ontology is to satisfy the users by answering competency questions. These competency questions were defined in the previous specification process by research project managers. The terms in the ontology were used for query Thai Rice Research Database and other search systems. The efficiency of the use of the ontology is measured in terms of precision and recall over query searches results.

Precision can be seen as a measure of exactness or fidelity, whereas recall is a measure of completeness. In an information retrieval scenario, precision is defined as the number of relevant documents retrieved by a search divided by the total number of documents retrieved by that search, and recall is defined as the number of relevant documents retrieved by a search divided by the total number of existing relevant documents (which should have been retrieved).

$$\text{Precision} = \frac{|\{\text{relevant documents}\} \cap \{\text{documents retrieved}\}|}{|\{\text{documents retrieved}\}|}$$

$$\text{Recall} = \frac{|\{\text{relevant documents}\} \cap \{\text{documents retrieved}\}|}{|\{\text{relevant documents}\}|}$$

The ontology development process is an iterative process: once identified that precision or recall do not satisfy user needs (e.g. concepts have been missing from the ontology), the developed ontology could be improved by going back to any of the mentioned steps of the Knowledge acquisition phase.

The experiment was conducted using five competency questions which were selected from the Rice Researchers Meeting. These questions were used to create queries for evaluation by comparing result from keyword-base search (conventional search) and ontology-based query expansion (ontology search). The questions and search queries are listed below:

Table 19 Query of the five competency questions define by query approach

Question	Approach	Query	Query item no.
1. How many Jasmine rice researches literature is defined by each subjects from well know classification schemes?	a - conventional search	(jasmine rice or jasmine rices) AND subject categories code	1a(n), when n is item no. of subject categories
	b - ontology search	concept of jasmine rice AND subject categories code	1b(n), when n is item no. of subject categories
2. How many researches focus on rice biological control organism?	a - conventional search	(rice or rices) AND biological control organisms	2a1
	b - ontology search	object concept of [concept rice] “hasBiologicalControl Agent” and their synonym	2b1
3. What is the most popular rice disease research in Thailand?	a - conventional search	(rice or rices) AND (disease or diseases) :actually this query should retrieve by disease name but users don't know all of the rice disease name so this query approach was only able to assigned query term as "disease".	3a1

Table 19 (Continued)

Question	Approach	Query	Query item no.
	b - ontology search	object concept disease(n) of [concept rice] with relation "hasDisease" OR pathogen(n) which disease(n) has relation "hasCause"	3a(n), when n is item no. of disease
4. How many rice research papers contain chemical fertilizer and organic fertilizer?	a - conventional search	(rice or rices) AND (chemical fertilizers or chemical fertilizer)	4a1
	a - conventional search	(rice or rices) AND (organic fertilizers or organic fertilizer)	4a2
	b - ontology search	[concept rice] AND ([concept chemical fertilizers] OR all subclass of [concept chemical fertilizers]	4b1
	b - ontology search	[concept rice] AND ([concept organic fertilizers] OR all subclass of [concept organic fertilizers]	4b2

Table 19 (Continued)

Question	Approach	Query	Query item no.
5. How many research papers concern rice pest control, divided by type of pest, namely “field pest” and “stored product pest”?	a - conventional search	(rice or rices) AND (field pest or field pests) AND (pest control OR (control method or control methods) OR (pesticide or pesticides))	5a1
	a - conventional search	(rice or rices) AND (stored product pest or stored product pests) AND (pest control OR (control method or control methods) OR (pesticide or pesticides))	5a2
	b - ontology search	(object concept pest of [concept rice] with relation “hasPest” and has relation “hasRelatedType” = [concept field pest]) AND (subclass of concept [pest control] OR subclass of concept [control method] OR subclass of concept [pestticide])	5b1
	b - ontology search	(object concept pest of [concept rice] with relation “hasPest” which has relation “hasRelatedType” = [concept stored product pest]) AND (subclass of concept [pest control] OR subclass of concept [control method] OR subclass of concept [pesticide])	5b2

Note: - There are 27 AGRIS subject categories related with rice production. These categories were used for defining queries for question no. 1 (Table 25)

- The terms of concepts used to create queries are preferred terms and all of their synonym which represent that concept (both in Thai and English) such as: acronym, abbreviation term, spelling variance term, singular/plural, chemical symbol, trade name, common name, local name, etc.

Thai Rice Research Database was used for testing the information retrieval process for all queries. This database is a bibliographic database which collects rice research literature by transfer data from Thai National AGRIS Database and Kasetsart University Conference Proceedings Database. All metadata in the Thai Rice Research Database apply to the AgMES (Agriculture Metadata Element Sets) standard. The total number of data in the database are 1,350 records. Even though the database is not a large one, but these selected rice research literatures were collected from all of the related research organizations in Thailand and cover 14 years, from 1994 to 2008.

Ontology Criteria Development Process

One of the main barriers to effective knowledge sharing by using ontologies, is the inadequate documentation of existing knowledge bases and ontologies. To address these problems all important assumptions in ontology development should be documented, both for criteria and guidelines.

The section below will describe the rice production ontology construction criteria. The creation ontology process is also summarized as a guideline. The process of creating criteria was done according to three stages:

Stage 1 – Define the criteria

An ontology is a data model that provides an organizational framework that allows reasoning about knowledge. The criteria for constructing an ontology should be defined as:

a. Criteria for defining concept

b. Criteria for defining term

c. Criteria for defining relationship

Stage 2 – Formulate preliminary set of criteria and apply them to the working process of rice production ontology construction. Those criteria, as a result, will be modified and adjusted according to its effectiveness in guiding the ontology construction process.

Stage 3 – Testing and evaluating the criteria. The criteria together with guidelines were presented to domain specific experts and information specialists who are knowledgeable about rice production. Then the criteria and guideline were revised. The Delphi technique makes use of domain specific expert to suggest and confirm the criteria. Questionnaires are designed (Appendix B) to address the ontology construction criteria. The questionnaire is aimed at a target population consisting of professionals in subject of agricultural sciences and plant production. Inputs from the experts provide additional credibility of the research effort and help to refine the criteria. Then the criteria were modified and used for refining the rice production ontology.

Delphi approach

The Delphi technique is an appropriate method for this research because it provides a standardized procedure for collecting and refining qualitative and quantitative data. This technique can develop sensitizing concepts or understanding from descriptive data and use statistical measurement.

The Delphi technique is designed to utilize three rounds of sequential individual questionnaire iterations to elicit and refine group judgments from a selected group of experts in a specific area to reach consensus on the desirability of certain events or outcomes without face-to-face contact. The end product is a consensus among experts by use of statistical information and includes their commentaries on each of the questionnaire items, usually organized as a written report by the Delphi investigator (Delbecq *et al.,* 1975; Helmer, 1967). As this technique uses a group of experts to deliberate a research issue or a problem anonymously, it overcomes some of the interpersonal obstacles associated with group decision-making. The technique has much to offer in terms of gaining opinions from a wide range of idea. However, this can generate large amounts of data. Duffield (1993) and Jerkins and Smith (1994) revised this approach by provide pre-existing information for ranking or response in round one.

The criteria in this study were defined by documentary review and collected from the process of constructing the ontology. Thus the Delphi technique approach was revised by provide criteria for rice production ontology construction as pre-existing information for round one.

Implementation of the Delphi technique. The Delphi technique involved the following steps:

1. Defining pre-existing criteria from ontology constructing experience and documentary review.

2. Developing the questionnaire.

3. Selecting members of the domain expert group to be participants.

4. Sendind the questionnaire to member.

5. Summarizing responses and distribute the summary.

6. Seeking second responses.

7. Summarize results.

Develop the questionnaire

The questionnaire was developed as pre-existing data set base on the rice production ontology which is designed through the process of knowledge capture both tacit and explicit knowledge and process of knowledge summarization, detailed in the previous steps of ontology construction "knowledge acquisition". All of them are close-ended with open-ended suggestion. The score of agreement was arranged in five levels, which are: 5= totally agree, 4= very much agree, 3= moderately agree, 2= slightly agree, and 1= least agree.

The questionnaire has 119 questions regarding ontology construction criteria and divided the criteria in to 3 main topics as: 1) Criteria for defining concept, 2) Criteria for defining term, and 3) Criteria for define relationship.

To prevent potential misunderstandings and ambiguity, three experts tested the questionnaire. The questionnaire was evaluated and modified as necessary before sending to the participants.

Select the participants for the Delphi technique group

There are no fixed rules available to establishing the number of experts require to form the Delphi panel, nor does consensus exit on the knowledge or expertise require for one to be included as a Delphi member. The size of Delphi panels covers a wide range, from 10 to 100. The choice depends on the nature, scope and importance of the study. The panel of 15-20 is the minimum number of respondents are needed (Dalkey, 1969).

The participants of the Delphi technique group of this research are experts in subject of agricultural sciences. Twenty seven experts were invited from three organizations: Faculty of Agriculture, Kasetsart University, Rice Department and Department of Agriculture, Ministry of Agriculture and Cooperatives (Appendix A).

Send the questionnaire to participants

The round one questionnaire was sent to the panelists. The expert were asked to perform three tasks: 1) review the list of defined criteria, 2) rate each competency using a 5-point rating score, 3) suggest any competency criteria which is necessary but not existed, and 4) return the questionnaire by a certain date.

The round-two questionnaire contained the same list of competencies questions and used the same 5-point rating score as the round one. The participants received also their previous ratings as well as the group median and inter quartile range for each competency. Participants were requested to review, and rate the items again.

Data analysis

The questionnaires were posed to the 27 experts for two rounds. The responses are summarized by descriptive analysis and statistical analysis method. Median, mean, inter quartile range were calculated. The median and means of the round two responses were rank-ordered. A list of desirable competencies specified to be criteria were concluded as a result of rice production ontology constructing criteria.

RESULTS AND DISCUSSION

The research results are present in five parts:

1. Rice production ontology;

2. Evaluation results;

3. Criteria for rice production ontology construction;

4. Guidelines for plant production ontology construction;

5. Rules for semi-automatic maintaining rice production ontology.

Results

Rice Production Ontology

The Rice Production Ontology (RPO) was constructed from scratch in consultation with domain-experts. This ontology covers the domain of rice production from cultivation to harvesting. Relevant knowledge related with rice production was analyzed, in particular: 65 text books and 17 website, the Thai AGROVOC Thesaurus, and a consultation with 27 experts in this field. Concepts and relations were formalized and verified in a form of datasheet and imported into the AGROVOC Concept Server Workbench tool. A Thai Agricultural Ontology Visualization tool and an Ontology Tree Editor were developed to present the ontology as a graph in order to facilitate ontology editor. Refinement in the loop was done by performing the transformation following the criteria validated by expert to improve the created ontology. The rice production ontology contains 2,322 concepts and 5,603 terms in a system of hierarchical and 57 associative relations and provides an organizational framework that allows reasoning about rice production knowledge.

Concepts of rice production ontology

The concepts of the Rice Production Ontology was categorized as classes to provide an initial comprehensive framework that will incorporate every other relevant concepts. The RPO categorization followed the plant production knowledge model which apply the whole plant model (Beverly *et al.* ,1993 and Figure 1). The categories are summarized in the following table:

Table 20 Concepts of the rice production ontology

Object concept	Process concept
Plant (rice, weed and host of pest)	Cultivation process
Animal (pest and natural enemy)	Harvesting process
Fungi (pest and natural enemy)	Protection and control process
Bacteria (pest and natural enemy)	Fertilizing process
Virus (pest)	Irrigation process
Chemical substance and element (fertilizer, pesticide, plant growth regulator, nutrient element)	Soil preparation
Soil	Plant genetic and breeding
Plant anatomy anatomy	Physiology function
Disease	
Disorder	
Environmental factor (water, light, temperature, etc.)	

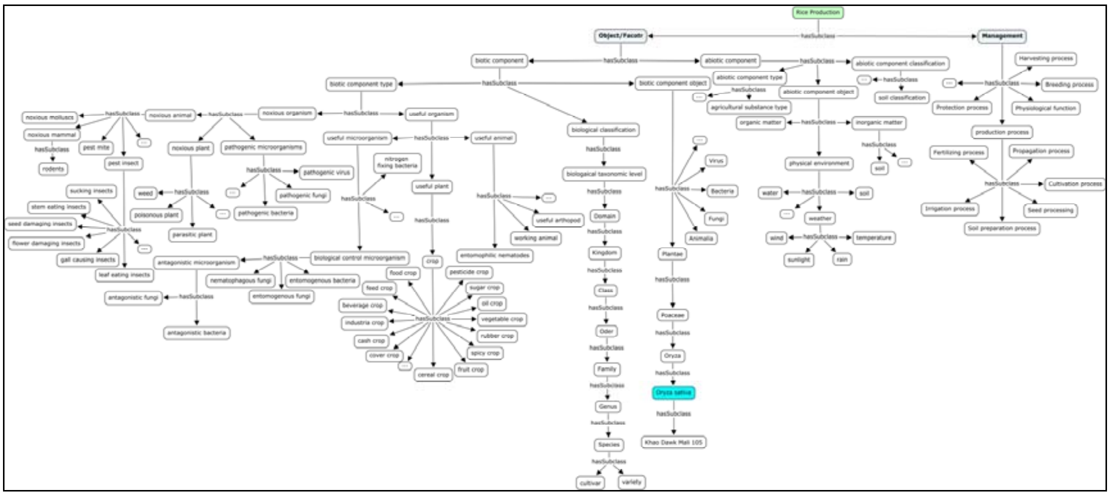


Figure 9 Conceptual model of rice production ontology

Component of the rice production ontology

As mentioned above, the structure of the ontology comprises concepts, terms, and relations. Concepts in this ontology were defined into three main groups as: Object entity concepts, Conceptual entity concepts, and Functional entity concepts, to clarify the concept classification.

The developed rice production ontology includes 2,322 concepts, 5,603 terms (Table 22) and 70 relations (Table 21, 23). About half of concepts and terms defined in the ontology are object entity concepts, the rest are conceptual entity concepts and functional entity concepts.

Having compared all the concepts from the rice production ontology with the existing terms in the FAO AGROVOC Thesaurus we found that about 2,687 terms in the ontology (48 percent of terms) are already existed in the Thai AGROVOC Thesaurus.

A comparison between the relationship in the rice production ontology with the existing relationship in the AGROVOC CS, result that 19 relationships are presented in both systems, while 51 new relationships were defined in this ontology (Table 23).

Table 21 Number of rice production ontology relationships

Relationship	number
Equivalence relationship	12
Hierarchical relationship	1
Associative relationship	57
Total	70

Table 22 Number of rice production ontology concepts and terms

Concept entity	Concept	Term
Object entity concept	**1,305**	**2,925**
Plant	291	633
Animal	530	1110
Fungi	41	57
Bacteria	16	21
Virus	11	12
Environmental factor	19	41
Plant nutrient	25	143
Soil series	240	480
Soil amendment	5	10
Agricultural substance	127	418
Conceptual entity concept	**793**	**2,000**
Taxonomic unit	169	190
Plant anatomy	61	126
Property	503	1540
Disorder	14	27
Disease	26	80
Symptom	20	37
Functional entity concept	**224**	**678**
Cultivation process	45	149
Harvesting process	12	29
Soil preparation process	18	51
Fertilizing process	30	99
Irrigation process	22	60
Propagation process	15	41
Seed processing	11	30
Breeding method	23	64
Protection process	34	109
Physiological function	14	46
Total	**2,322**	**5,603**

Table 23 Description of rice production ontology relationships

Relationship	Inverse relationship	Type	Status
hasSubClass	isSubClassOf	Hierarchical relationship	Existing in CS
hasLexicallization	isLexicallizationOf	Equivalence relationship	Existing in CS
hasSynonym	isSynonymOf	Equivalence relationship	Existing in CS
hasCommonName	isCommonNameOf	Equivalence relationship	Existing in CS
hasLocalName	isLocalNameOf	Equivalence relationship	Existing in CS
hasChemicalSymbol	isChemicalSymbolOf	Equivalence relationship	New defined
hasChemicalFormula	isChemicalFormulaOf	Equivalence relationship	Existing in CS
hasTradeName	isTradeNameOf	Equivalence relationship	Existing in CS
hasTranslation	isTranslationOf	Equivalence relationship	Existing in CS
hasAcronym	isAcronymOf	Equivalence relationship	Existing in CS
hasAbbreviation	isAbbreviationOf	Equivalence relationship	Existing in CS
hasSpellingVariant	isSpellingVariantOf	Equivalence relationship	Existing in CS
hasPlural	hasSingular	Equivalence relationship	Existing in CS
hasPlantProductionProcess	isPlantProductionProcessOf	Associative relationship	New defined
hasCultivationProcess	isCultivationProcessOf	Associative relationship	New defined
hasCultivationMethod	isCultivationMethodOf	Associative relationship	New defined
hasSoilCultivationProcess	isSoilCultivationProcessOf	Associative relationship	New defined
hasSoilCultivationMethod	isSoilCultivationMethodOf	Associative relationship	New defined
hasFertilizingProcess	isFertilizingProcessOf	Associative relationship	New defined
hasFertilizingMethod	ishasFertilizingMethodOf	Associative relationship	New defined
hasHarvestingProcess	isHarvestingProcessOf	Associative relationship	New defined
hasHarvestingMethod	isHarvestingMethodOf	Associative relationship	New defined
hasIrrigationProcess	isIrrigationProcessOf	Associative relationship	New defined

Table 23 (Continued)

Relationship	Inverse relationship	Type	Status
hasIrrigationMethod	isIrrigationMethodOf	Associative relationship	New defined
hasPropagationProcess	isPropagationProcessOf	Associative relationship	New defined
hasPropagationMethod	isPropagationMethodOf	Associative relationship	New defined
hasSeedProductionProcess	isSeedProductionProcessOf	Associative relationship	New defined
hasSeedProductionMethod	isSeedProductionMethodOf	Associative relationship	New defined
hasArrangementProcess	isArrangementProcessOf	Associative relationship	New defined
hasCropingSystem	isCropingSystemOf	Associative relationship	New defined
hasFarmingSystem	isFarmingSystemOf	Associative relationship	New defined
hasBreedingMethod	isBreedingMethodOf	Associative relationship	New defined
hasProtectionProcess	isProtectionProcessOf	Associative relationship	New defined
hasControlMethod	isControlMethodOf	Associative relationship	New defined
hasInfectingProcess	isInfectingProcessOf	Associative relationship	New defined
hasInfectingPart	isInfectingPartOf	Associative relationship	New defined
hasInfectingPeriod	isInfectingPeriodOf	Associative relationship	New defined
hasinfectingArea	isinfectingAreaOf	Associative relationship	New defined
hasCause	isCauseOf	Associative relationship	New defined
produce	isProducedFrom	Associative relationship	New defined
hasAffectingFactor	isAffectingFactorOf	Associative relationship	New defined
hasEnvironmentalFactor	isEnvironmentalFactorOf	Associative relationship	New defined
hasInjuriousFactor	ishasInjuriousFactorOf	Associative relationship	New defined
hasPathogen	isPathogenOf	Associative relationship	New defined
hasPest	isPestOf	Associative relationship	Existing in CS
hasWeed	isWeedOf	Associative relationship	New defined

Table 23 (Continued)

Relationship	Inverse relationship	Type	Status
hasVector	isVectorOf	Associative relationship	New defined
hasHost	isHostOf	Associative relationship	New defined
hasIncreasingFactor	isIncreasingFactorOf	Associative relationship	New defined
hasDecreasingFactor	isDecreasingFactorOf	Associative relationship	New defined
hasControlFactor	isControlFactorOf	Associative relationship	New defined
hasBiologicalControlAgent	isBiologicalControlAgentOf	Associative relationship	New defined
hasNaturalEnemy	isNaturalEnemyOf	Associative relationship	New defined
hasControlSubstance	isControlSubstanceOf	Associative relationship	New defined
hasPropagationMaterial	isPropagationMaterialOf	Associative relationship	New defined
hasSoilImpovementMaterial	isSoilImpovementMaterialOf	Associative relationship	New defined
hasPhysiologicalFunction	isPhysiologicalFunctionOf	Associative relationship	New defined
hasProperty	isPropertyOf	Associative relationship	Existing in CS
hasRelatedType	isRelatedTypeOf	Associative relationship	Existing in CS
hasTaxonomicLevel	isTaxonomicLevelOf	Associative relationship	Existing in CS
hasComposition	isCompositionOf	Associative relationship	New defined
hasHabit	isHabitOf	Associative relationship	New defined
hasBehaviour	isBehaviourOf	Associative relationship	New defined
hasPart	isPartOf	Associative relationship	Existing in CS
isResistantTo	isHarmlessFor	Associative relationship	New defined
isSusceptibleTo	isHarmfulFor	Associative relationship	New defined
hasSymptom	isSymptomOf	Associative relationship	Existing in CS
hasDisease	isDiseaseOf	Associative relationship	Existing in CS
hasDisorder	isDisorderOf	Associative relationship	New defined
hasAppearancePart	isAppearancePartOf	Associative relationship	New defined

Ontology visualization

Visualization tools such as Prefuse and Touch Graph are opensource tools which were selected to display this ontology. Prefuse was adjusted to display the ontology as an overview. Touch Graph was used to develop the Thai Agricultural Ontology Visualization Tool and pluged into the AGROVOC Concept Server Workbench to present the Thai Rice Production Ontology. The graph can be visualized in Thai or English; it is necessary to select the target concept and then click the visualized function. Moreover, the display can be both in hierarchical or vertical view, and the user can retrieve information from a predefined database by searching using the concept selected in the graphical view. All terms of that concept or the whole subclasses will be generated from the ontology and sent to the search mechanism in the connected database.

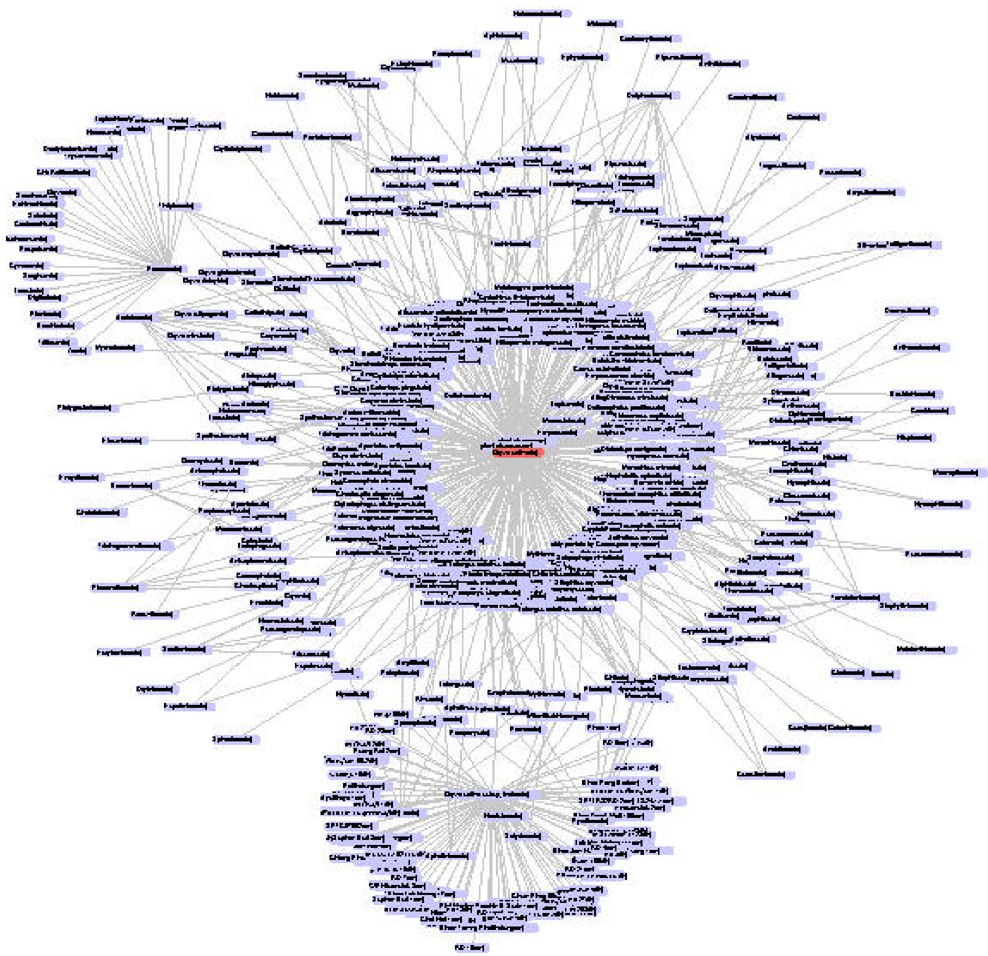


Figure 10 Thai Rice Production Ontology in the full view display

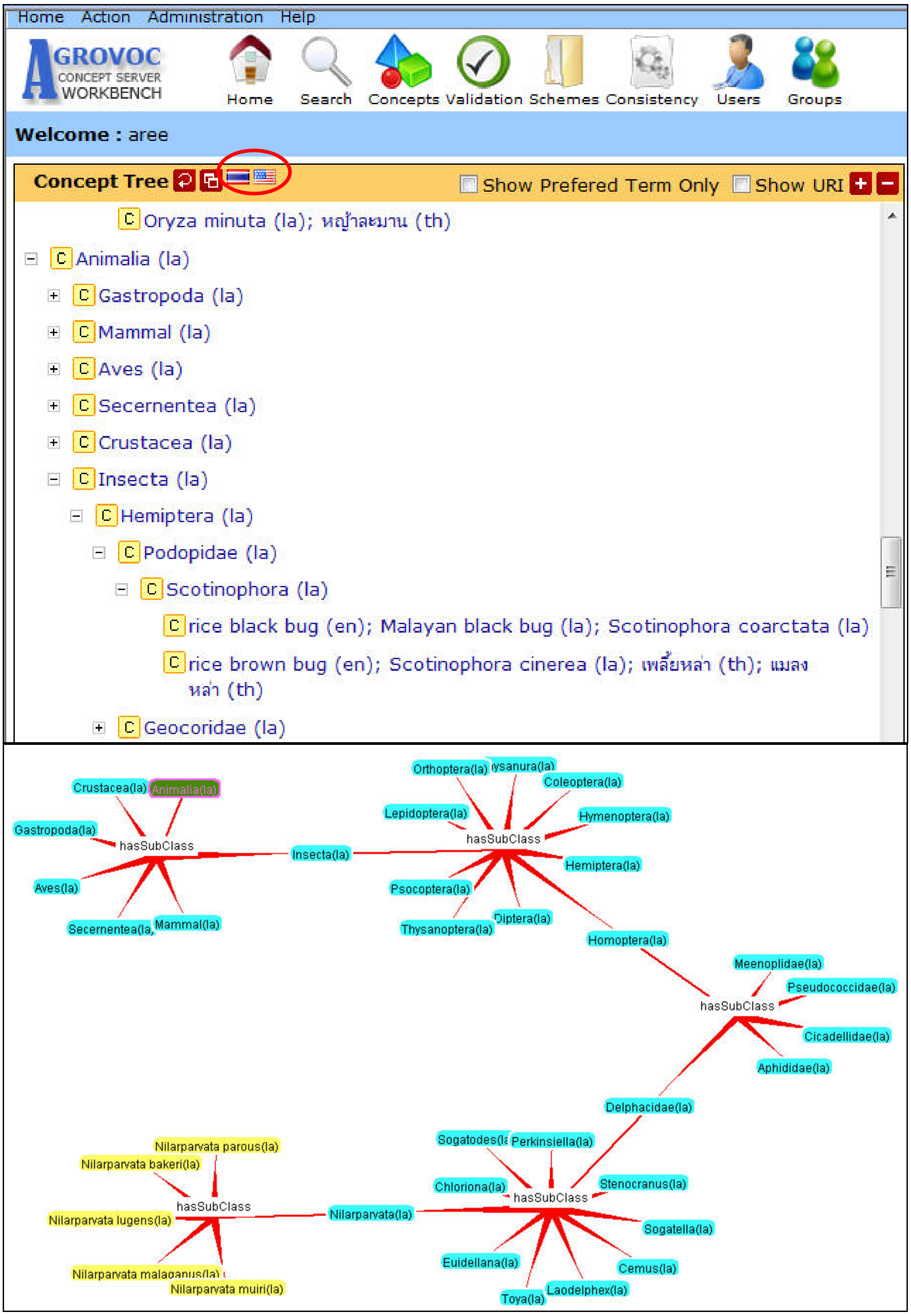


Figure 11 Thai Rice Production Ontology concept hierarchy displayed with the Thai Agricultural Ontology Visualization Tool in the AGROVOC CS WB

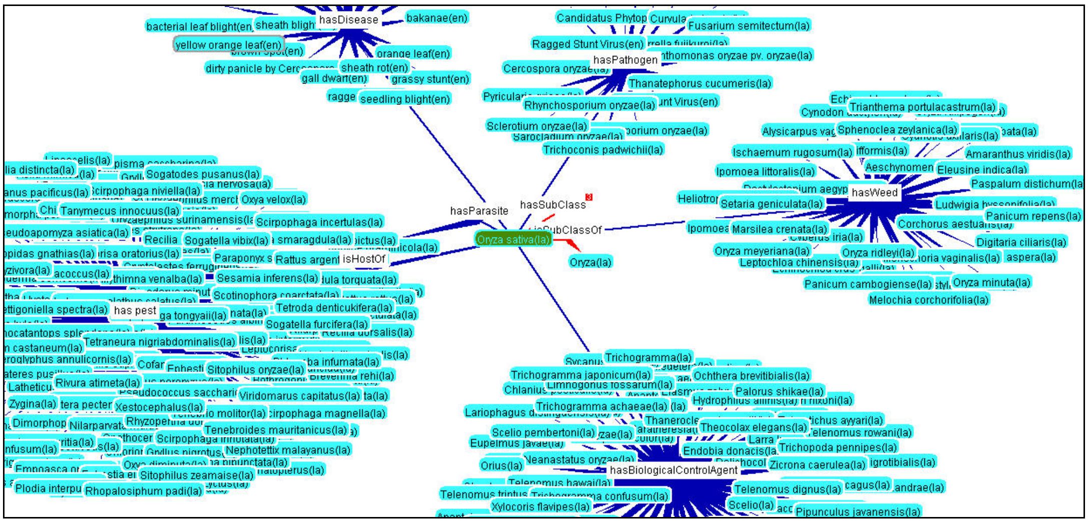


Figure 12 Section of the Thai Rice Production Ontology related to the concept[rice]

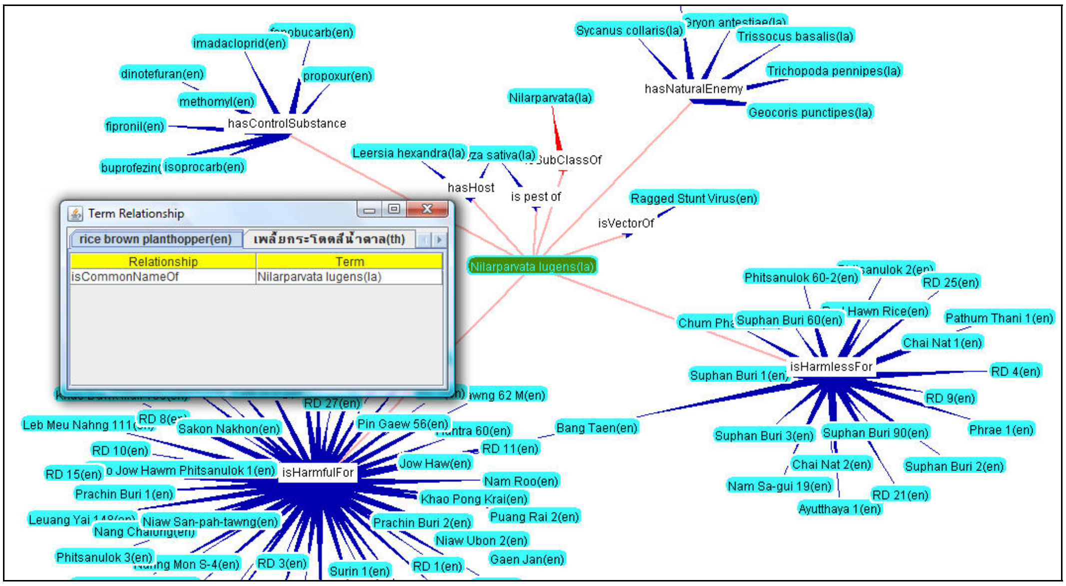


Figure 13 Description table of term relationships for the selected concept in the Thai Rice Production Ontology

The table above displays the common names in Thai and English for the concept[brown planthopper] and the corresponding term relationship "hasCommonName".

