Towards Ontology-based Expert System Development and Evaluation for Rice Disease Identification and Control Recommendation

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Abstract. Various knowledge related to rice cultivation has been widely published on the web. Conventionally, this knowledge is manually studied by end-users for rice diseases and pests identification to prevent production losses. Despite their benefits, the knowledge has not yet been encoded in a machine-processable form. We improve this gap by turning the unstructured or semi-structured knowledge of rice diseases and their controls into the structured ones by using ontologies and semantic technologies. We externalize knowledge from existing reliable sources only. As a result, the developed ontologies offer axioms that describe abnormal appearances in rice diseases (and insects) and their corresponding controls. We also develop an expert system called RiceMan based on our ontologies to support technical and non-technical users for the identification of diseases and insects from their observed abnormalities. We also introduce a composition service to aggregate users’ observation data with others for realizing spreadable diseases and controls. This composition mechanism, together with ontology reasoning, lies at the heart of our methodology. Finally, we evaluate our methodology practically with four groups of stakeholders in Thailand: senior agronomists, junior agronomists, agricultural students, and ontology specialists. Both ontologies and the RiceMan application are evaluated to ensure their usefulness and usability in various aspects. Our experimental results show that ontology reasoning is a promising approach for this domain problem.

Keywords: Ontology-based Expert System, Semantic-based Application, Ontology Evaluation, Rice Disease Ontology

1. Introduction

Rice is an essential crop for most of the world’s population. A critical challenge in cultivation is to handle rice diseases and paddy insects that can affect the plants. Rice plants can be damaged from both abiotic factors (i.e., the environment and nutrient factors such as drought, cold, and a phosphorus deficiency) and biotic factors (i.e., animals, bacteria, fungi, viruses, and phytoplasma). When they are damaged, different kinds of observable abnormal characteristics can occur. In real-life situations, these infections are handled by farmers in manual and ad-hoc manners. For instance, they may reason from their knowledge or consult with experts, such as experienced farmers and agronomists. However, this is not an efficient method since different experts can have diverse skills and background knowledge. Indeed, knowledge should be refined and be externalized to every farmer so that he/she can recognize diseases from abnormal characteristics and pick up treatments appropriately.

Existing knowledge related to rice plant cultivation has been widely published on the web. On the
one hand, this information enables rice farmers to enhance their background knowledge and adapt it to their circumstances. For instance, they can search through websites and seek desirable knowledge for identifying why a disease occurs and how to handle it properly. On the other hand, farmers need to consume vast and diverse sources to find the desired knowledge. Furthermore, such published knowledge usually is not encoded in a machine-processable form. Hence, computing resources, including expert systems, cannot utilize it well. Such problem motivates us to improve the gap by constructing structured knowledge with well-defined semantics and developing an expert system for rice disease identification and treatment recommendation to support a user’s decision. At a high-level, our motivations amount to investigations of the design and modeling of rice disease ontologies and their adoption to practical applications at rice fields. Our research questions (RQs) are as follows:

- RQ1: How can rice disease and paddy insect knowledge-base be modeled from unstructured resources?
- RQ2: How rice disease knowledge-base can be applied in practice by users?
- RQ3: Is the designed expert system appropriate to use by different types of stakeholders?

In this work, we focus on an application of ontologies that can support users’ decisions for examining rice plant problems. It is an extended study of our proceeding works [1, 2]. Specifically, the idea of modeling rice disease knowledge as an ontology for disease detection was first proposed in [1]; however, a few cases were presented to show the feasibility. The idea was further investigated in [2], in which the first versions of RiceDO and TreatO were developed to cover 22 rice diseases and paddy insects. Additionally, a semantic-based framework for supporting the rice disease and treatment identification was preliminarily outlined. In this paper, we extend and implement the framework called RiceMan, and then perform a thorough evaluation. The contributions of this work are threefold:

1. Existing ontologies are investigated, remodeled, revised, and evaluated practically from the viewpoints of four groups of stakeholders;
2. An expert system called RiceMan is designed and developed for rice disease identification and control recommendation;
3. We evaluate the benefits of applying a knowledge-based system in agriculture.

We immensely discuss these points in Sections 3 and 4. The related works, extensive empirical evaluation, and the conclusion are discussed in Section 2, Section 5, and Section 6, respectively.

2. Related Works

This section reviews notable recent farming knowledge and expert systems in an agricultural domain.

2.1. Existing Ontologies

Table 1 summarizes and compares various existing ontologies in the agriculture domain w.r.t. their main focus and covered knowledge.

AGROVOC [3] is a well-known vocabulary covering many areas such as food, nutrition, agriculture, fisheries, forestry, and the environment. Despite its huge size, the presented vocabulary is not applicable for rice disease identification and control recommendation due to the lack of specific rice plant axioms.

Agriculture Activity Ontology (AAO) [4] is a part of the Common Agricultural Vocabulary (CAVOC). It has been developed as a common vocabulary for supporting cooperation between different farm management systems. It defines farm activities’ expressions based on description logics with eight kinds of essential attributes, e.g., purposes, actions, equipment, and crop names. The National Agricultural Library Thesaurus (NALT) [5] is an agricultural vocabulary and glossary in English and Spanish. It covers 17 subject categories such as food, animals, biologicals, farms, and insects.

The Plantome [9] provides a suite of reference ontologies for plants such as Plant Trait Ontology (TO) [5, 6], Phenotype And Trait Ontology (PATO) [7], Plant Ontology (PO) [8-10], and others. TO provides nine broad categories to represent plant traits, which are measurable characteristics of plants. PATO provides definitions of phenotypic qualities (properties and attributes) that can be used to define phenotypes across species domains. Examples of qualities are red, ectopic, high temperature, fused, small, edematous, and arrested [16]. Plant Ontology Consortium develops PO to model plants’ knowledge. Thus, it describes

\[1\]https://agclass.nal.usda.gov
\[2\]https://plantome.org
\[3\]https://browser.plantome.org/amigo
\[4\]https://github.com/pato-ontology/pato
Ontology/Domain of Interest

<table>
<thead>
<tr>
<th>Ontology/Vocabulary</th>
<th>Food, nutrition, agriculture,</th>
<th>Pathogen name</th>
<th>Part</th>
<th>Production</th>
<th>Disease name</th>
<th>Disease damage</th>
<th>Treatment name</th>
<th>Treatment usage</th>
<th>Growth stage</th>
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<td>AGROVEC [3]</td>
<td>agriculture, fisheries, animal, environment, forestry, and etc.</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<tr>
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<tr>
<td>National Agricultural Library Thesaurus (NALT)</td>
<td>Agricultural terms and glossary</td>
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<tr>
<td>Trait Ontology (TO) [5, 6]</td>
<td>Plant trait</td>
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<tr>
<td>Phenotype and Trait Ontology (PATO) [7]</td>
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<td>-</td>
<td>x</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Rice Ontology (CO_320) [11]</td>
<td>Rice trait</td>
<td>x</td>
<td>-</td>
<td>-</td>
<td>x</td>
<td>x</td>
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<td>x</td>
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<td>Plant Disease Ontology (PDO) [12]</td>
<td>Defining of rice diseases based on the causal agents</td>
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<td>-</td>
<td>x</td>
<td>x</td>
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<td>Plant Protection Ontology (PPOnontology) [13, 14]</td>
<td>Diagnosis and control of barley disorders</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>-</td>
<td>x</td>
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<tr>
<td>RiceDO and TreatO [2]</td>
<td>Diseases, insects abnormalities, and controls</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Thai Rice Knowledge Ontology [15]</td>
<td>Rice variety, disease, weed and pest</td>
<td>x</td>
<td>x</td>
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</tbody>
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Table 1
Existing, relevant ontologies and vocabularies in the agriculture domain†

† Note that ‘x’ means coverage, ‘o’ means partial coverage, and ‘-’ means no coverage.

5www.cropontology.org/ontology/CO_320/Rice
6www.cropontology.org/
7https://github.com/Planteome/plant-disease-ontology
8http://wiki.plantontology.org/index.php/Plant_Disease_Ontology_(PDO)
9https://sites.google.com/site/ontoworks/ontologies
10https://sites.google.com/site/ppontology/home

anatomical structures and growth stages in the plant bodies (e.g., roots, stems, leaves, fruits, and seeds).

Several rice plant knowledge-bases have been developed using the OWL, RDF, and OBO formats. For example, Crop Ontology Rice Trait Ontology (CO_320)5 [11] is a part of Crop Ontology (CO)6 [17, 18], providing validated trait names as well as the terminology of phenotypic and genotypic data of a rice plant. Plant Disease Ontology (PDO)7,8 [12] provides a list of maize, wheat, and rice diseases, structurally classified into three main categories, i.e., bacteria, fungi, and viruses. Plant Protection Ontology (PPOnontology)9,10 [13, 14] classifies barley’s disorder into abiotic and biotic. The biotic disorder is also classified further into bacteria, fungi, and viruses. Rice Disease Ontology (RiceDO) and Treatment Ontology (TreatO) [2] initially model rice diseases and insects according to their abnormal characteristics of rice plants and define relevant biological and chemical controls using ontological classes and relation expressions. In [15], Thai rice knowledge ontology has been automatically constructed from semi-structured data in the Thai rice knowledge web portal published by [19]. Unfortunately, the data about rice’s abnormal appearances are not covered due to the unstructured and incomplete information in the web portal.

