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An Ontology-based Supporting System for Integrated Farming towards a Concept of the Sufficiency Economy

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บทคัดย่อ

ทฤษฎีเศษฐกิจพอเพียงเป็นแนวทางปฏิบัติที่ได้รับพระราชทานมาสู่สังคมไทย โดยได้มีการนำไปประยุกต์ใช้ในแนวทางด้านการเกษตร และเรียกกันว่า “แนวทางเกษตรทฤษฎีใหม่” ทฤษฎีดังกล่าวได้กล่าวถึงหลักการทางด้านการเกษตรที่ถือหลักการและแนวคิดเรื่องการพึ่งพาตนเองและความยั่งยืนของทรัพยากรภายในพื้นที่เพาะปลูกโดยเน้นการบูรณาการส่วนต่าง ๆ งานชิ้นนี้ จึงนำทฤษฎีดังกล่าวมาแปลงเป็นออนโทโลยีเพื่อจัดเก็บองค์ความรู้ของทฤษฎีใหม่ และนำมาใช้เป็นฐานความรู้ให้กับการวางแผนการทำการเกษตรตามสภาพแวดล้อมและความต้องการของเกษตรกรแต่ละราย โดยการตัดสิดใจได้ใช้กลไกอนุมานตามหลักเหตุผลและข้อเท็จจริงร่วมกับออนโทโลยีมาพัฒนาเป็นระบบให้คำแนะนำสำหรับกระบวนการขั้นตอนการทำการเกษตรแบบทฤษฎีเศษฐกิจพอเพียง ระบบนี้ได้ออกแบบมาให้คำแนะนำการทำการเกษตรในแต่ละส่วน รวมทั้งการจัดการเพื่อให้เกิดการพึ่งพาตนเองและความยั่งยืนของทรัพยากร จากการทดลอง ผู้วิจัยพบว่าคำแนะนำได้รับการประเมินความถูกต้องร้อยละ 94.75 เมื่อเปรียบเทียบกับความคิดเห็นของผู้เชี่ยวชาญด้านการเกษตร

ABSTRACT

Sufficiency Economy has been a guideline in several aspects in Thai culture and has been applied to agriculture theory called The New Agriculture Theory. Its core concept is to maintain self-reliant and sustainable resources within one’s own farmland by integrating farming parts. To promote the theory, we propose the first framework to support farmers who are interesting in exploiting the theory by providing a suggestion on how to be self-reliant and sustainable farm. Ontologies are designed to capture domain knowledge of the theory along with inference rules for making a logical suggestion of farming process. An inference engine is utilized to suggest a logical setting plan according to environment and need of individual farmer. Not only a self-reliant and sustainable procedure in farm setting is suggested, but the framework also provides an optimizing selection for each agriculture part. By testing, we found that the recommendations are accurate for 94.75% when they are compared with experts' opinion.

Keywords: Integrated farming, Ontology, Inference engine, Recommendation system, Sufficiency economy

1. INTRODUCTION

In agriculture, management is an important factor to determine successful business (Muhammad et al., 2004). Using available resources to optimize the production is a heart of this era of agriculture. Hence, the term integrated farming, a combination of several crop types to enhance their benefit (Boller et al., 2004)(The European Initiative for Sustainable Development in Agriculture, 2012) has been proposed and proved useful in agriculture production. In Thailand, a *Philosophy of Sufficiency Economy* (Chariyamakarn et al., 2015) by King Bhumibol Adulyadej has been a pillar of living concept for Thai citizens since it was mentioned. This concept has been applied to several fields including agriculture. His majesty specifically developed this concept into the new agriculture theory: *Integrated and Sustainable Agricultural System* (Office of the National Economic and Social Development Board, 2007)(The Office of the Royal Development Projects Board, 2016) in order to create more practical and systematical methods for farmers to follow as a concrete example of the application of the *Philosophy of Sufficiency Economy.*

Surprisingly, the new agriculture theory conforms to the concept of integrated farming as they both focus on sustaining in the production process and relevance within the combination. Since then, the new agriculture theory has become the suggestive method in agriculture in Thailand, and it is greatly supported and encouraged to farming by the government (Office of the National Economic and Social Development Board, 2016). Roughly, the method is to suggest that a farm is separated into four parts as rice cultivation part, fruit cultivation part, animal husbandry part and pond part as shown in Figure 1 (The details of the new agriculture theory are described in Section II.)