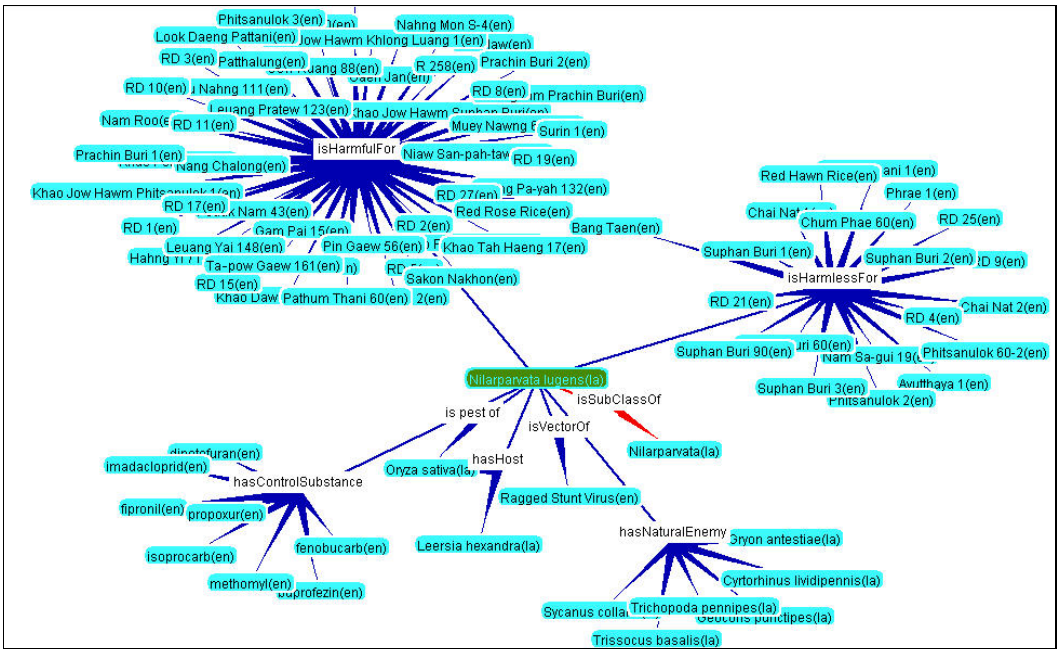


Figure 14 Thai Rice Production Ontology concept with associative relationships

The image above visualize the associative relationships (isPestOf, hasHost, isVectorOf, hasControlSubstance, hasNaturalEnemy, isHarmfulFor, isHarmlessFor) for the concept of brown planthopper.

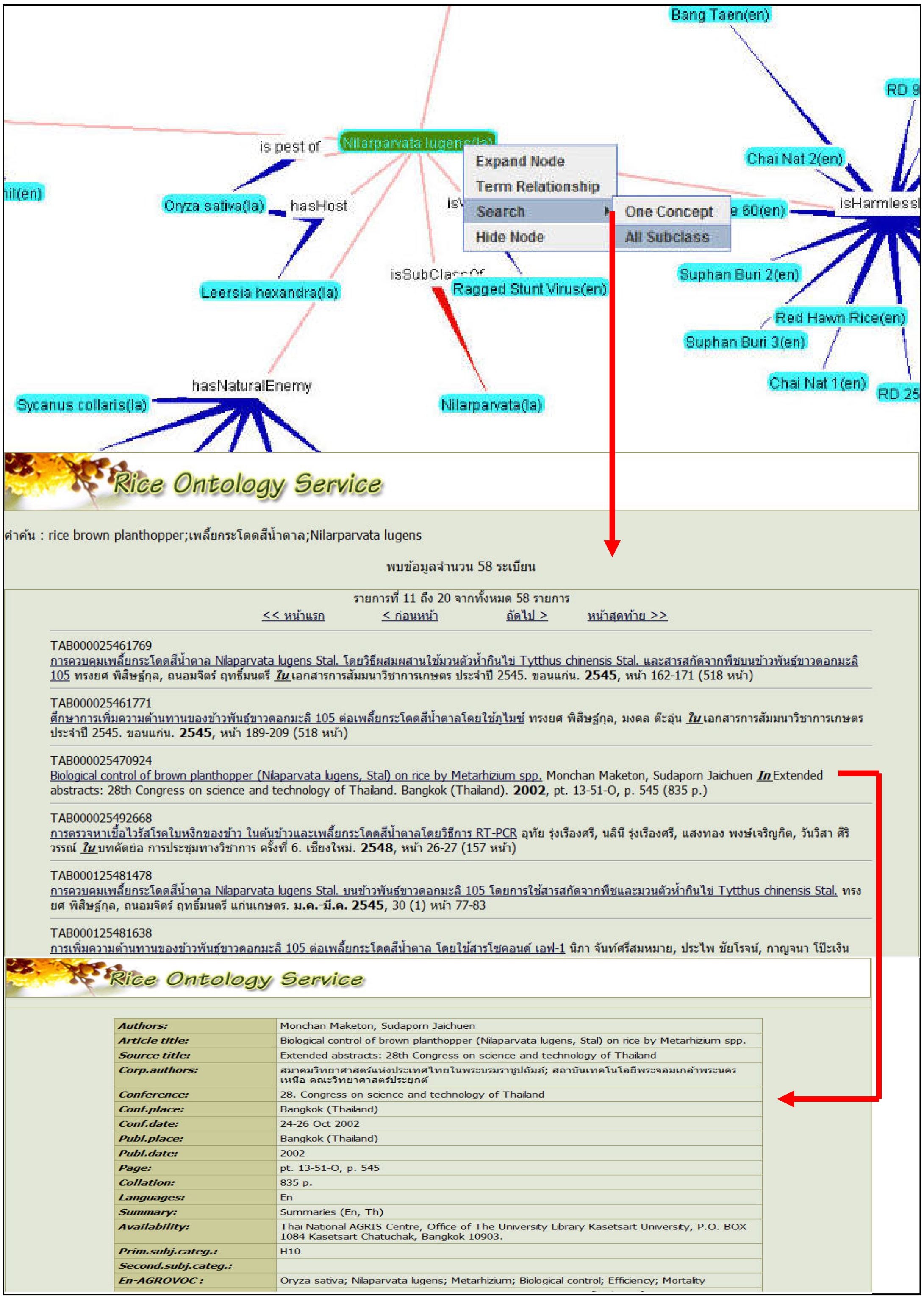


Figure 15 Thai Rice Production Ontology Visualization with search function and search results

The Thai Agricultural Ontology Visualization Tool is connected with a search function: by right clicking at the target concept, the user can select the function “Search”. Two options have been implemented: search by the selected concept or search by the selected concept and the whole subclasses. Terms of the selected concept will be generated and sent to query the Thai Rice Research Database; results are displayed with metadata.

Rice production ontology evaluation results

An ontology can provide context-aware search capabilities specific to the area of interest. The enhancement, extension, and disambiguation of user query terms become possible with the addition of enriched domain and context specific information (Soergel *et al*, 2004). The rice production ontology query expansion can improve information retrieval performance and answer questions which a retrieval system without ontology cannot do.

The rice production ontology is evaluated over its capabilities of satisfaction over the elaborated competency questions. Terms in the ontology were used to query in Thai Rice Research Database (containing 1,350 metadata records). The retrieval efficiency was measured in terms of its precision and recall.

The experiment was conducted using five competency questions; 93 queries were defined. The retrieval experiment compared a keyword-base search (conventional search) and name entity representation supported with ontology-based query expansion (ontology search). Results showed that the precision and recall rates increased averagely from 0.08 to 0.72 and 0.01 to 0.64 respectively (Table 48).

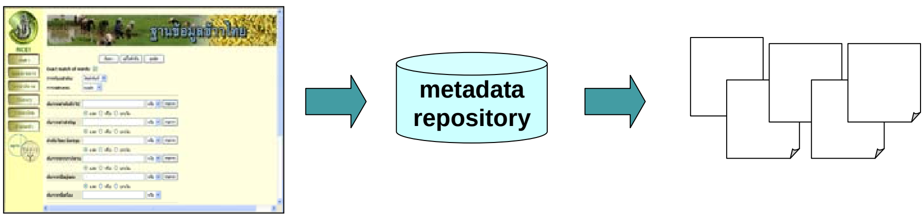


Figure 16 Conventional search mechanism

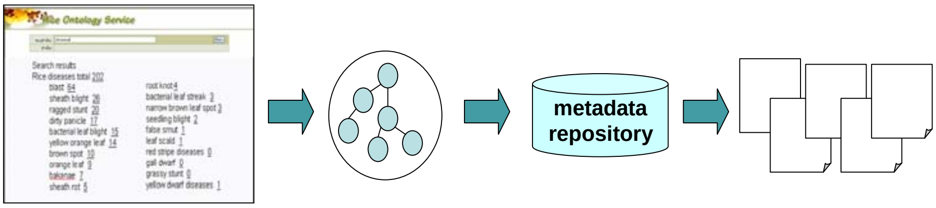


Figure 17 Ontology search mechanism

Figure 18 Conventional search result as a simple list

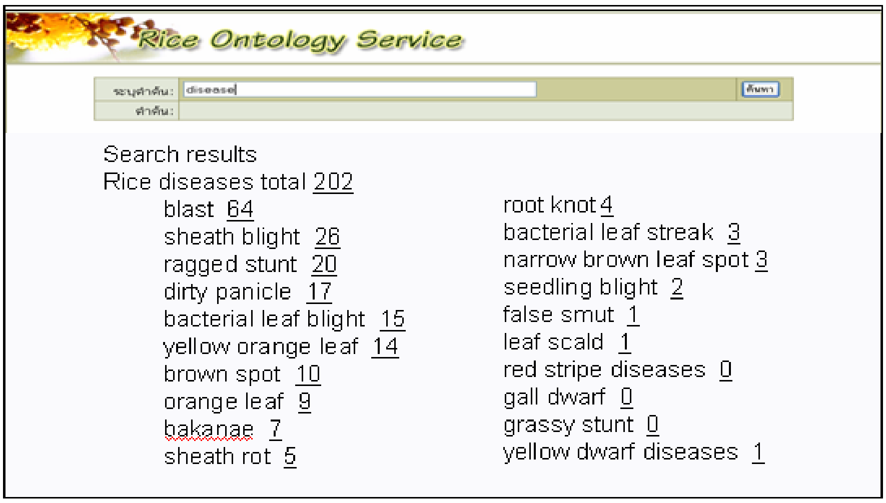


Figure 19 Ontology search result defined by disease names

As conventional search engines cannot interpret the sense of the user's search, not all the documents that discuss the concept can be retrieved, the ambiguity of the query leads to the retrieval of irrelevant information. Conventional search engines that match query terms against a keyword-based index will fail to match relevant information when the keywords used in the query are different from those used in the index, despite having the same meaning (synonym). Lack of context, many search engines fail to take into consideration aspects of the user's context to help disambiguate their queries.

The five competency questions from the rice research experts were used for testing. 93 queries were defined and described as follows:

1. Question: Jasmine rice is the most popular rice variety of Thailand. How many research on Jasmine rice exists in each subject?

Keywords: jasmine rice

Query by conventional method:
Query term 1a1=(jasmine rice OR jasmine rices) AND each subject categories

Query by ontology :
Query concept 1b1= [concept jasmine rice] AND each subject categories
Query term 1b1= (jasmine rice or Khao Dawk Mali 105 or Khao Dok Mali 105 or KDML 105 or Khao Hom Mali or ขาวดอกมะลิ 105 or ข้าวหอมมะลิ or หอมมะลิ 105 or พันธุ์ขาวดอกมะลิ 105 or ข้าวพันธุ์ขาวดอกมะลิ 105) AND each subject categories

The subject categories used in the query search were from the AGRIS/CARIS Subject Categorization Scheme. The subject category code were used for classification in the Thai Rice Research Database. The subject categories related with plant production were selected and here presented in Table 25.

Table 24 Jasmine rice terms and synonym

Preferred term	Relation	Synonym
Khao Dawk Mali 105	hasSynonym	Jasmine rice
Khao Dawk Mali 105	hasSynonym	Khao Dok Mali 105
Khao Dawk Mali 105	hasSynonym	Khao Hom Mali
Khao Dawk Mali 105	hasAcronym	KDML 105
Khao Dawk Mali 105	hasTranslation	ขาวดอกมะลิ 105
Khao Hom Mali	hasTranslation	ข้าวหอมมะลิ
ขาวดอกมะลิ 105	hasSynonym	หอมมะลิ 105
ขาวดอกมะลิ 105	hasSynonym	พันธุ์ขาวดอกมะลิ 105
ขาวดอกมะลิ 105	hasSynonym	ข้าวพันธุ์ขาวดอกมะลิ 105

Table 25 Plant production subject categories

Code	Description
F01	Crop husbandry
F02	Plant propagation
F03	Seed production
F04	Fertilizing
F06	Irrigation
F07	Soil cultivation
F08	Cropping patterns and systems
F30	Plant genetics and breeding
F40	Plant ecology
F50	Plant structure
F60	Plant physiology and biochemistry
F61	Plant physiology – Nutrition
F62	Plant physiology – Growth and development
F63	Plant physiology – Reproduction
F70	Plant taxonomy and geography
H01	Protection of plants – General aspects
H10	Pests of plants
H20	Plant diseases
H50	Miscellaneous plant disorders
H60	Weeds
P30	Soil science and management
P31	Soil surveys and mapping
P32	Soil classification and genesis
P33	Soil chemistry and physics
P34	Soil biology
P35	Soil fertility
P36	Soil erosion, conservation and reclamation

2. Question: How many researches focus on rice biological control organisms?

Keywords: rice, biological control organisms

Query by conventional method:

Query term 2a1= (rice OR rices) AND (biological control organism OR biological control organisms)

Query by ontology :

Query concept 2b1= object concept of [concept rice] "hasBiologicalControlAgent"

Query term 2b1= (*Chlanius posticalis or Ophionea indica or Thaneroclerus buquetii or Tilloidea notata or Micraspis discolor or Berosus or Hydrophilus affinis or Laccophilus difficilis or Paederus fuscipes or Palorus shikae or Dolichopus or Medetera or Ochthera brevitibialis or Pipunculus javanensis or Argyrophylax nigrotibialis or Dolichocolon vicinum or Exorista hyalipennis or Palexorista lucagus or Paratheresia or Trichopoda pennipes or Orius or Xylocoris flavipes or Geocoris ochropterus or Geocoris punctipes or Limnogonus fossarum or Cyrtorhinus lividipennis or Arbela nitidula or Zicrona caerulea or Amphibolus venator or Sycanus collaris or Aphelinus gossypii or Centrodora oophaga or Plastonoxus or Apanteles antipoda or Apanteles baoris or Apanteles taragamae or Bracon chinensis or Bracon hebetor or Bracon hispae or Cotesia flavipes or Dacnusa or Macrocentrus philippinensis or Antrocephalus pandens or Pseudogonatopus hospes or Elasmus brevicornis or Elasmus hyblaeae or Elasmus zehneri or Ooencyrtus malayensis or Tetrastichus ayyari or Tetrastichus or Eupelmus javae or Neanastatus oryzae or Endobia donacis or Anagrus optabilis or Platygaster oryzae or Anisopteromalus calandrae or Cerocephala dinoderi or Chaetospila elegans or Lariophagus distinguensis or Propicroscytus mirificus or Theocolax elegans or Gryon antestiae or Gryon nixoni or Macroteleia or Scelio pembertoni or Scelio or Telenomus beneficiens or Telenomus dignus or Telenomus hawai or Telenomus rowani or Telenomus triptus or Trissocus basalis or Larra bicolor or Larra luxonensis or Trichogramma achaeae or Trichogramma australicum or Trichogramma confusum or Trichogramma japonicum or Trichogramma or Conocephalus longipennis* or ground beetle or checkered beetle or ladybird beetle or water scavenger beetle or rove beetle or predatory beetle or long-legged fly or shore fly or big-headed fly or tachinid fly or minute pirate bug or big-eyed bug or water strider or leaf bug or damsel bug or stink bug or dark brown assassin bug or yellow-winged assassin bug or aphelinid or bethylid or braconid or chacidid or dryinid wasp or encyrtid wasp or eulophid wasp or eupelmid wasp or eurytomid wasp or mymarid wasp or platygasterid wasp or pteromalid wasp or scelionid wasp or sphecid wasp or trichogrammatid or long horned grasshopper or ด้วงดิน or ด้วงกินมอด or ด้วงเต่าสีส้ม or แมลงเหนี่ยง or ด้วงก้นกระดก or มอดตัวห้ำ or แมลงวันขายาว or แมลงวันชายน้ำ or แมลงวัน

ตาโต or แมลงวันก้นขน or มวนดอกไม้ or มวนตาโต or มวนจิงโจ้น้ำ or มวนหญ้า or มวนกิ่งไม้ or มวนพิฆาต or มวนเพชฌฆาตสีน้ำตาลไหม้ or มวนเพชฌฆาตดำปีกเหลือง or แตนเบียนอะฟีลินิด or แตนเบียนบีธีลิด or แตนเบียนบราโคนิด or แตนเบียนคาลสิด or แตนขาคีม or แตนขาจาน or แตนเบียนเอนเซอร์ติด or แตนเบียนยูโลฝิด or แตนเบียนยูเพลมิด or แตนเบียนยูรีโทมิด or แตนเบียนมายมาริด or แตนเบียนพลาติแกสเตอริด or แตนเบียนเทอโรมาลิด or แตนเบียนเซลิโอนิด or ต่อหมาร่า or แตนเบียนไข่ทริโคแกรมม่า or ตั๊กแตนหนวดยาว)

Concepts and terms related with biological control agent in the rice production ontology presented in table below.

Table 26 Example of concept and relation "hasBiologicalControlAgent"

Subject concept represent by preferred term	Relation	Object concept represent by preferred term
Oryza sativa	hasBiologicalControlAgent	*Chlanius posticalis*
Oryza sativa	hasBiologicalControlAgent	*Ophionea indica*
Oryza sativa	hasBiologicalControlAgent	*Thaneroclerus buquetii*
Oryza sativa	hasBiologicalControlAgent	*Tilloidea notata*
Oryza sativa	hasBiologicalControlAgent	*Micraspis discolor*

Table 27 Example of biological control agent terms and synonyms

Preferred term	Relation	Synonym
Chlanius posticalis	hasCommonName	ground beetle
Ophionea indica	hasCommonName	ground beetle
Thaneroclerus buquetii	hasCommonName	checkered beetle
Tilloidea notata	hasCommonName	checkered beetle
Micraspis discolor	hasCommonName	ladybird beetle

3. Question: What is the most popular rice disease research in Thailand?

Keywords: rice, diseases

Query by conventional method:

Query term 3a(n)= can not create query since the system can not interpret and define each rice disease's name

Query by ontology :

Query concept 3b(n)= object concept disease(n) of [concept rice] with relation “hasDisease” OR object concept of pathogen(n) which disease(n) has relation “hasCause”

Query term 3b1= blast or โรคไหม้ or *Pyricularia grisea or Magnaporthe grisea or Pyricularia oryzae*

Query term 3b2= narrow brown leaf spot or โรคใบขีดสีน้ำตาล or *Cercospora oryzae or Sphaerulina oryzina*

Query term 3b3= brown spot or โรคใบจุดสีน้ำตาล or *Helminthosporium oryzae or Cochiobolus miyabeanus or Bipolaris oryzae or Drechslera oryzae*

Query term 3b4= sheath blight orโรคกาบใบแห้ง or โรคขี้กลาก or *Thanatephorus cucumeris or Rhizoctonia solani*

Query term 3b5= bakanae orโรคถอดฝักดาบ or โคนเน่า or โรคหลาว or *Gibberrella fujikuroi or Fusarium moniliforme*

Query term 3b6= sheath rot orโรคกาบใบเน่า or โรคแท้ง or *Sarocladium oryzae or Sarocladium attenuatum or Acrocylindrium oryzae*

Query term 3b7= *Curvularia lunata or Cochiobolus lunatus*

Query term 3b8= *Fusarium semitectum*

Query term 3b9= *Cercospora oryzae*

Query term 3b10= *Sarocladium oryzae or Sarocladium attenuatum or Acrocylindrium oryzae*

Query term 3b11= *Helminthosporium oryzae or Cochiobolus miyabeanus or Bipolaris oryzae or Drechslera oryzae*

Query term 3b12= *Trichoconis padwichii or Alternaria padwickii*

Query term 3b13= false smut or โรคดอกกระถิน or *Ustilaginoidea virens or Claviceps oryzae-sativae*

Query term 3b14= leaf scald or โรคใบวงสีน้ำตาล or *Rhynchosporium oryzae or Phragmosperma oryzae*

Query term 3b15= seedling blight or โรคกอเน่า or *Sclerotium oryzae or Corticium rolfsii*

Query term 3b16= bacterial leaf blight or โรคขอบใบแห้ง or *Xanthomonas oryzae pv. Oryzae*

Query term 3b17= bacterial leaf streak or โรคใบขีดโปร่งแสง or *Xanthomonas translucens* f. sp. *Oryzicola*

Query term 3b18= red stripe diseases or โรคใบแถบแดง or *Microbacterium*

Query term 3b19= yellow orange leaf or โรคใบสีส้ม or RiceYellow Orange Leaf Virus

Query term 3b20= ragged stunt orโรคใบหงิก or โรคจู๋ or Ragged Stunt Virus

Query term 3b21= gall dwarf or โรคหูด or Rice Gall Dwarf Virus

Query term 3b22= grassy stunt or โรคเขียวเตี้ย or Grassy Stunt Virus

Query term 3b23= orange leaf or โรคใบสีแสด or *Candidatus* Phytoplasma

Query term 3b24= yellow dwarf diseases or โรคเหลืองเตี้ย or *Candidatus Phytoplasma oryzae*

Query term 3b25= root knot o rโรครากปม or *Meloidogyne graminicola*

The highest number of the query results is the answer of the most popular rice disease. Concepts and terms related with rice diseases in the rice production ontology were listed as examples in table below.

Table 28 Example of concepts of relation "hasDisease"

Subject concept represent by preferred term	Relation	Object concept represent by preferred term
Oryza sativa	hasDiseases	blast
Oryza sativa	hasDiseases	narrow brown leaf spot
Oryza sativa	hasDiseases	brown spot
Oryza sativa	hasDiseases	sheath blight
Oryza sativa	hasDiseases	bakanae

Table 29 Example of disease terms and synonyms

Preferred term	Relation	Synonym
blast	hasTranslation	โรคไหม้
narrow brown leaf spot	hasTranslation	โรคใบขีดสีน้ำตาล
brown spot	hasTranslation	โรคใบจุดสีน้ำตาล
sheath blight	hasTranslation	โรคกาบใบแห้ง
โรคกาบใบแห้ง	hasSynonym	โรคขี้กลาก

Table 30 Example of pathogen terms and synonyms

Preferred term	Relation	Synonym
Pyricularia grisea	hasSynonym	*Magnaporthe grisea*
Pyricularia grisea	hasSynonym	*Pyricularia oryzae*
Cercospora oryzae	hasSynonym	*Sphaerulina oryzina*
Helminthosporium oryzae	hasSynonym	*Cochiobolus miyabeanus*
Thanatephorus cucumeris	hasSynonym	*Rhizoctonia solani*

4. Question: How many rice researches contains information about chemical fertilizers and organic fertilizers?

Keywords: rice, chemical fertilizers, organic fertilizers

Query by conventional method:

Query term 4a1= (rice or rices) AND (chemical fertilizers or chemical fertilizer)

Query term 4a2= (rice or rices) AND (organic fertilizers or organic fertilizer)

Query by ontology :

Query concept 4b1= [concept rice] AND ([concept chemical fertilizers] OR all subclass of [concept chemical fertilizers]

Query concept 4b2= [concept rice] AND ([concept organic fertilizers] OR all subclass of [concept organic fertilizers]

Query term 4b1= (*Oryza sativa* or rice or ข้าว) AND ((chemical fertilizers or ปุ๋ยเคมี or inorganic fertilizers or ปุ๋ยอนินทรีย์) OR (compound fertilizers or nitrogen potassium fertilizers or NPK fertilizers or phosphorus potassium fertilizers or single fertilizers or calcium fertilizers or magnesium fertilizers or micronutrient fertilizers or nitrogen fertilizers or phosphate fertilizers or rock phosphate or super phosphate or potash fertilizers or sulphur fertilizers or mineral fertilizers or chemical fertilizer or binary fertilizers or mixed fertilizers or blended fertilizers or ternary compounds fertilizers or secondary fertilizers or trace element fertilizers or ammonium fertilizers or nitrate fertilizers or phosphorus fertilizers or mineral phosphate or potassium fertilizers or sulfur fertilizers or ปุ๋ยเชิงประกอบ or ปุ๋ยเชิงเดี่ยว or ปุ๋ยไนโตรเจนฟอสฟอรัส or ปุ๋ยไนโตรฟอสเฟต or ปุ๋ยไนโตรเจนโพแทสเซียม or ปุ๋ยเอ็นพีเค or ปุ๋ยฟอสฟอรัสโพแทสเซียม or ปุ๋ยแคลเซียม or ปุ๋ยแมกนีเซียม or ปุ๋ยจุลธาตุ or ปุ๋ยไนโตรเจน or ปุ๋ยฟอสเฟต or หินฟอสเฟต or ปุ๋ยซูเปอร์ฟอสเฟต or ปุ๋ยโพแทส or ปุ๋ยซัลเฟอร์) OR their singular/plural term)

Query term 4b2= (*Oryza sativa* or rice or ข้าว) AND ((organic fertilizers or ปุ๋ยอินทรีย์) OR (green manures or farm manure or compost or biofertilizer or animal manure or humate fertilizers or ปุ๋ยพืชสด or ปุ๋ยคอก or ปุ๋ยหมัก or ปุ๋ยชีวภาพ) OR their singular/plural term)

Concepts and terms related with chemical fertilizer and organic fertilizer in the rice production ontology were described in table below.

Table 31 Chemical fertilizers concept and subclass concepts

Super class concept represent by preferred term	Relation	Subclass concept represent by preferred term
inorganic fertilizers	hasSubClass	compound fertilizers
compound fertilizers	hasSubClass	nitrogen potassium fertilizers
compound fertilizers	hasSubClass	NPK fertilizers
compound fertilizers	hasSubClass	phosphorus potassium fertilizers
inorganic fertilizers	hasSubClass	single fertilizers
single fertilizers	hasSubClass	calcium fertilizers
single fertilizers	hasSubClass	magnesium fertilizers
single fertilizers	hasSubClass	micronutrient fertilizers
single fertilizers	hasSubClass	nitrogen fertilizers
single fertilizers	hasSubClass	phosphate fertilizers
phosphate fertilizers	hasSubClass	rock phosphate
phosphate fertilizers	hasSubClass	super phosphate
single fertilizers	hasSubClass	potash fertilizers
single fertilizers	hasSubClass	sulphur fertilizers

Table 32 Chemical fertilizers terms and synonyms

Preferred term	Relation	Synonym
inorganic fertilizers	hasSynonym	mineral fertilizers
inorganic fertilizers	hasSynonym	chemical fertilizer
compound fertilizers	hasSynonym	binary fertilizers
compound fertilizers	hasSynonym	mixed fertilizers
compound fertilizers	hasSynonym	blended fertilizers
NPK fertilizers	hasSynonym	ternary compounds (fertilizers)
micronutrient fertilizers	hasSynonym	secondary fertilizers
micronutrient fertilizers	hasSynonym	trace element fertilizers
nitrogen fertilizers	hasSynonym	ammonium fertilizers
nitrogen fertilizers	hasSynonym	nitrate fertilizers
phosphate fertilizers	hasSynonym	phosphorus fertilizers
rock phosphate	hasSynonym	mineral phosphate
potash fertilizers	hasSynonym	potassium fertilizers
sulphur fertilizers	hasSynonym	sulfur fertilizers
inorganic fertilizers	hasTranslation	ปุ๋ยอนินทรีย์
compound fertilizers	hasTranslation	ปุ๋ยเชิงประกอบ
single fertilizers	hasTranslation	ปุ๋ยเชิงเดี่ยว
nitrogen phosphorus fertilizers	hasTranslation	ปุ๋ยไนโตรเจนฟอสฟอรัส
nitrophosphates	hasTranslation	ปุ๋ยไนโตรฟอสเฟต
nitrogen potassium fertilizers	hasTranslation	ปุ๋ยไนโตรเจนโพแทสเซียม
NPK fertilizers	hasTranslation	ปุ๋ยเอ็นพีเค
phosphorus potassium fertilizers	hasTranslation	ปุ๋ยฟอสฟอรัสโพแทสเซียม
calcium fertilizers	hasTranslation	ปุ๋ยแคลเซียม
magnesium fertilizers	hasTranslation	ปุ๋ยแมกนีเซียม
micronutrient fertilizers	hasTranslation	ปุ๋ยจุลธาตุ
nitrogen fertilizers	hasTranslation	ปุ๋ยไนโตรเจน
phosphate fertilizers	hasTranslation	ปุ๋ยฟอสเฟต
rock phosphate	hasTranslation	หินฟอสเฟต
superphosphate	hasTranslation	ปุ๋ยซูเปอร์ฟอสเฟต
potash fertilizers	hasTranslation	ปุ๋ยโพแทส
sulphur fertilizers	hasTranslation	ปุ๋ยซัลเฟอร์

Table 33 Organic fertilizers concept and child concepts

Subject concept represent by preferred term	Relation	Object concept represent by preferred term
organic fertilizers	hasSubClass	green manures
organic fertilizers	hasSubClass	farm manure
organic fertilizers	hasSubClass	compost
organic fertilizers	hasSubClass	biofertilizer

Table 34 Organic fertilizers terms and synonyms

Preferred term	Relation	Synonym
farm manure	hasSynonym	animal manure
farm manure	hasSynonym	humate fertilizers
organic fertilizers	hasTranslation	ปุ๋ยอินทรีย์
green manures	hasTranslation	ปุ๋ยพืชสด
farm manure	hasTranslation	ปุ๋ยคอก
compost	hasTranslation	ปุ๋ยหมัก
biofertilizer	hasTranslation	ปุ๋ยชีวภาพ

5. Question: How many researches contain information about rice pest control, define by type of pest such as “field pest” and “stored product pest”?