It is worth noting that CO_320 and PDO exploit annotations in modeling the pathogens and short descriptions of each disease. In contrast, PPOnontology models disease names, appearances, and pathogens as individuals in the ontology. These modeling choices make it
difficult for ontology users for their applications, such as inferring for implicit diseases from a symptom expression. RiceDO and TreatO [2] employ a different modeling approach using ontology class definitions to improve this gap. Despite their existence, they have not yet been evaluated and used empirically. These unaddressed points motivate us to justify and revise towards their practical implementation at rice fields.

This paper extensively revises the two ontologies RiceDO and TreatO based on reliable sources and domain specialists’ involvement. We pay attention to improving the modeled knowledge towards developing and evaluating our ontology-based system for rice disease identification and control recommendation.

### 2.2. Farming Knowledge Systems and Expert Systems for Plant Disease Diagnosis

Table 2 presents existing online farming knowledge portals and plant disease diagnosis systems.

| **PlantVillage** [20] | Open-access database providing accessible knowledge of various crops and enabling more plant disease expert systems’ development. | **Plantwise Knowledge Bank** [21, 22] | Pest identification tools and a database of factsheets about plant health via a website and a mobile application. | **Evidence in [21]** shows that the combination of online factsheets and plant doctors to advise farmers is helpful in practice; however, the application contains too much information and is difficult for farmers. Interestingly, [23] reports that 86% of trained plant doctors in China indeed provide comprehensive pest management recommendations, leading to sustainable farming. **CROPROTECT** [24] is a UK-based website that aims to provide remote farmers with access to knowledge about crops, pests, weeds, and disease management. **RiceXpert** [25] is a mobile application for disseminating rice plant knowledge, e.g., rice diseases, paddy insects, non-insect pests, weeds, nutrients, as well as trendy news, a fertilizer calculator, and online advisory services from experts via text, photo, and voice. **IRRI rice knowledge bank** [26] provides diagnostic tools and factsheets for rice disease management. A mobile application is built on top of IRRI, called **Rice Crop Manager**, also provides guidance for rice, maize, and wheat farmers to manage their farms. **Agrobase** [27] is a web and mobile application that provides agronomic knowledge of various crops, pests, weeds, plant diseases, pesticides, insecticides, and herbicides. It is used among crop, vegetable, fruit, nut, horticultural, and livestock farmers to reach higher farming productivity.

**Rice Doctor diagnostic tool** [28, 29] offers a diagnostic service to identify rice plant problems via its website and mobile application. It narrows down the results based on questions and answering. The diagnostic result contains knowledge derived from the IRRI factsheets [26]. **Smart Rice Farm V.2** [30] is a mobile application launched by the Rice Department and Land Development of Thailand to supports farmers during the rice production process. It offers a rice planting calendar, a fertilizer calculator, a cost analysis per area, soil information, and management knowledge such as diseases, pests, and treatments. **Plantix** [31, 32] is a pests and diseases diagnosis tool that employs a machine learning technique to recommend a customized treatment corresponding to an identified disease based on an input photo. It supports the knowledge of pests and diseases of more than 46 plants and provides a fertilization calculator.

Still, there exist various expert systems for plant disease diagnosis. An android-based application [33] is developed to identify fruit diseases from photos by using K-Means to segment each damaged area and using an artificial neuron network (ANN) to classify the diseases. A desktop application for diagnosing six papaya plant diseases [34] is developed as an IF-THEN rule-based system, using CLIPS and Delphi language. In [35], a fuzzy logic rule-based web application for diagnosing banana diseases and pests contains 37 symptoms for five pests and four diseases of banana plants. **In [36]**, a web-based system for managing nine rice diseases and pests is introduced. Its knowledge-base covers 32 damages for a rice plant.

**Several expert systems** [1, 2, 37, 38] utilize ontologies and semantic web technologies for crop planning and diagnosis of plant diseases. An expert system in [37] employs an ontology and rules for recommending rice varieties and their corresponding crop calendar based on geographic and temporal information. Its

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11 [www.plantvillage.psu.edu/]
12 [www.plantwise.org/KnowledgeBank]
13 [www.croprotect.com/]
15 [www.knowledgebank.irri.org/]
16 [www.agrobaseapp.com/united-states]
17 [http://www.knowledgebank.irri.org/decision-tools/rice-doctor/diagnostic-tool]
18 [https://play.google.com/store/apps/details?id=rice.ictc&hl=en]
knowledge-base and rules cover rice varieties, disease and pest resistance, soil types, and ecosystems. For disease diagnosis purposes, [38] presents a Phytopathology ontology covering plants, diseases, causes, a comprehensive set of symptoms, recommendations, etc. The knowledge is modeled as individuals (ABox) with rules developed based on SWRL. On the other hand, [1, 2] RiceDO and TreatO ontologies model rice diseases, abnormalities, and controls as TBox axioms using the description logic-based formalism. This paper aims to improve RiceDO and TreatO to meet the accepted standards and utilize both ontologies for identifying rice diseases and controls with the developed expert system called RiceMan.

3. Ontology Development for RiceMan

RiceMan exploits OWL for modeling knowledge about rice diseases and controls which enables the disease identification and control recommendation to be functioned by an ontology reasoner equipped within the framework.

3.1. Ontology Requirements

We carefully elaborate competency questions (CQs) to clarify the ontology usage’s scope. Ontologies do not merely store knowledge, but also entail implicitly valid knowledge to the users. To validate the entailment’s soundness, CQs are also used during the system evaluation tasks. The CQs used in this research are shown below:

- **CQ1**: What are the recognizable diseases when a rice plant has an appearance \( A \)?
- **CQ2**: What are the recognizable diseases when a rice plant has appearances \( A, B, \) and \( \ldots \) ?
- **CQ3**: What are the possible appearances of a disease \( A \)?
- **CQ4**: What are the possible biological controls of a disease \( A \)?
- **CQ5**: What are the possible chemical controls of a disease \( A \)?

3.2. Ontology Design and Development

This subsection explains our two ontologies: RiceDO and TreatO, used by RiceMan, where CQ1 – CQ3 are addressed by RiceDO, and CQ4 – CQ5 by TreatO.

3.2.1. RiceDO and TreatO: Original Design

RiceDO and TreatO were initially introduced in [2] to model terminological knowledge with classes and properties related to traits and phenotype of various rice diseases in Thailand. Their main objectives were to support querying about potential diseases that might occur on a rice plant, given an expression of abnormal characteristics with a DL query language. Such query could be either a single appearance (such as a gray spot) or multiple ones (such as a gray spot with a yel-
low oval spot). The ontologies covered 22 rice diseases and paddy insects in Thailand and coincided with the aforementioned CQs. However, the modeled knowledge was verbose and impractical for the disease identification and control recommendation. To overcome these issues, we further investigated and redesigned the ontologies. Thus, incorrect and improper design issues were identified, including (1) unused classes, (2) classes and properties with ungrammatical semantics, (3) classes with semantic overlapping, (4) inappropriateness of class-subclass relationships, and (5) lack of restrictions in domains/ranges of properties.

3.2.2. RiceDO v2: Revised Design

RiceDO v2 is redesigned to address the aforementioned issues and is enhanced to support interoperability with related ontologies. Three reliable knowledge sources are used to formulate axioms in RiceDO: (1) Rice Knowledge Bank (RKB) from IRRI [26], and (3) Rice Ontology (CO_320) [39]. Here, we consider Thai-RKB as the primary knowledge source for modeling our ontology, while the other two are used for pieces of information absent in Thai-RKB.

We adopt the design principle of TBox-based knowledge representation from a well-known medical ontology called SNOMED CT\(^\text{19}\). Following this design principle, RiceDO v2\(^\text{20}\) consists of nine top-level classes under the RiceDOTop and 11 object properties in the object property hierarchy, as shown in Figure 1. RiceDO v2 uses the special-purpose property called abnormalityGroup to axiomatize a group of various characteristics that can occur together on a certain disease. We illustrate this in Figure 1 for the rice brown spot fungal disease in which the property abnormali-

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19https://www.snomed.org/
20http://purl.org/rice/do
tyGroup is used to group characteristics ‘light yellow halo spot on leaf’ during the tillering growth stage; that is, abnormalityGroup some SpotOnLeaf and (hasColor some LightYellow) and (hasGrowthStage some Tillering) and (hasShape some Halo));

Another radical change in RiceDO v2 is to redefine Insect as a kind of Pest instead of RiceDisease as in its first version. In addition, the class PestDamage is redefined to characterize damages caused by pests. Furthermore, the class PlantDisease subsumes 18 diseases which are categorized under four classes, namely PlantBacterialDisease, PlantFungalDisease, PlantPhytoplasmaDisease, and PlantViralDisease.