Although, the concept has been made into a practical method, the method is still difficult to follow for farmers. Since individual farmers have their different settings and aims, applying the concept will be varied for each individual and requires a well-trained expert to suggest insight details. Hence, the centers to provide consulting were set up throughout the country. Unfortunately, the existing number is apparently insufficient for incoming requests.

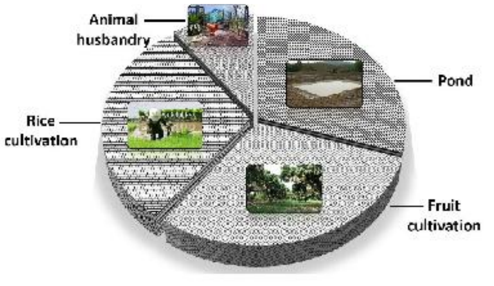

Figure 1 Recommedned land parts based on The New Theory

In this work, our goal is to create the first and novel computer based system to help providing a suggestion to farmers who are interesting to apply the concept of the new agriculture theory. The system will rationally provide the detail in setting up the farm as well as the suggestion of appropriate options based on individuals' setting and requirement. Ontology (Natalya et al., 2001) will be exploited as domain knowledge representation since the domain knowledge of each part in the new theory is logically linked to one another.

2. BACKGROUND

2.1 Integrated farming

Integrated Farming is defined as a farming system where high quality food, feed, fiber and renewable energy are produced by using resources such as soil, water, air and nature as well as regulating factors to farm sustainably and with as little polluting inputs as possible (Boller et al., 2004). The main concept of the integrated farming is about a management approach focusing on a farm in a whole as cross-linked unit. By aiming to balance and adapt to demand of the crops and livestock, the fundamental role and function of agro-ecosystems on nutrient cycle are considered.

Integrated farming in Europe has been suggested and supported by European Initiative for Sustainable Development in Agriculture (EISA). They published an integrated farming framework) (The European Initiative for Sustainable Development in Agriculture, 2012) in 2012. The framework is to respond to the change in a demanding of economic, environmental, social and welfare issues as well as the fundamentals of sustainable agriculture. In fact, the framework mentions mainly on parameters famers need to consider in the farming process and management. There is yet no tool supporting the processes.

2.2 The New Theory: Integrated and Sustainable Agricultural System

The New Theory: Integrated and Sustainable Agricultural System is the application of the *Philosophy of Sufficiency Economy* to the agricultural sector. His Majesty King Bhumibol initiated this theory to help Thai farmers who suffer from the impacts of economic crisis, natural disasters and other unproductive natural conditions (Office of the National Economic and Social Development Board, 2007). Though the concepts are similar to the integrated farming, the focus of The New Theory is to be self-reliant and survive through unexpected circumstance. Hence, the major focus of the theory is for farmers to make sustainable cycle by optimizing the use of recyclable resources of their own and surrounding environment.

His Majesty developed the New Theory as a system of integrated and sustainable agriculture. The main concept is to use and recycle resources effectively such as water resource development and conservation and soil rehabilitation and conservation. The aim is to optimize farmland with a sense of reducing unnecessary cost by recycling waste within the agriculture process (Office of the National Economic and Social Development Board, 2007). In tune with the Philosophy of Sufficiency Economy, His Majesty introduced the concrete and viable approach to manage farmland. Efficient water management was also developed to ensure year-around farming. The land is divided into four parts (illustrated in Figure 1) as follows.

The first 30% is designated for a pond to store rainwater during the rainy season while during the dry season it serves to supply water to grow crops and raise aquatic animals and plants.

The second 30% is set aside for rice cultivation during the rainy season for the family's daily consumption throughout the year to cut down on expenses and allow the farmers to be self-reliant.

The third 30% is used for growing fruit and perennial trees, vegetables, field crops and herbs for daily consumption. The recommended fruits are, for example, mango, coconut, tamarind, and jackfruit.

The last 10% is set aside for accommodation, animal husbandry, and other required structures.