Keywords: rice pest, field pest, stored product pest, pest protection, pest control method

Query by conventional method

Query term 5a1= (rice or rices) AND (field pest or field pests) AND (pest control OR control method or control methods OR pesticide or pesticides)

Query term 5a2= (rice or rices) AND (stored product pest or stored product pests) AND (pest control OR control method or control methods OR (pesticide or pesticides)

Query by ontology:

Query concept 5b1= (object concept pest of [concept rice] with relation “hasPest” which has relation “hasRelatedType” = [concept field pest]) AND (subclass of concept [pest control] OR subclass of concept [control method] OR subclass of concept [pestticide])

Query concept 5b2= (object concept pest of [concept rice] with relation “hasPest” which has relation “hasRelatedType” = [concept stored product pest]) AND (subclass of concept [pest control] OR subclass of concept [control method] OR subclass of concept [pestticide])

Query term 5b1= (*Acrida willemsei or Aiolopus thalassinus or Alissonotum cribratellum or Ampittia dioscorides or Ampittia maroides or Atherigona exigua or Atherigona oryzae or Atractomorpha psitasina or Balclusa rubrostriata or Balclutha incisa or Balclutha viridinervis or Balclutha viridis or Baliothrips defomis or Baoris farri farri or Baoris oceia or Borbo cinnara or Bothrogonia indistincta or Brevennia rehi or Caliothrips striatopterus or Caryanda diminuta or Catantops pinguis or Cemus pulchella or Chilo auricilius or Chilo infuscatellus or Chilo polychrysus or Chilo supressalis or Chloriona or Cicadulina bipunctata or Cnaphalocrocis medinalis or Cofana spectra or Cofana unimaculata or Deltocephalus intermidius or Deltocephalus pacificus or Dicladispa armigera or Dimorphopterus or Empoasca onukii or Empoasca vitis or Empoascanara alami or Esanthelphusa or Euidellana celadon or Eusarcocoris guttiger or Eusarcocoris ventralis or Glossocratus orientalis or Gryllotalpa africana or Gryllotalpa orientalis or Gryllus nigrotus or Gryllus testaceus or Heteronychus poropyrus or Heteropternis respondens or Hieroglyphus annulicornis or Hieroglyphus banian or Hyarotis adrastus prabha or Hydrellia or Hydrellia griseola or Hydrellia philippina or Hydronomidius molitor or Hysteroneura setariae or Kolla mimica or Laodelphex striatellus or Leptocorisa chinensis or Leptocorisa oratorius or Leptocorisa varicornius or Leucopholis rorida or Lochura punctulata or Locusta migratoria manilensis or Lotongus calathus balta or Lotongus calathus calatus or Lotongus schaedia or Macrosteles larvis or Macrosteles striifrons or Marasmia exigua or Meloidogyne graminicola or Milanitis leda ismene or Milanitis leda leda or Monochirus minor or Mythimna separata or Mythimna venalba or Naranga aenescens or Neodartus acocephaloides or Nephotettix apicalis or Nephotettix malayanus or Nephotettix nigropictus or Nephotettix virescens or Nezara viridula smaragdula or Nezara viridula torquata or Nilarparvata bakeri or Nilarparvata lugens or Nilarparvata malaganus or Nilarparvata muiri or Nilarparvata parous or Nirvana pallida or Nisia nervosa or Nymphula depunctalis or Orseolia oryzae or Oxya diminuta or Oxya hyla or Oxya hyla intricata or Oxya velox or Pachyacris vinosa or Paracoccus or Paramesodes albinervosus or Paraponyx stagnalis or Parnara naso or Pelopidas gnathias or Pelopidas mathias mathias or Perkinsiella saccharicida or Phlaeoba antennata or Phlaeoba infumata or Piezodorus rubrofasciatus or Pomacea canaliculata or Pseudoapomyza asiatica or Pseudococcus saccharicola or Quilta oryzae or Rattus rattus or Recilia distincta or Recilia dorsalis or Recilia infermus or Rhopalosiphum padi or Rivura atimeta or Sayamia or Scaphoideus knappi or Scirpophaga incertulas or Scirpophaga innotata or Scirpophaga magnella or Scirpophaga niviella or Scirpophaga tongyaii or Scotinophora cinerea or Scotinophora coarctata or Sesamia inferens or Sogatella furcifera or Sogatella kolophon or Sogatella vibix or Sogatodes pusanus or Spathosternum prasiniferum or Spodoptera mauritia or Spodoptera pectens or Stenchaetothrips biformis or Stenocatantops splendens or Stenocranus pacificus or Stirellus rotundus or Tanymecus innocuus or Tetraneura nigriabdominalis or Tetroda* *denticukifera or Tettigoniella spectra or Thaia oryzivora or Toya propinqua or Trionymus or Viridomarus capitatus or Xestocephalus or Zygina* or cereal armyworm or rice skipper or African steaight swift or armyworm or bush hopper or cereal bug or common evening brown or corn leaf miner or cricket or cutworm or dark-headed stem borer or formosan swift or golden apple snail or grasshopper or gray planthopper or green hairy caterpillar or green horned caterpillar or jassid or leaf acridid or leafhopper or maize black thrips or Malayan black bug or mealybug or migratory locust or mole cricket or nematode or orange rice leafhopper or paddy bug or paddy hispa or paintbrush swift or pink stem borer or planthopper or reed bug or RF or RGM or rice aphid or rice armyworm or rice black bug or rice brown bug or rice brown planthopper or rice caseworm or rice cutworm or rice ear bug or rice gall midge or rice grasshopper or rice green leafhopper or rice green semilooper or rice hispa or rice jassid or rice leaf folder or rice leaf miner or rice leaf roller or rice leafhopper or rice mealybug or rice red leafhopper or rice root aphid or rice root weevil or rice stink bug or rice swarming caterpillar or rice thrips or rice weevil or rice whorl maggot or ricefield crab or rice-swarming caterpillar or roof rat or seedling maggot or ship rat or small branded swift or small brown planthopper or small green leaf hopper or small green stink bug or small rice grasshopper or spoted munia or stem borer or stink bug or striped stem borer or sugarcane borer or sugarcane brown aphid or sugarcane brown planthopper or sugarcane stalk borer or sugarcane yellow top borer or tree flitter or white grub or white leafhopper or white stem borer or white-backed planthopper or white-tipped palmer or yellow top borer or zig zag leafhopper or จิ้งหรีด or ด้วงงวงรากข้าว or ด้วงดำ or ตั๊กแตนหนวดสั้น or ตั๊กแตนไฮโรไกลฟัส or นกกระติ๊ดขี้หมู or บั่ว or ปูนา or ผีเสื้อจิ๋วป่าพุ่ม or ผีเสื้อบินเร็ว or ผีเสื้อบินเร็วข้าว or ผีเสื้อมุมใต้ปีกขาว or ผีเสื้อลายใต้เลอะ or ผีเสื้อสายัณห์สีตาล or ผีเสื้อสีขาว or ผีเสื้อหนอนกระทู้กล้า or ผีเสื้อหนอนกระทู้ข้าว or ผีเสื้อหนอนกระทู้คอรวง or ผีเสื้อหนอนกระทู้ธัญพืช or ผีเสื้อหนอนกอแถบลาย or ผีเสื้อหนอนกอแถบลายม่วง or ผีเสื้อหนอนกอสีชมพู or ผีเสื้อหนอนข้าว or ผีเสื้อหนอนข้าวปีกพู่ or ผีเสื้อหนอนข้าวใหญ่ or ผีเสื้อหนอนเขาข้าว or ผีเสื้อหนอนคืบข้าว or ผีเสื้อหนอนเจาะลำอ้อย or ผีเสื้อหนอนปลอกข้าว or ผีเสื้อหนอนม้วนใบข้าว or ผีเสื้อหนอนลายเล็ก or ผีเสื้อหนอนสีขาว or ผีเสื้อหนอนสีครีม or ผีเสื้อหนอนห่อใบข้าว or เพลี้ยกระโดด or เพลี้ยกระโดดข้าว or เพลี้ยกระโดดสีน้ำตาล or เพลี้ยกระโดดสีน้ำตาลเล็ก or เพลี้ยกระโดดหลังขาว or เพลี้ยกระโดดอ้อย or เพลี้ยจักจั่นขาว or เพลี้ยจักจั่นข้าวปีกใส or เพลี้ยจักจั่นข้าวสีส้ม or เพลี้ยจักจั่นแดง or เพลี้ยจักจั่นปีกลายหยัก or เพลี้ยจักจั่นลายหยัก or เพลี้ยจักจั่นสีขาว or เพลี้ยจักจั่นสีเขียว or เพลี้ยจักจั่นอ้อย or เพลี้ยแป้ง or เพลี้ยแป้งข้าว or เพลี้ยไฟข้าว or เพลี้ยไฟดำข้าวโพด or เพลี้ยหล่า or เพลี้ยอ่อนข้าว or เพลี้ยอ่อนรากข้าว or เพลี้ยอ่อนอ้อยสีน้ำตาล or มวนเขียวข้าว or มวนเขียวเล็ก or มวนง่าม or มวนธัญญพืช or มวนปีกกุด or แมลงกระชอน or แมลงค่อม or แมลงดำหนาม or แมลงนูน or แมลงบั่ว or แมลงบั่วข้าว or แมลงวันเจาะยอดข้าว or แมลงวันต้นกล้า or แมลงวันหนอนชอนใบข้าว or แมลงสิง or แมลงหล่า or ไส้เดือนฝอย or หนอนกอข้าวสีครีม or

หนอนกอแถบลาย or หนอนกอแถบลายม่วง or หนอนกอสีชมพู or หนอนชอนใบข้าวโพด or หนอนปลอกข้าว or หนอนม้วนใบข้าว or หนอนแมลงวันเจาะยอดข้าว or หนอนห่อใบข้าว or หนูท้องขาว or หอยเชอรี่ or อีบู) AND ((bird control or brush control or disinfestation of living organism or insect control or mite control or mollusc control or nematode control or pest control or pest eradication or pest management or rodent control or vermin proofing or การกำจัดศัตรูพืช or การกำจัดสิ่งมีชีวิตที่เป็นอันตราย or การควบคุมนก or การจัดการศัตรูพืช or การป้องกันกำจัดแมลง or การป้องกันกำจัดไร or การป้องกันกำจัดศัตรูพืช or การป้องกันกำจัดสัตว์ฟันแทะ or การป้องกันกำจัดไส้เดือนฝอย or การป้องกันกำจัดหอย) OR (antifeedants or artificial hawks or attractants or bagging or bangers or biocontrol or biological control or biological techniques or bird scarers or chemical control or control methods or controlled burning or conventional pest management or cultural control or ecological control or feeding deterrents or feeding inhibitors or genetic control or integrated control or integrated disease control or integrated disease management or integrated pest control or integrated pest management or integrated protection or IPM or lures or mating disruption or netting (pest control) or pest control baits or pest repellents or phagodeterrents or physical control or phytorepellents or prescribed burning or quarantine or repellents or roguing or scarecrows or scares or sex attractants or sterile insect release or stubble burning or stubble burning or thermal control or thermal pest control or การควบคุมด้วยความร้อน or การควบคุมด้วยสารเคมี or การควบคุมโดยการเขตกรรม or การควบคุมโดยชีววิธี or การควบคุมโดยนิเวศวิธี or การควบคุมโดยพันธุกรรม or การควบคุมโดยวิธีทางกายภาพ or การควบคุมโดยวิธีผสมผสาน or การควบคุมโรคโดยวิธีผสมผสาน or การควบคุมศัตรูพืชด้วยความร้อน or การควบคุมศัตรูพืชโดยวิธีผสมผสาน or การจัดการโรคโดยวิธีผสมผสาน or การจัดการศัตรูพืชโดยวิธีดั้งเดิม or การจัดการศัตรูพืชโดยวิธีผสมผสาน or การดักตาข่าย or การทำให้แมลงเป็นหมัน or การป้องกันกำจัดศัตรูพืชโดยการคลุมถุง or การป้องกันกำจัดศัตรูพืชโดยชีววิธี or การป้องกันโดยวิธีผสมผสาน or การเผาซากพืช or การเผาตอซัง or การเผาที่ถูกควบคุม or การเผาในที่กำหนดไว้ or การยับยั้งการผสมพันธุ์ or เครื่องไล่นก or ด่านกักกัน or วิธีการควบคุม or สารขับไล่ or สารดึงดูดทางเพศ or สารยับยั้งการกินอาหาร or สารล่อ or หุ่นไล่กา or เหยี่ยวเทียม or อุปกรณ์ที่ทำให้สัตว์กลัว or ไอพีเอ็ม) OR (acaricides or antagonistic fungi or antagonistic microorganisms or aphicides or arboricides or avicides or bacterial antagonists or bacterial pesticides or bactericides or biopesticides or bird control chemicals or botanical insecticides or botanical pesticides or controlled release pesticides or corvicides or fungal antagonists or fungicides or insecticides or larvicides or microbial pesticides or miticides or molluscicides or nematicides or nematocides or pesticide synergists or pesticides or plant insecticides or rat poisons or rodenticides or slow release pesticides or slug killers or snail killers or vegetable insecticides or เชื้อรากำจัดจุลินทรีย์

or แบคทีเรียกำจัดจุลินทรีย์ or ยาฆ่านก or ยาฆ่าหอย or ยาเบื่อหนู or สมุนไพรกำจัดแมลง or สมุนไพรฆ่าแมลง or สารกำจัดจุลชีพ or สารเคมีกำจัดนก or สารฆ่าไร or สารฆ่าไส้เดือนฝอย or สารป้องกันกำจัดเชื้อรา or สารป้องกันกำจัดนก or สารป้องกันกำจัดแบคทีเรีย or สารป้องกันกำจัดเพลี้ย or สารป้องกันกำจัดแมลง or สารป้องกันกำจัดแมลงจากพืช or สารป้องกันกำจัดไร or สารป้องกันกำจัดศัตรูพืช or สารป้องกันกำจัดศัตรูพืชจากจุลินทรีย์ or สารป้องกันกำจัดศัตรูพืชจากแบคทีเรีย or สารป้องกันกำจัดศัตรูพืชจากพืช or สารป้องกันกำจัดศัตรูพืชชีวภาพ or สารป้องกันกำจัดศัตรูพืชแบบควบคุมการออกฤทธิ์ or สารป้องกันกำจัดศัตรูพืชแบบออกฤทธิ์ช้า or สารป้องกันกำจัดไส้เดือนฝอย or สารป้องกันกำจัดหนู or สารป้องกันกำจัดหอย or สารป้องกันกำจัดหอยทาก or สารเสริมฤทธิ์กำจัดศัตรูพืช))

Query term 5b2= (*Ahasverus advena or Alphitobius diaperinus or Alphitobius laevigatus or Anthrenus vorax or Araecerus fusciculatus or Attagenus pellio or Bandicota indica or Bandicota savilei or Carpophilus dimidiatus or Corcyra cephalonica or Cryptolestes ferrugineus or Cryptolestes pusillus or Cryptolestes turcicus or Dinoderus minutus or Ephestia cautella or Ephestia elutella or Ephestia kueniella or Gnathocerus cornutus or Lasioderma serricorne or Latheticus oryzae or Lepisma saccharina or Liposcelis or Lophocateres pusillus or Lyctus or Oryzaephilus merchator or Oryzaephilus surinamensis or Plodia interpunctella or Rattus argentiventer or Rhyzopertha dominica or Sitophilus oryzae or Sitophilus zeamaise or Sitotroga cerealella or Tenebrio molitor or Tenebroides mauritanicus or Tribolium castaneum or Tribolium confusum* or stored product pest or angomoise grain moth or bamboo borer or black fungus beetle or booklice or bristletail or cadelle or carpet beetle or cigarette beetle or cocoa weevil or confuse flour beetle or corn weevil or corn-sap beetle or flat beetle or flat grain beetle or flour beetle or great bandicoot or indian meal moth or lesser bandicoot or lesser grain borer or lesser mealworm or long-headed flour beetle or marchant grain beetle or powder-post beetle or red flour beetle or rice moth or rice weevil or ricefield rat or rusty grain beetle or saw toothed grain beetle or siamese grain beetle or tropical warehouse moth or yellow mealworm or ด้วงโกโก้ or ด้วงขนสัตว์ or ด้วงขี้ผง or ด้วงคาเดล or ด้วงงวงข้าว or ด้วงงวงข้าวโพด or ด้วงดำ or ด้วงดำกินเชื้อรา or ด้วงผลไม้แห้ง or ด้วงหนอนนก or ผีเสื้อข้าวเปลือก or ผีเสื้อข้าวโพด or ผีเสื้อข้าวสาร or ผีเสื้อรำ or มอดข้าวเปลือก or มอดข้าวสาร or มอดแบน or มอดแป้ง or มอดฟันเลื่อย or มอดไม้ไผ่ or มอดยาสูบ or มอดสยาม or มอดหัวป้อม or มอดหัวไม้ขีด or มอดหัวยาว or สามง่าม or หนูนาใหญ่ or หนูพุกเล็ก or หนูพุกใหญ่ or เหาหนังสือ) AND ((bird control or brush control or disinfestation of living organism or insect control or mite control or mollusc control or nematode control or pest control or pest eradication or pest management or rodent control or vermin proofing or การกำจัดศัตรูพืช or การกำจัดสิ่งมีชีวิตที่เป็นอันตราย or การควบคุมนก or การจัดการศัตรูพืช or การป้องกันกำจัดแมลง or การป้องกันกำจัดไร or การป้องกันกำจัดศัตรูพืช or การป้องกันกำจัดสัตว์ฟันแทะ or การป้องกันกำจัดไส้เดือนฝอย or การป้องกันกำจัดหอย) OR (antifeedants or artificial hawks or attractants or bagging or bangers or biocontrol or biological control or biological techniques or bird scarers or chemical control or control methods or controlled burning or conventional pest management or cultural control or ecological control or feeding deterrents or feeding inhibitors or genetic control or integrated control or integrated disease control or integrated disease management or integrated pest control or integrated pest management or integrated protection or IPM or lures or mating disruption or netting (pest control) or pest control baits or pest repellents or phagodeterrents or physical control or phytorepellents or prescribed burning or quarantine or repellents or roguing or scarecrows or scares or sex attractants or sterile insect release or stubble burning or stubble burning or thermal control or thermal pest control or การควบคุมด้วยความร้อน or การควบคุมด้วยสารเคมี or การควบคุมโดยการเขตกรรม or การควบคุมโดยชีววิธี or การควบคุมโดยนิเวศวิธี or การควบคุมโดยพันธุกรรม or การควบคุมโดยวิธีทางกายภาพ or การควบคุมโดยวิธีผสมผสาน or การควบคุมโรคโดยวิธีผสมผสาน or การควบคุมศัตรูพืชด้วยความร้อน or การควบคุมศัตรูพืชโดยวิธีผสมผสาน or การจัดการโรคโดยวิธีผสมผสาน or การจัดการศัตรูพืชโดยวิธีดั้งเดิม or การจัดการศัตรูพืชโดยวิธีผสมผสาน or การดักตาข่าย or การทำให้แมลงเป็นหมัน or การป้องกันกำจัดศัตรูพืชโดยการคลุมถุง or การป้องกันกำจัดศัตรูพืชโดยชีววิธี or การป้องกันโดยวิธีผสมผสาน or การเผาซากพืช or การเผาตอซัง or การเผาที่ถูกควบคุม or การเผาในที่กำหนดไว้ or การยับยั้งการผสมพันธุ์ or เครื่องไล่นก or ด่านกักกัน or วิธีการควบคุม or สารขับไล่ or สารดึงดูดทางเพศ or สารยับยั้งการกินอาหาร or สารล่อ or หุ่นไล่กา or เหยื่อยาเทียม or อุปกรณ์ที่ทำให้สัตว์กลัว or ไอพีเอ็ม) OR (acaricides or antagonistic fungi or antagonistic microorganisms or aphicides or arboricides or avicides or bacterial antagonists or bacterial pesticides or bactericides or biopesticides or bird control chemicals or botanical insecticides or botanical pesticides or controlled release pesticides or corvicides or fungal antagonists or fungicides or insecticides or larvicides or microbial pesticides or miticides or molluscicides or nematicides or nematocides or pesticide synergists or pesticides or plant insecticides or rat poisons or rodenticides or slow release pesticides or slug killers or snail killers or vegetable insecticides or เชื้อรากำจัดจุลินทรีย์ or แบคทีเรียกำจัดจุลินทรีย์ or ยาฆ่านก or ยาฆ่าหอย or ยาเบื่อหนู or สมุนไพรกำจัดแมลง or สมุนไพรฆ่าแมลง or สารกำจัดจุลชีพ or สารเคมีกำจัดนก or สารฆ่าไร or สารฆ่าไส้เดือนฝอย or สารป้องกันกำจัดเชื้อรา or สารป้องกันกำจัดนก or สารป้องกันกำจัดแบคทีเรีย or สารป้องกันกำจัดเพลี้ย or สารป้องกันกำจัดแมลง or สารป้องกันกำจัดแมลงจากพืช or สารป้องกันกำจัดไร or สารป้องกันกำจัดศัตรูพืช or สารป้องกันกำจัดศัตรูพืชจากจุลินทรีย์ or สารป้องกันกำจัดศัตรูพืชจากแบคทีเรีย or สารป้องกันกำจัดศัตรูพืชจากพืช or สารป้องกันกำจัดศัตรูพืชชีวภาพ or สารป้องกันกำจัดศัตรูพืชแบบควบคุมการออกฤทธิ์ or สารป้องกันกำจัดศัตรูพืชแบบออกฤทธิ์ช้า or สารป้องกันกำจัดไส้เดือนฝอย or สารป้องกันกำจัดหนู or สารป้องกันกำจัดหอย or สารป้องกันกำจัดหอยทาก or สารเสริมฤทธิ์กำจัดศัตรูพืช))

Concepts and terms related with field pest and stored product pest control in the rice production ontology were listed as examples in table below.

Table 35 Example of concept and relation “hasPest”

Subject concept represent by preferred term	Relation	Object concept represent by preferred term
Oryza sativa	hasPest	*Acrida willemsei*
Oryza sativa	hasPest	*Aiolopus thalassinus*
Oryza sativa	hasPest	*Alissonotum cribratellum*
Oryza sativa	hasPest	*Ampittia dioscorides*
Oryza sativa	hasPest	*Ampittia maroides*

Table 36 Example of pest concept with type “field pest”

Subject concept represent by preferred term	Relation	Object concept represent by preferred term
Acrida willemsei	hasRelatedType	field pest
Aiolopus thalassinus	hasRelatedType	field pest
Alissonotum cribratellum	hasRelatedType	field pest
Ampittia dioscorides	hasRelatedType	field pest
Ampittia maroides	hasRelatedType	field pest

Table 37 Example of field pest terms and synonym

Preferred term	Relation	Synonym
Acrida willemsei	hasCommonName	grasshopper
Acrida willemsei	hasLocalName	ตั๊กแตนหนวดสั้น
Alissonotum cribratellum	hasLocalName	แมลงนูน
แมลงนูน	hasSynonym	ด้วงดำ

Table 38 Example of pest concept with type "stored product pest"

Subject concept represented by preferred term	**Relation**	**Object concept represented by preferred term**
Ahasverus advena	hasRelatedType	stored product pest
Alphitobius diaperinus	hasRelatedType	stored product pest
Alphitobius laevigatus	hasRelatedType	stored product pest
Anthrenus vorax	hasRelatedType	stored product pest
Araecerus fusciculatus	hasRelatedType	stored product pest

Table 39 Example of stored product pest terms and synonym

Preferred term	**Relation**	**Synonym**
Ahasverus advena	hasCommonName	flat beetle
Alphitobius diaperinus	hasCommonName	lesser mealworm
Alphitobius laevigatus	hasCommonName	black fungus beetle
Ahasverus advena	hasLocalName	มอดแบน
Alphitobius diaperinus	hasLocalName	ด้วงดำ

Table 40 Example of pest control concept and child concepts

Top concept represent by preferred term	Relation	Child concept represent by preferred term
pest control	hasSubclass	bird control
pest control	hasSubclass	insect control
pest control	hasSubclass	mite control
pest control	hasSubclass	mollusc control
pest control	hasSubclass	nematode control
pest control	hasSubclass	rodent control

Table 41 Example of pest control terms and synonym

Preferred term	Relation	Synonym
pest control	hasTranslation	การป้องกันกำจัดศัตรูพืช
bird control	hasTranslation	การควบคุมนก
insect control	hasTranslation	การป้องกันกำจัดแมลง
mite control	hasTranslation	การป้องกันกำจัดไร
mollusc control	hasTranslation	การป้องกันกำจัดหอย
nematode control	hasTranslation	การป้องกันกำจัดไส้เดือนฝอย
rodent control	hasTranslation	การป้องกันกำจัดสัตว์ฟันแทะ
pest eradication	hasTranslation	การกำจัดศัตรูพืช
pest management	hasTranslation	การจัดการศัตรูพืช
pest control	hasSynonym	pest management
rodent control	hasSynonym	vermin proofing

Table 42 Example of control method concept and subclass concept

Super class concept represented by preferred term	Relation	Subclass concept represented by preferred term
control methods	hasSubclass	biological control
control methods	hasSubclass	chemical control
control methods	hasSubclass	cultural control
control methods	hasSubclass	genetic control
control methods	hasSubclass	integrated control
integrated control	hasSubclass	integrated pest management

Table 43 Example of control method terms and synonym

Preferred term	Relation	Synonym
control methods	hasTranslation	วิธีการควบคุม
biological control	hasTranslation	การควบคุมโดยชีววิธี
chemical control	hasTranslation	การควบคุมด้วยสารเคมี
cultural control	hasTranslation	การควบคุมโดยการเขตกรรม
genetic control	hasTranslation	การควบคุมโดยพันธุกรรม
integrated control	hasTranslation	การควบคุมโดยวิธีผสมผสาน
integrated pest management	hasTranslation	การจัดการศัตรูพืชโดยวิธีผสมผสาน

Table 44 Example of pesticide concepts and subclasses

Super class concept represented by preferred term	Relation	Subclass concept represented by preferred term
pesticides	hasSubclass	acaricides
pesticides	hasSubclass	avicides
pesticides	hasSubclass	insecticides
pesticides	hasSubclass	molluscicides
pesticides	hasSubclass	nematicides
pesticides	hasSubclass	rodenticides
pesticides	hasSubclass	biopesticides
pesticides	hasSubclass	pesticide synergists
pesticides	hasSubclass	fungicides
pesticides	hasSubclass	bactericides
biopesticides	hasSubclass	botanical pesticides
botanical pesticides	hasSubclass	botanical insecticides
biopesticides	hasSubclass	microbial pesticides
microbial pesticides	hasSubclass	bacterial pesticides
pesticides	hasSubclass	slow release pesticides

Table 45 Example of pesticide terms and synonym

Preferred term	Relation	Synonym
pesticides	hasTranslation	สารป้องกันกำจัดศัตรูพืช
acaricides	hasTranslation	สารป้องกันกำจัดไร
avicides	hasTranslation	สารป้องกันกำจัดนก
acaricides	hasSynonym	miticides
avicides	hasSynonym	bird control chemicals

Table 46 Query result from the conventional search

Query no.	Relevant	Retrieved	Retrieved and Relevant	Precision	Recall
1a0	230	3	3	1.00	0.01
1a1	52	1	1	1.00	0.02
1a2	56	0	0	0.00	0.00
1a3	5	0	0	0.00	0.00
1a4	59	0	0	0.00	0.00
1a5	3	0	0	0.00	0.00
1a6	4	0	0	0.00	0.00
1a7	4	0	0	0.00	0.00
1a8	86	1	1	1.00	0.01
1a9	2	0	0	0.00	0.00
1a10	9	0	0	0.00	0.00
1a11	15	0	0	0.00	0.00
1a12	2	0	0	0.00	0.00
1a13	7	0	0	0.00	0.00
1a14	2	0	0	0.00	0.00
1a15	0	0	0	0.00	0.00
1a16	0	0	0	0.00	0.00
1a17	13	0	0	0.00	0.00
1a18	18	0	0	0.00	0.00
1a19	11	0	0	0.00	0.00
1a20	4	0	0	0.00	0.00
1a21	0	0	0	0.00	0.00
1a22	0	0	0	0.00	0.00
1a23	0	0	0	0.00	0.00

Table 46 (Continued)

Query no.	Relevant	Retrieved	Retrieved and Relevant	Precision	Recall
1a24	8	0	0	0.00	0.00
1a25	1	0	0	0.00	0.00
1a26	10	0	0	0.00	0.00
1a27	2	0	0	0.00	0.00
1a28	1	0	0	0.00	0.00
2a1	29	0	0	0.00	0.00
3a1	51	0	0	0.00	0.00
3a2	3	0	0	0.00	0.00
3a3	11	0	0	0.00	0.00
3a4	28	0	0	0.00	0.00
3a5	7	0	0	0.00	0.00
3a6	3	0	0	0.00	0.00
3a7	9	0	0	0.00	0.00
3a8	8	0	0	0.00	0.00
3a9	8	0	0	0.00	0.00
3a10	8	0	0	0.00	0.00
3a11	10	0	0	0.00	0.00
3a12	8	0	0	0.00	0.00
3a13	0	0	0	0.00	0.00
3a14	1	0	0	0.00	0.00
3a15	3	0	0	0.00	0.00
3a16	11	0	0	0.00	0.00
3a17	4	0	0	0.00	0.00
3a18	0	0	0	0.00	0.00
3a19	12	0	0	0.00	0.00
3a20	12	0	0	0.00	0.00
3a21	0	0	0	0.00	0.00
3a22	0	0	0	0.00	0.00
3a23	0	0	0	0.00	0.00
3a24	1	0	0	0.00	0.00
3a25	4	0	0	0.00	0.00
4a1	286	64	50	0.78	0.17
4a2	167	48	45	0.94	0.27
5a1	61	0	0	0.00	0.00
5a2	5	0	0	0.00	0.00
Average	**22.95**	**1.98**	**1.69**	**0.08**	**0.01**

Table 47 Query result search by using ontology

Query no.	Relevant	Retrieved	Retrieved and Relevant	Precision	Recall
1b0	230	233	224	0.96	0.97
1b1	52	48	48	1.00	0.92
1b2	56	54	53	0.98	0.95
1b3	5	3	3	1.00	0.60
1b4	59	58	57	0.98	0.97
1b5	3	3	3	1.00	1.00
1b6	4	2	2	1.00	0.50
1b7	4	4	4	1.00	1.00
1b8	86	93	86	0.92	1.00
1b9	2	2	2	1.00	1.00
1b10	9	9	9	1.00	1.00
1b11	15	12	12	1.00	0.80
1b12	2	2	2	1.00	1.00
1b13	7	7	7	1.00	1.00
1b14	2	2	2	1.00	1.00
1b15	0	0	0	0.00	0.00
1b16	0	0	0	0.00	0.00
1b17	13	12	11	0.92	0.85
1b18	18	16	16	1.00	0.89
1b19	11	6	6	1.00	0.55
1b20	4	3	3	1.00	0.75
1b21	0	0	0	0.00	0.00
1b22	0	0	0	0.00	0.00
1b23	0	0	0	0.00	0.00
1b24	8	7	7	1.00	0.88
1b25	1	1	1	1.00	1.00
1b26	10	11	10	0.91	1.00
1b27	2	2	2	1.00	1.00
1b28	1	1	1	1.00	1.00

Table 47 (Continued)

Query no.	Relevant	Retrieved	Retrieved and Relevant	Precision	Recall
2b1	29	19	12	0.63	0.41
3b1	51	64	44	0.69	0.86
3b2	3	3	3	1.00	1.00
3b3	11	10	10	1.00	0.91
3b4	28	26	26	1.00	0.93
3b5	7	7	7	1.00	1.00
3b6	3	5	3	0.60	1.00
3b7	9	3	3	1.00	0.33
3b8	8	1	1	1.00	0.13
3b9	8	2	1	0.50	0.13
3b10	8	3	1	0.33	0.13
3b11	10	7	3	0.43	0.30
3b12	8	1	0	0.00	0.00
3b13	0	1	0	0.00	0.00
3b14	1	1	1	1.00	1.00
3b15	3	2	2	1.00	0.67
3b16	11	15	11	0.73	1.00
3b17	4	3	3	1.00	0.75
3b18	0	0	0	0.00	0.00
3b19	12	14	11	0.79	0.92
3b20	12	20	12	0.60	1.00
3b21	0	0	0	0.00	0.00
3b22	0	0	0	0.00	0.00
3b23	0	9	0	0.00	0.00
3b24	1	1	1	1.00	1.00
3b25	4	4	4	1.00	1.00
4b1	286	276	221	0.80	0.77
4b2	167	124	113	0.91	0.68
5b1	61	36	22	0.61	0.36
5b2	5	0	0	0.00	0.00
Average	**22.95**	**21.15**	**18.41**	**0.72**	**0.64**

Table 48 Query results compared between conventional search approach and ontology-based search approach

Approach	Search result (Average)				
	Relevant	**Retrieved**	**Retrieved and Relevant**	**Precision**	**Recall**
Conventional search	22.95	1.98	1.69	0.08	0.01
Ontology search	22.95	21.15	18.41	0.72	0.64

The comparison between the conventional search results and the ontology-based search results, indicated that the precision and recall rates of the ontology-based search (0.72 and 0.64) are significantly higher than the conventional search (0.08 and 0.01). When the results were defined for each query, most of each precision rate from conventional search was higher than ontology-based search, while the average of the conventional search precision score is rather low compared to the corresponding ontology-based search one. This is because the conventional method can not interpret query search and create many queries out of it, and therefore can not retrieve any information in some queries. For the recall value, both average and each query of ontology search are respectively higher than the conventional search recall value. This means that the ontology is more capable to explore the topics of the queries and increase search results. The more search query were expanded, the more irrelevant results were increased. On the other hand, exploring the query increased the search results and enlarge the prospect of user to access the needed information.

There were many other competency questions by experts which were used for testing, but the result are not presented here. For example: Research policy maker had a question regarding zoning policy and the kind of plants/crops which have both a positive and negative relationship with rice. A rice protection researcher wanted to access all of rice protection research defined by type of pest, type of disease, type of hosts, type of ecological factors for forecasting and planning to controlled pests and diseases epidemic cause by global climate change. All of the results using queries form ontology are reach the user need and give more accurate and useful results than the conventional query approach.

Criteria for rice production ontology construction

As the ontology development process requires information organization, its proper documentation is important not only to facilitate construction, but also for the maintenance and the reuse of this ontology. The documentation in this research was created as a guidelines and criteria, and rules for maintenance were also developed from the ontology construction process. It is expected that these criteria, guidelines, and rules can be applied for the construction and maintenance of other plant production ontologies.

To develop the rice production ontology criteria, there was a need to integrated knowledge from research and literature together with expert opinions. The ability to make effective decisions to validate the criteria has led to use the consensus methods such as the Delphi Technique (details were described in the process of Delphi technique implementation in the research method).

The Delphi Technique was terminated after two rounds because consensus for all questions had been reached. Data were collected from 27 experts and a data analysis was conducted after first round and second round questionnaire. The median, the mean, and the inter quatile range were calculated for all competencies questions inserted in the 5-point rating scale questionnaire. The median and the mean were rank-ordered. At the conclusion of the Delphi study, the desirable criteria for constructing a rice production ontology, which can be used for other plant production ontology construction, were formulated.