Moreover, RiceDO v2 complies with good modeling practices. Regarding the interoperability, RiceDO v2 reuses terms and handles potential mappings with existing ontologies: PDO, PO, and PATO. Rice disease names are imported from PDO. Besides, terms of plant parts and growth stages are mapped to existing equivalent classes in PO by using owl:equivalentClass. Similarly, terms of colors and shapes are mapped to the existing ones in PATO. Mapping terms to PO and PATO is used instead of importing to maintain the meaning and simplicity of the RiceDO v2’s class hierarchy to be suitable and straightforward for our target application.

3.2.3. TreatO V2: Revised Design

In [40]’s work, four approaches for handling rice diseases are discussed: physical practices, host resistance, biological controls, and chemical controls. Coalesced with CQs, the early TreatO focused on modeling biological and chemical control knowledge. The defined axioms characterized controls of each disease and paddy insect. Three knowledge sources were considered to model TreatO: RKB’s fact sheets [26] and plant disease management knowledge [40, 41].

TreatO v2 contains corrected classes and properties to resolve ungrammatical semantics on the ‘is-a’ relation. In addition, it classifies control agents into bacteria, fungi, and viruses. Moreover, it has restrictions on all properties, and include the class RiceDisease from RiceDO v2. Figure 2 illustrates the new TreatO v2 with an example of a class description of the chemical control agent to its related disease.

4. RiceMan Application Development

This section designs and develops RiceMan application corresponding to the previously defined CQs and the elicited requirements to support users’ decisions.

4.1. System Requirements

Figure 3 depicts the use case diagram of RiceMan, covering three groups of target users: farmers, agronomists, and scholars. Firstly, farmers can use RiceMan to understand possible causes and suitable treatments for their plants. However, according to the discussion with agronomists, many farmers in Thailand prefer to consult with agronomists. Thus, we consider agronomists who are responsible for supporting farmers to seek suitable treatments as the second target group. They need to understand the relationship between abnormalities and diseases and the relationship between diseases and treatments quite well. Without intelligent tools, they need to memorize all complex relationships to support farmers. Although the domain knowledge covers 18 diseases, its search space is complex since any disease can be indicated from various combinations of abnormalities: 28 colors, 11 shapes, 29 symptoms, 24 plant parts, and five growth stages. While RiceDO’s disease axioms do not contain all combinations, a particular disease could contain up to 15 combinations. Besides, a user can aggregate the current observation with others in the past, which can increase the complexity of the constructed queries. Remembering the possible diseases from multiple abnormality groups is not easy even for the expert agronomists. Hence, RiceMan advances agronomists’ working methods by offering intelligent functionalities for knowing about diseases and treatments. RiceMan provides a more reliable approach than purely utilizing offline documentations. Lastly, scholars use RiceMan to support their scholarly activities. Since RiceMan identifies diseases based on observation and suggests treatments based on the identified diseases, then students and researchers can utilize this functionality to simulate specific scenarios for their study and research. The reasoning capability equipped with RiceMan is a perfect tool for this purpose.

Important use cases of the system are explained as follows:

- **Add Observations:**
  RiceMan uses observation data as its input. An observation data contains information from an
Fig. 2. TreatO ontology hierarchy: classes, object properties, and an example of axiom

Fig. 3. RiceMan use case diagram

observation of a human, describing his/her observed situation. Upon the finding of abnormal appearances appeared on a rice plant, a user can use RiceMan to create observation data that indicates the observed appearances.

– **Find Possible Diseases:**
To find possible diseases, RiceMan identifies both explicit and implicit diseases in RiceDO, corresponding to a created observation. RiceMan employs logical reasoning to consider the logical relationships defined in RiceDO for this purpose.

– **Compose Observations (w.r.t. a Distance and a Duration):**
By default, RiceMan identifies diseases according to the logical relationship modeled in RiceDO. However, concerning the fact that some rice diseases and paddy insects are spreadable to nearby areas, a user may choose to include observations made within the specific distance and duration. This functionality is called the observation composition. It calculates the distance between different latitudes and longitudes and considers the duration in the unit of days.
4.2. System Design

We design RiceMan according to the client-server architecture, in which a responsive web client communicates through the server via JSON application programming interfaces (APIs). Figure 4 depicts the system architecture’s design, implemented by Java, OWL API\(^2\), and MySQL (for storing observation data).

The main reasoning technique used in RiceMan is subsumption. That is, to enable the search of recognizable diseases and potential treatments with subsumption reasoning, we convert each observation object as a class expression for reasoning. After the potential diseases are indicated, we also employ the subsumption reasoner to identify their corresponding treatments.

The web server exposes five main APIs. First, API `createObservation` provides a service to store observations into the database. Second, API `getSubclassListOfObservation` returns a list of disease names which are sub-categories of an observation. This API can also be parameterized for the composition with other observations if a distance and a duration are satisfied. Internally, when this API is called, a corresponding OWL class expression will be determined and be subsequently used by the OWL reasoner to find their subclasses from the RiceDO ontology. The third and fourth APIs are `getBiologicalTreatmentsOfDisease` and `getChemicalTreatmentsOfDisease`, respec-
4.3. Query Construction and User Interface

We design and develop two algorithms for creating DL queries from a user’s input by complying with the design of our ontologies.

The first algorithmic procedure is for converting an observation object in the database into an OWL class expression. This procedure consists of three steps: (1) we nest a set of symptoms, places, shapes, growth stages, transmission, and colors using existential quantification via properties hasSymptom, hasSymptomAt, hasShape, hasGrowthStage, hasTransmission, and hasColor, respectively; (2) we conjunct these nested expressions; and (3) we nest all using existential quantification via property abnormalityGroup. Figure 5 (a) illustrates a constructed OWL class expression representing a query of an observation object.

The second algorithmic procedure is for treatment recommendation. We nest a given disease name via property isBiologicalControlAgentOf (or isChemicalControlAgentOf depending upon a user’s request) using existential quantification. Figure 5 (b) – (c) illustrates our procedural steps of recommending treatments for a recognizable disease.

Figure 6 shows a sequence of RiceMan’s user interfaces that display the results of our queries as follows. From steps 1 – 3, the user inputs the observed abnormalities as a brown oval spot on a leaf. Step 4 allows the user to define thresholds for a distance and a duration. In step 5, RiceMan returns the identified disease(s). In step 6, the user can click on the disease identified to get recommended treatments. Steps 7 – 8 show the group of all possible abnormalities of a disease followed by the suggested controls.

4.4. Observation Data Composition

RiceMan implements the observation composition mechanism to identify diseases from multiple observations. If observations are located nearby each other, occur coincidentally, and are composable, then they are composed and are collectively treated as a single observation for the disease and paddy insect identification. Since observations are represented as OWL-class expressions in RiceMan, it is a natural method in RiceMan to use the intersection in OWL as an implementation of this mechanism. Figure 7 illustrates a real-world example in which each OWLClass observation $O_1$, $O_2$, and $O_3$ occur in different geolocations and dates as follows:

- $O_1 = \text{abnormalityGroup some (hasSymptom some Pimple) and (hasSymptomAt some Leaf) and (hasColor some Yellow), which occurs at geolocation } (10.030000, 99.100100) \text{ on September 15, 2020};$
- $O_2 = \text{abnormalityGroup some (hasSymptom some Spot) and (hasSymptomAt some Leaf) and (hasShape some Oval) and (hasColor some Brown), which occurs at geolocation } (10.050040, 99.500300) \text{ on October 23, 2020};$
- $O_3 = \text{abnormalityGroup some (hasSymptom some Spot) and (hasSymptomAt some Leaf) and (hasColor some Brown) and abnormalityGroup some (hasSymptom some Spot) and (hasSymptomAt some Leaf) and (hasColor some Gray), which occurs at geolocation } (10.060040, 99.500400) \text{ on October 23, 2020};$
Here, we suppose that \( O_1 \) is collected first; after that, \( O_2 \) and \( O_3 \) are collected. RiceMan users can opt in to compose past observations with the current observation for disease identification. RiceMan implements the following steps for this mechanism:

1. **Retrieve past observations that satisfy three conditions:** a distance threshold, a date threshold, and a composability boolean, from the database;
2. **Create an OWL class expression from a database object that represents a current observation manifested with certain characteristics and intersects it with the retrieved past OWL class expressions;**
3. **Use the new observation for the subsequent disease identification with subsumption reasoning.**

The observation composition mechanism helps RiceMan users delve into specific results when a single observation captures partial or broad abnormalities. Nevertheless, this mechanism may yield the same results as considering a single observation. That is when there are no observations that satisfy the three conditions. For instance, using the composition function with \( O_2 \)
Select non-compose option

Select compose option

Fig. 8. Usage of composition function

yields the same results as without using this function, i.e., it returns rice brown spot fungal disease. This is because there are no nearby observations with $O_2$. On the other hand, RiceMan yields rice blast fungal disease, rice sheath rot fungal disease, and rice brown spot fungal disease for $O_3$ when the composition function is not chosen by the user (cf. the top part of Figure 8). In contrast, it yields rice brown spot fungal disease for $O_3$ when this composition functionality is opted in (cf. the bottom part of Figure 8). When a single observation contains broad abnormal characteristics, diverse results can be obtained. Hence, this composition mechanism helps users narrow the disease identification from many possible disease results.