Based on the abovementioned parts, the reason behind it is that rice is the staple food consumed by every Thai household. It is estimated that each family must grow rice on approximately 5 rai (8,000 square meters) of land to have enough rice for year-round consumption without having to extraneously buy it, thus enabling them to be self-reliant. Moreover, there must be a sufficient reserve of water to be used for cultivation in the dry season or during the dry spell. Therefore, it is necessary to set aside a part of the land to dig a pond on the principle that there must be enough water for cultivation the whole year round. According to His Majesty the King's calculation, to cultivate 1 rai (1,600 square meters) of land requires about 1,000 cubic meters of water. So, for growing 5 rai of rice and 5 rai of field crops or fruit trees (10 rai in all) there must be about 10,000 cubic meters of water per year.

The New Theory has been promoted by Thai government and becomes a suggestive method in Thai agriculture. For the farmers' point of view, the theroy gains their poppularity and trust as a reliable framework to follow. Several farms have applied the theroy and show a good result. Some were selected as prototypical farms for other farmers to follow. However, there are many farmers who want to apply the theory, but the theroy is difficult to understand as the setting and need are different for each individual. They need more pratical methods and adaptable suggestions specific to their information.

3. SYSTEM IMPLEMENTATION

In this work, we propose a framework of a supporting system for suggesting agriculture process based on The New Theory: Integrated and Sustainable Agricultural System. The framework will provide a detail on how to do a sustainable agriculture and a suggestion to maximize outcomes of each farm part based on best practice documents by recent research studies. For the purposes, we designed the expert system based framework as illustrated in Figure 2 Inputs are information defined by farmers. An ontology representation (Natalya et al., 2001) is selected to represent knowledge of the agricultures and The New Agriculture Theory. An inference engine along with rules is exploited to make a logical decision for recommending the optimized setting for each farmer. Outputs of the framework are a recommendation to set up the farmland and a detail of each cultivation part, such as a selection of varieties of plant and suggesting planting process.

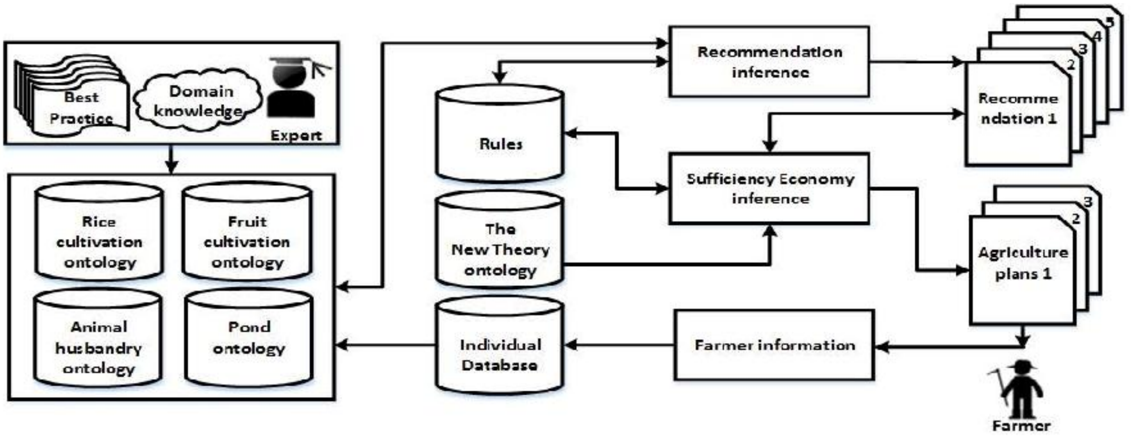

Figure 2 Recommended land parts based on The New Theory

3.1 Ontology design

This part describes our ontologies used in the framework. There are two ontologies: agriculture ontology and The New Theory ontology. The former is a representation of domain knowledge of agriculture to suggest an optimizing setting according to farmers' information. This includes Rice cultivation, fruit cultivation, livestock, and pond management. Since fruit and livestock can be several, we selected the most common candidate as mango and hen, respectively, to be prototypically represented in the current ontology. The latter is an ontology for providing knowledge about The New Theory. It consists of knowledge to manage parts of farmland to gain sustainability and self-reliance. This includes the method to manage resources to suit the land, to recycle wastes of agriculture into an input of another part and to position each part to save the cost and unnecessary energy. The both ontologies were designed as a heavyweight ontology (Mizoguchi et al., 2003) so they can provide the knowledge in logical details for recommender.