The criteria for the rice production ontology construction involve criteria for defining concepts, criteria for defining terms, and criteria for defining relations, divided as follows:

1. Criteria for defining concepts

1.1. Criteria for defining rice production process

1.2. Criteria for defining rice characteristics

1.3. Criteria for defining rice ecology

1.4. Criteria for biological taxonomic classification

1.5. Criteria for soil classification

1.6. Criteria for rice classification

1.7. Criteria for classify type of organism and non-organisms related with rice

2. Criteria for defining terms

3. Criteria for defining relationships

Based on the documents review and the Delphi technique two round responses, the total criteria (119 items) from rice production ontology construction were analyzed to identify the desirable criteria, which rated totally agree (score level 5) and very agree (score level 4). All of the 27 experts arrived to 21 items of the criteria (inter quartile range = 0). To establish a consensus, there are no significant differences between the two rounds of responses. Most of the experts reached a consensus for the criteria for constructing the rice production ontology with a high level score. The results of two rounds questionnaire were presented below:

Table 49 Comparison of results in the first round and second round questionnaire

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
1	**Process of rice production**								
1.1.	Plant cultivation	4.89	5	5	0	5	5	5	0
1.2.	Soil preparation	4.85	5	5	0	4.89	5	5	0
1.3.	Irrigation	4.62	5	5	0	4.74	5	5	0
1.4.	Fertilizing	4.74	5	5	0	4.78	5	5	0
1.5.	Propagation	3.7	4	4	2	4.11	4	4	1
1.6.	Seed production and	4.22	5	5	1	4.63	5	5	1
1.7.	Genetics and breeding	4.22	5	5	2	4.7	5	5	0
1.8.	Cropping system	4.14	5	4	1	4.41	5	5	1
1.9.	Plant pest control	4.56	5	5	1	4.63	5	5	1
1.10.	Plant disease control	4.56	5	5	1	4.59	5	5	1
1.11.	Weed control	4.52	5	5	1	4.56	5	5	1
1.12.	Plant disorder control	3.96	4	4	1	4.11	4	4	1
2	**Rice anatomy and**								
2.1	Anatomy	4.37	5	5	1	4.59	5	5	1
2.2	Morphology	4.63	5	5	0	4.89	5	5	0
2.3	Cytology	4.48	5	5	1	4.67	5	5	1
2.4	Physiology	4.63	5	5	0	4.85	5	5	0
3	**Ecological factor of rice: organism**								
3.1	Plant-weed	4.56	5	5	1	4.67	5	5	1
3.2	Animal	4.59	5	5	1	4.62	5	5	1
3.3	Fungi	4.59	5	5	1	4.67	5	5	1
3.4	Bacteria and Phytoplasma	4.44	5	5	1	4.59	5	5	1
3.5	Virus	4.26	5	5	1	4.67	5	5	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
4	**Ecological factor of rice: non organism**								
4.1	Light	4.89	5	5	0	4.96	5	5	0
4.2	Water	4.81	5	5	0	4.89	5	5	0
4.3	Climate and pollution	4.59	5	5	1	4.78	5	5	0
4.4	Plant nutrition	4.77	5	5	0	4.81	5	5	0
4.5	Soil	4.81	5	5	0	4.89	5	5	0
4.6	Fertilizer	4.7	5	5	1	4.78	5	5	0
4.7	Plant growth regulator	3.63	3	3	1	3.44	3	3	1
4.8	Pesticide	4.18	5	5	2	4.41	5	5	1
5	**Classification of organism**	4.04	4	4	1	4.26	4	4	1
6	**Organism relate with rice**	4.11	4	4	1	4.41	4	4	1
7	**Classification of Kingdoms – Plantae**	4.37	5	5	1	4.7	5	5	1
8	**Classification of Kingdoms - Animalia**	4.11	5	4	2	4.41	5	4	1
9	**Classification of Kingdoms - Fungi**	4	5	4	2	4.33	4	4	1
10	**Classification of Domain – Bacteria**	4	5	4	2	4.33	4	4	1
11	**Classification of Virus**	3.92	5	4	2	4.33	4	4	1
12	**Classification of soil**	4.37	5	5	1	4.59	5	5	1
13	**Type of rice**								
13.1	Rice type defined by harvesting date	4.44	5	5	1	4.67	5	5	1
13.2	Rice type defined by evolution	4.48	5	5	1	4.7	5	5	1
13.3	Rice type defined by irrigation type	4.63	5	5	1	4.74	5	5	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	**Mode**	**Median**	**Interquartile range**	**Mean**	**Mode**	**Median**	**Interquartile range**
13.4	Rice type defined by growing environment	4.67	5	5	1	4.7	5	5	1
13.5	Rice type defined by growing season	4.74	5	5	0	4.85	5	5	0
13.6	Rice type defined by planting type	4.52	5	5	1	4.59	5	5	1
13.7	Rice type defined by seed grain as	4.41	5	5	1	4.62	5	5	1
13.8	Rice type defined by photoperiod insensitivity as	4.7	5	5	0	4.85	5	5	0
13.9	Rice type defined by seed starch composition	4.67	5	5	1	4.74	5	5	1
14	**Type of animal related with rice**								
14.1	**Beneficial animal**	4.37	5	5	1	4.51	5	5	1
14.2	**Noxious animal**	4.37	5	5	1	4.48	5	5	1
14.3	**Insect pest**	4.48	5	5	1	4.63	5	5	1
15.	**Type of plant related with rice**								
15.1	**Useful plant**	4.18	4	4	1	4.29	4	4	1
15.2	**Noxious plant**	4.41	5	5	1	4.48	5	5	1
16.	**Type of microorganism related with rice**								
16.1	**Useful microorganism**	4.37	5	4	1	4.4	5	4	1
16.2	**Noxious microorganism**	4.51	5	5	1	4.51	5	5	1
17.	**Type of agricultural substance related with rice**								
17.1	**Pesticide**	4.67	5	5	1	4.67	5	5	1
17.2	**Plant growth substance**	4.41	4	4	1	4.41	4	4	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
17.3	**Fertilizer**	4.37	5	5	1	4.44	5	5	1
17.3.1	Inorganic fertilizer defined as: single fertilizer…	4.63	5	5	1	4.59	5	5	1
17.3.1.1	Single fertilizer defined as: nitrogen fertilizer,…	4.48	5	5	1	4.59	5	5	1
17.3.1.2	Compound fertilizer defined as: NPK fertilizer,	4.51	5	5	1	4.56	5	5	1
17.3.2	Organic fertilizer defined as: biofertilizer, …	4.59	5	5	1	4.56	5	5	1
18.	**Criteria for defining term represented concept**								
18.1	**Organism** : use Scientific name represent plant, animal and related organism. Define common name in English and local name in Thai as synonym	4.7	5	5	0	4.85	5	5	0
18.2	**Soil** : use Soil Series define by Land Development Department to represent soil series in Thailand	4.74	5	5	0	4.89	5	5	0
18.3	**Agricultural chemical substance** : use substance common name in Thai and English for representing and use substance trade names as synonym	4.67	5	5	0	4.89	5	5	0

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	**Mode**	**Median**	**Interquartile range**	**Mean**	**Mode**	**Median**	**Interquartile range**
18.4	**Plant nutrient**: use element name represent plant nutrient. Define chemical symbol or chemical formula as synonym	4.74	5	5	0	4.89	5	5	0
18.5	**Non-organism** : use the most accepted name entity in the subject domain as preferred term, the less defined as synonym (non preferred term)	4.59	5	5	1	4.7	5	5	1
18.6	**Bi-lingual term** : define term representation in English and Thai for all name entity, use Latin for scientific name	4.59	5	5	1	4.7	5	5	1
18.7	Common word must be singular and noun word or noun phrase. Except the specific defined plural or singular noun	4.59	5	5	1	4.63	5	5	1
18.8	Non-capitalize term except name or specific term, such as: Scientific name, Soil series name, Cultivar name, geographical name	4.7	5	5	0	4.89	5	5	0

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
19.	**Relationship of in rice production ontology**								
19.1	Relationship between rice and production process are: Plant cultivation, Soil preparation, …	4.62	5	5	1	4.78	5	5	0
19.2	Relationship between rice and pest	4.59	5	5	1	4.67	5	5	1
19.3	Relationship between rice and disease or disorder	4.41	5	5	1	4.56	5	5	1
19.4	Relationship between rice and pathogen	4.44	5	5	1	4.56	5	5	1
19.5	Relationship between rice and weed	4.48	5	5	1	4.56	5	5	1
19.6	Relationship between rice and soil	4.63	5	5	1	4.63	5	5	1
19.7	Relationship between rice and element	4.59	5	5	1	4.59	5	5	1
19.8	Relationship between rice and fertilizer	4.55	5	5	1	4.89	5	5	1
19.9	Relationship between rice and growth regulator	3.89	4	4	2	4.07	4	4	1
19.10	Relationship between rice and pesticide	4.33	5	5	1	4.52	5	5	1
19.11	Relationship between rice and element	4.7	5	5	1	4.7	5	5	1
19.12	Relationship between rice and light	4.7	5	5	1	4.74	5	5	1
19.13	Relationship between rice and climate and pollution	4.55	5	5	1	4.59	5	5	1
19.14	Relationship between rice cultivar and rice type	4.41	5	5	1	4.48	5	5	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
19.15	Relationship between rice cultivar and anatomy	4.15	5	4	1	4.29	4	5	1
19.16	Relationship between rice cultivar and physiology	4.44	5	5	1	4.59	5	5	1
19.17	Relationship between rice cultivar and resistant	4.41	5	4	1	4.44	4	4	1
19.18	Relationship between rice cultivar and susceptible	4.37	4	4	1	4.41	4	4	1
19.19	Relationship between rice cultivar and resistant pest	4.41	5	4	1	4.44	4	4	1
19.20	Relationship between rice cultivar and susceptible pest	4.37	4	4	1	4.41	4	4	1
19.21	Relationship between soil and soil fertility	4.44	5	5	1	4.59	5	5	1
19.22	Relationship between soil and soil improvement	4.41	5	5	1	4.59	5	5	1
19.23	Relationship between fertilizer and fertilizer type	4.33	5	5	1	4.48	5	5	1
19.24	Relationship between fertilizer and soil	4.56	5	5	1	4.56	5	5	1
19.25	Relationship between fertilizer and fertilizer	4.37	5	5	1	4.48	5	5	1
19.26	Relationship between disease and pathogen	4.41	5	5	1	4.48	5	5	1
19.27	Relationship between pathogen and vector	4.41	5	5	1	4.48	5	5	1
19.28	Relationship between pathogen and host	4.18	5	4	2	4.29	5	4	1
19.29	Relationship between disease and plant anatomy	4.15	4	4	1	4.14	4	4	1
19.30	Relationship between disease and symptom	4.33	5	5	1	4.48	5	5	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
19.31	Relationship between disease and ecology	4.56	5	5	1	4.59	5	5	1
19.32	Relationship between disease and control method	4.63	5	5	1	4.63	5	5	1
19.33	Relationship between disease and agricultural	4.44	5	5	1	4.48	5	5	1
19.34	Relationship between pest and pest type	4.22	5	4	1	4.33	5	4	1
19.35	Relationship between pest and host	4.15	5	4	2	4.37	5	4	1
19.36	Relationship between pest and plant anatomy	4	4	4	2	4.14	4	4	1
19.37	Relationship between pest and infecting characteristic	4.37	5	5	1	4.52	5	5	1
19.38	Relationship between pest and ecology	4.44	5	5	1	4.59	5	5	1
19.39	Relationship between pest and natural enemy	4.26	5	5	1	4.41	5	5	1
19.40	Relationship between pest and control method	4.52	5	5	1	4.56	5	5	1
19.41	Relationship between pest and agricultural substance	4.41	5	5	1	4.56	5	5	1
19.42	Relationship between weed and weed type	4.11	5	4	2	4.26	4	4	1
19.43	Relationship between weed and ecology	4.3	5	5	1	4.48	5	5	1
19.44	Relationship between weed and control method	4.41	5	5	1	4.56	5	5	1
19.45	Relationship between weed agricultural substance	4.37	5	5	1	4.52	5	5	1

Table 49 (Continued)

No.	Criteria for rice production ontology construction	First round				Second round			
		Mean	Mode	Median	Interquartile range	Mean	Mode	Median	Interquartile range
19.46	Relationship between disorder and element	4.52	5	5	1	4.59	5	5	1
19.47	Relationship between disorder and causing factor	4.63	5	5	1	4.67	5	5	1
19.48	Relationship between disorder plant anatomy	4.48	5	5	1	4.56	5	5	1
19.49	Relationship between disorder and control method	4.52	5	5	1	4.59	5	5	1
19.50	Relationship between substance common name and agricultural substance	4.14	5	4	2	4.41	4	4	1
19.51	Relationship between agricultural substance and plant physiology or cytology	4.14	5	4	1	4.37		4	1

Sixteen experts suggested to revise some names of concepts such as: waxy rice, soil preparation, entomopathogenic bacteria, entomopathogenic fungi, beneficial animal, rice type, and rice seed properties. Seven experts suggested adding some more concepts: highland rice, aquatic weed, pollution, and geographical properties which effect rice production.

Two experts confirmed the answer agree less (score=1) for one cireteria, it is criteria for define relationship between rice and irrigation in the rice production process. The experts discussed that most of rice areas in Thailand are rainfed areas so it is difficult to control watering in these rainfed areas.

The least agreed criterion was the relationship between rice and growth regulator (plant growth substance), fifteen experts (55.56%) defined level of agreement of this criterion in middle level (level 3: agree). The reason is plant growth regulator is not normally used for rice production or cereal crop but used for the other crops, especially fruit crop.

Based on the range of responses received, all criteria defined by numbers of expert and degree of agreement were summarized. There are 118 items of criteria that have the high level of agreement (level 5: totally agree and 4: very agree) by the judgments of at least 24 over 27 experts.

Table 50 Degree of agreement on each criteria defined by number of experts (total number is 27)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	**level 4**	**level 3**	**level 2**	**level 1**
1	**Process of rice production**					
1.1.	Plant cultivation	27	0	0	0	0
1.2.	Soil preparation	25	1	1	0	0
1.3.	Irrigation	22	3	2	0	0
1.4.	Fertilizing	23	2	2	0	0
1.5.	Propagation	9	14	2	2	0
1.6.	Seed production and processing	19	7	0	1	0
1.7.	Genetics and breeding	22	3	1	1	0
1.8.	Cropping system	14	10	3	0	0
1.9.	Plant pest control	20	4	3	0	0
1.10.	Plant disease control	18	7	2	0	0
1.11.	Weed control	18	6	3	0	0
1.12.	Plant disorder control	7	17	2	1	0
2	**Rice anatomy and physiology**					
2.1	Anatomy	17	9	1	0	0
2.2	Morphology	24	3	0	0	0
2.3	Cytology	18	9	0	0	0
2.4	Physiology	23	4	0	0	0
3	**Ecological factor of rice: organism**					
3.1	Plant-weed	18	9	0	0	0
3.2	Animal	17	10	0	0	0
3.3	Fungi	17	9	0	0	0
3.4	Bacteria and Phytoplasma	16	11	0	0	0
3.5	Virus	18	9	0	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	**level 4**	**level 3**	**level 2**	**level 1**
4	**Ecological factor of rice: non organism**					
4.1	Light	26	1	0	0	0
4.2	Water	24	3	0	0	0
4.3	Climate and pollution	21	6	0	0	0
4.4	Plant nutrition	22	5	0	0	0
4.5	Soil	24	3	0	0	0
4.6	Fertilizer	21	6	0	0	0
4.7	Plant growth regulator	2	9	15	1	0
4.8	Pesticide	16	7	3	1	0
5	**Classification of organism**	8	18	1	0	0
6	**Organism relate with rice**	11	16	0	0	0
7	**Classification of Kingdoms – Plantae**	19	8	0	0	0
8	**Classification of Kingdoms - Animalia**	13	12	2	0	0
9	**Classification of Kingdoms - Fungi**	11	14	2	0	0
10	**Classification of Domain – Bacteria**	11	14	2	0	0
11	**Classification of Virus**	11	14	2	0	0
12	**Classification of soil**	17	9	1	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	**level 4**	**level 3**	**level 2**	**level 1**
13	**Type of rice**					
13.1	Rice type defined by harvesting date	18	9	0	0	0
13.2	Rice type defined by evolution	19	8	0	0	0
13.3	Rice type defined by irrigation type	20	7	0	0	0
13.4	Rice type defined by growing environment	20	6	1	0	0
13.5	Rice type defined by growing season	24	2	1	0	0
13.6	Rice type defined by planting type	18	7	2	0	0
13.7	Rice type defined by seed grain as	18	8	1	0	0
13.8	Rice type defined by photoperiod sensitivity as	24	2	1	0	0
13.9	Rice type defined by seed starch composition	20	7	0	0	0
14	**Type of animal related with rice**					
14.1	**Beneficial animal**	16	9	2	0	0
14.2	**Noxious animal**	15	10	2	0	0
14.3	**Insect pest**	18	8	1	0	0
15.	**Type of plant related with rice**					
15.1	**Useful plant**	11	14	1	1	0
15.2	**Noxious plant**	15	10	2	0	0
16.	**Type of microorganism related with rice**					
16.1	**Useful microorganism**	13	12	2	0	0
16.2	**Noxious microorganism**	16	9	2	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	level 4	level 3	level 2	level 1
17.	**Type of agricultural substance related with rice**					0
17.1	**Pesticide**	19	7	1	0	0
17.2	**Plant growth substance**	13	14	0	0	0
17.3	**Fertilizer**	14	11	2	0	0
17.3.1	Inorganic fertilizer defined as: single fertilizer…	17	9	1	0	0
17.3.1.1	Single fertilizer defined as: nitrogen fertilizer,…	17	9	1	0	0
17.3.1.2	Compound fertilizer defined as: NPK fertilizer, ...	16	10	1	0	0
17.3.2	Organic fertilizer defined as: biofertilizer, …	18	6	3	0	0
18.	**Criteria for defining term represented concept**					
18.1	**Organism** : use Scientific name represent plant, animal and related organism. Define common name in English and local name in Thai as synonym	25	0	2	0	0
18.2	**Soil** : use Soil Series define by Land Development Department to represent soil series in Thailand	25	1	1	0	0
18.3	**Agricultural chemical substance** : use substance common name in Thai and English for representing and use substance trade names as synonym	25	1	1	0	0
18.4	**Plant nutrient**: use element name represent plant nutrient. Define chemical symbol or chemical formula as synonym	25	1	1	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	level 4	level 3	level 2	level 1
18.5	**Non-organism** : use the most accepted name entity in the subject domain as preferred term, the less defined as synonym (non preferred term)	20	6	1	0	0
18.6	**Bi-lingual term** : define term representation in English and Thai for all name entity, use Latin for scientific name	20	6	1	0	0
18.7	Common word must be singular and noun word or noun phrase. Except the specific defined plural or singular noun	19	6	2	0	0
18.8	Non-capitalize term except name or specific term, such as: Scientific name, Soil series name, Cultivar name, geographical name	25	1	1	0	0
19.	**Relationship of in rice production ontology**					
19.1	Relationship between rice and production process are: Plant cultivation, Soil preparation, …	21	6	0	0	0
19.2	Relationship between rice and pest	19	7	1	0	0
19.3	Relationship between rice and disease or disorder	16	10	1	0	0
19.4	Relationship between rice and pathogen	16	10	1	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	level 4	level 3	level 2	level 1
19.5	Relationship between rice and weed	16	10	1	0	0
19.6	Relationship between rice and soil	18	8	1	0	0
19.7	Relationship between rice and element	17	9	1	0	0
19.8	Relationship between rice and fertilizer	17	9	1	0	0
19.9	Relationship between rice and growth regulator	9	13	3	2	0
19.10	Relationship between rice and pesticide	16	9	1	0	0
19.11	Relationship between rice and element	19	8	0	0	0
19.12	Relationship between rice and light	20	7	0	0	0
19.13	Relationship between rice and climate and pollution	17	9	1	0	0
19.14	Relationship between rice cultivar and rice type	16	9	1	1	0
19.15	Relationship between rice cultivar and anatomy	13	11	1	2	0
19.16	Relationship between rice cultivar and physiology	17	9	1	0	0
19.17	Relationship between rice cultivar and resistant pathogen	13	13	1	0	0
19.18	Relationship between rice cultivar and susceptible pathogen	12	14	1	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	level 4	level 3	level 2	level 1
19.19	Relationship between rice cultivar and resistant pest	13	13	1	0	0
19.20	Relationship between rice cultivar and susceptible pest	12	14	1	0	0
19.21	Relationship between soil and soil fertility	18	7	2	0	0
19.22	Relationship between soil and soil improvement	18	7	2	0	0
19.23	Relationship between fertilizer and fertilizer type	17	8	2	0	0
19.24	Relationship between fertilizer and soil	17	8	2	0	0
19.25	Relationship between fertilizer and fertilizer application	15	10	2	0	0
19.26	Relationship between disease and pathogen	16	8	3	0	0
19.27	Relationship between pathogen and vector	16	8	3	0	0
19.28	Relationship between pathogen and host	13	10	3	1	0
19.29	Relationship between disease and plant anatomy	9	14	3	1	0
19.30	Relationship between disease and symptom	15	10	2	0	0
19.31	Relationship between disease and ecology	18	7	2	0	0
19.32	Relationship between disease and control method	18	8	1	0	0
19.33	Relationship between disease and agricultural substance	15	10	2	0	0
19.34	Relationship between pest and pest type	13	11	2	1	0
19.35	Relationship between pest and host	13	11	3	0	0

Table 50 (Continued)

No.	Criteria for rice production ontology construction	Degree of agreement				
		level 5	level 4	level 3	level 2	level 1
19.36	Relationship between pest and plant anatomy	9	14	3	1	0
19.37	Relationship between pest and infecting characteristic	16	9	2	0	0
19.38	Relationship between pest and ecology	18	7	2	0	0
19.39	Relationship between pest and natural enemy	14	10	3	0	0
19.40	Relationship between pest and control method	17	8	2	0	0
19.41	Relationship between pest and agricultural substance	16	10	1	0	0
19.42	Relationship between weed and weed type	11	12	4	0	0
19.43	Relationship between weed and ecology	15	10	2	0	0
19.44	Relationship between weed and control method	16	10	1	0	0
19.45	Relationship between weed agricultural substance	15	11	1	0	0
19.46	Relationship between disorder and element	18	8	0	1	0
19.47	Relationship between disorder and causing factor	19	7	1	0	0
19.48	Relationship between disorder plant anatomy	16	10	1	0	0
19.49	Relationship between disorder and control method	17	9	1	0	0
19.50	Relationship between substance common name and agricultural substance type	13	12	2	0	0
19.51	Relationship between agricultural substance and plant physiology or cytology	12	13	2	0	0

The criteria were developed by integrating explicit knowledge and tacit knowledge and use consensus methods for validation. Criteria for rice production ontology construction which expected to be applied for the construction of other plant production ontologies were concluded as follows:

1. **Criteria for defining concepts**

Concepts in rice production ontology were defined into 6 conceptual entity concepts, 2 object entity concepts and 5 functional entity concepts. Object entity concepts were divided to organism object entity concept and non-organism object entity concept. Functional entity concepts were classify as : plant production process entity concept, breeding method entity concept, protection process entity concept, infecting process entity concept, physiological function entity concept. Plant production process entity concept was divided to cultivation process, harvesting process, soil preparation process, fertilizing process, irrigation process, propagation process and seed processing.

Table 51 Rice production ontology concept categories

Conceptual entity concepts	Object entity concepts	Functional entity concepts
taxonomic unit	**organism**	**plant production process**
..biological taxonomic unit	..plantae	..cultivation process
..soil taxonomic unit	..animalia	..harvesting process
….soil series	..fungi	..soil preparation process
behavior	..bacteria	..fertilizing process
..animal behavior	..virus	..irrigation process
..plant habit	**non-organism**	..propagation process
composition	..environmental factor	..seed processing
..plant anatomy	….water	**breeding method**
..chemical composition	….light	**protection process**
property	….weather	..control method
..biological property	….pollutant	
..soil property	..geographical area	

Table 51 (Continued)

Conceptual entity concepts	Object entity concepts	Functional entity concepts
type	..plant nutrient	**infecting process**
..organism type	..soil	**physiologic function**
….rice type	..soil amendment	..growth period
….weed type	..agricultural substance	
….pest type	….fertilizer	
….pathogen type	….pesticide	
….host	….plant growth regulator	
…...host animal	..product	
…...host plant		
….biological control agent type		
..non-organism type		
….agricultural substance type		
….soil type		
….irrigation type		
….pest control type		
….cultivation system type		
…...farming system		
…...cropping system		
appearance		
..duration		
..disorder		
..disease		
..symptom		

1.1 Object entity concept classification

Object entity concepts were defined into two groups: organisms and non-organisms. Criteria for classifying the organism and non-organism concepts are detailed as follows:

1.1.1 Criteria for classify organism concepts

The classification of organisms for the rice production ontology followed the biological taxonomic classification proposed by Woese *et al*. (1990). Organisms were divided in 3 domains: Bacteria, Archaea, Eukarya. The Eukarya domains subdivided into Kingdoms: Plantae, Animalia, Fungi, Amoebozoa, Chromalveolata, Rhizaria, and Excavata.

Kingdoms divids into Phylum, Class, Order, Family, Genus, and Species. Species can be further subdivided into Subspecies, Varieties, and Cultivars.

Virus are not yet definitively classified as living or non-living. The Virus classification in this research use the International Committee on Taxonomy of Viruses (1999) which classify virus as: Order, Family, Genus, and Species.

Organisms related with rice in the rice production ontology are classified with: 1 Domain (Bacteria), 3 Kingdoms (Plantae, Animalia, Fungi) and 1 Group (Virus). The detailed classification for each Kingdoms for organisms is described as follows:

a) Classification of Kingdoms – Plantae

The classification in taxonomic levels of plants in the rice production ontology, starts with Family, and end at Subspecies or Variety or Cultivar: Family → Genus → Species → Subspecies, Variety, Cultivar

b) Classification of Kingdoms - Animalia

The classification in taxonomic levels of animal in the rice production ontology, starts with Class, and end at Species: Class → Order → Family → Genus → Species

c) Classification of Kingdoms - Fungi

The classification in taxonomic levels of Fungi in the rice production ontology, starts with Class, and end at Species: Class → Order → Family → Genus → Species

e) Classification of Domain – Bacteria

The classification in taxonomic levels of Bacteria in the rice production ontology, starts with Class , and end at Species: Class → Order → Family → Genus → Species

f) Classification of Virus

The classification in taxonomic levels of virus in rice production ontology, starts with Family, and end at Virus name: Family → Genus → Virus name

1.1.2 Criteria for classify soil

For developing the rice production ontology, the soil classification followed the "Keys to Soil Taxonomy" (USDA, 2006). The classification of soil taxonomy are: Soil Order, Soil Suborder, Soil Great group, Soil Subgroup, Soil Family and Soil Series.

1.1.3 Criteria for classify non-organism concepts

The non-organism concepts order would be categorized according to its order in group or category that it belongs.

1.2 Conceptual entity concept classification

Conceptual entity concepts are concepts which present characteristic or properties of object entity concepts. The more connections between object entity concepts and conceptual entity concept exists, the more properties of object entity concept will be defined. These concepts and relationship are useful for concept-base search and contextualization of knowledge. There are some examples of conceptual entity concept classification, presented here below:

1.2.1 Conceptual entity concept in term of "biological taxonomic unit"

Organisms were classified hierarchically; each concept in the hierarchy must be connect with conceptual entity concept in term of "biological taxonomic unit" through the relation "hasTaxonomicLevel". This connection will facilitate the reasoning about the taxa of each organism concepts, for example:

concept[*Poaceae*] hasTaxonomicLevel concept[Family]
concept[*Oryza*] hasTaxonomicLevel concept[Genus]

1.2.2 Conceptual entity concept in term of "Type"

Most of the organisms and non-organisms were defined by characteristic or properties and related with conceptual entity concepts in term of "Type", for example:

concept[rice] hasRelatedType concept[cereal crop]
concept[brown planthopper] hasRelatedType concept[insect pest]

In the ontology there are also some classification of concept defined by type or properties, as described below:

Classification of rice defined by characteristic

a) Rice type defined by harvesting date: early maturity rice, medium maturity rice, and late maturity rice.

b) Rice type defined by evolution: wild rice, and cultivate rice.

c) Rice type defined by irrigation type: irrigated rice, and rainfed rice.

d) Rice type defined by growing area: lowland rice, deepwater rice, floating rice, upland rice, and high land rice (high land paddy rice and high land upland rice).

e) Rice type defined by growing season: major rice, and off-season rice.

f) Rice type defined by planting type: transplanted rice, broadcasting rice, and direct seeded rice.

g) Rice type defined by seed grain: short grain rice, medium grain rice, long grain rice, and special long grain rice.

h) Rice type defined by photoperiod sensitivity: photoperiod sensitive rice, and photoperiod insensitive rice.

i) Rice type defined by seed starch composition: waxy rice (sticky rice) or glutinous rice, and non-waxy rice or non-glutinous rice.

Classification of organisms related with rice

The types of animals related with rice have been defined as follows:

a) Beneficial animals: pollinator and natural enemy.

b) Noxious animals: noxious mammal, noxious bird, noxious mollusca, noxious crustacea, insect pest, pest mite and nematode.

c) Insect pests: root eating insect, stem eating insect, leaf eating insect, flower damaging insect, fruit damaging insects and seed damaging insect, chewing insect and sucking insect, insect vector.

Classification of plants defined by type

a) Useful plants: food crop, feed crop, medicinal crop, spice crop, fibre crop, fuel crop, rubber plant, oil crop, dye plant, gum plant, ornamental plant, soil reclamation plant, cover plant, protective plant, erosion control plant, structural plant, trap crop, pesticide crop, etc.

b) Noxious plants, such as weeds defined by characteristic: narrow leaf weed, broad leaf weed, aquatic. Weeds defined by growing season: annual weed, perennial weed.

Classification of microorganisms defined by type

a) Useful microorganisms: nitrogen fixing microorganism, biological control microorganism (entomopathogenic bacteria, entomopathogenic fungi, nematophagous fungi).

b) Noxious microorganisms (pathogenic microorganisms): pathogenic fungi, pathogenic bacteria, and pathogenic virus.

Classification of non-organisms related with rice

Type of agricultural substances related with rice identified in the rice production ontology:

a) Pesticides: avicide, rodenticide, molluscicide, insecticide, acaricide, nematicide, fungicide, bactericide, herbicide, pesticide synergist and biopesticide (botanical pesticide, microbial pesticide).

b) Plant growth substances: plant growth stimulant, plant growth retardant, plant growth inhibitor, germination inhibitor.

c) Fertilizers, defined as: inorganic fertilizer, organic fertilizer, biofertilizer, organomineral fertilizer, liquid fertilizer, liquid gas fertilizer, slow release fertilizer. For inorganic fertilizers are defined as: single fertilizers (such as: nitrogen fertilizer, phosphate fertilizer, potash fertilizer, sulphur fertilizer, calcium fertilizer, magnesium fertilizer, micronutrient fertilizer), compound fertilizers (such as: NPK fertilizer, nitrogen phosphorus fertilizer, nitrogen potassium fertilizer, phosphorus potassium fertilizer) and organic fertilizers (such as compost, farm manure, green manure).

1.3 Functional entity concept classification

Functional entity concepts, such as cultivation process, fertilizing process, soil preparation process, etc. would be categorized according to its function order in group.

2. Criteria for defining term

2.1 Terms Classification – All terms which represent concepts should be identified with either one of the following groups;

2.1.1 Preferred terms

This is the term that preferably lexicalize the concept. The preferred term is the main term representative of a concept when that concept can be described by various different terms. There is only one term designated as the preferred term; the other terms are considered as non-preferred terms or synonyms.

Never use acronyms, abbreviation names, or symbols as preferred terms. Consider selecting preferred terms from related thesauri, dictionaries or terms that are accepted or recommended by experts in that domain.

2.1.2 Non-preferred terms or synonyms

These are the terms with the same meaning as the preferred term but are not selected as main concept representatives. Some of the non-preferred terms are also called synonyms.

Non-preferred terms or synonyms can be in the form of: term variants such as spelling variants, terms in singular or plural, common names, local names, scientific names, trade names, chemical symbols, chemical formulas, acronym, abbreviation names.

2.2 Term format

General practice dictates that terms that were used as preferred term for representing concepts must be standardized as follows:

2.2.1 Common word must be singular and to be noun word or noun phrase. Except the specific defined plural or singular noun.

2.2.2 Non-capitalize these terms except specific names, such as: scientific names, soil series names, cultivar names, trade names, geographical names.

2.3.3 Bi-lingual terms: define terms representation in English and Thai for all name entity, use Latin for scientific names.

2.3.4 Organisms: use scientific names representing plants, animals and related organisms. Define common names in English and local names in Thai as synonyms.

2.2.5 Non-organisms: use the most accepted name entity in the subject domain as preferred term, the less defined as synonym (non preferred term).

2.2.6 Soil: use Soil Series names defined by the Land Development Department (2008) to represent soil series in Thailand.

2.2.7 Agricultural chemical substances: use substance common names in Thai and English for representing and use substance trade names as synonyms.

2.2.8 Plant nutrients: use element name represent plant nutrients. Define chemical symbols or chemical formulas as synonyms.