5. RiceMan: Ontology and System Evaluation

Figure 9 illustrates our evaluation design to validate important aspects of the developed ontologies and the RiceMan system.

5.1. Ontology Evaluation

5.1.1. Ontology Validation

We carried out this part of evaluation with five ontology experts, who were ontology engineers from NECTEC23 and ontology experts from AIT24 with experiences in modeling and applying ontologies in their work. Four important criteria were considered.

23National Electronics and Computer Technology Center
24Asian Institute of Technology
2. Consistency:
We performed consistency checking in RiceDO and TreatO according to the six sub-criteria proposed in [42]: (1) no duplicated classes, (2) no class cycles in the class hierarchy, (3) no duplicated properties, (4) no property cycles, (5) no invalid ranges, and (6) no invalid domains. As a result, the participants found a few mistakes in some object properties’ domains, and we had corrected them. Finally, all participants agreed that the revised ontologies contain no inconsistency according to the aforementioned criteria.

3. Query validation
To ensure the practicability of applying the ontologies w.r.t. CQs, we carried out a task-based evaluation, in which we presented for each task the prepared queries corresponding to the defined CQs and their results. The participants verified whether the results were correct, and the queries were written efficiently. Table 4 shows that every query was formulated correctly and efficiently except for Query#4 (i.e., 92%) due to its semantics’ incorrectness. Note that we skipped the evaluation of CQ 3 (i.e., finding the abnormalities of any disease) because it was natural to retrieve axioms of abnormalities modeled in RiceDO. Besides, we validated that our shortened axioms usage enabled us to write concise queries. Though this aspect was not part of CQs, it was helpful to realize the effectiveness towards writing practical queries.

4. Ontology satisfaction:
Finally, the participants were given a questionnaire to analyze their satisfaction with the usage of ontologies. In summary, the participants were satisfied with RiceDO in terms of identifying rice diseases based on either single or multiple abnormalities as well as its convenience in querying by means of the shortened axioms (score 100%). For TreatO, the participants were satisfied with its query facilities for searching of controls (score 88 – 92%). Moreover, the participants agreed that both ontologies could improve work efficiency (score 100%) and they were willing to use them (score 96%). Overall, the ontologies gained high satisfaction with an average score of 95.5%. For more details, see Table A.1 in the Appendix.

5.1.2. Ontology Usage
This part of evaluation was conducted to verify that our ontologies’ implicit knowledge is valuable and can effectively facilitate our users with respect to the three important criteria: completeness, accuracy and usefulness. Two groups of senior agronomists; two plant
The participants were asked to compare the modeled knowledge with the referenced knowledge sources (IRRI and Thai-RKB) [19]. Secondly, we verified the completeness based on domain experts’ knowledge to ensure that it was applicable in practice. RiceDO covers most of the rice diseases in Thailand; however, it covers relatively fewer insects in our modeled knowledge. Though the number of insects’ coverage seems insufficient, two of them frequently occur in rice fields, and three of them are carriers for some rice diseases (such as GallDwarf disease and Rice Tungro disease).

### 2. Accuracy of modeled knowledge:

To evaluate our modeled knowledge’s accuracy, two aspects were considered: 1) the correctness of the modeled axioms, and (2) the appropriateness of our vocabulary. Precisely, the participants were asked to consider if the modeled axioms were correct or not. Similar steps were carried out to verify the appropriateness of the vocabulary. Table 6 shows the results of this evaluation in percentage. Note that 13 (out of 18) rice diseases, which are frequently found in Thailand rice fields, and four paddy insects are selected for this validation. For error analysis, the correctness of rice diseases’ axioms was lower than those of other classes due to two main reasons. The first reason was the inconsistency between knowledge sources and domain experts. Some participants voted the axioms as incorrectly defined because they did not coincide with their experiences although they were modeled properly according to the referenced knowledge sources (IRRI and Thai-RKB). Concerning the appropriateness of the used vocabulary, some participants felt that some terms were not suitable although they were used in the knowledge sources. We found that the vocabulary’s appropriateness relies on a proper term selection and a proper English-Thai translation.

### 3. Usefulness of inferred knowledge:

To evaluate the practical applicability of the ontologies, we asked the participants to review the prepared inferred knowledge based on six scenarios. Specifically, scenarios #1 – #2 identify rice diseases from single and multiple abnormality groups (usefulness score: 48% and 70%); Scenario #3 queries for all abnormality groups of disease (76%); Scenarios #4 – #5 query for a disease’s biological and chemical control agents (42% and 48%); Scenario #6 focuses on disease classification into possible diseases and warning diseases w.r.t. nearby and recent observation data (90%) (cf. Table A.2). From the results, Scenarios #2, #3, and #6 obtained prominently high scores, indicating that the proposed functions help the participants reduce the searching times compared to the manual search. The participants agreed that the multiple observation data and the composition mechanism, and ontology reasoning are promising for those scenarios.

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25The Division of Rice Research and Development under the Rice Department, Ministry of Agriculture and Cooperatives, Thailand
5.2. RiceMan Application Usability Evaluation

We performed two-phased usability evaluation of RiceMan.

5.2.1. Phase 1: RiceMan English Version

Four senior agronomists from DRRD (i.e., one plant pathologist, two entomologists, and one IT agronomist) were involved in assessing RiceMan in the English version. They used RiceMan on their mobile devices to complete four provided tasks. For tasks #1 and #2, the participants were asked to identify rice diseases from a given single observation and multiple observations, respectively. For tasks #3 and #4, they were asked to identify biological and chemical controls from the returned diseases. After their completion, the participants provided their opinions by answering ten questions based on SUS (System Usability Scale) [43] (cf. Table A.3 in the Appendix for more information). Recall that a SUS score above 68 is considered as being above average. Numerically, the average SUS score we obtained is 56.3, which means ‘below average’. This result was controversial to the former ontology evaluation, which concluded that the developed composition mechanism with ontology reasoning is a promising approach. We analyzed the results and described our lessons learned:

1. RiceMan supported only the English language; however, the participants were Thai and did not feel comfortable using the application;
2. Two entomologists preferred RiceMan to contain more information about paddy insects;
3. The steps of adding multiple observations were inconvenient to use even though every participant agreed with the usefulness of this functionality. We realized that this difficulty could be improved, e.g., by presenting relevant pictures;
4. The number and the diversity of participants were still limited.

5.2.2. Phase 2: RiceMan Thai Version

In this phase, a new user interface of RiceMan application in Thai language was made and used for usability evaluation by two groups of participants: senior-year agricultural students and junior agronomists. The first group of participants were five senior-year students26 and have knowledge about rice diseases and paddy insects from their coursework, but were not much familiar with them. The students used RiceMan via their mobile phones to perform the same 4 tasks as experimented in Phase 1, and then answered 10 SUS questions. The average SUS score among the students was 70.5. Since it was above 68, then the Thai version of RiceMan was acceptable from the agricultural students’ viewpoints. The participants were interested in applying reasoning techniques in the rice plant knowledge for identifying diseases and treatments. The feedback shows that the application can support their study and improve the search in many real-life use cases. Since they had experience in farm work, they believed that the application can benefit the farmers, especially those interested in using new technologies to support their works. However, most users were facing difficulties with using the application.

The second group of participants were ten junior agronomists from Ayutthaya Rice Research Center who worked on transferring technology to farmers, focused on rice varieties’ research and development, and advised farmers. Similarly, they performed the same four tasks on their mobile phones, and then answered SUS questionnaire. The average SUS score obtained was 64.3, close to the standard average of SUS.

The Thai version of RiceMan demonstrates a significant improvement from the English version. Although the score was less than the standard average, the participants agreed that the application could significantly help them identify diseases and treatments, compared with searching through manuals and websites. It shows that RiceMan is applicable for use from the participants’ viewpoints since it offers helpful and sufficient functionalities for real-life situations even though the current version seems challenging to use for farmers.

We summarize our lessons learned as follows:

**UI/UX design:**

1. The design of the observation data’s input form should be improved to make it easier to use and to support various kinds of abnormality appearances.
2. Since RiceMan is a responsive web application, the input form varies among iOS and Android devices. The participant who used an iOS device faced some difficulty as the input was a picker instead of a drop-down box.
3. The treatment names should be shown in italics.