Table 1 Details of main branches of agriculture ontology

Class Name	Sub Classes	Properties
Farmer	-	has Location* has Tilapia Pond* has Budget (integer) ... has Instrument* has Irrigation (boolean)
Fertilizer	Chemical_fertilizer Manure	has nitrogen value (float) has phosphorus value (float) has potassium value (float) has price fertilizer (integer)
Soil	Clay Loam ... Sand Silty Clay	has Nutrition* has Ph value (float) ... has Soil Surface* has drainage rate (float)
Rice Cultivation	-	has Rice Seed* has Fertilizer Program* ... has Water Program*
Rice Seed	Non glutinous rice -- Khao Dawk Mali 105 -- Phitsanulok 2 Glutinous rice -- RD2 -- Niaw San-pah-tawng	has varieties name (string) has height rice (integer) ... has Disease Invulnerability* has Pest Invulnerability*
Fertilizer Program	Fertilizer_Spout Period ... Fertilizer_Rippening Period	has Fertilize* has amount (float)
Livestock	Hen Poultry ... Inland Fishery	has Animal Food* has Habitat* has Lightning* has Temperature (float)
Water Management	Water Storage Water Usage	has volume (float) has Water* ... has Storage*

The agriculture ontology consists of fifteen main branches exemplified in Table 1 The rice cultivation ontology is reused from "A Framework of Ontology based Recommendation for Farmer Centered Rice Production" (Chariyamakarn et al., 2015) as the base of our ontology since it was carefully designed to suggest the best solutions based on individual farmers in which the same to the purpose of this work. Then, extension of other agriculture parts is designed according to its structure based on the best practices relative to the agriculture domains provided by Thai government and responsible organizations. The best practices used in this work are soil guide (Attanandana, 2007), rice cultivation (Department of AgricultureMinistry of agriculture and cooperatives, 2015) and mango cultivation (Department of Agricuture Extension, 2001). For this ontology, the current scope of the agriculture is limited to rice cultivation based on rice variety found and growth in Thailand, mango cultivation (a representative of fruit cultivation), and hen farming a representative of livestock).

From Table 1 (in Table, * denotes object property and data type of data property is given in parenthesis), class *Fertilizer* has two subclass and has four properties. Its subclass is Chemical *Fertilizer* and *Manure.* The properties of this class are all data property inherited to its subclasses. They are *nitrogen value*, *phosphorous value, potassium value* and price. Another example to be explained is *Rice Cultivation.* It does not have a subclass but has several properties. This class contains object properties such as *has_Rice_Seed* that has a class constrain to class *Rice Seed* (also shown in Table 1).

The New Theory Ontology, unlike the agriculture ontology to represent a proper setting for agriculture, contains knowledge of resource cycling for sustainability of each part in farmland to optimize the use of recyclable things and surrounding environment to the fullest. It consists of nine classes where the main class is *The New Agriculture Theory*. Details of The New Theory Ontology are exemplified in Table 2

Table 2 Details of the new Agriculture Theory Ontology

Class Name	Sub Classes	Properties
The New Agriculture Theory	-	has Cultivation Part* has sustainability rate (integer) has Reusing Resource*
Reusing Resources	Reusing Waste Reusing Energy	has Recycling Resource* has replacement amount (integer)
Cultivation Part	Rice Field Fruit Field Pond Livestock	has Land Position* ... has Cultivation Input* has Cultivation Output*
Cultivation Output	Livestock Output -- Animal Dung -- Leftover Food ... Rice Output -- Rice Husk ... -- Straw	has amount (float)
Recycling Resource	-	has Cultivation Input* has Cultivation Output*

With ontologies, the classes are mapped to users' information and related data for instantiation using OAM framework (Buranarach et al.,2016).