3. Criteria for defining relationships

Criteria for defining relationships in the ontology were classified in to three criteria, they are:

3.1 Equivalence relationships

These relations link terms in the same concept. Equivalence relations are are presented in table below:

Table 52 Relations and inverse relations of the equivalence relationships

Equivalence relationships	
Relation	**Inverse relation**
hasLexicalization	isLexicallizationOf
hasSynonym	isSynonymOf
..hasCommonName	isCommonNameOf
..hasLocalName	isLocalNameOf
..hasChemicalSymbol	isChemicalSymbolOf
..hasChemicalFormula	isChemicalFormulaOf
..hasTradeName	isTradeNameOf
..hasTranslation	isTranslationOf
..hasAcronym	isAcronymOf
..hasAbbreviation	isAbbreviationOf
..hasSpellingVariant	isSpellingVariantOf
..hasPlural	hasSingular

Table 53 Pattern and example of equivalence relationships

Relation	Pattern	Example
hasLexicalization	[concept] hasLexicalization [preferred term]	[concept rice] hasLexicalization [*Oryza sativa]*
hasSynonym	[preferred term] hasSynonym [synonym term]	[*Poaceae*] hasSynonym [*Gramineae*]
hasCommonName	[concept organism] hasCommonName [organism common name]	[*Oryza sativa*] hasCommonName [rice]
hasLocalName	[concept organism] hasLocalName [organism local name]	[*Oryza sativa*] hasLocalName [Khao Chao]
hasChemicalSymbol	[preferred term of element] hasChemicalSymbol [chemical symbol]	[nitrogen] hasChemicalSymbol [N]
hasChemicalFormula	[preferred term of substance] hasChemicalFormula [chemical formula]	[sulphur dioxcide] hasChemicalFormula [SO2]
hasTradeName	[preferred term of chemical substance] hasTradeName [trade name]	[isoprocarb] hasTradeName [Mipcin]
hasTranslation	[term] hasTranslation [other language term]	[nitrogen] hasTranslation [ไนโตรเจน]
hasAcronym	[preferred term] hasAcronym [acronym term]	[plant growth regulator] hasAcronym [PGR]
hasAbbreviation	[preferred term] hasAbbreviation [abbreviation term]	[abstract] hasAbbreviation [abst]
hasSpellingVariant	[preferred term] hasSpellingVariant [other spelling term]	[sulphur] hasSpellingVariant [sulfer]
hasPlural	[singular term] hasPlural [plural term]	[rice] hasPlural [rices]

3.2 Hierarchical relationships

This group represent relationships between concepts in the same tree. It is a hierarchical linkage like the subclass and superclass or mother and child concept relations. The hierarchical relationship has only one relation, which is the "hasSubclass" and has inverse relation "isSubclassOf".

Table 54 Relation and inverse relation of hierarchical relationships

Hierarchical relationships	
Relation	**Inverse relation**
hasSubclass	isSubclassOf

Table 55 Pattern and example of hierarchical relationships

Relation	**Pattern**	**Example**
hasSubclass	[superclass concept] hasSubclass [subclass concept]	[Plantae] hasSubclass [*Poaceae*]
hasSubclass	[superclass concept] hasSubclass [subclass concept]	[*Poaceae*] hasSubclass [*Oryza*]
hasSubclass	[superclass concept] hasSubclass [subclass concept]	[*Oryza*] hasSubclass [*Oryza sativa]*

3.3 Associative relationships

These are relations between concepts in different hierarchies. They can be related in different ways and can be divided into functional relationships and conceptual relationships.

Table 56 Relation and inverse relation of associative relationships

Relation	Inverse relation
hasFunctionallyRelatedTo	**isFunctionallyRelatedOf**
..hasPlantProductionProcess	isPlantProductionProcessOf
….hasCultivationProcess	isCultivationProcessOf
…...hasCultivationMethod	isCultivationMethodOf
….hasSoilPreparationProcess	isSoilPreparationProcessOf
……hasSoilPreparationMethod	isSoilPreparationMethodOf
….hasFertilizingProcess	isFertilizingProcessOf
……hasFertilizingMethod	isFertilizingMethodOf
….hasHarvestingProcess	isHarvestingProcessOf
……hasHarvestingMethod	isHarvestingMethodOf
….hasIrrigationProcess	isIrrigationProcessOf
……hasIrrigationMethod	isIrrigationMethodOf
….hasPropagationProcess	isPropagationProcessOf
……hasPropagationMethod	isPropagationMethodOf
….hasSeedProductionProcess	isSeedProductionProcessOf
……hasSeedProductionMethod	isSeedProductionMethodOf
….hasArrangementProcess	isArrangementProcessOf
…...hasCropingSystem	isCropingSystemOf
…...hasFarmingSystem	isFarmingSystemOf
..hasBreedingMethod	isBreedingMethodOf
..hasProtectionProcess	isProtectionProcessOf
….hasControlMethod	isControlMethodOf
..hasInfectingProcess	isInfectingProcessOf
….hasInfectingPart	isInfectingPartOf
….hasInfectingPeriod	isInfectingPeriodOf
….hasinfectingArea	isinfectingAreaOf
bringAbout	isBroughtFrom
..hasCause	isCauseOf
..produce	isProducedFrom

Table 56 (Continued)

Relation	Inverse relation
hasAffectingFactor	isAffectingFactorOf
..hasEnvironmentalFactor	isEnvironmentalFactorOf
..hasInjuriousFactor	ishasInjuriousFactorOf
….hasPathogen	isPathogenOf
….hasPest	isPestOf
….hasWeed	isWeedOf
..hasVector	isVectorOf
..hasHost	isHostOf
..hasIncreasingFactor	isIncreasingFactorOf
..hasDecreasingFactor	isDecreasingFactorOf
….hasControlFactor	isControlFactorOf
…...hasBiologicalControlAgent	isBiologicalControlAgentOf
……..hasNaturalEnemy	isNaturalEnemyOf
…...hasControlSubstance	isControlSubstanceOf
hasMaterial	isMaterialOf
..hasPropagationMaterial	isPropagationMaterialOf
..hasSoilImpovementMaterial	isSoilImpovementMaterialOf
hasPhysiologicalFunction	isPhysiologicalFunctionOf
hasConceptuallyRelatedTo	**isConceptuallyRelatedOf**
..hasProperty	isPropertyOf
..hasRelatedType	isRelatedTypeOf
..hasTaxonomicLevel	isTaxonomicLevelOf
..hasComposition	isCompositionOf
..hasHabit	isHabitOf
..hasBehaviour	isBehaviourOf
..hasPart	isPartOf
..isResistantTo	isHarmlessFor
..isSusceptibleTo	isHarmfulFor
..hasAppearance	isAppearanceOf
….hasSymptom	isSymptomOf
….hasDisease	isDiseaseOf
….hasDisorder	isDisorderOf
….hasAppearancePart	isAppearancePartOf

Table 57 Pattern and example of associative relationship

Relation	Pattern	Example
hasPest	[concept rice] hasPest [concept pest]	[*Oryza sativa*] hasPest [*Nephotettix apicalis*]
hasDisease	[concept rice] hasDisease [concept disease]	[*Oryza sativa*] hasDisease [yellow orange leaf]
hasPathogen	[concept rice] hasPathogen [concept pathogen]	[*Oryza sativa*] hasPathogen [RiceYellow Orange Leaf Virus]
hasWeed	[concept rice] hasWeed [concept weed]	[*Oryza sativa*] hasWeed [*Oryza rufipogon]*
hasDisorder	[concept rice] hasDisorder [concept plant disorder]	[*Oryza sativa*] hasDisorder [nitrogen deficiencies]
hasAffectingFactor	[concept rice] hasAffectingFactor [concept soil series]	[*Oryza sativa*] hasAffectingFactor [Soil Series Thanyaburi]
hasAffectingFactor	[concept rice] hasAffectingFactor [concept plant nutrient]	[*Oryza sativa*] hasAffectingFactor [nitrogen]
hasAffectingFactor	[concept rice] hasAffectingFactor [concept fertilizer]	[*Oryza sativa*] hasAffectingFactor [nitrogen fertilizer]
hasEnvironmentalFactor	[concept rice] hasEnvironmentalFactor [concept environmental factor]	[*Oryza sativa*] hasEnvironmentalFactor [water]
hasEnvironmentalFactor	[concept rice] hasEnvironmentalFactor [concept environmental factor]	[*Oryza sativa*] hasEnvironmentalFactor [light]
hasEnvironmentalFactor	[concept rice] hasEnvironmentalFactor [concept environmental factor]	[*Oryza sativa*] hasEnvironmentalFactor [temperature]

Table 57 (Continued)

Relation	Pattern	Example
hasRelatedType	[concept rice cultivar] hasRelatedType [concept rice type]	[RD 6] hasRelatedType [glutinous rice]
hasComposition	[concept rice seed] hasComposition [concept composition]	[rice seed] hasComposition [amylose]
produce	[concept rice] produce [concept rice product]	[*Oryza sativa*] produce [seed]
hasPart	[concept rice] hasPart [concept plant anatomy]	[*Oryza sativa*] hasPart [leaf sheath]
hasPhysiologicalFuncti on	[concept rice] hasPhysiologicalFunction [concept plant physiology]	[*Oryza sativa*] hasPhysiologicFunction [plant photosynthesis]
hasTaxonomicLevel	[concept rice] hasTaxonomicLevel [concept biological taxonomic unit]	[*Oryza sativa*] hasTaxonomicLevel [Species]; [RD 6] hasTaxonomicLevel [Cultivar]
hasHabit	[concept rice] hasHabit [concept plant habit]	[*Oryza sativa*] hasHabit [grass]
hasBehaviour	[concept animal] hasBehaviour [concept animal behavior]	[*Nilarparvata lugens*] hasBehaviour [stem sucking]
isResistantTo	[concept rice cultivar] isResistantTo [concept disease]	[RD 6] isResistantTo [brown spot]
isSusceptibleTo	[concept rice cultivar] isSusceptibleTo [concept disease]	[RD 6] isSusceptibleTo [bacterial leaf blight]
isResistantTo	[concept rice cultivar] isResistantTo [concept pest]	[RD 6] isResistantTo [*Meloidogyne graminicola*]
isSusceptibleTo	[concept rice cultivar] isSusceptibleTo [concept pest]	[RD 6] isSusceptibleTo [*Nilarparvata lugens*]

Table 57 (Continued)

Relation	Pattern	Example
hasProperty	[concept soil type] hasProperty [concept soil property]	[organic soil] hasProperty [soil water balance]
hasProperty	[concept soil series] hasProperty [concept soil property]	[Soil Series Kula Ronghai] hasProperty [soil salinity]
hasSoilImpovementMaterial	[concept soil series] hasSoilImpovementMaterial [concept soil amendment]	[Soil Series Rangsit] hasSoilImpovementMaterial [liming materials]
hasFertilizingProcess	[concept fertilizer] hasFertilizingProcess [concept fertilizer application method]	[nitrogen fertilizer] hasFertilizingProcess [broadcasting]
hasCause	[concept disease] hasCause [concept pathogen]	[yellow orange leaf] hasCause [RiceYellow Orange Leaf Virus]
hasCause	[concept symptom] hasCause [concept disease]	[yellow orange leaf symptom] hasCause [yellow orange leaf]
hasSymptom	[concept rice] hasSymptom [concept symptom]	[*Oryza sativa*] hasSymptom [yellow orange leaf symptom]
hasVector	[concept pathogen] hasVector [concept vector]	[RiceYellow Orange Leaf Virus] hasVector [Nephotettix apicalis]
hasHost	[concept pathogen] hasHost [concept host plant]	[RiceYellow Orange Leaf Virus] hasHost [Oryzae rufipogen]
hasAppearancePart	[concept disease] hasAppearancePart [concept plant anatomy]	[yellow orange leaf] hasAppearancePart [leaf]
hasIncreasingFactor	[concept disease] hasIncreasingFactor [concept environmental factor]	[blast] hasIncreasingFactor [humidity]

Table 57 (Continued)

Relation	Pattern	Example
hasDecreasingFactor	[concept disease] hasDecreasingFactor [concept environmental factor]	[bacterial leaf streak] hasDecreasingFactor [light]
hasControlMethod	[concept disease] hasControlMethod [concept control method]	[blast] hasControlMethod [chemical control]
hasIncreasingFactor	[concept disease] hasIncreasingFactor [concept agricultural substance]	[red stripe disease] hasIncreasingFactor [nitrogen fertilizer]
hasControlSubstance	[concept disease] hasControlSubstance [concept agricultural substance]	[red stripe disease] hasControlSubstance [carbendazim]
hasRelatedType	[concept pest] hasRelatedType [concept organism type]	[*Nilarparvata lugens*] hasRelatedType [field pest]
hasHost	[concept pest] hasHost [concept host plant/animal]	[*Nilarparvata lugens*] hasHost [*Leersia hexandra*]
hasInfectingPart	[concept pest] hasInfectingPart [concept plant anatomy]	[*Nilarparvata lugens*] hasInfectingPart [stem]
hasIncreasingFactor	[concept pest] hasIncreasingFactor [concept environmental factor]	[*Nilarparvata lugens*] hasIncreasingFactor [humidity]
hasDecreasingFactor	[concept pest] hasDecreasingFactor [concept ecological factor]	[*Nilarparvata lugens*] hasDecreasingFactor [temperature]
hasBiologicalControlAgent	[concept rice] hasBiologicalControlAgent [concept biological control agent]	[*Oryza sativa*] hasBiologicalControlAgent [*Cyrtorhinus lividipennis*]

Table 57 (Continued)

Relation	Pattern	Example
hasNaturalEnemy	[concept pest] hasNaturalEnemy [concept natural enemy]	[*Nilarparvata lugens*] hasNaturalEnemy [*Cyrtorhinus lividipennis]*
hasControlMethod	[concept pest] hasControlMethod [concept control method]	[*Nilarparvata lugens*] hasControlMethod [biological control]
hasIncreasingFactor	[concept pest] hasIncreasingFactor [concept agricultural substance]	[*Nilarparvata lugens*] hasIncreasingFactor [nitrogen fertilizer]; [*Nilarparvata lugens*] hasIncreasingFactor [pyrethrins]
hasControlSubstance	[concept pest] hasControlSubstance [concept agricultural substance]	[*Nilarparvata lugens*] hasControlSubstance [isoprocarb]
hasRelatedType	[concept weed] hasRelatedType [concept weed type]	[*Echinochloa crus-galli*] hasRelatedType [annual weed]
hasIncreasingFactor	[concept weed] hasIncreasingFactor [concept ecological factor]	[*Echinochloa crus-galli*] hasIncreasingFactor [humidity]
hasDecreasingFactor	[concept weed] hasDecreasingFactor [concept ecological factor]	[*Echinochloa crus-galli*] hasDecreasingFactor [light]
hasControlMethod	[concept weed] hasControlMethod [concept control method]	[*Echinochloa crus-galli*] hasControlMethod [cultural control]
hasControlSubstance	[concept weed] hasControlSubstance [concept agricultural substance]	[*Echinochloa crus-galli*] hasControlSubstance [pretilachlor]
hasIncreasingFactor	[concept weed] hasIncreasingFactor [concept agricultural substance]	[*Oryza rufipogon*] hasIncreasingFactor [nitrogen fertilizer]

Table 57 (Continued)

Relation	Pattern	Example
hasCause	[concept plant disorder] hasCause [concept plant nutrient]	[nitrogen deficiencies] hasCause [nitrogen]
hasCause	[concept plant disorder] hasCause [concept ecological factor]	[nitrogen deficiencies] hasCause [soil texture]
hasSymptom	[concept plant disorder] hasSymptom [concept symptom]	[nitrogen deficiencies] hasSymptom [chlorosis]
hasControlMethod	[concept plant disorder] hasControlMethod [concept control method]	[nitrogen deficiencies] hasControlMethod [fertilizer application]
hasControlSubstance	[concept plant disorder] hasControlSubstance [concept agricultural substance]	[nitrogen deficiencies] hasControlSubstance [nitrogen fertilizer]
hasRelatedType	[concept agricultural substance] hasRelatedType [concept agricultural substance type]	[uniconazole] hasRelatedType [plant growth substances]
hasCultivationProcess	[concept rice] hasCultivationProcess [concept cultivation process]	[*Oryza sativa*] hasCultivationProcess [sowing]; [*Oryza sativa*] hasCultivationProcess [weeding]
hasHarvestingProcess	[concept rice] hasHarvestingProcess [concept harvesting process	[*Oryza sativa*] hasHarvestingProcess [threshing]
hasSoilPreparationProcess	[concept rice] hasSoilPreparationProcess [concept soil preparation process]	[*Oryza sativa*] hasSoilPreparationProcess [ploughing]
hasIrrigationMethod	[concept rice] hasIrrigationMethod [concept irrigation method]	[*Oryza sativa*] hasIrrigationMethod [flood irrigation]

Table 57 (Continued)

Relation	Pattern	Example
hasRelatedType	[concept irrigation process] hasRelatedType [concept irrigation type]	[furrow irrigation] hasRelatedType [continuous irrigation]
hasFertilizingProcess	[concept rice] hasFertilizingProcess [concept fertilizing process]	[*Oryza sativa*] hasFertilizingProcess [topdressing]
hasPropagationProcess	[concept rice] hasPropagationProcess [concept propagation process]	[*Oryza sativa*] hasPropagationProcess [seeding]
hasPropagationMaterial	[concept propagation process] hasPropagationMaterial [concept propagation material]	[seeding] hasPropagationMaterial [seed]
hasSeedProductionProcess	[concept rice] hasSeedProductionProcess [concept seed processing] (seed in meaning of propagation)	[*Oryza sativa*] hasSeedProductionProcess [seed dressing]
hasBreedingMethod	[concept rice] hasBreedingMethod [concept breeding method]	[*Oryza sativa*] hasBreedingMethod [hybridizing]
hasCropingSystem	[concept rice] hasCroppingSystem [concept cropping system]	[*Oryza sativa*] hasCroppingSystem [crop rotation]
hasFarmingSystem	[concept rice] hasFarmingSystem [concept farming system]	[*Oryza sativa*] hasFarmingSystem [organic farming]
hasControlMethod	[concept pest] hasControlMethod [concept control method]	[*Nephotettix apicalis*] hasControlMethod [traping]
hasControlMethod	[concept disease] hasControlMethod [concept control method]	[bacterial leaf blight] hasControlMethod [chemical control]

Table 57 (Continued)

Relation	Pattern	Example
hasControlMethod	[concept weed] hasControlMethod [concept control method]	[*Oryza rufipogon*] hasControlMethod [weedingll]
hasControlMethod	[concept plant disorder] hasControlMethod [concept control method]	[nitrogen deficiencies] hasControlMethod [fertilizer application]
hasRelatedType	[concept control process] hasRelatedType [concept pest control type]	[chemical control] hasRelatedType [insect control]
hasInfectingPeriod	[concept pathogen] hasInfectingPeriod [concept duration or growth period]	[*Xanthomonas oryzae* pv. *Oryzae*] hasInfectingPeriod [rainy season]
hasinfectingArea	[concept pathogen] hasinfectingArea [concept geographical area]	[*Xanthomonas oryzae* pv. *Oryzae*] hasinfectingArea [Pathumtani]

These criteria can be extended and can be used for constructing other plant production ontologies.

Guidelines for plant production ontology construction

As the ontology development process requires information organization and decision makings, it is very practical to expect that setting up some specific criteria and creating a document containing guidelines for building a domain-specific ontology will considerably facilitate the construction of other ontologies in a broader domain.

These guidelines are an attempt to consolidate the experiences gained from developing a Thai Rice Production Ontology. However, those guidelines could also be useful in other plant production ontology construction, especially cereal crops. It could also form a basis for an international collaboration on constructing the world rice production ontology, in term of knowledge sharing and reuse.

In the subsequent sections, the guidelines report on a comprehensive methodology for building a rice production ontology. This also includes a set of techniques and methods for each step of the constructing process.

The guidelines for developing a plant production ontology is divided in to five parts: (Appendix D)

1. Guidelines for Ontology specification;

2. Guidelines for Knowledge acquisition;

3. Guidelines for Ontology conceptualization;

4. Guidelines for Ontology formalization;

5. Guidelines for Implementation.

Rules for semi-automatic maintenance of the rice production ontology

Updating and correcting are the main activities of ontology maintenance. The maintenance can be done manually, automatically, or semi-automatically. A low cost and high quality approach is to execute a semi-automatic maintenance. The maintenance process proposed by this research will be carried out jointly by man and machine based upon the criteria analyzed in the previous section “Criteria for rice production ontology construction”. The experts and information specialists will make a manual correction and confirmation of the output from the process. In order to do the semi-automatic maintenance process, it is necessary to have specific rules as described below.

The rules presented below are not the main result of this research. These rules were created by analysing the ontology construction process. The main objective of these rules is to define a set of guidelines for computer operation so that concepts and terms can semi-automatically be added into the selected ontology. These rules are an additional result from this research which are created in order to facilitate the ontology maintenance process by humans and computers.

The rules for semi-automatically adding concepts and terms into ontology are defined in human language and tested by information specialists so the rules under scope of this research will not extend to the operation processed by computer.

In this research, the rules are generated from several processes, such as: process of extracting keywords; process of analyzing new terms, new concepts, and relationships; and process of validation (this last implemented by human). The testing keywords were extracted from titles, descriptors and abstracts of the Thai Rice Research Database. Electronic documents from the Thai Rice Knowledge Bank (Rice Department, 2008) were used for testing and defining relationship in this process.

The precondition for this activity is that there must be some existing terms repository as raw material. By “terms repository” we intend those words that represent documents, usually called “Keywords”. Extracting keywords from documents and inputting them into the ontology can be done automatically by the computer. However, for this research, the testing process was done by human.

Five rules for maintaining or adding terms and concepts into the rice production ontology were derived. These rules were finalized by inspecting and tracking the relevant and irrelevant search results of the retrieved output in the ontology evaluation process, carried out with 93 queries. The rules for maintaining the rice production ontology are described as follows:

The first rule – Rule for selecting documents relevant to the main topic

This rule is used for selecting documents that are related to the ontology's main topic; the irrelevant documents will be excluded. The rule is that ***there must be at least one keyword in the title or descriptors field of the document match with term-represent-concept.*** In this case the target main topic is "Rice plant". Concept [Rice plant] maybe represented by any term and their synonyms such as: scientific name, common name, local name, translated term. From this rule, the research documents related with "Rice" will be selected.

The second rule – Rule for defining the scope of content of the selected documents from the first rule

This rule aims to define more specifically the scope of content of the selected documents related to the rice production. It is said that ***there must be at least one keyword from the title or from the descriptors, or at least 3 keywords in the abstract of the documents which are selected from the first rule, match with term-represent-concept in the rice production ontology.*** This rule refers to all synonyms that have the same meaning. namely, acronyms, abbreviation terms, scientific names, common names, local names, trade names, chemical symbols, translated terms and also their other synonyms (except term-represent-concept of [Rice plant] because the input documents of this rule has already selected for "Rice plant" from the first rule). Only the documents which meet this criterion will be selected, as more appropriate for the domain.

The third rule – Rule for assigning new terms or new concepts

Any extracted keywords from documents which passed the second rule and do not duplicate with any term-representing-concept in the ontology, will be regarded as a new term or candidate of a new concept in the ontology. If the new term is not a synonym of the existing terms in the ontology it will be assigned as a new concept (represented by term).

To decide whether the new term is a synonym or not, it is important to check all term relationships in the research documents, such as "has another name" or "has scientific name" or "has common name" or "has trade name" or "has the same meaning". In case of the new term is a synonym, link the new term to the existing preferred term in the ontology with equivalence relation in Table 52. Terms which are not synonyms will be candidate of new concepts (represented by this new term). To validate and assigning new terms as a new concepts it should be finally confirmed by expert.

In short, the approach to assign new terms or new concepts can be summarized as follows:

If term[X] is a keyword which does not match with any existing term in the ontology
then term[X] is a new term or a new concept

If term[X] has the same meaning of any term in the ontology
then term[X] is new term for the same concept (synonym)
else term[X] is candidate of a new concept

If term[X] is candidate of a new concept and validated by expert that term[X] is not synonym of any existing terms in the ontology
then term[X] is a new concept which is represented by term[X]
else term[X] is a new synonym of an existing term (with a relation decided by the expert).

The fourth rule – Rule for assign hierarchical (subclass) relationship

Define the new concept as subclass of any top concept or any other concept in the ontology by classify the new concept using the rice production ontology concept category (ref. Table 51). If the new concept can not be defined as subclass of any existing concepts, the new concept is a new top-level concept.

Generally, terms that belongs to concepts which have subclass relations, may often have relationships with a phrase such as "is a", "compose of" or "such as", etc. Identify the new concept as subclass under any upper-level concept which can be connected with the subclass relation of that concept. If there are not any subclass relations like "such as", "compose of" to refer to, try to classify the new concept by the rice production ontology concept category in Table 51.

The approach to assign a hierarchical relation for the new concept can be concluded as follows:

term[Y] has subclass term[X]

While

term[X] is object term which represent new concept[X] from the third rule
term[Y] is subject term which related with term [X] as upper concept

If term[Y] is duplicate or is a synonym of any concept in the ontology
then concept of term[X] is subclass of concept-term[Y]
else term[X] will be processed by expert

For example:

"*Oryza rufipogon*" is a new concept
"*Oryza rufipogon*" is in Genus "*Oryza*"

term [*Oryza*] represents the concept [*Oryza*] in the ontology
then concept of term[*Oryza rufipogon*] is a subclass of concept [*Oryza*]

The fifth rule – Rule for assign associative relationship

Associative relations for a new concept should be defined between the new concept (the "subject" in a ternary relation subject-predicate-object) and other existing concept (the "object" in a ternary relation subject-predicate-object) not in the same hierarchy.

Define associative relation of the new concept from the fourth rule by seeking verbs or role name between the new concept and other subject concept. Compare the role name with associative relation existed in the ontology (Table 56). If the role name correspond with the existing associative relation and the subject term which is related is duplicated with any term in the ontology, then the new concept has associative relation with that subject term concept.

The approach to assign associative relation for a new concept can be summarized as follows:

concept[Y] relation[B] concept[X]

While

term[X] is object term which represent new concept[X] from the fourth rule
term[Y] is subject term which represent concept[Y] related with term[X] by associative relationship
relation[B] is associative relation combined term[X] and term[Y] (which means concept[Y] relation[B] concept[X] because term[X] lexicalize concept[X] and term[Y] lexicalize concept[Y]).

If relation[B] correspond with any associative relation in Table 5 and term[Y] duplicated with any term in the ontology

then concept of term[X] relate with concept of term[Y] by inverse of relation[B]
else term[X] will be processed by expert

For example:

"rice has pest brown planthopper"

If "has pest" matched with relation "hasPest" in table 5 and "rice" matched with term of concept [rice] in the ontology
then relation[B] = "hasPest" , term[Y]= "rice", term[X]= "brown planthopper"
and concept represent by term[brown planthopper] relate with concept represent by term[rice] with relation "isPestOf" (inverse relation of "hasPest")

Discussion

Rice growth and rice quality are effected by the complex interactions of the rice itself with external factors (e.g. nutrients, environmental factors). Cultivars development, to satisfy consumer demand and low-cost production, will help alleviate environmental and health concerns. New crops and cultivars, with greater pest resistance, drought tolerance, and decreased fertilizer requirements, will reduce the need of purchased inputs (fertilizers, water, pesticides, etc.). Researches on management system, to improve the ability of production material, to accomplish production goals without harming the environment or consumers, is highly needed (Beverly *et al*., 1993).

The rice production ontology has collected and combined rice with the multipart effecting factors by many categories of relationships. Concept entities and relationships of the ontology were formed by analyzing plant production knowledge based on the "Whole Plant Model" by Beverly *et al.* (1993) in Figure 1 and "Environmental and biological factors affecting crop production management on a field scale" in Table 1. Then rice production related factors (Table 5) were summarized and concept entities with relations (Table 51, 52, 54 and 56) were defined as knowledge organization for plant production ontology construction.

Knowledge management systems or domain independent applications use knowledge bases built in a form of ontology. An ontology for a specific domain is not a goal in itself. Developing an ontology has per objective to define a set of data which specific programs may use. The propose of this research was to develop a rice production ontology to be used as background knowledge for agricultural research knowledge management systems. The quality of the ontology only can be assessed by using it in applications for which it is designed for.

Since an ontology is a basic infrastructure and description of a specific knowledge in a specific domain it is therefore very difficult to construct ontology without any criteria and guidelines. Criteria and guidelines can facilitate the construction of agricultural ontology for plant production related issues in the broader domain than rice. The rice production ontology was evaluated by using the Thai AGRIS search engines in a query enrichment process. The evaluation is carried out by judging how the ontology can help to answer the five competency questions from agricultural researchers and policy makers. The following section will analyze and discuss the outputs of this research: the ontology development process, the ontology construction criteria, the evaluation process, and the rice production ontology.

Rice production ontology and construction criteria

Ontology design is a creative process and no two ontologies designed by different people would be the same. The potential applications of the ontology and the designer's understanding will undoubtedly affect ontology design choices. Some ontology-design ideas in this research originated from the ontology construction guidelines written by Noy and McGuinness (2001) and by Pinto and Martins (2004). However, the guidelines produced from this research are different. The created guidelines and criteria are specific for the rice production topic, and based on plant production knowledge which depends on the complex interactions of plants and environmental factors.

The Rice Production Ontology provided 2,322 concepts and 5,603 terms in a hierarchical system and with 57 different types of associative relations. More than half of the concepts are object entity concepts of pest animals, disease organisms and agricultural substances such as pesticides and fertilizers. A minor number are functional entity concepts which indicate the function of rice production processes. The rice production ontology was created as a skeleton ontology to be used by rice production research knowledge management systems, therefore the class hierarchy is not too detailed. The ontology was designed to cover all topic related concepts comprehensively and do not need to be specialized more than the application needs. For example, the ontology includes content related to rice morphology. This category contains few concepts concerning the vegetative and reproductive part of rice which was related to production. This ontology does not include all the properties of rice but presents the most relevant properties such rice cultivar resistance to pest or diseases. The rice cultivar characteristics (described with other information such as size, color, growth rate, etc.) were omitted. In addition, associative relationships between concepts were not added for the whole concepts: relations between the reactions of whole pesticides with each pest were not included. The interconnections between concepts were defined for the scope and purpose of the ontology use only.

Developing concept hierarchy

Several patterns were designed and tested during the construction of the Rice Production Ontology. After defining a considerable number of new classes and implement them in the ontology, a checking process for identifying hierarchies was done. Finally, approaches and criteria for defining a range of classes were established.

When defining the scope of a concept category, it is necessary to find the concepts or data values that may compose this category. In general, do not choose an overly wide-ranging category. All the sub-classes in the each category should be described by specific concepts.

This research proposed a plant production knowledge model as a systematic top-down view of the rice production domain (Figure 1, Table 1 and Table 5), with subsequent specialization of the concepts. This approach is easy to implement and efficient to organize subclass concepts. For more clarity, the top level concepts were defined into three groups: conceptual entity concepts, object entity concepts, and functional entity concepts. The object entity concepts were divided into organisms and non-organisms.

The biological taxonomic classification was applied for defining the hierarchical structure of organisms. Taxa of organisms are Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species. Species can be divided into Subspecies, Variety, and Cultivar. This research applied the classification principle for each class of organism.

The hierarchical structure of the Plant concept starts by using Kingdom (Plantae) as top level concept and has sub levels including: Family, Genus, Species, Subspecies or Variety or Cultivar.

The Animal and Fungi hierarchical structure starts by using Kingdom (Animalia, Fungi and Bacteria) at top level and has sub levels: Class, Order, Family, Genus, Species.

The Virus hierarchical structure starts by using the Group (Virus) at top level and has sub levels: Family, Genus and Virus name. The Virus classification is subject of ongoing debates and has different proposals.

The taxonomic classification which apply for each class of organism in different level follows the principle of agricultural science domain. For example, rice (*Oryza sativa*) has upper level concept Genus *Oryza*, which has upper level concept Family *Poaceae* (*Gramineae*), which has upper level concept Kingdom *Plantae*; this is clear enough to identify rice and it is not necessary to refer to the Order Poales. For animals it is instead different: for example, rice gall midge (*Orseolia oryzae*) is a rice insect pest which has upper level concept the Genus *Orseolia*, which has upper level concept the Family *Cecidomyiidae*, then the Order *Diptera*, then the Class *Insecta*, under the Kingdom *Animalia*. As we can see, identify the Class level "*Insecta*" makes the identification of insects more clear.

The hierarchical concepts of non-organisms were defined with a soil classification and classified as non-organism. The Soil Taxonomy classification by USDA was used. The classification of soil is defined as: Soil Order, Soil Suborder, Soil Great group, Soil Subgroup, Soil Family and Soil Series. The order of generic non-organisms concepts would be categorized according to its position in the group or in the category that it belongs.