**Display information:**

1. The participants preferred to have photos of plant parts to support the observation data’s input forms and photos of diseases and insects on the result page;

26Chulalongkorn University, School of Agriculture Resources
2. The treatment names should be translated into Thai and provided with the product/brand names.
3. Some agronomists were specialists in insects and preferred to have more knowledge of paddy insects.

6. Conclusion

This paper proposes the design and development of RiceMan, an ontology-based expert system for rice disease identification and control recommendation, which has been originally outlined in [2]. As part of our development, we make further progress on improving the two ontologies for rice disease in Thailand: RiceDO and TreatO. Together with the composition mechanism, these two ontologies lie at the heart of RiceMan’s functionalities. RiceMan facilitates users to identify diseases w.r.t. RiceDO’s TBox axioms and suggests controls w.r.t. TreatO’s TBox axioms. Though both ontologies are initially built for RiceMan, they can be potentially extended for other expert systems in the agriculture domain with some revisions to comply with the adapted problems.

To ensure its usability and practicability, we evaluate ontologies and RiceMan in comprehensive viewpoints of four user groups: (1) ontology specialists, (2) senior agronomists, (3) junior agronomists, and (4) scholars/agricultural students. From the ontology specialists’ perspective, RiceDO and TreatO are modeled soundly, appropriately, and consistently; and hence can support the users to write efficient queries. From the senior agronomists’ perspective, the knowledge related to rice diseases is modeled almost completely, but the knowledge regarding paddy insects may be insufficient. The correctness of the modeled axioms is acceptable, but requires some improvement in terms of the vocabulary with domain experts. Regarding RiceMan usability evaluation, the evaluators found themselves pleasant with the Thai version, even though they faced some difficulties in the observation data input with the current user interface. This shows that RiceMan is a promising approach for the rice disease identification and control recommendation problem.

There are several future directions. Firstly, RiceDO and TreatO can be enhanced with modeling of axioms from various aspects of information and reliable knowledge sources. Secondly, we aim at incorporating more closely with agronomists at multiple stages of ontology development to clean up some inconsistency that may happen between the adopted knowledge sources and domain experts who own tacit knowledge about rice fields. Besides, we are interested in semi-modeling the knowledge with automatic construction techniques using machine learning.

References

Appendix

Table A.1
Ontology Satisfaction from the ontology specialists’ perspective

<table>
<thead>
<tr>
<th>#</th>
<th>Ontology usage satisfaction</th>
<th>Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Searching for possible rice diseases, which are related to a single abnormality, can be facilitated by queries on RiceDO.</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Searching for possible rice diseases, which are related to many abnormalities, can be facilitated by queries on RiceDO.</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Using the defined subclasses of SymptomCharacteristic (shortened axioms) is more convenient than writing the full definitions in queries.</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Searching for possible treatments (Bio. and Chem.) for a disease can be facilitated by queries on TreatO.</td>
<td>88</td>
</tr>
<tr>
<td>5</td>
<td>Searching for possible treatments (Bio. and Chem.) for many diseases can be facilitated by queries on TreatO.</td>
<td>92</td>
</tr>
<tr>
<td>6</td>
<td>RiceDO and TreatO ontologies can be extended to cover other factors e.g. image of symptoms, image of shapes, and detailed treatment, etc.</td>
<td>88</td>
</tr>
<tr>
<td>7</td>
<td>Assume that you are not a domain expert (Rice Plant), you feel that querying for diseases and treatments can save your time than finding from a website or a book.</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>If you want to identify rice diseases and treatments, you would like to use both ontologies.</td>
<td>96</td>
</tr>
</tbody>
</table>

Overall ontology usage satisfaction score
95.5%

Table A.2
Usefulness of inferred knowledge based on the six scenarios, evaluated by senior agronomists

<table>
<thead>
<tr>
<th>#</th>
<th>Scenarios</th>
<th>Usefulness Avg. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Searching for possible diseases from a single abnormality group.</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>Searching for possible diseases from multiple abnormality groups.</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>Searching for all abnormality groups of a disease.</td>
<td>76</td>
</tr>
<tr>
<td>4</td>
<td>Searching for biological controls of a disease.</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>Searching for chemical controls of a disease.</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>The classification of diseases into possible diseases and warning diseases w.r.t. considering nearby observations.</td>
<td>90</td>
</tr>
</tbody>
</table>

Overall ontology usefulness score
62.3%

Table A.3
Usability test of RiceMan application based on System Usability Scale, evaluated by senior agronomists, junior agronomists, and students

<table>
<thead>
<tr>
<th>#</th>
<th>System Usability Scale Items</th>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>------------------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>1</td>
<td>I think that I would like to use this system frequently.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>I found the system unnecessarily complex.</td>
<td>3.25</td>
<td>2.2</td>
</tr>
<tr>
<td>3</td>
<td>I thought the system was easy to use.</td>
<td>3.75</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>I think that I would need the support of a technical person to be able to use this system.</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>5</td>
<td>I found the various functions in this system were well integrated.</td>
<td>3</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>I thought there was too much inconsistency in this system.</td>
<td>3</td>
<td>1.8</td>
</tr>
<tr>
<td>7</td>
<td>I would imagine that most people would learn to use this system very quickly.</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>I found the system very cumbersome to use.</td>
<td>2.25</td>
<td>1.4</td>
</tr>
<tr>
<td>9</td>
<td>I felt very confident using the system.</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>10</td>
<td>I needed to learn a lot of things before I could get going with this system.</td>
<td>2.75</td>
<td>2.8</td>
</tr>
</tbody>
</table>

SUS Score
56.3 | 70.5 | 64.3
Response Letter

Revision Logs

Note: In the revised paper, the parts with major revisions were highlighted in yellow.

<table>
<thead>
<tr>
<th>Revisions</th>
<th>Pages</th>
<th>Sections</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision #1</td>
<td>2, 4, 5</td>
<td>1, 2.2</td>
<td>Clarified the manuscript's new contribution and pointed out its differences from the previous publications.</td>
</tr>
<tr>
<td>Revision #2</td>
<td>2, 3 (Table 1)</td>
<td>2.1</td>
<td>Provided the comparison of well-known domain ontologies, i.e., TO and PATO.</td>
</tr>
<tr>
<td>Revision #3</td>
<td>7</td>
<td>3.2.2</td>
<td>Provided an additional explanation about terms reuse from other ontologies.</td>
</tr>
<tr>
<td>Revision #4</td>
<td>2- 4, 16, 17</td>
<td>2, Ref.</td>
<td>Added the missing URL links to project pages.</td>
</tr>
<tr>
<td>Revision #5</td>
<td>6-7 (footnote)</td>
<td>3.2</td>
<td>Provided resolved HTTP URIs of RiceDO and TreatO.</td>
</tr>
<tr>
<td>Revision #6</td>
<td>6, 7, 9</td>
<td>3.2.2, 4.2</td>
<td>Clarified more information about the design principles of RiceDO and TreatO.</td>
</tr>
</tbody>
</table>
| Revision #7| 13 (Figure 9), 12-15 | 5, 5.1.2 | Reorganized and revised Section 5 by:  
1. Insertion of Figure 9 to outline the evaluation design comprising the evaluation objectives, evaluation criteria, and methods and evaluators.  
2. Giving further description of the evaluators' information, the evaluation methods used, and the results in Sections 5.1.1, 5.1.2, and 5.2.  
3. Reorganizing and shortening the entire Section 5.  
4. Moving three tables which give evaluation details into Appendix. |
<p>| Revision #8| 14, 15           | 5.1.2    | Clarified the usefulness of inferred knowledge in Section 5.1.2 to point out the value of our expert system and ontologies for expert agronomists. |
| Revision #9| 7                | 4.1      | Clarified the search space in Section 4.1. |</p>
<table>
<thead>
<tr>
<th>Revision #</th>
<th>Page Numbers</th>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5-7</td>
<td>3.2, 3.2.2</td>
<td>Reduced the historical part on the improvements of ontologies and provided more insight in Section 3.2.2.</td>
</tr>
<tr>
<td>11</td>
<td>2, 3</td>
<td>2.1</td>
<td>Reviewed and included NALT in the review in Section 2.</td>
</tr>
<tr>
<td>12</td>
<td>4, 5</td>
<td>2.2</td>
<td>Included and compared the suggested papers in Section 2.2.</td>
</tr>
<tr>
<td>13</td>
<td>5</td>
<td>3.1</td>
<td>Corrected the ambiguous term used as suggested from “feasible” to “recognizable” as suggested.</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td>Made minor correction as suggested by Reviewer#2.</td>
</tr>
</tbody>
</table>
| 15         | 2-5          | 2       | • Removed the introductory paragraphs,  
|            |              |         | • Revised and combined Sections 2.2 and 2.3. |
| 16         | 2-4          | 2.1, 2.2 | Corrected name, prefix, and citation as suggested and added literature review of Rice Doctor. |
| 17         | 3, 5         | 2.1, 2.2 | Corrected Table 1 and add Table 2. |
| 18         | 12           | 5.1.1   | Clarified the affiliations of evaluators (ontology specialists). |
| 19         | 8 (Figure 3) | 4.1     | Revised Figure 3 by removing knowledge engineers and its related explanation. |
| 20         | 11 (Figure 6)| 4.3     | Moved Figure 6 to Section 4.3. |
| 21         | 12 (Figure 8)| 4.4     | Cleaned up Figure 8. |
| 22         | 16           | 6       | Revised the content as suggested. |
| 23         | all          | all     | Corrected typos, grammatical issues and unnatural sentences to improve the revised manuscript’s readability. |
### Reviewer #1