3.2 Inference rules

To obtain two different answers, rules to produce recommendation are split into two sets. The first set is to recommend the best solutions of choices based on farms' setting and need. The second set is for a method to gain sustainable setting according to The New Agriculture Theory mentioned in Section 2.2. The form of the production rule is divided into two components in a form as follow:

IF <condition(s)> THEN <action>

When the conditions are all met, the action will be executed. The condition part is matched to incoming farmer information while the action part is a list of all possible solutions. In this work, production rules are matched in a forward chaining so the output of the first rule will be considered in the later rules. The examples of the production rule in this work are given in Figure 3.

IF <FIELD is in AREA has PEST PREVALENCE = ***Brown Plant Hopper***> AND < FIELD is in AREA has DISEASE PREVALENCE = ***Brown Spot***>

THEN <RICE SEED = <RICE SEED has Pest Invulnerability = ***Brown Plant Hopper***> AND <RICE SEED has Disease Invulnerability = ***Brown Spot***>>

IF<RICE SEED has Pest Invulnerability = ***Brown Plant Hopper***> AND <RICE SEED has Disease Invulnerability = ***Brown Spot***>

THEN <RICE SEED = RD4> AND <RICE SEED = RD6>

IF <FARMER has Preferred RICE SEED = ***RD1***>AND <FIELD is in AREA has DISEASE PREVALENCE = ***Bacterial Leaf Blight***>

THEN <FARMER *prepare*<INSTRUMENT = ***Streptomycin***> AND <INSTRUMENT = ***Oxytetracycline***> AND {*suggest preventing Fertilizer with high* ***Nitrogen***}

IF <CULTIVATION_INPUT = ***fertilizer***> AND <FERTILIZER = ***MANURE***>

THEN <FERTILIZER = ***ANIMAL_DUNG***>

Figure 3 Examples of Inference Rules

3.3 Instatiation and inference engine

In this work, two databases are used. The first one is farmer database that is to store information of farmers including a location, a size of a farmland, available resources and tools, etc. Another one is an environment database to keep information related to an agriculture area in Thailand such as soil type, temperature, humidity, prevalent disease and pest. Both databases are mapped to ontology for the benefit of logical relation among information.

This work applies Ontology Application Management (OAM) framework (Buranarach et al., 2016) for the core of the engine to map data to ontology class and to inference the results. OAM framework provides user interface to easily map database schema to the designed ontologies. Our input data are personal information from famers in which to be stored into the farmer database. The user data, such as location of the farmland, can tell several details but they need to consult the environment database. For example, farmland location can inform the related information such as soil type, temperature, humidity, prevalent disease and pest. This information can help the rules to generate a recommendation more effectively based on facts.

Table 3 Some parts of information from farmers' setting

Case No.	Location	Total Farm Size (km^2)	Rice	Rice Area Size (km^2)	Rice Seed Variety	Mango	Mango Area Size (km^2)	Selected Mango Variety	Hen Poultry	Amount of Hen	Water Source
1	Nakhon Ratchasima	30	Yes	16	RD29	Yes	8	Maha Chanok	Yes	30	Pond
2	Nonthaburi	85	Yes	70.4	Chai Nat1	Yes	11.2	Falan	No	-	Pond
3	Chiang Rai	32	Yes	24	Phitsanulok2	Yes	4.8	Nam Dok Mai	Yes	55	Irrigation
4	Sakon nakhon	20	Yes	14.4	Chai Nat 80	Yes	3.2	Chok Anan	Yes	100	Pond
5	Bangkok	20	Yes	19.2	Pathum Thani1	No	-	-	Yes	45	Rain & Irrigation

To make a solid recommendation, inference engine is needed. Rule generator (Buranarach et al., 2015) from OAM allows user to create rules using decision table in a spreadsheet format without understanding complex syntax of an inference rule. Hence, in this work, rules as shown in Table 3 are created in spreadsheet format and applied to inference engine via OAM. This also provides easiness for experts to correct and approve the designed rules.

4. EXPERIMENT AND DISCUSSION

We set up an experiment to test usefulness of the framework. Since the recommending result varies from the input cases, we collected a setting of different farms as testing cases. We selected five cases since the number of farms following the theory currently is very few. The selected farms are prototype farms according to The New Agriculture Theory. The cases are given in Table 3.