After defining the systematic top-down class hierarchy, a bottom-up and a middle-out approach were used for completing the ontology hierarchy. Bottom-up approach started with the most specific class of the hierarchy from the ontology formalization process. Most of the extracted terms were coming from text or research literature and corresponds to specific classes or concept instances. For example, rice gall midge is one kind of pest insect. It is the most specific Class Animal. Since the animal class hierarchical structure was already designed using the top-down approach (Kingdom, Class, Order, Family, Genus, Species), the concept "rice gall midge" was created bottom-up form the leaves of the hierarchy into the upper concepts as follows:

Organism class hierarchical

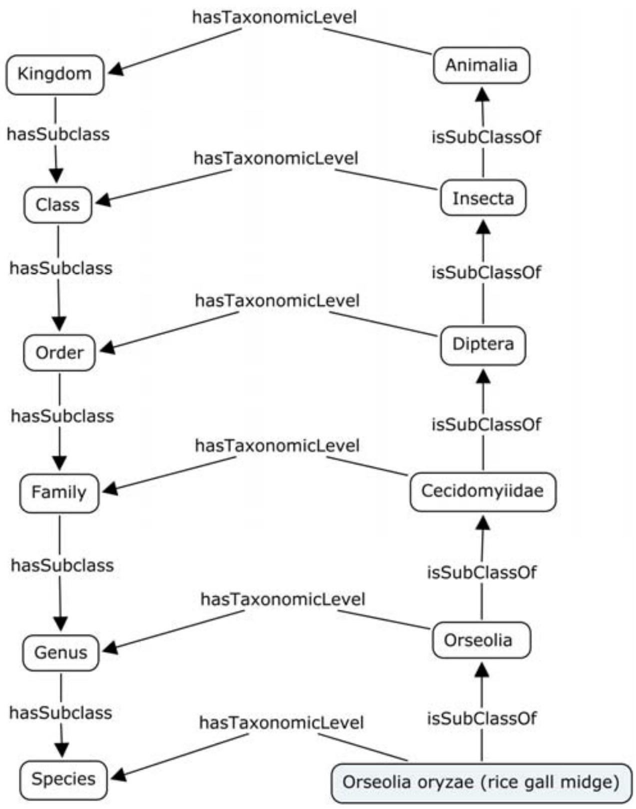


Figure 20 Defining the class hierarchy by top-down and bottom-up approach

For some class, a middle-out approach is necessary: it is a combination of the top-down and bottom-up approach. The most salient concepts were assigned first, then generalized and specialized appropriately. For example, for the concept rice (*Oryza sativa*), we identify that Rice is a kind of cereal crop. So the plant hierarchical structure was ordered by Kingdom, Family, Genus, Species, Subspecies or Variety or Cultivar. The concept rice will be defined using the middle-out approach as follows:

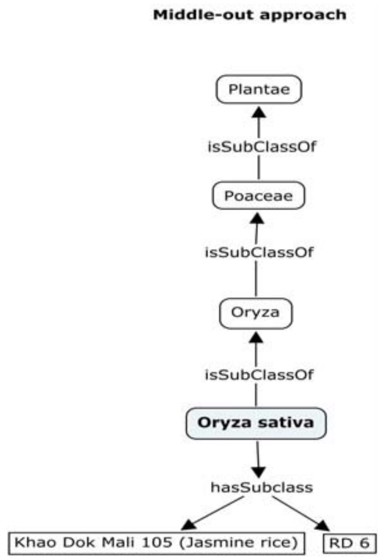


Figure 21 Defining the class hierarchical using the middle-out approach

Non-organisms class hierarchy

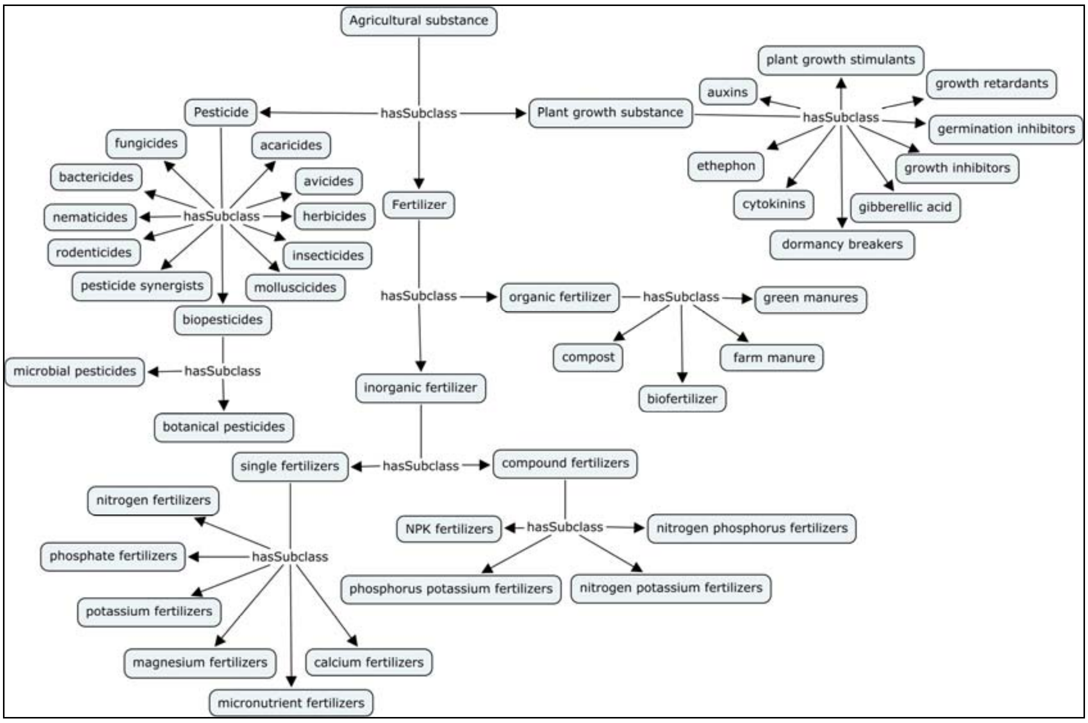


Figure 22 Top level conceptual entity concepts and hierarchy for the agricultural substances

Hierarchical concepts and relations were defined by assigning the top level and the bottom level concept, decided what are the most specific and most generic items that are going to be represented in the ontology. This ontology was designed to be used as a knowledge base for increasing efficiency of rice research knowledge retrieval systems. Class concepts in this ontology covered all the related factors involved with rice production and rice individuals (Table 5). For example, concepts of pesticide for rice pest control were defined with the common names but were not specified in details with chemical composition or chemical formula. Also, property values for pesticides, such as application rate and percent of active ingredient, were not defined. On the other hand, if the ontology was designed to serve farmers and provide answer about pesticide application for pest control, each pesticide substance and composition would have to be defined more, with specific concepts and properties.

Specific distinction of each concept can be defined as property value or as a set of classes. An ontology editor has to decide which ones are the important concepts in the specific domain, and if they have any relationships with other objects. If a distinction is important in the domain creates objects with different values. For example, there are many properties for rice divided by characteristics, such as: growth habit, photoperiod sensitivity property, seed composition, seed size, etc. Each cultivar of rice has different properties, as Jasmine rice is a lowland rice (growth habit), photoperiod sensitivity rice, aromatic non-glutinous rice (seed composition), medium grain rice (seed size). This research proposed to define the important property value of each object using a conceptual entity concept named “Type”. Each concept was designed to make inter-connections between object-entity concepts and the conceptual-entity concept “Type” with the relationship “hasRelatedType” (ref. Table 51). Doing so, one object-entity concept can be linked with many conceptual-entity concepts based on every “type”: we will then have many associative relationships (“hasRelatedType”) instead of creating a lot of “isSubclassOf” relations, which may create ambiguities. This model is useful for information retrieval systems and facilitate ontology construction by distinguish object-entity concepts from conceptual-entity concept and functional-entity concepts.

Sini and Yadav (2009) created guidelines for building knowledge models. These guidelines present many examples of concepts and relations to help the definition of the model. One of the examples, is the relationship model for “are” or “isSubClassOf” as follows:

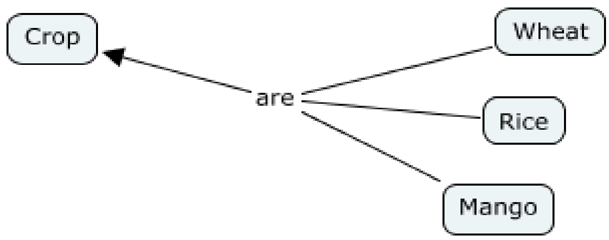


Figure 23 Example of “are” relationships
Source: Sini and Yadav (2009)

When compare this example of “are” relationship model with the modeling presented in this research, they are rather different. The relationship “are” in this model has the same meaning of the relationship “isSubclassOf” (inverse relationship of “hasSubclass” in this research), therefore it is a class hierarchy. The hierarchical model of organisms in this research of plant or rice plant, was designed to use the biological taxonomic classification. Plant or rice characteristics were defined as conceptual-entity concepts and connected with the object-entity concepts with the relationship “hasRelatedType”. The figure below presented the modeling guidelines proposed in this research:

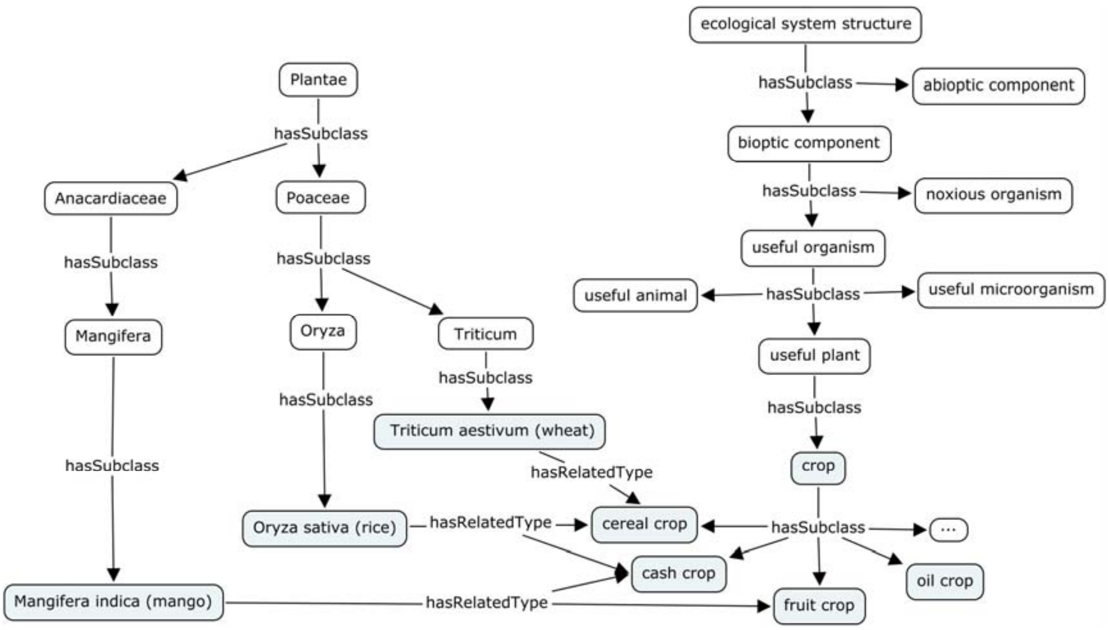


Figure 24 Example of concepts and relationships between plants and crops modeling

In this model, the concepts rice, mango, and wheat are represented by their scientific name, are capable to have inter-connection with many type of properties as cereal crop, cash crop, fruit crop or any as they were, with out to be a subclass of each property class.

Terms representing concepts

To make the ontology easier to understand and avoid some common modeling mistakes, term format must be standardized. Using the same form all the time also prevents a designer from making modeling mistakes.

Noy and McGuinness (2001) suggest to define naming conventions for concepts in an ontology and strictly adhering to the conventions. This makes the ontology easier to understand. They propose to use consistent capitalization for concept name as: capitalize class names and use lower case for slot names (assuming the system is case-sensitive), use plural rather than singular and avoid abbreviations in concept names. Together with consideration of the system feature such as: Does the system have the same name space for classes, slots, and instances? Is the system case-sensitive? What delimiters does the system allow in the names? That is, can names contain spaces, commas, asterisks, and so on?

This research used the AGROVOC CS WB as ontology development application. This application is not case sensitive and allows having same terms in different concepts, the name can contain spaces, commas, and does not have any delimitation, except the limitation of assigning data property value which is not designed yet.

The terms format in this research must be bi-lingual noun word or noun phrase in English and Thai because the designed purpose of this ontology is to be utilized locally and internationally; terms must be in singular and non-capitalized. Except specific capitalized terms. For example, “rice” is a common term and non-capitalized, while “Khao Dawk Mali 105” is a jasmine rice cultivar name, which is a specific term. “carbosulfan” is a common name of pesticide and is non-capitalized, while “'Posse” is a trade name (specific name) for carbosulfan.

Most of the new defined terms in the rice production ontology is singular. Exceptions are the terms which comes from the AGROVOC thesaurus, as all terms in the AGROVOC thesaurus are plural. The terms which were taken from AGROVOC will be held as the former format. The idea to define terms in singular is mainly to facilitate the creation of the query for information retrieval by using word truncation: the use of singular format is easier for the creation of queries. However, whether the term is singular or plural, it should be consistent throughout the whole ontology.

Rice production ontology evaluation

Many search engines fail to take into consideration aspects of the user’s context to help disambiguate their queries. As conventional search engines cannot interpret the sense of the user’s search, the ambiguity of the query leads to the retrieval of irrelevant information. The conventional search engines that match query terms against a keyword-based index will fail to match relevant information when the keywords used in the query are different from those used in the index, despite having the same meaning (Davies *et al.,* 2006).

A well-structured ontology can facilitate users to explore and clarify the needed information and find useful related information. The thai rice production ontology can be applied to enrich the rice knowledge service system by assisting users to explore the query and support intelligent knowledge retrieval mechanism.

The rice production ontology was evaluated and used to answer five competency questions defined in the process of ontology specification. Retrieval efficiency as precision and recall rate were used for evaluation. The five competency questions were divided into 93 queries for testing. The differences between the conventional search and ontology-based search are highly significant. The conventional search has average precision and recall rates of 0.08 and 0.01. The ontology-based search has average precision and recall rates of 0.72 and 0.64. Therefore, the precision and recall rates of the ontology-based search are about 9 times and 64 times higher than the conventional search (Table 48).

In information retrieval contexts, precision and recall are measured in terms of a set of retrieved documents and a set of relevant documents. Precision is a measure of exactness or fidelity, whereas recall is a measure of completeness. A perfect precision score of 1.0 means that every result retrieved by a search was relevant whereas a perfect recall score of 1.0 means that all relevant documents were retrieved by the search.

The rice production ontology is capable to explore the query topics and increase search results more than the conventional search. This can be confirmed by the precision and recall score of the ontology search which are higher than conventional search. From the search results, relevant records by some queries are higher than retrieved records. This is because concepts and terms collected in the ontology are not comprehensive enough. In the same time, some relevant queried records are less than retrieved records. This mean the system queried the irrelevant results. From the results, most of the irrelevant results are retrieved from abstracts, while the relevant results were queried from titles and keywords. To reduce the irrelevant results we may improve by searching only in title and well defined keywords, or apply more semantic techniques in the retrieval system. Also, for increasing and provide more comprehensive search results to serve the users needs, we may consider to enrich the Thai Rice Research Database as one of the important issue.

When analysing the queries, we should consider all the competency questions raised by rice experts and research administrators in a consultation meeting, and many subjects which were proposed. As jasmine rice is the most important rice cultivar of Thailand, this cultivar satisfy consumer for sensory quality and well-known in the market worldwide. Unfortunately, jasmine rice is susceptible to various kinds of pests and diseases and has low productivity. The focusing point for this issue from researchers are how to increase the productivity of jasmine rice while standardize the quality. So the researchers want to know all research literature related with jasmine rice defined in each subject of rice production and protection. On the other view of users who are plant protection experts, they noticed that in the recent years, agricultural researcher and farmers are facing a new problem from the climate change. Change in the weather patterns can bring the issue of disease outbreak and pest dissemination, the turn out of new pests and diseases will be the important issue in the near future. Thus the focus group need to know all of research literature about pest and disease of rice and they want to rate the existing disease research to know which one is the most or less studied. Together, they want to rate the existing disease research to know which disease is most or least needed to study for the future. Also, they want to identify the existing research on rice pest control as paddy field pest and rice stored product pest for further reviewing. Paddy field pest is the subject which was researched mainly by the Ministry of Agriculture and Cooperatives, whereas the after harvesting product is involved by private sector as rice miller and rice stockholder. Research project managers are planning to initiate collaborative research on rice stored product pest control with millers and stockholders. Alternatively, the trend of agricultural production is in the line of organic farming. In fact, biological control agents or natural enemies of rice pest and organic fertilizer were also proposed as subject for this theses. From all of these issues, five competency questions were concluded by the focus group.

In these five competency questions, there is a question which the conventional search could not answer or retrieve enough documentation for. The question is "What kind of rice disease has the highest research literatures?" (question no. 3). Without background knowledge from the ontology, a conventional search can search only term "rice diseases" but is not capable to define names of rice diseases and can not create a query using these disease names. On the other hand, ontology base system can recognize terms in the ontology by following the relation "hasDisease" and "hasCause", then define all of the rice disease names together with pathogen names and their synonyms. This query with the use of the ontology can identify rice diseases into 25 disease concepts lexicalized with 55 terms between which: 25 disease names in English, 25 disease names in Thai, and 5 synonyms (Table 29). In addition, 22 pathogen concepts (some diseases have the same pathogens) are identified by following the relationship "hasCause" between disease concepts and pathogen concepts. Pathogen concepts lexicalize with 22 pathogen scientific names and 15 synonyms (Table 30).

For the first questions, "How many Jasmine rice research papers exisits defined by each subject of a predetermined classification scheme?, the formulated query is "jasmine rice" combine with "subject category code" with the Boolean operator "AND". Common terms for this query are "jasmine rice" and it's plural. With the ontology-based search, the concept of jasmine rice was expanded with it's synonyms both in Thai and English. There are 10 terms which lexicalize the jasmine rice concept (Table 24). As the Thai Rice Research Database uses the AGRIS/CARIS Subject Categorization Scheme for classification, there are 28 subject categories (Table 25) related with rice production.

The second question is, "How many research papers focus on rice biological control organism?". Most of the research literature which focus on biological control organism or natural enemy of rice pest usually specify organism names. This is why, using the terms "biological control organism" or "natural enemy" are not possible to find a lot of documents. From the rice production ontology, the concept[biological control organism] connects with the concept[rice] by the associative relationship [hasBiologicalControlAgent]. 150 terms from 80 concepts were identified to use useful for this query.

"How many rice research papers contain information about chemical fertilizer and organic fertilizer?". This question is very general. There are only two key terms: "chemical fertilizer" and "organic fertilizer". Normally, the chemical fertilizer includes the type of fertilizers, such as: compound fertilizer, nitrogen fertilizer, potassium fertilizer, phosphorus potassium fertilizers, NPK, etc. For organic fertilizer, they may contain: green manure, farm manure, compost, etc. How can the conventional system specify these terms?, and how can the system identify which term is a chemical or organic fertilizer? This problem can be solved by apply the ontology to specify terms by following the hierarchical relationship "hasSubclass". With this relationship, the chemical fertilizer concept and organic fertilizer concept will be identified into many subclasses. Then, terms and synonyms of these subclasses concepts will be used for the query. For the chemical fertilizer concept, 14 subclasses concepts were collected and lexicalized with 46 terms. The Organic fertilizer concept has 4 subclasses represented by 12 terms (Table 32).

For the last question "How many research papers contain information about rice pest control, grouped by type of pest such as "field pest" and "stored product pest"?", the associated common keywords for this search are "field pest" and "stored product pest". The conventional retrieval system can not provide the query term specifically. Whereas the ontology-based search system can specify names of paddy field pests and rice stored product pests enhance with the pest scientific names and common names, local names in Thai and English. In the ontology there are 186 rice pest species, 150 are paddy field pests and 36 stored product pests (see example in Table 35 and Table 36). Terms lexicalizing paddy field pest concepts include: scientific names, common names, and local names for a total of 150 terms, 5 synonyms in English, 23 synonyms in Thai, and 3 acronyms (see example in Table 37). Terms lexicalizing stored product pest concepts include: scientific names, common names, local names, for a total of 36 terms and 3 synonyms in Thai (see example in Table 38). The terms expanded from the paddy field pest and stored product pest by the rice production ontology totally sum up to 592 terms. To complete the query, all of these terms were combine with terms representing the concept "pest control". As pest control relates with control methods and pesticides, the scope of pest control should contain: concept[pest control], concept[control method], concept[pesticide] and their subclasses. There are 46 subclasses represented by 171 terms related with pest control (see example in Table 43 and Table 45). Moreover, the query of pest control can be enlarged by the rice pesticide common names and trade names, which are about 230 in total.

CONCLUSION AND RECOMMENDATION

The modern information systems are moving form “data processing” towards “concept processing”. Unit of processing is becoming more a semantic concept which carries an interpretation and exists in a context together with other concepts. An ontology is a structure capturing semantic knowledge about a certain domain by describing relevant concepts and relations between them. Most researches have been carried out to facilitate automatic and semi-automatic ontology development. Their purpose is essentially to minimize the high cost of ontology construction incurred by the manual domain-expert-driven approach. However, an ontology is representative for a specific knowledge domain; hence the necessity to bring in experts in that respective domain to build well-structured ontology that can accurately represent knowledge. This research proposed to start with developing a well-defined ontology skeleton created from scratch with the help of domain experts and prepare rules for future use to update the ontology using a semi-automatic approach. From this, a prototype of Thai Rice Production Ontology was developed. Criteria and guidelines were initiated to facilitate other plant production ontology construction.

The Thai Rice Production Ontology provides an organizational framework with 2,322 concepts and 5,603 terms in a hierarchical system, with 57 associative relations and 12 equivalent relations, that allows reasoning about rice production knowledge. The relationships in the rice production ontology were compared with the existing relationships in the AGROVOC CS: 19 relationships are the same as in the AGROVOC CS and 51 new relationships were defined. Having compared all the concepts from the rice production ontology with the existing terms in the FAO AGROVOC Thesaurus we can conclude that 2,687 terms (about 48 percent) in the ontology were already existed in the Thai AGROVOC Thesaurus.

Concepts and relations were formalized and verified in the form of a datasheet and imported into the AGROVOC Concept Server Workbench tool. A *Thai Agricultural Ontology Visualization tool* and an Ontology *Tree Editor* were developed to present the ontology graphically and facilitate ontology editors in their tasks. Refinement was done in a loop by perform the transformation following the criteria validated by expert to improve the created ontology.

The evaluation of the rice production ontology is done by identify how extensively the ontology can be used to reply to the competency questions. The rice production ontology query expansion can increase information retrieval efficiency and answer questions which a traditional retrieval system without ontology can not do. Terms in the ontology were used to query the Thai Rice Research Database (1,350 records). The efficiency of the query measures in terms of its precision and recall rate. The experiment was conducted using five competency questions, in which 93 queries were defined. Retrieval experiments comparing conventional search and ontology-based search supported with the rice production ontology-based query expansion. Results show that precision and recall are increased averagely from 0.08 to 0.72 and

0.01 to 0.64 respectively, which identify the ontology-based search more efficient than the conventional search about 9 and 64 times more.

The documentation in this research was processed and elaborated as guidelines and criteria. In addition, rules for maintaining an ontology were created from the development process. Criteria for rice production ontology construction are criteria for defining concept, criteria for defining term, and criteria for defining relationship. Criteria for defining concept are: criteria for classify organism concepts, criteria for classify soil concept, criteria for classify non-organism concepts. Criteria for defining term are: criteria for terms classification and criteria for assigning term format. Criteria for defining relationships are criteria for defining equivalence relationships, criteria for defining hierarchical relationships and criteria for defining associative relationships. The Delphi Technique was used for validate the created criteria with the support of 27 domain specific experts.

Rules for semi-automatically addition of concepts and terms into the ontology were defined in human language and tested by information specialists so the rules under scope of this research will not extend to the operation processed by computer. The rules were derived from the ontology development process. The objective of these rules is to set guidelines for computer operation so that they can be utilized for semi-automatically adding terms and concepts into the rice production ontology. So these rules can facilitate the human-based and computer-based maintenance process.

Contributions from this research should support knowledge service organization, research planning section, and research project managers in making decisions based on the knowledge-base and create research knowledge management initiatives. This research effort also helped to establish criteria and guidelines for agricultural ontology construction, increasing efficiency of research information retrieval system and enhanced service quality for research knowledge management efforts.

Finally, this research demonstrated that ontology plays a critical role in knowledge acquisition and knowledge management processes. It helps make knowledge storage and retrieval process significantly more intelligent. So it is very reasonable to encourage the construction of many more ontologies. What then follows is the need for tools that improve efficiency for constructing new ontologies, by transferring and merging the existing ones.

Developing domain specific ontologies is the biggest challenge for good information retrieval and knowledge services, therefore it is advisable that experts and information specialists in each specific knowledge domain should collaboratively start developing their respective ontology. Furthermore, collaboration and cooperation among related organizations or ontology editors should be established, so that the developed ontology could be reused and interoperate with each other for substantial development.

LITERATURE CITED

Allee, V., 1997. **The Knowledge Evolution: Expanding Organizational Intelligence**. Newton, MA: Butterworth-Heinemann.

Asawanopakiat, P. 2004. **A System for Searching and Integrating Biological Data by Using Bio-Ontology**. M.S. Thesis Kasetsart University.

Attanandana., T. and W. Prateep 2008. **Natural of Soil and Fertilizer**. Korn Creation Press, Bangkok.

Baumard, P. 1999**. Tacit Knowledge in Organizations**. UK: Sage Publications, London.

Beretta, R. 1996. A critical review of the Delphi technique. **Nurse Researcher** 3(4): 79-89.

Beverly, R. B., J. G. Latimer, and D. A. Smittle. 1993. Preharvest physiological and cultural effects on postharvest quality, pp. 74-98. *In* R. L. Shewlelt, and S. E. Prussia, eds., **Postharvest Handling: A Systems Approach.** Academic Press, Inc., San Diego.

Brewstera, C. and K. O'Harab. 2007. Knowledge representation with ontologies: Present challenges-Future possibilities. **Int. J. Human-Computer Studies** 65: 563–568.

Cavalier-Smith, T. (1998). **A Revised Six-kingdom System of Life**. Evolutionary Biology Programme, Canadian Institute for Advanced Research, Department of Botany, University of British Columbia, Vancouver, EC, Canada.

Chongkid., B. 2004. **Rice and Production Technology**. Thammasat University Publishing, Bangkok.

Cline, A. 2000. **Prioritization process using Delphi technique**. Carolla Development. Available Source: http://www.carolla.com/wp-delphi.htm, December 23, 2007.

Crisp, J., D. Pelletier, C. Duffield, A. Adams and S. Nagy. 1997. **The Delphi method: Nursing Research** 46, 116-118.

Dalkey, N.C. 1969. **The Delphi Method: An Experimental Study of Group Opinion**. RM-5888-PR. Santa Monica, CA: Rand Corporation.

Davies, J., R. Studer and P. Warren. 2006. **Semantic Web Technologies: Trends and Research in Ontology-based Systems**. John Willey & Sons, England.

De Datta, S.K. 1981. **Principles and Practices of Rice Production**. Wiley-interscience publication, New York.

Dean, M., D Connolly, FV Harmelen, J Hendler and I. Horrocks**.** 2002. **Web Ontology Language (OWL).** W3C Working Draft. Available Source: http://www.w3.org/TR/2002/WD-owl-ref-20021112/, January 12, 2008.

Delbecq, A.L., A.H. Van de Ven, and D. H. Gusafan. 1975. **Group Techniques for Program Planning**: **a Guide to Normal Group and Delphi Processes.** Glenview, IL: Scott, Foresman.

Department of Agriculture. 1999. **Good Agricultural Practice for Rice**. Office of Rice Research and Development, Phitsanulok.

Dooren, Ir. Corn van. 2005. **Rice Value Chain Analysis "Each life starts with a little seed".** Report for IFAT/EFTA/FLO. 156 p.

Drucker, P. 1994. **Post-Capitalist Society**. NY: Harper Business, New York.

Duffield, C. 1993. The Delphi technique: a comparison of results obtained using two expert panels. **International Journal of Nursing Studies** 30(3): 227-237.

Ellis, K., 2003. K-span:Building a bridge between learning and knowledge management. **Training** 40(10): 46.

FAO. 1998. **AGRIS/CARIS Categorization Scheme**. FAO-AGRIS—3 Rev. 5.1 (En). Rome.

______ 1999. **AGROVOC Multilingual Agricultural Thesaurus** (English version). 4th ed., Rome.

______ 2008. **AGROVOC Concept Server**. Agricultural Information Management Standards. Available Source: http://www.fao.org/aims/agrovoccs.jsp, June 25, 2008.

Groth, D. and F. Lee. 2003. Rice diseases. pp. 413-436. *In* C.W. Smith John and R.H. Dilday, eds. **Rice Origin, History, Technology and Production**. Wiley & Sons, Inc., New Jersey.

Gruber, T. 1993. A translation approach to portable ontology specifications. **Knowledge Acquisition** l5(2): 199-120.

______ 2007. **Ontology**. Ontology (Computer Science) definition in Encyclopedia of Database Systems, Springer-Verlag. Available Source: http://tomgruber.org/writing/ontology-definition-2007.htm, January 15, 2008.

Gruninger, M. and M.S. Fox. 1995. Methodology for the design and evaluation of ontologies, pp 51-60. *In* **Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing**, IJCAI-95, Montreal.

Guarino, N. 1998. Formal Ontology and Information Systems, pp. 135-143. *In* N. Guarino, ed. **Proceeding of the 1st International Conference**, Trento.

Harriman, P.L. 2007. Ontology. *In* **Encyclopedia Americana**, Grolier Online. Available Source: http://ea.grolier.com/cgi-bin/article?assetid=0295840-00, January 23, 2007.

Hasson, F., S. Keeney and H. Mckenna. 2000. Research guidelines for the Delphi survey technique. **Journal of Advanced Nursing** 32(4):1008-1015.

van Heijst, G., A. Th. Schreiber and B.J. Wielinga. 1997. Using explicit ontologies in KBS development. **International Journal of Human-Computer Studies** 46(2/3):183-292.

Helmer, O. 1967. **Systematic use of expert opinion** (Report No. P-3721). The Rand Corporation, Santa Monica.

Hulden, M. 2007. **CWR Ontology–Project report a practical approach on creating a restricted ontology for Crop Wild Relatives**. Project report.

Imsombut, A. 2007. **Automatic Thai Ontology Construction from Corpus, Thesaurus, and Dictionary**. Doctor of Engineering (Computer Engineering), Kasetsart University.

International Rice Research Institute. 2008. **Rice knowledge bank**. Cereal knowledge bank. Available Source: http://www.knowledgebank.irri.org/Rice/ Ricedefault.htm, February 9, 2008.

International Committee on Taxonomy of Viruses. 1999. **Virus Taxonomy. Classification and Nomenclature of Viruses**. 7th Report of the International Committee on Taxonomy. Academic Press, New York, San Diego.

Jaiswal, P., S. Avraham, K. Ilic, E.A. Kellogg, S. McCouch, A. Pujar, L. Reiser, S.Y. Rhee, M.M. Sachs, M. Schaeffer, L. Stein, P. Stevens, L. Vincent, D. Ware, and F. Zapata. 2005. Plant Ontology (PO): a controlled vocabulary of plant structures and growth stages. **Comparative and Functional Genomics** 6 (7-8): 388-397.

Jerkins, D. and T. Smith. 1994. Applying Delphi methodology in family therapy research. **Contemporary Family Therapy** 16, 411-430.

Kawtrakul, A., M. Suktarachan and A. Imsombut. 2004. Automatic Thai ontology construction and maintenance system. *In* **Proc. of OntoLex Workshop on LREC**. Lisbon, Portugal

Komut, T. 2004. **An Ontology–Based Behavioral Semantics for WSDL**. Thesis Master of Engineering (Computer Science), Chulalongkorn University.

KPMG. 1999. **Knowledge Management Research Report 2000**. KPMG Consulting, United Kingdom.

Kukhamau., A. 2004. Weed Management in Peddy Field, pp 101-107. *In* Phureewirochkul., W. Orapin, W. and Phannee, W. **Rice**. Department of Agriculture, Bangkok.

Land Development Department. 2008. **Group of Soil Series.** Soil group database. Available Source: http://www.ldd.go.th/ldd/, January 12, 2008.

Lassila, O. and McGuinness, D. 2001. **The Role of Frame-Based Representation on the Semantic Web**. Standford University. Available Source: ftp://ftp.ksl.stanford.edu/pub/KSL_Reports/KSL-01-02.html#_ftn2, December 8, 2007.

Liang, A.C., B. Lauser, M. Sini, J. Keizer and S. Katz. 2006. **From AGROVOC to the Agricultural Ontology Service/Concept Server An OWL model for**

managing ontologies in the agricultural domain. Available Source: http://owl-workshop.man.ac.uk/acceptedPosition/submission_31.pdf

Luh, B. S. 1991. **Rice**. Van Nostrand Reinhold, New York.

Maedche, A. 2001. **Development and applications of ontologies** (ECML / PKDD‘2001 Tutorial). Research Center for Information Technologies at the University of Karlsruhe, Germany.

McKenna, H. 1994. The Delphi technique: a worthwhile approach for nursing? **Journal of Advance Nursing** 19, 1221-1225.

Mew, T.W. 1991. Rice Diseases, pp. 187-236. *In* B.S. Luh. ed., **Rice**. Van Nostrand Reinhold, New York.