<table>
<thead>
<tr>
<th>#</th>
<th>Comment / Concern</th>
<th>Response</th>
</tr>
</thead>
</table>
| 1  | It is not clear how this current work differs from the other works already published. [1]  
    [2]  
    [3]  
    https://doi.org/10.1007/s00354-019-00072-0,  
    https://doi.org/10.4018/JITR.2017100103,  
    https://doi.org/10.1145/3291280.3291786  
    Thus my advice to authors is to clarify this point in the manuscript. | Let us clarify that [3] and [1] are our previous works. In [3], we first proposed the idea of modeling rice disease knowledge as an ontology for disease detection; however, a few cases were presented to show the feasibility. The idea was further investigated in [1] which became the first versions of RiceDO and TreatO.  
    In [2], the authors presented a Phytopathology ontology covering plants, diseases, causes, a comprehensive set of symptoms, recommendations, etc. The knowledge has been modeled as individuals (ABox) with SWRL rules.  
    On the other hand, in this manuscript, RiceDO and TreatO model rice diseases, abnormalities, and controls as TBox axioms using the description logic-based formalism. We focus on improving RiceDO and TreatO to meet the accepted standards. In addition, we utilize both RiceDO and TreatO ontologies to identify rice diseases and controls with the developed expert system called RiceMan.  
    **Author Action:** We clarified this issue in Section 1 and Section 2.2 of the manuscript.  
    **Reference Log:** Revision #1                                                                                                                                                                                                 |
| 2  | Some important domain ontologies are missing such as the Plant Trait Ontology and the Phenotype And Trait Ontology. Why did the authors not evaluate them? | Thank you very much for suggesting these related domain ontologies.  
    We added the comparison of Plant Trait Ontology (TO) and the Phenotype And Trait Ontology (PATO) into Section 2.1 and Table 1 of the revised manuscript.                                                                 |


<p>| | | |</p>
<table>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>3</strong></td>
<td>The authors did not discuss terms reuse from other ontologies and how potential mappings between ontologies could be managed.</td>
<td>Thank you for pointing this out. We agree that the original manuscript does not contain this discussion, especially how RiceDO and TreatO have been improved to meet the accepted standards of ontology modeling. In the revised manuscript, we pointed out the reusing terms from PDO. That is, we imported rice disease names from PDO. Also, we revised our ontology by mapping equivalent classes in PO and PATO with <code>owl:equivalentClass</code> instead of importing to maintain the meaning and simplicity of the RiceDO v2. <strong>Author Action:</strong> We revised Section 3 by explaining how we reuse terms from other ontologies, i.e., PDO, PO, and PATO. <strong>Reference Log:</strong> Revision #3</td>
</tr>
</tbody>
</table>
| **4** | There are some missing URL links to project pages.  
- Ref 7: have a more recent and paper published in a journal  
- Ref 8: please provide a web URL for the working group  
- Ref 11: please provide a web URL  
- Refs 12 and 13: please provide a web URL | We added the web URLs to the project pages, including their citation information. We also correct some citations. Regarding Ref #7 and #8 of CO_320, we replaced them with the recent publication i.e., “Pietragalla, J., Valette, L., Shrestha, R., Laporte, M. A., Hazekamp, T., & Arnaud, E. (2020). Guidelines for creating crop-specific ontologies to annotate phenotypic data, version 2.0”. For Ref #8, we provided a web URL as a footnote. Regarding the 5 references: Ref #11 (PDO), Ref #12 and #13 (PPOntology), #15 (Thai |
| Refs 15 and 22: please provide a web URL | Rice knowledge web), and #22 (IRRI rice knowledge bank), we also provided their web URLs. Note that, in the new manuscript, the mentioned references changed as follows: Ref #7 → Ref #11, Ref #11 → Ref #12, Ref #12 → Ref #13, Ref #13 → Ref #14, Ref #15 → Ref #19, Ref #22 → Ref #26. **Author Action:** We corrected the citation information in Section 2 and provided more URLs to the project pages as mentioned above. **Reference Log:** Revision #4 |
## Reviewer #2

<table>
<thead>
<tr>
<th>#</th>
<th>Comment / Concern</th>
<th>Response</th>
</tr>
</thead>
</table>
| 1  | The article is an easy and understandable read, yet the English wording is not adequate for a journal publication. I started reporting some typos and sentences I would fix, but I noticed soon that, while the quality of the writing does not affect much the understandability, the article is overly affected by many typos and incorrect expressions. While this is not affecting my opinion on the possibility to publish it, I consider it a necessary step, if the article is accepted for publication, to revise it or to have it revised by a proficient English writer. | We agree that the original manuscript contains English problems.  

**Author Action:** We corrected typos and unnatural sentences to improve the revised manuscript’s readability.  

**Reference Log:** Revision #23                                                                                                                                                                                                                                                                                          |
| 2  | The ontology URI does not resolve on the Web. The authors provide the link to the project in GitHub; nonetheless, if this is a mature work that has to be presented in a journal, the related ontologies should be published according to SW/LOD best practices. | Thanks for the suggestion. We use resolved HTTP URI for the revised ontologies and provide their persistent URLs instead of GitHub links.  

For RiceDO,  
• URI: [http://purl.org/ricedo](http://purl.org/ricedo)  

For TreatO,  
• URI: [http://purl.org/treato](http://purl.org/treato)  

**Author Action:** We updated the ontology IRIs in RiceDO and TreatO and also provided their persistent URLs in Sections 3.2.2 and 3.2.3.  

**Reference Log:** Revision #5                                                                                                                                                                                                                                                                                          |
| 3  | Concerning the ontologies, I am a bit skeptical about the excessive modeling of everything as classes. E.g, from fig. 1, I see that not just diseases, but even colors are classes. It is not clear to me how these instances are mapped. It is difficult for me to judge. | Let us clarify that, according to the definition of description logic-based knowledge base, ontologies can be modeled in two ways: TBox only or TBox with ABox. SNOMED CT is an example of well-known medical ontologies that only models the knowledge |
even to judge certain choices that might seem not obvious e.g why is the same instance of spotOnLeaf having as color an individual that is both Brown and BrownishYellow?

I try to guess what the objective is: take a newly created individual (e.g., representing an observed, unknown disease, and the effects of it on a plant) that manifests some characteristics, classify it by means of reasoning, and get the disease as a resulting computed class. However, the same could be possible by getting the classification through the reasoner and, in turn, the instances (i.e. the diseases, or treatments, depending on what is searched) of the retrieved classes as candidates for identifying the observed disease. Maintaining the dataset would also be easier,

Maintaining the dataset would also be easier, as many new facts could be represented through new data in the ABox instead of new axioms in the TBox. I am indeed surprised that nobody objected this as TBox axioms. Our ontologies, RiceDO and TreatO, also follow this design principle when modeling agricultural knowledge.

When only TBox is used in the modeling, two reasoning problems will usually be considered: the class satisfaction testing and the subsumption checking. Our work currently uses a subsumption checking technique for rice disease identification and control recommendation. That is, given two class expressions, the reasoning algorithm will determine whether a class expression subsumes another class expression or not.

In our context of disease identification, one class expression is the definition of a rice disease, and another expression is for the characteristics that represent an observation. Our goal is to search for disease names that are subclasses of a class expression representing the observation. We also do similarly for control recommendation. That is, we apply a subsumption reasoner to search for treatment names that are subclasses of a class expression representing a disease.

To illustrate our process, let us use the example you consider in your concern:

1. Assume that a user has an observation that manifests with a brown spot on a leaf. Our algorithm will convert it into an OWL class expression: "hasSymptom some Spot and hasSymptomAt some Leaf and hasColor some Brown".

2. With subsumption reasoning in RiceDO, the algorithm can return disease names that are subsumed by the observation expression.

3. To recommend treatments by using TreatO, the algorithm will construct an OWL class expression from an identified disease name such as
4. With subsumption reasoning in TreatO, the algorithm can return treatment names that are subsumed by a disease expression.

**Author Action:** We clarified our ontologies’ design choice in Section 3.2.2 and explained how the ontologies are applied with subsumption reasoning in RiceMan in Section 4.2.