For these five cases, we asked experts of the theory to give a suggestion on the setting. The suggestion of the experts are to agree or disagree with the setting from farmers and if disagree, what part and how it is to be corrected according to the concept of the theory. Since the setting features are different for each case, the number of answers to be given is different. The answers of the experts will be compared with the results generated from the proposed framework. In case that the answer of expert matches to the generated recommendation, it will be counted as accurate, and vice versa. For the value type answer that is mentioned in range, a generated value recommendation in the range will positively be counted. The accuracy results are summarized in Table 4.

From the results, we found that the recommendations of the proposed framework were mostly matched to those from the human experts for 94.75%. Most of the *Agree* with farmers' setting were correctly matched while most of unmatched answers were from the different suggestions in *Disagree* term. Some of the unmatched results came from the difference in correcting suggestions. For more understanding, let us explain some of the cases in detail.

Table 4 Accuracy result by comparing answer and generated recommendation

Case No.	Matching Answers		Accuracy
	Agree	Disagree	
1	10/11	3/4	86.67%
2	9/9	5/5	100%
3	14/14	3/3	100%
4	13/13	2/3	93.75%
5	8/8	6/7	93.33%
	Avg.		94.75%

For Case No.1, there are fifteen points to mention in the setting. There are eleven points that experts' opinion agrees with the setting while the generated recommendation agrees with ten points. The difference in this suggestion is that experts agreed with rice seed selection for *RD29* but the framework was against this seed and recommended another seed, *Pathumthani1*. In fact, both *RD29* and *Pathumthani1* mostly share common attributes and match the terrain and time setting perfectly. However, from the database, there was information that there was a report of prevalence of a pest called *whitebacked planthopper* in Nakhon Ratchasima area (a province in North-eastern region of Thailand). Hence, the generated recommendation attempted to avoid the pest and suggested the seed that immunes to the pest. For this case, experts gave an opinion that this pest is a minor threat to rice cultivation and can easily be controlled with natural based insecticide and farm management. For discussion of this subject, since the proposed system does not know in which information is minor or major threat, it treats all criteria equally and cannot make decision as flexible as human experts can. To overcome this issue, a weight value of importance should be given to rules for more likely to imitate human inference.

For *Disagree* terms, we found several different points in comparing human and machine recommendation. Since several settings are improper according to the theory, *Disagree* terms were given to the setting from both generated recommendation and experts. However, the suggestions on correction from both were different. In details, we found that recycling resource process was the cause of the difference. The framework consistently gave a suggestion of using bran (waste in milling rice process) to feed a hen while expert suggests it on feeding fish kept in a pond. These two options are both acceptable from a point of view in The New Agriculture Theory. However, from personal discussion with experts, they revealed that, in only case of having a hen barn over a fishpond, feeding hens with bran would obtain better recycling since leftover bran should fall into the pond and produce less waste in the process.

In a summary, the results of the framework were mostly matched to experts' suggestion. There are some different answers, but they were acceptable. However, experts gave a comment that more fruit and livestock types should be added to meet more users' variation in setting.

5. CONCLUSION AND FUTURE WORK

This paper presents a framework for supporting farmers who want to participate in The New Agriculture Theory. It will provide a recommendation on how to set up a farmland based on their environment and setting. The recommendation is not only a suggestion for selection a suitable seed variety or a proper farming procedure, but it also gives a setting plan to recycle resources within agriculture process to maximize a sustainable farming. Ontologies and rules in the framework were carefully designed to use with an inference engine powered by OAM for logical and empirical decision-making. By experiment results, the framework was proved to be useful and reliable for obtaining 94.75% accuracy comparing to actual cases of prototype farmland exploiting The New Agriculture Theory.

To improve our framework, we plan to extend the agriculture ontology to cover more kind of fruits and livestock. We also plan to find a calculable measurement to determine a rate for sustainability. The measurement will be used to score the capability for self-reliant and sustainable process. It will help in determining the more suitable and maximizing method in case that there are several methods for making sustainable agriculture. Lastly, we plan to include an optimizing model for maximize the farming output and sustainability in farming for suggesting the best individual plan according to the Sufficiency Economy concept.

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