Mizoguchi, R., J. Vanwlkenhuysen, M. Ikeda. 1995. Tasks ontology for reuse of problem solving knowledge, pp. 46-57. *In* N. Mars, ed. **Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing (KBKS’95)**. University of Twente, Enschede, Netherlands, IOS Press, Amsterdam, Netherlands.

Mongkol., C. 1993. **Rice**. Department of Teacher Education, Bangkok.

Muenpai, N. 2005. **Performance Enhancement of Thai Information Retrieval System using Noun Phrase Variant and Ontology**. Thesis Master of Engineering (Computer Engineering), Kasetsart University.

Nabheerong, N. and L. Wathanakul, 1971. **Rice Diseases and Pests Thailand**. Rice Protection Research Centre, Rice Department, Thailand.

Noy, N. F. and D.L. McGuinness. 2001. **Ontology Development 101: A Guide to Creating Your First Ontology**. Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report SMI-2001-0880. Standford University.

Office of Agricultural Economics. 2008. Rice. **Rice Production and Trade**. Available Source: http://www.oae.go.th/, January 18, 2008.

Office of the National Research Council of Thailand (NRCT). 2008. **National Research Plan and Strategy in 2008-2010**. NRCT, Bangkok.

Ogden, C.K., I.A. Richards. 1923. **The Meaning of Meaning**. 8th ed. New York, Harcourt, Brace & World, Inc.

Osotsapar, Y. 2003. **Plant Nutrient**. Kasetsart University Publishing, Bangkok.

Panichsakpatana, S., S. Sassanarakkit and S. Vacharotayan. 1991. Uitlization of waste materials for soil amelioration: B. Utilization of some organic wastes as N source for lowland rice, 156-168. *In* Tomio.,Y., K. Yamaxaki, M. Nakano, M. Fukami, A. Ushikubo and Y. Sato. eds, **Dynamics and its control of soils in tropical monsoon regions: Reprot of survey and research in Thailand**. Ministry of Educa.

Pinto, H.S. and J.P. Martins. 2004. Ontologies: How can they be built. **Knowledge and Information System** 6: 441-464.

Rice Department. 2008. **Thai Rice Knowledge Bank**. Rice Thailand. Available Source: http://www.ricethailand.go.th/rkb/index.html, May 3, 2008.

Shuvisitkul., E. 2001. **Technology of Rice Production.** Rice Research Institute, Bangkok.

Sini, M. and V. Yadav. 2009. Building **Knowledge Models for Agropedia Indica Requirements**. Guidelines v. 1.0. Available Source: http://agropedia.iitk.ac.in/km_guidlines.pdf, January 12, 2009.

Slaughter, L.A. and D. Soergel. 2003. How Physicians' Answers Relate to Health Consumers' Questions. pp. 28-39. *In* **Proceedings of the ASIST Annual Meeting**, v 40.

Smittle, D. A., 1986. Influence of cultivar and temperature on bean yield and quality. **J**. **Amer. Soc. Hort. Sci**. 111: 655-659

Soergel, D., B. Lauser, A. Liang, F. Fisseha, J. Keizer and S. Katz. 2004. Reengineering thesauri for new applications: the AGROVOC example. **Journal of Digital Information** 4(4). Article No. 257, 2004-03-17. Available Sources : http://jodi.tamu.edu/Articles/v04/i04/Soergel/ November 15, 2007.

Suwanarit, A., S. Kreetapirom , S. Buranakarn, P. Suriyapromchai, W. Varanyanond and P. Tungtrakul. 1997. Effects of Sulfur Fertilizer on Grain Qualities of Khaw Dauk Mali-105 Rice. **Kasetsart J. (Nat. Sci.)** 31 : 305-316.

Takeya, M., H. Numa and K. Doi. 2003. Ontology Using Role Concept Recognized on Biological Relationships and Its Application. **Genome Informatics** 14: 685-686.

Thunkijjanukij, A. 2005. **Refining AGROVOC and creating global agricultural thesaurus: Recommendations from Thai AGROVOC development experience**. Thai National AGRIS Centre Kasetsart University, Bangkok.

Thunkijjanukij, A., P. Lertpongwipoosana and T. Damrongson. 2005. 'Thai Agriculture Thesaurus', pp.244-251. *In* **The 43th Proceedings of Kasetsart University Annual Conference**. 1-4 February 2005. Kasetsart University, Bangkok.

Thunkijjanukij, A., P. Lertpongwipoosana, T. Damrongson, P. Tongumpai, K. Phomphunjai, W. Srijankul, J. Suansawan, O. Kongpitak and S. Buddeewong.. 2006. **Development of Thai Agricultural Thesaurus : Final report**. Thai National AGRIS Centre, Main Library, Kasetsart University.

Uschold, M. and M. Gruninger. 1996. **Ontologies: Principles, Methods and Applications**. AIAI-TR-191. The University of Edinburgh.

USDA. 2006. **Keys to Soil Taxonomy**. 10^{th} edition. United States Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. Available Sources : http://soils.usda.gov/technical/classification/taxonomy/, January 15, 2008.

Vincent, P.L.D., E.H. Coe and M.L. Polacco. 2003. *Zea mays* ontology–a database of international terms. **Trends in Plant Science** 8 (11). 517-520.

Woese, C.R., O. Kandler and M.L. Wheelis, 1990. Towards a natural system of organisms: Proposal for the domains Archaea, Bacteria, and Eukarya, pp. 4576-4579. *In* **Proceedings of National Academic Science USA**. Vol. 87, June 1990.

APPENDICES

Appendix A Delphi participant name list

No.	Position	Name	Specialize subject	Affiliation
1	Professor	Supamard Panichsakpatana	Soil science	Faculty of Agriculture, Kasetsart University
2	Professor	Tasnee Attananawa	Nutrient Management	Faculty of Agriculture, Kasetsart University
3	Assistant Prof.	Piboon Kanghae	Soil Survey, Genesis and Classification, Land Evaluation and Land Use Planning	Faculty of Agriculture, Kasetsart University
4	Lecturer	Somchai Anusontpornperm	Soil construction, Soil Management, Soil Classification	Faculty of Agriculture, Kasetsart University
5	Associate Prof.	Narong Singburaudom	Disease of Field Crop, Breeding for Disease Resistance	Faculty of Agriculture, Kasetsart University
6	Associate Prof.	Somsiri Sangchote	Seed Pathology and Postharvest Diseases	Faculty of Agriculture, Kasetsart University
7	Associate Prof.	Wiboon Chongrattanametee kul	Insect Ecology and Integrated Pest Management	Faculty of Agriculture, Kasetsart University
8	Associate Prof.	Kosol Charernsom	Entomology (Insects)	Faculty of Agriculture, Kasetsart University
9	Assistant Prof.	Veravan Amornsuk	Entomology	Faculty of Agriculture, Kasetsart University
10	Associate Prof.	Juangjun Duargpratra	Seed Technology, Postharvest of Field Crop, Sustainable Land Use and Natural Resource Management	Faculty of Agriculture, Kasetsart University
11	Lecturer	Sutkhet Nakasathien	Crop Physiology and Biotechnology	Faculty of Agriculture, Kasetsart University
12	Associate Prof.	Prapa Sripichitt	Biotechnology and Plant Breeding	Faculty of Agriculture, Kasetsart University
13	Associate Prof.	Jindarath Verawudh	Crop production	Faculty of Agriculture, Kasetsart University
14	Lecturer	Sarawut Rungmekarat	Weed Management, Crop science	Faculty of Agriculture, Kasetsart University
15	Associate Prof.	Paiboon Paireepairit	Plant Science	Faculty of Agriculture, Kasetsart University

No.	Position	Name	Specialize subject	Affiliation
16	Professor	Saichol Ketsa	Postharvest Physiology	Faculty of Agriculture, Kasetsart University
17	Associate Prof.	Chalongchai Babpraserth	Plant Science	Faculty of Agriculture, Kasetsart University
18	Associate Prof.	Surasak Nilnond	Crop Physiology	Faculty of Agriculture, Kasetsart University
19	Associate Prof.	Uamporn Veesommai	Plant Diversity	Faculty of Agriculture, Kasetsart University
20	Associate Prof.	Yingyong Paisooksantivatana	Tropical Plant Diversity	Faculty of Agriculture, Kasetsart University
21	Assistant Prof.	Kanokwan Thanomchit	Crop Physiology and Production	Faculty of Agriculture, Kasetsart University
22	Researcher	Nongrat Nilpanit	Plant Pathology	Rice Department, Ministry of Agriculture and Cooperatives
23	Researcher	Sukanya Kongngoen	Soil science	Rice Department, Ministry of Agriculture and Cooperatives
24	Researcher	Anchalee Prasertsak	Seed Technology	Rice Department, Ministry of Agriculture and Cooperatives
25	Researcher	Orapin Watanesk	Rice Breeding, Morphology and Classification	Rice Department, Ministry of Agriculture and Cooperatives
26	Researcher	Kingkaw Kunkot	Plant Nutrition and Soil Microbiology	Rice Department, Ministry of Agriculture and Cooperatives
27	Researcher	Peerawan patanavipart	Plant Pathology	Plant Diseases Research Group, Department of Agriculture, Ministry of Agriculture and Cooperatives

Appendix B Research questionnaire

Research questionnaire
Ontology Development for Agriculture Research Knowledge Management : Case Study of Thai Rice

Criteria for building the Rice Production Ontology introduced in this questionnaire have been derived from literature review on rice production. The sources are texts and research document both in Thai and English. Content were summarized into the format that suitable for ontology construction.

As a consequence, in order for the rice production ontology prototype to be valid and reliable, I would like you to express your opinion as to the criteria for developing rice production ontology in the following items:

1. Criteria for defining rice production process
2. Criteria for defining rice characteristic
3. Criteria for defining rice ecology
4. Criteria for biological taxonomic classification
5. Criteria for soil classification
6. Criteria for rice classification
7. Criteria for classify type of organism and non-organisms related with rice
8. Criteria for defining term
9. Criteria for defining relationship

Name: ....
Position: ....
Subject specialize: ....

Please mark ✓ in the opinion cell as you see appropriate, based on the following score meaning

5 means you totally agree with the given issue
4 means you very much agree with the given issue
3 means you moderately agree with the given issue
2 means you slightly agree with the given issue
1 means you agree with the given issue the least

How much do you agree with the following criteria;

Rice production process

No.	Criteria	Degree of agreement				
		5	**4**	**3**	**2**	**1**
1.	**Process of rice production**					
1.1.	Plant cultivation (from planting to harvesting)					
1.2.	Soil cultivation					
1.3.	Irrigation					
1.4.	Fertilizing					
1.5.	Propagation					
1.6.	Seed production and processing					
1.7.	Genetics and breeding					
1.8.	Cropping system					
1.9.	Plant pest control					
1.10.	Plant disease control					
1.11.	Weed control					
1.12.	Plant disorder control					
1.13.	Other, please define					

Suggestion ....

Rice anatomy and physiology

No.	Criteria	Degree of agreement				
		5	**4**	**3**	**2**	**1**
2.	**Rice anatomy and physiology**					
2.1	Anatomy					
2.2	Morphology					
2.3	Cytology					
2.4	Physiology					
2.5	Other, please define					

Rice ecology

No.	Criteria	Degree of agreement				
		5	4	3	2	1
3.	**Ecological factor of rice: organism**					
3.1	Plant, for example: weed					
3.2	Animal, for example: pest, natural enemy					
3.3	Fungi, for example: pathogen, antagonistic fungi					
3.4	Bacteria and Phytoplasma, for example: pathogen bacteria, bacterial antagonists					
3.5	Virus, for example: pathogen virus					
4.	**Ecological factor of rice: non organism**					
4.1	Light					
4.2	Water (included moisture content in soil and air)					
4.3	Climate and pollution					
4.4	Plant nutrition					
4.5	Soil					
4.6	Fertilizer					
4.7	Plant growth regulator					
4.8	Pesticide					
4.9	Others, please define					

Suggestion ....
....

Biological taxonomic classification

No.	Criteria	Degree of agreement				
		5	4	3	2	1
5.	**Classification of organism for developing rice ontology follow the classification concept proposed by** Woese, C. R. *et al*. in 1990. Organism defined in 3 Domain as: Bacteria, Archaea, Eukarya and Domain Eukarya divide to Kingdoms as: Plantae, Animalia, Fungi. Kingdom divide to Phylum, Class, Order, Family, Genus, Species. Species can be divided to Subspecies, Variety, Cultivar Except Virus which is not yet definitively living or non-living. Classification in this research use International Committee on Taxonomy of Viruses (1999) to classify virus as: Order, Family, Genus, Species					
6.	**Organism relate with rice in the rice production ontology classify as:** 1 Domain, 3 Kingdoms and 1 group, they are: Domain - Bacteria, Kingdoms - Plantae, Animalia, Fungi and group- Virus					
7.	**Classification of Kingdoms – Plantae** for developing rice production ontology start with Family, end at Subspecies or Variety or Cultivar as: Family -> Genus -> Species -> Subspecies, Variety, Cultivar					
8.	**Classification of Kingdoms - Animalia** for developing rice production ontology start with Class, end at Species as: Class -> Order -> Family -> Genus -> Species					
9.	**Classification of Kingdoms - Fungi** for developing rice production ontology start with Class, end at Species as: Class -> Order -> Family -> Genus -> Species					

No.	Criteria	Degree of agreement				
		5	4	3	2	1
10.	**Classification of Domain – Bacteria** for developing rice production ontology start with Class , end at Species as: Class -> Order -> Family -> Genus -> Species					
11.	**Classification of Virus** for developing rice production ontology start with Family , end at Species as: Family -> Genus -> Species					
12.	**Classification of soil** for developing rice production ontology use "Keys to Soil Taxonomy" by United States Department of Agriculture Natural Resources Conservation Service (2006) as: Soil Order, Soil Suborder, Soil Great group, Soil Subgroup, Soil Family, Soil Series					

Suggestion --

No.	Criteria	Degree of agreement				
		5	4	3	2	1
13.	**Type of rice defined for rice production ontology**					
13.1	Rice type defined by harvesting date as: early maturity rice, medium maturity rice and late maturity rice					
13.2	Rice type defined by evolution as: wild rice and cultivate rice					
13.3	Rice type defined by irrigation type as irrigated rice and rainfed rice					
13.4	Rice type defined by ecology as: lowland rice, deepwater rice, floating rice, upland rice, high land rice (high land paddy rice and high land upland rice)					
13.5	Rice type defined by growing season as: major rice and off-season rice					
13.6	Rice type defined by planting type as: transplanted rice, broadcasting rice and direct seeded rice					
13.7	Rice type defined by seed grain as: short grain rice, medium grain rice, long grain rice and special long grain rice					
13.8	Rice type defined by photoperiod sensitivity as: photoperiod sensitive rice and photoperiod insensitive rice					
13.9	Rice type defined by seed starch composition as: waxy rice or glutinous rice and non-waxy rice or non-glutinous rice					

Suggestion ....

....

Classification of organism and non-organism related with rice

No.	Criteria	Degree of agreement				
		5	4	3	2	1
14. 14.1	**Type of animal related with rice for developing rice production ontology** **Beneficial animal** as: pollinator and natural enemy					
14.2	**Noxious animal** as: noxious mammal, noxious bird, noxious mollusca, noxious crustacea, insect pest, pest mite and nematode					
14.3	**Insect pest** as: - root eating insect, stem eating insect, leaf eating insect, flower damaging insect, fruit damaging insects and seed damaging insect - chewing insect and sucking insect - insect vector					
15. 15.1	**Type of plant related with rice for developing rice production ontology** **Useful plant** as: food crop, feed crop, medicinal crop, spice crop, fibre crop, fuel crop, rubber plant, oil crop, dye plant, gum plant, ornamental plant, soil reclamation plant, cover plant, protective plant, erosion control plant, structural plant, trap crop, pesticide crop					
15.2	**Noxious plant** weed defined by characteristic as: narrow leaf weed, broad leaf weed, aquatic weed and cyperus, defined by growing season as: annual weed, perennial weed					

Number	Criteria	Degree of agreement				
		5	**4**	**3**	**2**	**1**
16.	**Type of microorganism related with rice for developing rice production ontology**					
16.1	**Useful microorganism** as: nitrogen fixing microorganism, biological control microorganism (entomopathogenic bacteria, entomopathogenic fungi, nematophagous fungi)					
16.2	**Noxious microorganism** pathogenic microorganism as: pathogenic fungi, pathogenic bacteria and pathogenic virus					
17.	**Type of agricultural substance related with rice for developing rice production ontology**					
17.1	**Pesticide** as: avicide, rodenticide, molluscicide, insecticide, acaricide, nematicide, fungicide, bactericide, herbicide, pesticide synergist and biopesticide (botanical pesticide, microbial pesticide)					
17.2	**Plant growth substance** as: plant growth stimulant, plant growth retardant, plant growth inhibitor, germination inhibitor					

No.	Criteria	Degree of agreement				
		5	4	3	2	1
17.3	**Fertilizer** as: inorganic fertilizer, organic fertilizer, organomineral fertilizer, liquid fertilizer, liquid gas fertilizer, slow release fertilizer					
17.3.1	Inorganic fertilizer defined as: single fertilizer, compound fertilizer					
17.3.1.1	Single fertilizer defined as: nitrogen fertilizer, phosphate fertilizer, potash fertilizer, sulphur fertilizer, calcium fertilizer, magnesium fertilizer, micronutrient fertilizer					
17.3.1.2	Compound fertilizer defined as: NPK fertilizer, nitrogen phosphorus fertilizer, nitrogen potassium fertilizer, phosphorus potassium fertilizer					
17.3.2	Organic fertilizer defined as: biofertilizer, compost, farm manure, green manure					

Suggestion --

Term and concept criteria

No.	Criteria	Degree of agreement				
		5	4	3	2	1
18.	**Criteria for defining term represented concept**					
18.1	**Organism** : use Scientific name represent plant, animal and related organism. Define common name in English and local name in Thai as synonym					
18.2	**Soil** : use Soil Series define by Land Development Department to represent soil series in Thailand					
18.3	**Agricultural chemical substance** : use substance common name in Thai and English for representing and use substance trade names as synonym					
18.4	**Plant nutrient**: use element name represent plant nutrient. Define chemical symbol or chemical formula as synonym					
18.5	**Non-organism** : use the most accepted name entity in the subject domain as preferred term, the less defined as synonym (non preferred term)					
18.6	**Bi-lingual term** : define term representation in English and Thai for all name entity, use Latin for scientific name					
18.7	Common word must be singular and noun word or noun phrase. Except the specific defined plural or singular noun					
18.8	Non-capitalize term except name or specific term, such as: Scientific name, Soil series name, Cultivar name, geographical name					
18.9	Others, please define					

Suggestion --

Relationship criteria

No.	Criteria	Degree of agreement				
		5	4	3	2	1
19.	**Relationship of in rice production ontology**					
19.1	Relationship between rice and production process are: Plant cultivation, Soil preparation, Irrigation, Fertilizing, Propagation, Seed production and processing, Genetics and breeding, Cropping systems, Plant pests control, Plant diseases control, Weeds control, Plant disorders control					
19.2	Relationship between rice and pest					
19.3	Relationship between rice and disease or disorder					
19.4	Relationship between rice and pathogen					
19.5	Relationship between rice and weed					
19.6	Relationship between rice and soil					
19.7	Relationship between rice and element					
19.8	Relationship between rice and fertilizer					
19.9	Relationship between rice and growth regulator					
19.10	Relationship between rice and pesticide					
19.11	Relationship between rice and element					
19.12	Relationship between rice and light					
19.13	Relationship between rice and climate and pollution					
19.14	Relationship between rice cultivar and rice type					
19.15	Relationship between rice cultivar and anatomy					
19.16	Relationship between rice cultivar and physiology					
19.17	Relationship between rice cultivar and resistant pathogen					

No.	Criteria	Degree of agreement				
		5	4	3	2	1
19.18	Relationship between rice cultivar and susceptible pathogen					
19.19	Relationship between rice cultivar and resistant pest					
19.20	Relationship between rice cultivar and susceptible pest					
19.21	Relationship between soil and soil fertility					
19.22	Relationship between soil and soil improvement					
19.23	Relationship between fertilizer and fertilizer type					
19.24	Relationship between fertilizer and soil					
19.25	Relationship between fertilizer and fertilizer application					
19.26	Relationship between disease and pathogen					
19.27	Relationship between pathogen and vector					
19.28	Relationship between pathogen and host					
19.29	Relationship between disease and plant anatomy					
19.30	Relationship between disease and symptom					
19.31	Relationship between disease and ecology					
19.32	Relationship between disease and control method					
19.33	Relationship between disease and agricultural substance					
19.34	Relationship between pest and pest type					
19.35	Relationship between pest and host					
19.36	Relationship between pest and plant anatomy					
19.37	Relationship between pest and infecting characteristic					
19.38	Relationship between pest and ecology					
19.39	Relationship between pest and natural enemy					

No.	Criteria	Degree of agreement				
		5	4	3	2	1
19.40	Relationship between pest and control method					
19.41	Relationship between pest and agricultural substance					
19.42	Relationship between weed and weed type					
19.43	Relationship between weed and ecology					
19.44	Relationship between weed and control method					
19.45	Relationship between weed agricultural substance					
19.46	Relationship between disorder and element					
19.47	Relationship between disorder and causing factor					
19.48	Relationship between disorder plant anatomy					
19.49	Relationship between disorder and control method					
19.50	Relationship between substance common name and agricultural substance type					
19.51	Relationship between agricultural substance and plant physiology or cytology					
19.52	Others, please define					

Suggestion ....
....

Appendix C AGROVOC-CS Workbench User Manual

AGROVOC-CS Workbench User Manual (http://naist.cpe.ku.ac.th/agrovoc/)

- This part of the AGROVOC-CS Workbench is accessible to all users.
- All users are allowed to create, edit and delete concepts, terms and relationships.
- It depends on the user privileges what happens in case of these actions (a non-logged-in user for example will change a term's status to 'proposed deprecated' if he clicks on delete.
- The creation of a new term or concept will enter the system with the status 'proposed' or 'guest-proposed', depending on if you are a registered user or logged in on a guest account.
- All the actions will be reassessed and validated by authorized registered validators and publishers).
- The concept tree on the left shows the tree view of all the concepts of the active ontology.
- Each item in the tree is represented with the main term of that concept in the chosen languages set in the preferences.
- In the right panel contains the details of a concept (basic information, definition, change history, scope note, relationships between this and other concepts, images and terminology information of that concept). Select a concept to visualize the details of this concept.

Step 1: Click on the concept icon in the main menu or on Concepts in the 'Action' drop-down menu to enter this module.

Click [+] sign to expand the tree node to show the concept.
Click [-] sign to collapse the tree node to hide the concept.
Step 1a: Click the node to select the concept.

Step 2: Click [Show/Hide URI] link to view the complete URI of the concept. The complete URI is shown below the concept tree. e.g. URI: http://www.fao.org/aos/agrovoc#c_28938

Step 3: Click [new] button to add new concept.

Create a new concept

concept Name	Language	Position
<enter the new concept>	[العربية]	[sub property]
	[Cesky]	[same level]
	[English]	
	[Español]	
	[Français]	

[日本語]
[Português]
[Slovak]
[ไทย]
[中文]

[Submit] [Cancel]

Step 3a: Enter the main label of the new concept in the text box.
Step 3b: Select the language for the main label of new concept.
Step 3c: Select the postion for the new concept.

[child] the new concept will be a sub concept of the selected concept.
[same level] the new concept will be entered as a sibling of the selected concept into the hierarchy

---

Step 3d: Click [Submit] button to add new concept or [Cancel] button to cancel the add operation.
- 'Creating new concept' message will be displayed until the add operation is not completed.

Step 4: Click [del] button to delete the selected concept.

Delete concept
Are you sure to delete
<name of the selected concept>(<language>)?
[delete] [cancel]

Step 4a: Click [delete] button to delete the selected concept.

- 'Work in progress...' message will be displayed until the delete process is completed.

Step 4b: Click [cancel] button to cancel the delete operation.
NOTE: The concept will stay in the system, with the status 'proposed deprecated' and will be assessed by an authorized validator.

Step 5: Click on the [info tab] to view the basic information of the selected concept.

Property Value
has date created 2006-09-12

has date last updated 2006-09-12
has status published

Step 6: Click on the [definition tab] to view the definition of the selected concept.
No. Definition
1 definition of dummy concept 1(en)
Create Update Source
2006-10-11 2006-10-11 NAL

Step 6a: Click "[+] new definition" to add new definition to the concept.

Definition	[new definition]
Language	--none-- عربية Cesky English Español Français 日本語 Português Slovak ไทย 中文
EXT source	- -none-- FAOTERM CABINAL WIKIPEDIA Dictionary OtherBook Journal Article AGROVOC Wordnet
URL	[source URL]

[submit][cancel]

Step 6b: Click "[+]new translation" to add new definition in another language (i.e. translation of the same definition of the same source)

Definition [definition in another language]
Language --none--
عربية
Cesky
English
Español
Français
日本語
Português
Slovak
ไทย
中文

[submit][cancel]

Step 6c: Click [edit icon] in the definition displayed area to edit that definition.
Step 6d: Click [delete icon] in the definition displayed area to delete that definition.
Step 6e: Click [number[-]] in No. column to delete definition and its tranlations.
Step 6f: Click [edit icon] in source column to edit URL and source

---

Edit external source
Note: The source of a definition contains, where this definition has been taken from. If it is a definition that's created by the user choose AGROVOC as source, since it has been created within the AGROVOC Concept Server

EXT source - -none--
FAOTERM
CABINAL
WIKIPEDIA
Dictionary
Other Book
Journal Article
AGROVOC
Wordnet
URL [source URL]

[submit][cancel]

Step 7: Click on the [has scope note tab] to view the scope note of the selected concept.

Step 7a: Click [[+]new value] to add the new scope note to the concept

Value [new scope note]
Language --none--
عربية
Cesky
English
Español
Français
日本語
Português
Slovak
ไทย
中文

[submit][cancel]

Step 7b: Click [edit icon] in the value of scope note displayed area to edit that value.
Step 7c: Click [delete icon] in the value of scope note displayed area to delete that value.

Step 8: Click on the [has history change tab] to view the changed history of the selected concept.

Value lang
history 1 en
history 2 en

Step 8a: Click [[+] new value] to add the new history to the concept

Value [new history]
Language --none--
عربية
Cesky
English
Español
Français
日本語
Português
Slovak
ไทย
中文

[submit][cancel]

Step 8b: Click [edit icon] in the value of history displayed area to edit that value.
Step 8c: Click [delete icon] in the value of history displayed area to delete that value.

Step 9: Click [Relationship tab] to view the relationship between the selected concept to another concept

Relationship	Destination concept
has portion	concept 4(en
has source	concept 3(en)
includes subprocess	concept 2(en)
is part of	concept 4(en)

Step 9a: Click [new Relationship] to add new relationship from the selected concept to another concept.

Source concept
Relationship affects
afflicts
benefits
from causes grows
is has member
has part has
.....

Destination Browse (Click browse to get the destination concept)
[submit] [cancel]

Step 9b: Click [edit icon] in front of each relationship to edit the relationship.
Step 9c: Click [delete icon] in front of each relationship to delete the relationship.

Step 10 : Click [term tab] to view all terms that are related to the selected concept.
Language term
English agriculture (main)
** (main) means that term is the main term in case it has more than one term in the same language.

Step 10a: Click [[+] new term] to create the new term related to the selected concept.

Term	[new scope note]
Language	--none--
	عربية
	Cesky
	English
	Español
	Français
	日本語
	Português
	Slovak
	ไทย
	中文
	[x] Main term
	[submit][cancel]

** check on main term checkbox to set that term as a main term.

Step 10b: Click [edit icon] in front of each term to edit term.
Step 10c: Click [delete icon] in front of each term to delete term.
Step 10e: Click [term] to view detail of term.
This will open a new window, the term module, which provides detailed information about this term

Term Information | Term Relationship | has spelling variant | Term Codes

---

Step 11 (in term pop up window): Click on [information tab] to view detail of term.

Property	Value
has date created	2006-09-11
has date last updated	2006-09-11
has status	published

Step 12: Click on [relationship tab] to view the relationship between this and other terms.

Relationship Destination Term
has abbreviation dum. conc. 1(en)
has acronym dc1(en)

Step 12a: Click on [[+] new relationship] to add new relationship.

Source dummy concept 1(en)

Relationship --none--
is scientific name of

has scientific name
has tranlsation
has synonymis acronym of
has abbreviation has acronym

Destination browse (Click browse button to get the destination term)
[submit] [cancel]

Step 12b: Click [edit icon] in front of each relationship to edit relationship.
Step 12c: Click [delete icon] in front of each relationship to delete relationship.

Step 13: Click [has spell variant] to view spelling variants of this term. (for example organization, organisation)

Value	lang
dummy concept 1	en
dummy concept 1	en

Step 13a: Click on [[+] new value] to add new value.
Step 13b: Click [edit icon] in front of each value to edit spelling variant.
Step 13c: Click [delete icon] in front of each value to spelling variant.
<u>Step 14</u>: Click [Term code] to view specific codes of this term
- These codes correspond to internal term codes of this term in other vocabularies, thesauri and knowledge organization systems.
- They can help to identify the term in the respective external systems and be used for information retrieval in systems that make use of these term codes.

#NOTE: In the current version, concept image tab is under construction.

Appendix D Guidelines for plant production ontology construction

This guideline is a starting point that would help a new ontology editor to develop plant production ontology in each specify plant. However, there is no single correct ontology for any domain. The ideas present in this guideline are concluded from experiences in developing the rice production ontology and all of the criteria which proposed in this guideline are verified by a group of domain experts. Hopefully, this guideline may be useful for experts and information specialists who interested in creating an ontology in their specific domain.

Guidelines for ontology construction are documentation according how to develop an ontology for the desirable propose. The documentation is principally important not only to facilitate for construction, but also for maintenance and reuse the ontology. These guidelines are attempt to consolidate experience gained from developing a prototype ontology for Thai rice production research knowledge management and assume that they could also be useful in other plant production ontology construction for the same propose.. A set of techniques for each step of the constructing process were described in five parts, as follows:

a. Guideline for Ontology specification
b. Guideline for Knowledge acquisition
c. Guideline for Ontology conceptualization
d. Guideline for Ontology formalization
e. Guideline for Implementation

Guideline for Ontology specification

Start to develop ontology by defining domain and scope. The easiest way to do are sketching and answering two kinds of questions, they are:

1. Basic questions. The basic questions is a list of question which clarify the propose of ontology and help to limit the scope of the model. Examples of basic questions are:
    a. What is the domain that the ontology will cover?
    b. For what we are going to use the ontology?
    c. For what types of questions the information in the ontology should provide answers?
    d. Who will use the ontology?
    e. Who will maintain the ontology?

2. Competency questions. The competency questions are list of questions that a knowledge base based on the ontology should be able to answer. These competency questions should be obtained from the ontology user or target group and do not need to be exhaustive.

Guideline for Knowledge acquisition

This step is to extract as much domain specific knowledge from knowledge resources. The processes are:

1. Collect and review related knowledge resources and categorize them systematically. The categories should coverage all topics related with the interested domain.

2. Capture knowledge from both explicit knowledge and tacit knowledge from expert. There are many techniques for acquiring knowledge from expert, such as: interview, discussion and focus group. Explicit knowledge resources are the domain specific text book, research literature, dictionary, thesaurus and any document emphasize on the specific subject, tacit knowledge resides inside people, such as: experiences, intuition, insights)

3. Knowledge analysis and summarization. Study and summarize all knowledge related with the scope of domain, formulate these knowledge in a structural form, then revise and confirm by expert (see example of knowledge summary table in Table 6-15). This ontology concept model was developed base on the whole plant model (Beverly et al., 1993) which described about physiological response to environmental effects.

Guideline for Ontology conceptualization

This is the stage where conceptual model of ontology will be built following the specification in the previous step. As ontology is a data model that represents a set of concepts within a domain and the relationships between those concepts. So the main components of ontology are concepts and relations. Concept can be defined as a class hierarchy, they are superclass, subclass. Relationships between concepts have two levels as: hierarchical relationship and associative relationship. Hierarchical relationship is relationship in the same hierarchy between superclass amd subclass. Associated relationship is relationship between concepts which is not in the same hierarchy. Conceptual modeling has processes as follows (see Table 5, 51, 52, 54, 56 and Figure 9) :

1. Identify concepts

Identify concepts from the knowledge summary in the previous step by using both top-down and bottom-up approach. The steps for identify concepts were divided as follows:

a. List concepts from the previous rice production knowledge summary, divide in two group as top level concept and bottom level concept.