**Reference Log:** Revision #6

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<th>4</th>
<th>What kind of participants performed that part of the evaluation? For instance, if they are only domain experts (at least DEs seem to be required for replying to the first CGs about appropriateness, but the article only provides the composition of the pool for the part of the evaluation discussed in 5.3.1: DEs only, even though for that part this is acceptable, and 5.3.2), do they have the proper knowledge for evaluating the modeling or they just intuitively checked the constraints wrt the knowledge they have of the domain?</th>
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<td>While I am not strongly objecting a-priori and definitively the choices being made, these should be better clarified along the paper (and yet from the point where they are presented)</td>
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<td></td>
<td>These should be better clarified instead of merely prosing what is written in Manchester syntax (which is obvious for most readers proficient in the field) as done in section 3.2.1</td>
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5. We do agree that the submitted manuscript contains an unclear explanation of evaluation and participants. Hence, let us clarify here for concerns in **comment #4 and comment #5**.

We added Figure 9 into the manuscript to clarify the overall evaluation design as well as reorganized/revised the entire Section 5 to address the comments in more detail. In brief, our evaluation can be separated into RiceDO & TreatO ontology evaluation and RiceMan system evaluation. Corresponding evaluation criteria, methods used together with the participants performing the evaluation were depicted.

Regarding Ontology Evaluation, we considered two important aspects: the Ontology Validation and the Ontology Usage. The **ontology validation** involved five ontology specialists, who were familiar with ontology modeling and had proper knowledge to validate the modeling of RiceDO and TreatO (cf. Section 5.1.1).

To evaluate the **ontology usage**, four domain experts (agronomists) who had proper knowledge on rice plants but not ontology modeling were involved in the evaluation of the modeled knowledge (axioms) in Section 5.1.2. Specifically, they
while I recognize the effort put in providing different angles on the evaluation, it does not provide real numbers for grasping the value added by the automatic support of the tool. The CQs are clear, but the dimension of the problem not that much.

verified whether the modeled knowledge is complete (in terms of the diseases and insects’ coverage), accurate (in terms of the axioms’ precision), and applicable (in terms of how the inferred knowledge is useful for expert agronomists).

Lastly, to evaluate RiceMan’s functionalities and usability from different types of users’ perspectives, expert agronomists, non-expert agronomists, and agricultural students were involved. They used RiceMan application to perform several tasks which applied the developed ontologies, the reasoning techniques, and the developed composition mechanism together. In addition, SUS questionnaire was used to determine the usability and satisfaction from the users’ point of view.

Here, let us further clarify the value added by the constructed ontologies and the developed RiceMan application, which can enable users to identify rice diseases and controls, especially from multiple abnormalities. Refer to the Ontology Usage Evaluation (Subsection 5.1.2) with respect to the usefulness of inferred knowledge from the view point of expert agronomists. For example, a scenario of searching from multiple abnormality groups yielded 70% of the usefulness. In contrast, a single abnormality group search yielded only 48% usefulness since searching from one abnormality was considered simple for these experts. Hence, the system is useful to the expert agronomists, especially when an observation data contains many abnormalities.

Author Action: We reorganized and revised Section 5 to clarify the mentioned issues. Our revisions include:
1. Insertion of Figure 9 to indicate the evaluation design comprising the evaluation goals, evaluation criteria, and methods, and evaluators involved.
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| 6    | The authors mention 18 kinds of diseases; now, wrt the claim in section 4.1: "Without Intelligent tools, they [the agronomists] need to memorize all complex relationships in order to support farmers.", 18 diseases do not seem to be a big issue for somebody who has studied and is continuously updated for that specific job. While a relatively small dimension doesn't diminish the value and importance of automatic means for disease recognition and for suggesting remedies (e.g. the authors mention that farmers still prefer to rely on agronomists rather than applications, but this could change in the future if the applications provide sufficient reliability and ease of use), the evaluation should at least better outline any complexities, if present. e.g. besides the number of diseases, what is the size of the search space?

Rough estimation of all the parameters involved in the classification problem, of the range of the properties representing these parameters, could provide this background. |
<p>| 2.  | Further description of the evaluators' information, the evaluation methods used, and the results in Sections 5.1.1, 5.1.2, and 5.2. |
|     | <strong>Reference Log:</strong> Revision #7, Revision #8 |
| 7    | Possibly, all the &quot;historical&quot; part on the improvements |
| 8    | We agree that the historical part of the improvements can be compacted a little. |
| 9    | <strong>Author Action:</strong> We clarified this point in Section 4.1 and Section 5.1.2. |
|     | <strong>Reference Log:</strong> Revision #8, Revision #9 |</p>
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<td>8</td>
<td>The evaluation could also provide more information on the pool of participants for what concerns the first part and on the different dimensions involved in the classification, so to make it clear what the value added is in adopting such expert system even for a prepared agronomist. <strong>Reference Log:</strong> Revision #7, Revision #8</td>
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<td>9</td>
<td>I see that, other than ontologies, thesauri have been considered as well (e.g. AGROVOC). Have the authors looked into NALT (the NAL thesaurus)? It’s the thesaurus of the National Agricultural Library of the U.S. Department of Agriculture (USDA). As far as I recall, it’s less “horizontal” than Agrovoc, definitely not multilingual (a point in which Agrovoc excels) but it should have a very deep coverage of many aspects related to agriculture, possibly those on plant and pesticides. <strong>Author Action:</strong> We included NALT in our review in Section 2.1. <strong>Reference Log:</strong> Revision #11</td>
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<td>10</td>
<td>A note about Agrovoc: more than axioms (its vocabulary includes the properties we explored the two properties, i.e., hasPest/pestOf in AGROVOC. Although</td>
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hasPest/pestOf, which would be surely interesting for the topic of the presented article), as mentioned in the paper, the vocabulary is missing factual data (the properties are populated with 4 plant/pest pairs). After all, it is a thesaurus, and despite the sporadic leaps at managing more structured information, the core objectives remain hierarchy and multilingualism.

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<th>11</th>
<th>I suggest including the following reference, as it is a rice crop planning system and has thus a certain overlap with the presented article: MEDES ‘15: Proceedings of the 7th International Conference on Management of computational and collective intElliGence in Digital EcoSystems October 2015 Pages 250–257 <a href="https://doi.org/10.1145/2857218.2857272">https://doi.org/10.1145/2857218.2857272</a></th>
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both properties has names similar to our property: isCarrierOf, their meanings and purposes are different:
1. *pestOf* is defined as “a pest X is a pest of a plant Y”, i.e., the domain of *pestOf* is a pest and the range is a plant.
2. *isCarrierOf* is defined as “a pest X is a carrier of a disease Y”, i.e., the domain of *isCarrierOf* is a pest and the range is a disease.

Since the scope of RiceDO does not yet cover rice varieties, it does not need the properties hasPest/pestOf in its current version v2. However, based on the fact that different rice varieties can have different pests, the future version of RiceDO could reuse hasPest/pestOf to capture this useful knowledge.

**Author Action:** We only clarified this fact in the response letter.

| 11 | We compared the recommended paper (https://doi.org/10.1145/2857218.2857272) in Section 2.2. In brief, this paper focuses on using ontology to recommend a plan for growing rice plants and a proper rice variety based on geographic and temporal information.

Compared to our work, we focused on using ontologies to recognize potential diseases and recommend controls based on abnormal characteristics that manifest an observation.

**Author Action:** We added into Section 2.2 a review of this related work (cf. Reference #37)

**Reference Log:** Revision #12
| 12 | What is the meaning of “feasible” in section 3.1? I guess the use of the word is wrong. Does it mean “recognizable” there? | We appreciate the suggestion and already replaced the term “feasible” with “recognizable”.  
**Author Action:** We corrected this error in Section 3.1.  
**Reference Log:** Revision #13 |
| --- | --- | --- |
| 13 | 1. abstract it's - - > their  
2. Numerous existing knowledge --> knowledge is uncountable and can’t be regarded as “numerous”  
3. S2. Why “despite” ? the two things: ontologies and literature are not in contradiction  
4. S2. Why the references on the rice ontology include Agroportal? If that was meant as a reference because it is hosted there (no better reference?) then it should be more precise. Even the other reference is too vague: rather than citing the WG that created it, a link to the specifications should be provided. Same for reference 12 to PPO  
5. Note on table 1: not coverage --> “not covered” or “no coverage”  
6. S2.1-r43: “as instances of the ontology”, better to say “as individuals in the ontology”.  
7. P4r11: “sustainable farming”  
8. P5r9: “the focused was to define” --> “the focus was on defining”  
9. Tables 2,3 are not consistent in the header. The header is always “Average (%)” but the values are: only average in the single records in table 2 and then average and percentage in the concluding record, and only percentage in table 3 | Thanks for the suggestions.  
**Author Action:** We revised the following sections.  
1. Abstract  
2. Introduction  
3. Section 2 - Background  
4. Section 2 - Background  
5. Table 1 (caption)  
6. Section 2.1  
7. Section 2.2  
8. Section 3.2.1  
9. Table 2, 3, 4, 7: Change the average scale into 100%. Note that we have moved Table 4 and 7 to the Appendix.  
**Reference Log:** Revision #14 |
## Reviewer #3

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<th>Comment / Concern</th>
<th>Response</th>
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| 1 | Overall Comments and Summary  
This paper details the modifications made to the existing ontologies RiceDO and TreatO, and RiceMan, a semantic-based framework, which were all three introduced in a 2019 paper by the same authors (Jearanaiwongkul et al., 2019). | Let us clarify that the 2019 paper is our previous work. In that work, we first proposed the preliminary versions of RiceDO and TreatO and initially outlined a semantic-based framework called RiceMan for supporting the rice disease and treatment identification. In this manuscript,  
(1) we further continued to investigate and improved RiceDO and TreatO, (2) we improved the design of RiceMan more concretely and implemented the system for practical use, and (3) we thoroughly evaluated our developed ontologies RiceDO, TreatO, and also evaluated the RiceMan application in different dimensions.  