The concepts can be defined in to three categories as: conceptual entity concept, object entity concept and functional entity concept (see Table 51)

b. Define subclass concept and instance hierarchically

c. Define superclass concept from the bottom-level concept which summarize from the knowledge summarization process.

d. Classify concepts by using the designed criteria for classification plant, animal, Fungi, Bacteria, Virus, Soil and non-organism as follows:

i. **Classification of Plant (Kingdom Plantae)** - start with Family, end with Subspecies or Variety or Cultivar : Family → Genus → Species → Subspecies, Variety, Cultivar

ii. **Classification of Animal (Kingdoms Animalia) -** start with Class, end with Species : Class → Order → Family → Genus → Species

iii. **Classification of Fungi (Kingdoms Fungi**) - start with Class, end with Species : Class → Order → Family → Genus → Species

iv. **Classification of Bacteria (Domain Bacteria)** - start with Class , end with Species as: Class → Order → Family → Genus → Species

v. **Classification of Virus (Group Virus**) - start with Family , end at Species as: Family → Genus → Species

vi. **Classification of Soil –** classify as: Soil Order, Soil Suborder, Soil Great group, Soil Subgroup, Soil Family, Soil Series (USDA, 2006 :Keys to Soil Taxonomy)

vii. **Classification of non-organism** for concepts of non-organism order would be categorized according to its order in group or category that it belongs.

2. Create inter-connection between concept as hierarchy and related relationship

3. Create informal sketchy models by using the previous summarized knowledge. Example of modeling tool are such as: Cmap, MindManager, etc.

Guideline for Ontology formalization

This stage is used to transform the conceptual model into a formal model. Concepts are represent by term and hierarchically organized through a structuring relation. Creating conceptual model to a formal form are steps as below:

1. Summarize concept and concept relationships from the conceptual model. All of the concepts and relationships defined in the previous conceptual model should be listed.

2. Define term represent concept

2.1 Terms Classification – All terms which represent concept should be identified with either one or the other of the following 2 groups;

a. Preferred term – in the ontology this is the term that lexicalized concept. Preferred term is main term representative of a concept when that concept can be described by various different terms. There is only one term designated as the preferred term the rest will be regarded as non-preferred terms or synonym. Never use acronym, abbreviation name, or symbol as preferred term. Consider selecting preferred term in related thesaurus, dictionary or term that is accepted or recommended by expert in that domain.

b. Non-preferred term or synonym – in the ontology this is the term that possesses the same meaning as the preferred term but is not selected as concept representative. The non-preferred term also called synonym.

Non-preferred term or synonym can be in the form of: Term variants such as spelling variant term, term in singular or plural, common name, local name, scientific name, trade name, chemical symbol, chemical formula, trade name, acronym, abbreviation name, translated term in other languages

2.2 Term format

General practice dictates that terms that were used as preferred term for representing concepts must be standardized as follows:

a. Common word must be singular and to be noun word or noun phrase. Except the specific defined plural or singular noun

b. Non-capitalize term except name or specific term, such as: Scientific name, Soil series name, Cultivar name, geographical name, etc.

c. Bi-lingual term : define term representation in English and Thai for all name entity, use Latin for scientific name

d. Organism : use Scientific name represent plant, animal and related organism. Define common name in English and local name in Thai as synonym

e. Non-organism : use the most accepted name entity in the subject domain as preferred term, the less defined as synonym (non preferred term)

f. Soil : use Soil Series define by Land Development Department to represent soil series in Thailand

g. Agricultural chemical substance : use substance common name in Thai and English for representing and use substance trade names as synonym

h. Plant nutrient: use element name represent plant nutrient. Define chemical symbol or chemical formula as synonym

3. Define relationship

a. Use relation "hasSubclass" as hierarchical relationship.

b. Assign associative relationship by selecting relationship from the existing (Table 56) or define a new one by identify verbs related between concepts and assign relation name by forming a meaningful statement (relationship names are written starting with lower case and capitalizing other words, without any space), see example pattern of relation in Table 57.

c. Create associative relationship between concept and concept in difference hierarchy.

d. Define equivalence relationship between concept and term, term and term, term and string. (see Table 52 and study pattern from Table 53)

4. Define concept properties , they are: properties, scope note or description. Data type property can be used to link a concept or an instance to a specific value. The data connected to the concept via this relationship can be a specific data type.

5. Fill in datasheet for transforming conceptual model to formal model. (see Table 16, 17, 18)

Guideline for Implementation

This guideline use AGROVOC Concept Server Workbench tool (AGROVOC CS WB, http://www.fao.org/aims/agrovoccs.jsp for implementation. Example that use throughout this guideline is base on an example knowledge extract from Thai rice production literature and capture from agricultural domain experts.

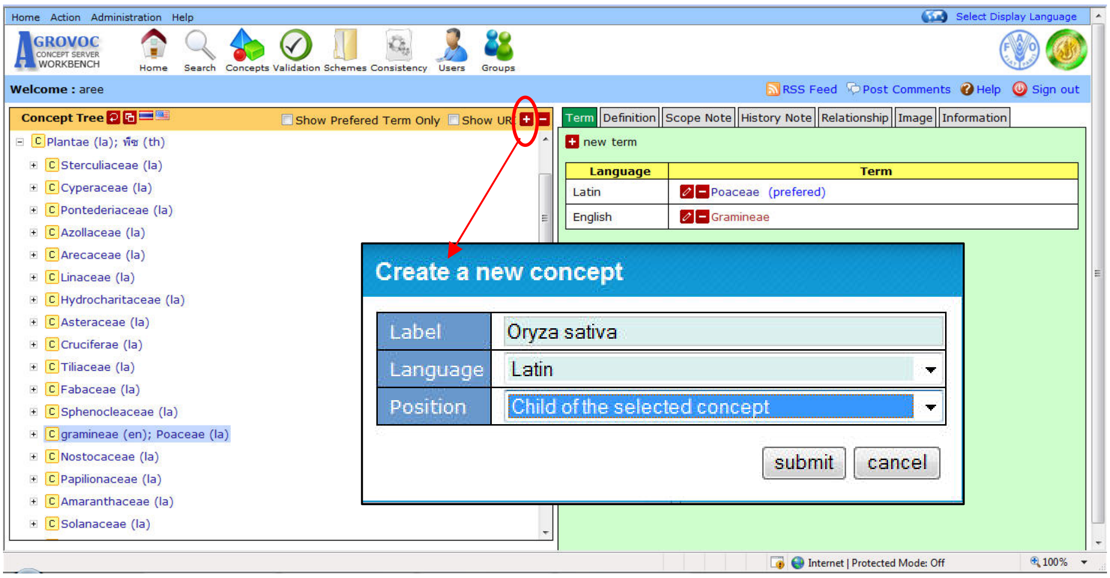
Step to use CS create concept and relation can conclude as follows:

1. Create a new concept

a. Enter the main label (term represented concept or preferred term) of the new concept in the text box.

b. Select the language for the main label of new concept.

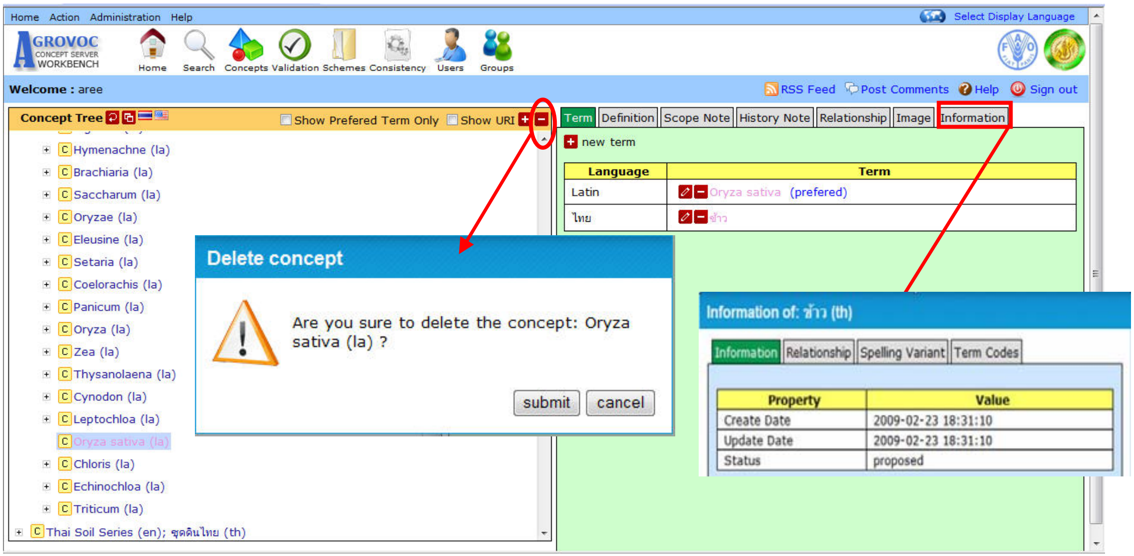
c. Select the position for the new concept. Define the position of the new concept as a child or mother concept in the hierarchy



2. View and Edit the selected concept

a. Click on the [info tab] to view the basic information of the selected concept. Property value show : created date, last updated date and status.

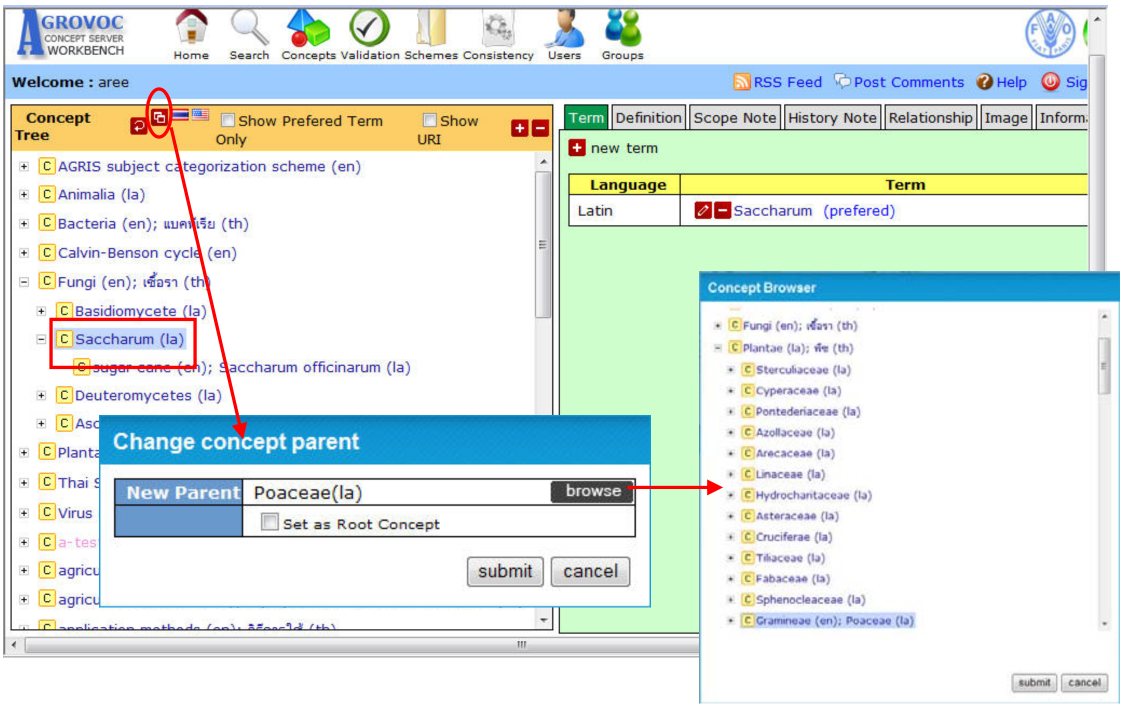
b. Click [delete] button to delete the selected concept and confirmed. The concept will stay in the system, with the status 'proposed deprecated' and will be assessed by an authorized validator.



3. Move concept by using tree editor
   a. Select the target concept which need moving to the other parent concept.

   b. Click [change concept parent icon], browse and select the new parent concept. Select the check box "Set as Root concept" in case want to move the target concept to be a root concept.

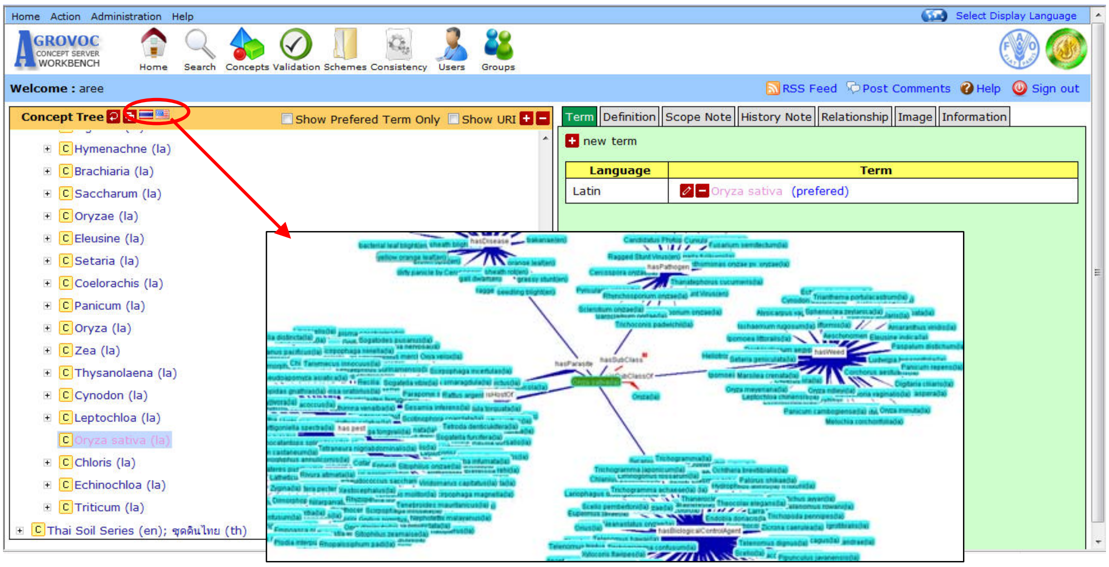
   c. Click [submit], then the target concept together with all child concept in the same hierarchy will be moved to the new parent concept.



4. Visualize concept by using Thai Agricultural Ontology Visualization Tools

   a. Select concept which want to display in graph view.

   b. Click [graph view in English] for English visualization or click [graph view in Thai] for display ontology with Thai lexicalization.



5. Create and Edit term

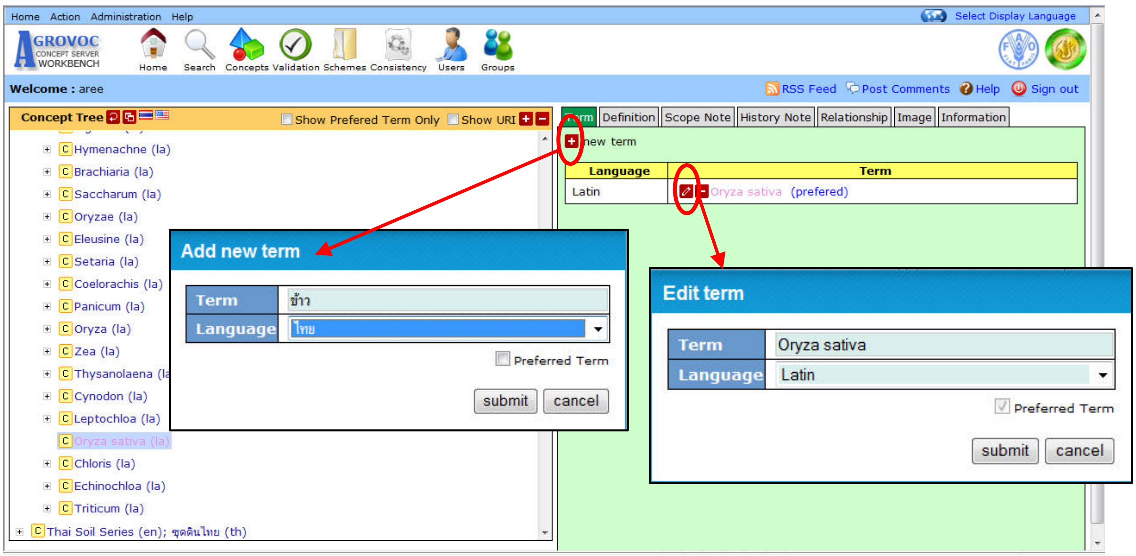
   a. Add synonym term (non-preferred term) of the main label (preferred term) and select language for the created synonym

   b. Click term tab to view all terms that are related to the selected concept.

   c. Click term to view detail of term. This will open the term module and provides detailed information about this term, they are: term information (created date, last updated date and status), term relation, spelling variant, term code.

   d. Click [edit icon] in front of each term to edit term.

   e. Click [delete icon] in front of each term to delete term.



6. Create and Edit concept definition

a. Add new definition to the concept. Define the selected concept definition by: Select language and add new definition in that language. Add URL and sources of that concept. The source of a definition contains, where this definition has been taken from. If it is a definition that's created by the user choose AGROVOC as source, since it has been created within the AGROVOC Concept Server

b. Edit concept definition by: View the definition of the selected concept. Click [edit] icon in the definition displayed area to edit that definition. Click [delete] icon in the definition displayed area to delete that definition.

7. Create and Edit concept scope note

a. Add the new scope note to the concept by click add new value of scope note

b. View the scope note of the selected concept.

c. Click [edit] icon in the value of scope note displayed area to edit that value.

d. Click [delete] icon in the value of scope note displayed area to delete that value

8. Create relationship between concepts (Associated relationship)

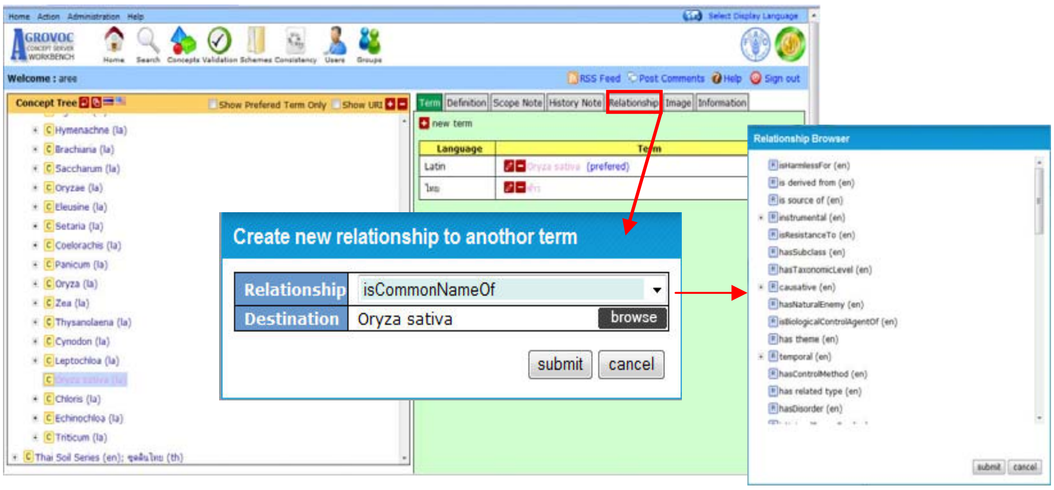
a. Select concept

b. Click [relationship tab] in part of concept to view the relationship between the selected concept to another concept

c. Click [new relationship] to add new relationship from the selected concept to another concept.

d. Click [edit icon] in front of each relationship to edit the relationship.

e. Click [delete icon] in front of each relationship to delete the relationship.



9. Create relationship between terms (relationship between synonym terms in the same concept)

a. Select term

b. Click [relationship tab] in part of term to view the relationship between this and other terms.

c. Click [new relationship] to add new relationship from the selected term to another term.

d. Click [edit icon] in front of each relationship to edit the relationship.

e. Click [delete icon] in front of each relationship to delete the relationship.

Maintenance is an important function in a life cycle of ontology development. The main activities of ontology maintenance are updating and correcting the implemented ontology. Maintenance can be done by manually, automatically or semi-automatically. The best approach is the joint process by domain experts and computer based upon the criteria. Major functions to make the ontology up-to-date are to maintain concepts, relationships and terms.

Appendix E Rice production and agricultural knowledge resources (These text books and websites were used in the ontology construction process, some of these literatures were refered in "Literature Cited")

Text book

1. Attanandana., T. and Prateep w. 2008. **Natural of Soil and Fertilizer**. Korn Creation Press, Bangkok.

2. Ampong-Nyarko, K. and S.K. De Datta, 1991. **A Handbook for Weed Control in Rice.** IRRI, Philippines. 113 p.

3. Beverly, R. B., J. G. Latimer, and D. A. Smittle. 1993. Preharvest physiological and cultural effects on postharvest quality, pp. 74-98 *In* R. L. Shewlelt, and S. E. Prussia, eds., **Postharvest Handling: A Systems Approach**. Academic Press, Inc.,San Diego.

4. Brickell, C.D., B.R. Baum, W.L.A. Hettersheid, A.C. Leslie, J. Mcneill, P. Trehane, F. Vrugtman and J.H. Wiersema. 2004. **International Code of Nomenclature for Cultivated Plants "Cultivated plant code".** 7th edition. IUBS Commission for the Nomenclature of Cultivated Plants.

5. Cavalier-Smith, T. (1998). **A Revised Six-kingdom System of Life**. Evolutionary Biology Programme, Canadian Institute for Advanced Research, Department of Botany, University of British Columbia, Vancouver, EC, Canada.

6. Chamswarng C. 1978. **Plant Diseases and Their Control. Department of Plant Pathology. Faculty of Agriculture, Kasetsart University.**

7. Charernsom., K. and Wiwat S. 1994. **Host list of natural enemies of insect pests in Thailand.** National Biological Control Research Center., Nakhonpathom.

8. Chettanachit,D.,Somkid D., Amara S.,Matee B.,Wichuda R. and Janya A. 1990. **The Technic of Prevention and Elimination on Brown Planthopper**. Rice Research Institute, Department of Agriculture.

9. Chettanachit,D., Nongrat N.,Parkpian A.,Wichit S.,Wichuda R.,Rasamee D.,Yoauvapa T.,Vanchai R. and Janya A. 2002. **The hand book of Rice Diseases.** Department of Agriculture.

10. Chongkid., B. 2004. **Rice and Production Technology**. Thammasat University Publishing, Bangkok.

11. De Datta, S.K. 1981. **Principles and Practices of Rice Production**. Wiley-interscience publication, New York.

12. Department of Agriculture. 1996. **Rice: Knowledge of Farmer.** Bureau of Rice Research and Development, Pathumthani

13. Department of Agriculture. 1999. **Good Agricultural Practice for Rice**. Office of Rice Research and Development, Phitsanulok.

14. Department of Agriculture. 2002. **Good Agricultural Practice for Irrigated Rice.** Department of Agriculture, Bangkok.

15. Department of Agriculture. 2002. **Evolution of Thai Rice Production**. Rice Department, Bangkok.

16. Department of Agriculture. 2004. **Charecteristics of Thai Native Cultivars Handbook. Department of Agriculture, Bangkok.**

17. Department of Agriculture. 2005**. Rice Handbook.** Department of Agriculture, Bangkok.

18. Department of Agricultural Extension. 2004. **Farmer handbook:Seed Production in Farm by GAP.** Department of Agricultural Extension.

19. Department of Agricultural Extension. n.d. **Guideline on Regulation Standard of Agricultural Extension Center and Rice Productions.** Deapartment of Agricultural Extension, Bangkok

20. Disthaporn., S. 1989. **Farmer Control Rice Diseases**. Thailand Plant Pathologist Society.

21. Dooren, Ir. Corn van. 2005. **Rice Value Chain Analysis "Each life starts with a little seed".** Report for IFAT/EFTA/FLO. 156 p.

22. Faculty of Agriculture, Kasetsart University.1995. **Training of Rice Diseases and Pest Control.** Kasetsart University**,** Research and Development Institute, Kamphaeng Saen Campus.

23. FAO. 1998. **AGRIS/CARIS Categorization Scheme**. FAO-AGRIS—3 Rev. 5.1 (En). Rome.

24. FAO. 1999. **AGROVOC Multilingual Agricultural Thesaurus** (English version). 4th ed., Rome.

25. Godfrey, L. D. . 2005. **UC Pest Management Guidelines** : Rice. UC IPM Online Program. Available Source: http://www.ipm.ucdavis.edu/PMG/ r682300411.html, February 9, 2008.

26. Greuter, W., J. Mcneill and F.R. Barrie, 2000**. Internation Code of Botanical Nomenclature (St. Louis Code).** Koeltz Scientific Books, Köningstein

27. Grist, D.H. 1983. **Rice**. 5th ed. Longman Inc., New York. 601 p.

28. Groth, D. and F. Lee. 2003. Rice diseases. pp. 413-436. *In* C.W. Smith John and R.H. Dilday, eds. **Rice Origin, History, Technology and Production**. Wiley & Sons, Inc., New Jersey.

29. Hayashi, T., S. Nakamura, P. Visarathanonth, J. Uraichuen and R. Kengkanpanich. 2004. **Stored Rice Insect Pests and Their Natural Enemies in Thailand**. JIRCAS International Agricultural Series No. 13. 79 p.

30. Holm, L.G., D.L. Plucknett, J.V.Pancho and J.P. Herberger. 1977. **The World's Worst Weeds**. The university press of Hawaii, Honolulu. 609 p.

31. International Committee on Taxonomy of Viruses. 1999. **Virus Taxonomy. Classification and Nomenclature of Viruses**. 7th Report of the International Committee on Taxonomy. Academic Press, New York, San Diego.

32. Kukhamau., A. 2004. Weed Management in Peddy Field, pp 101-107. In Phureewirochkul., W. Orapin, W. and Phannee, W. **Rice**. Department of Agriculture, Bangkok.

33. Kunnuch., L. 2006. **Thai Rice Production Auditing System: Irrigated Rice.** Rice Department, Bangkok.

34. Kunnuch., L. 2006. **Thai Rice Production Auditing System: Rainfed Lowland Rice.** Rice Department, Bangkok**.**

35. Luh, B. S. 1991. **Rice**. Van Nostrand Reinhold, New York.

36. Maneechod., J. 2005. **Problems and Managements of Weedy Rice**. Department of Agriculture, Bangkok.

37. Mekwatanakarn., P., 2005. **Rice Blast Disease:The Procedure to Development Rice for Resistances to Blast.** Department of Agriculture.

38. Luh, B.S. 2004. **Rice**. Van Nostrand Reinhold, New York.

39. Ministry of Agriculture and Cooperatives. 2004. **Strategics of Rice 2004 - 2008.** Ministry of Agriculture and Cooperatives, Bangkok.

40. Ministry of Comerce Thailand. 1997. **Thai Rice Standard 1997**. Ministry of Comerce Thailand, Bangkok.

41. Molle., F. and Thippawal S. 2003. **Thailand's Rice Bowl : Perspectives on Agricultural and Social Change in the Chao Phraya Delta.** White Lotus,Bangkok

42. Mongkol., C. 1993. **Rice**. Department of Education, Bangkok.

43. Mungprasert., N.,Aong-ard.,V., Laddawan. K. and Jintana H. 2004. **The Chemical Fertilizer Application of Rice Following Soil Analysis.** Rice Research Institute, Bangkok.

44. National Bureau Agricultural Commodity and Food Standard. 2003. **Agricultural Commodity and Food Standard TACFS 4400-2003 Good Agricultural Practice for Thai Hom Mali Rice**. National Bureau Agricultural Commodity and Food Standard, Bangkok.

45. National Research Council of Thailand, Department of Agriculture and Thailand Association for Plant Breeding and Propagation. 1997. **Standards and Qualities of Jasmine Rice.** n.p.

46. National Science and Technology Development Agency and National Center for Genetic Engineering and Biotechnology. 2003. **Science and Technology with Thai Rice.** National Science and Technology Development Agency, Bangkok

47. Nabheerong, N. and L. Wathanakul, 1971. **Rice Diseases and Pests Thailand**. Rice Protection Research Centre, Rice Department, Thailand.

48. Office of the National Culture Commission. 1993. **Introductory Guide to the Thai Life Permanent Exhibition Rice and Thai Ways of Life.** The Office of the National Culture Commission, Bangkok.

49. Osotsapar, Y. 2003. **Plant Nutrient**. Kasetsart University Publishing, Bangkok.

50. Panichpat., V. 2003. **Improvement of Rice and Rice Seed Multiplication.** Rice Research Institute, Rice Department, Bangkok.

51. Patirupanusara., T., 2003. **The handbook of Control Rice Diseases.** Department of Agriculture.

52. Pitoonjareanlab., J., Tasana L.and Sudsakorn Y. 2002. **Good Cultivar Rice.** Department of Agricultural Extension, Bangkok.

53. Plant pathology and Microbiology Division. 2002. **Diseases of Field Crops Handbook.** Department of Agriculture.

54. Rakvidhyasastra., V., 2003. **Introductory Mycology.** Department of Plant Pathology. Faculty of Agriculture, Kasetsart University.

55. Rice Department. 2000. **Good rice quality production**. Office of Rice Production, Rice Department, Ministry of Agriculture and Cooperatives, Bangkok

56. Rice Department. 2008. **Knowledge Bank : Technology of Rice Production.** Rice Department, Bangkok.

57. Saburi, M. and T. Suzuki, T. n.d.. **Rice and Rice Pest Control**. Shell International Chemical Company. London. 43 p.

58. Shuvisitkul., E. 2001. **Technology of Rice Production.** Rice Research Institute, Bangkok.

59. Siamwalla., A.1979. **An Economsic of Rice in Thailand.** Thammasat University Publishing,Bangkok.

60. Sitiswang., P. 1981. **Fundamentals of Rice (Rice physiology from Pictures).** Department of Agriculture. Bangkok.

61. Smitinand, T. 2001. **Thai plant names**. Revised edition. The Forest Herbarium, Royal Forest Department.

62. Srichuwong., S. and Nitaya S. 1984. **Highland Economic Crop Diseases**. Department of Plant Pathology. Faculty of Agriculture, Chiangmai University.

63. Street, J.E. and P.K. Bollich. 2003. Rice Production. pp. 271-296 *In* C.W. Smith John and R.H. Dilday, eds. **Rice Origin, History, Technology and Production**. Wiley & Sons, Inc., New Jersey.

64. Vergara, B. S. 1970. **Rice Production Manual : Plant Growth and Development**. University of Philippines, Laguna.

65. Werapad., W., 1983. **Knownledge of Rice.** Thai Watana Panich Press Co., Ltd., Bangkok**.**

Website

1. Bioversity International. 2008. **CWR Global Portal**. Crop Wild Relatives Global Portal. Available Source: http://www.cropwildrelatives.org/, May 25, 2008.

2. Charoensom, K. 2004. **Insect of Thailand**. Thai agricultural knowledge network. Available Source: http://pikul.lib.ku.ac.th/insect/, June 25, 2007

3. Department of Agriculture. 2008. **Rice disease**. Disease group. Available Source: http://plantpro.doae.go.th/diseasegroup, February 12, 2008.

4. Department of Agriculture Extension. 2008. **Plant clinic**. Plant clinic. Available Source: http://agriqua.doae.go.th/plantclinic/clinic/plant/, January 15, 2008.

5. FAO. 2008. **AGROVOC Concept Server**. Agricultural Information Management Standards. Available Source: http://www.fao.org/aims/cs_relationships.htm, June 25, 2008.

6. FAO. 2008. **AGROVOC Thesaurus**. Available Source: http://www.fao.org/agrovoc, January 12, 2008.

7. International Rice Research Institute. 2008. **Rice knowledge bank**. Cereal knowledge bank. Available Source: http://www.knowledgebank.irri.org/Rice/ Ricedefault.htm, February 9, 2008.

8. Office of Agricultural Economics. 2008. Rice. **Rice Production and Trade**. Available Source: http://www.oae.go.th/, January 18, 2008.

9. Land Development Department. 2008. **Group of Soil Series.** Soil group database. Available Source: http://www.ldd.go.th/ldd/, January 12, 2008.

10. National Institute of Agrobiological Sciences. 2005. **Rice Ontology (RO)**. What is Rice Ontology? Available Source: http://www.ro.dna.affrc.go.jp/, January 23. 2008.

11. Plant Ontology Consortium. 2009. **Plant Ontology (PO)**. Plant Ontology Consortium Web site. Available Source: http://www.plantontology.org, January 28, 2009.

12. Rice Department. 2008. **Thai Rice Knowledge Bank**. Rice Thailand. Available Source: http://www.ricethailand.go.th/rkb/index.html, May 3, 2008.

13. RRDI. 1996. **Insecticide Recommendations for Rice Pest Control** . Major insect pests of rice . Available Source: http://www.agridept.gov.lk/Techinformations/Rice/Ri_pes.htm#insecticide, December 18,2007.

14. Scientific Agriculture Laboratory. 2008. **Fungicides**.. Available Source: http://www.fertilizersandpesticides.com/fungicides.html, January 15, 2008.

15. Thai National AGRIS Centre. 2004. **Thai Agriculture Thesaurus**. Thai AGROVOC. Available Source: http://pikul.lib.ku.ac.th, January 12, 2008.

16. Thai National AGRIS Centre. 2008. **Thai Rice Research Database**. Available Source: http://pikul.lib.ku.ac.th/rice1, January 12, 2008.

17. USDA. 2006. **Keys to Soil Taxonomy**. 10th edition. United States Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. Available Sources : http://soils.usda.gov/technical/classification/taxonomy/, January 15, 2008.

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