**Author Action:** We clarified the manuscript’s new contribution and pointed out its difference from the previous publication in Section 1.  

**Reference Log:** Revision #1                                                                                                                                                                                                                   |
| 2 | Overall, the manuscript is excessively long. The Background section could be condensed and made more concise, and sections 2.2 and 2.3 could be combined. I also suggest eliminating the introductory paragraphs in each section for example:  
(P2, L5): “We take a look into the literature of modeled knowledge base in agriculture area.”  
(P5, L20): “This section designs and develops ontologies for rice disease identification and control recommendation to be used by RiceMan system.”  
(P13, L32): “We discuss the design and execution of our evaluation in this section.” | We removed the introductory paragraphs throughout the manuscript.  
We revised, shortened, and combined Sections 2.2 and 2.3.  
We added Table 2 to compare the existing applications and web technologies as recommended by Concern #6 (of Reviewer #3).  
We reviewed two additional ontologies as recommended by Reviewer #1 in Section 2.1 and another paper as recommended by Reviewer #2 in Section 2.2.                                                                                                                                                                           |
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<th>Author Action: We revised Section 2.</th>
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<td>Reference Log: Revision #15, Revision #17, Revision #2, Revision #12</td>
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<td>3</td>
<td>There are a large number of grammatical issues and problems with the wording of the sentences throughout the manuscript. There are numerous issues with mixing up past and present tenses, and missing or misused articles. I suggest the authors should enlist the help of an English-speaking editor to address these issues.</td>
<td>We improved our English writing throughout the manuscript.</td>
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<td>Author Action: We corrected typos, grammatical issues and unnatural sentences to improve the revised manuscript’s readability.</td>
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<td>Reference Log: Revision #23</td>
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<tr>
<td>4</td>
<td>- In the Background section, the authors review a number of existing ontologies and semantic web technologies. In Section 2.1, the authors present a number of ontologies and vocabularies and there are a number of inaccuracies. AGROVOC (not ‘Agrovoc’) should not be referred to as an ontology, it is a controlled vocabulary.</td>
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<td>We corrected names/prefixes/citations in Section 2 and included Rice Doctor in our review as suggested by the reviewer.</td>
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<td>Author Action:</td>
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<td>- We corrected “Agrovoc” with “AGROVOC” and referred to it as a vocabulary instead of ontology.</td>
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<td>- We corrected the acronym of Crop Ontology Rice Trait Ontology “RO” with “CO_320” and we removed the statement that says it is modeled in the OWL format.</td>
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<td>- We corrected the citation of PO and CO_320 as recommended.</td>
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<td>- We included Rice Doctor in Section 2.2 (cf. References #28 - 29).</td>
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<td>Reference Log: Revision #16</td>
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|   | Agroportal as the reference for the CO Rice Ontology.  
|   | • In addition, the authors should also include the Rice Diagnostic tool 'Rice Doctor', developed by IRRI (http://www.knowledgebank.irri.org/decision-tools/rice-doctor). |
| 5 | It's confusing that some of the resources are discussed in the past tense, such as the Plant Ontology, PlantVillage and Plantwise Knowledge Bank, while others are discussed in the present tense, such as AGROVOC. Some of the sentences have a mixture of present and past tenses.  
|   | We improved our English writing throughout the manuscript.  
|   | **Author Action:** We corrected typos, grammatical issues and unnatural sentences to improve the revised manuscript's readability.  
|   | **Reference Log:** Revision #23 |
| 6 | Table 1 contains inaccurate information about the domains of the PO and the CO Rice Trait Ontology and would be more useful if it was a comparison of the other existing applications and web technologies detailed in Section 2.2 and 2.3.  
|   | We revised inaccurate information of PO and CO_320 in Table 1.  
|   | Also, we combined Sections 2.2, 2.3 and added Table 2 to compare the existing applications and web technologies  
|   | **Author Action:** We corrected Table 1 and added Table 2 in Section 2.  
|   | **Reference Log:** Revision #17 |
| 7 | In Section 3, the authors detail the design and revisions to the RiceDO and TreatO ontologies, based on the Competency Questions and the evaluation of the ontologies by two unnamed ‘ontology engineers’. Later, in Section 5.2, the revised ontologies were evaluated by “five evaluators who were ontology engineers and ontology experts” Since there is no information as to who did the evaluations and what their credentials were, it is difficult to put much stock into these evaluations.  
|   | Let us clarify that the design revisions and evaluation of RiceDO and TreatO involved two ontology engineers from Thailand’s National Electronics and Computer Technology Center (NECTEC) and three ontology experts from Asian Institute of Technology (AIT), Thailand.  
|   | We already added information about them in Section 5.1.1.  
|   | **Author Action:** We clarified this information in Section 5.1.1.  
<p>|   | <strong>Reference Log:</strong> Revision #18 |</p>
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| 8    | One of the most important principles of ontology design is to reuse relevant parts of existing ontologies. In the RiceDO, the rice diseases are imported from the PDO, but the ‘PlantPart’ and ‘GrowthStageGroup’ branch of the ontology does not import the relevant classes from the Plant Ontology. None of the classes in the RiceDO have textual definitions or unique identifiers (besides the classes from PDO). I suggest the authors should consult the list of principles of good ontology design (http://www.obofoundry.org/principles/fp-000-summary.html) by the OBO Foundry (Smith et al., 2007). We agree with the suggested principles of good ontology design. We revised RiceDO by reusing PlantPart and GrowthStage from PO and discussed in Section 3.2.2. Moreover, we provided textual definitions and unique identifiers for RiceDO v2 and TreatO v2 as suggested. In addition, we already used resolved HTTP URI for the revised ontologies and provided their persistent URLs instead of GitHub links. For RiceDO,  
  - URI: [http://purl.org/ricedo](http://purl.org/ricedo)  
For TreatO,  
  - URI: [http://purl.org/treato](http://purl.org/treato)  
**Author Action:** We mapped the relevant classes of RiceDO v2 to existing terms in PO and PATO using `owl:equivalentClass` to maintain the meaning and simplicity of the RiceDO v2.  
**Reference Log:** Revision #3, Revision #5 |
| 9    | In Section 4 System Requirements, and Figure 3 Use Case Diagram shows the primary users as being farmers, agronomists and scholars. The inclusion of knowledge engineers as "users" of the system does not make sense and could be removed. (P9, L34) We agree with the suggestion. Hence, we revised Figure 3 in Section 4 by removing knowledge engineers from the diagram and also removing its corresponding content in Section 4.1.  
**Author Action:** We revised Figure 3 and modified the content in Section 4.1.  
**Reference Log:** Revision #19 |
| 10   | Figure 6 and its description seems out of place. I suggest moving it up to Section 4, where the RiceMan Application development is discussed.  
**Author Action:** We moved Figure 6 to Section 4.3.  
**Reference Log:** Revision #20 |
| 11  | Figure 8 needs to be cleaned up to improve readability and labeled with numbers similar to Figure 6. | **Author Action:** We improved Figure 8 by providing labels.  
**Reference Log:** Revision #21 |
|-----|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| 12  | Section 5, the details of the evaluation of the RiceMan and the ontologies is much too long and detailed. This could be summarized in a few paragraphs and the extensive details and tables could be presented in a supplementary file. | **Author Action:** We revised, reorganized, and shortened Section 5. Moreover, we moved three Tables from Section 5 to the Appendix, as suggested by the reviewer.  
**Reference Log:** Revision #7 |
| 13  | Finally, the opening statement of the Conclusion is inaccurate, as the RiceMan application was introduced in the 2019 paper by the same authors.  
Also, the authors suggest that “Though RiceDO and TreatO are built for RiceMan, they can be extensively applied and reused for other development of expert systems for agriculture domain.” This is not true as these ontologies are presented, but may be possible with some revisions to bring them into compliance with accepted standards. | **Author Action:** We revised the inaccurate content in the conclusion.  
**Reference Log:** Revision #22 |