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An ontology-based approach to integration of hilly citrus production knowledge

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A B S T R A C T

Citrus planting is subject to a variety of complex factors, such as terrain and growth-stage. There are a few differences between citrus planting on hills and in other places. In this paper, we focus on the integration of hilly citrus production knowledge. We organize and convert the citrus production knowledge in the forms of texts, tables and pictures in technical reports and books into a hilly citrus fertilization and irrigation ontology. Three citrus decision services (fertilization, nutrient imbalance, and irrigation/drainage) are developed for fruit farmers in Chongqing, China, based on the ontology. We compare the system results and the reference values recommended by citrus experts to ensure that our system can provide correct and helpful advice for growers. The results of the fertilization service are completely consistent with the experts' expectations. The nutrient imbalance service meets growers' requests with a 98% accuracy, and the irrigation/drainage service can achieve 94% accuracy. Our work can also be further connected with other agricultural ontologies and integrated to be subclasses of AOS ontology.

1. Introduction

Citrus is one of the most popular and major fruits in southern China. In 2008, China surpassed Brazil as the country with the largest citrus yield in the world. Chongqing, with its unique hilly terrain, is one of the major citrus producers in China (Zeng and Yi, 2013).

A wide variety of agricultural data are available for agricultural production and research (Nagai et al., 2008). Full and efficient sharing and integration of agricultural data are the foundations for agricultural semantic interoperability (Roussey et al., 2011). Although abundant citrus expert knowledge exists in texts, tables, and pictures, it is unable to be processed by computers directly. Therefore, approaches are needed to convert various types of knowledge into computable resources.

Semantic technologies offer an efficient solution to integrating and converting the mass, multi-source, and heterogeneous agricultural data and knowledge (Vdovjak and Houben, 2001; Natalya, 2004; Sun et al., 2008; Jiang et al., 2009; Zhang et al., 2012). These semantic technologies include knowledge representation standards such as RDF (Resource Description Framework), RDFS (RDF Schema), OWL (Web Ontology Language), and SPARQL (Simple Protocol and RDF Query Language) (Prud and Seaborne, 2008; Allemang and Hendler, 2011).

The application of ontology in agriculture has been widely studied. FAO (Food and Agriculture Organization of the United Nations) proposed the AOS (Agricultural Ontology Service) project. The AGROVOC thesaurus was converted from the original term-based vocabulary into the ontology-based system under AOS and linked with multiple open well-established agricultural resources (FAO, 2014a). Currently, AGROVOC offers top-level structures and terms in agriculture for further developing domain-specific ontologies (FAO, 2014c). Since 2000, FAO has hosted the AOS workshops to promote the application of semantic technologies in agriculture (FAO, 2014e). MTSR (Metadata and Semantics Research) has also organized a series of workshops on metadata and ontologies for agriculture, food, and environment (MTSR, 2014).

Some researchers concentrated on making use of semantic ontology to conceptually model and integrate agricultural knowledge (Jiang et al., 2009; Beck et al., 2010; Sun et al., 2011; Cao et al., 2012; Zhang et al., 2012). Beck et al. (2010) and Yuan et al. (2013) chose citrus as the domain for their ontology. They paid more attention to the domain-specific ontology than to AGROVOC. Fewer studies were conducted on modeling and integrating hilly citrus knowledge compared to citrus planted in other places, such as plain areas.

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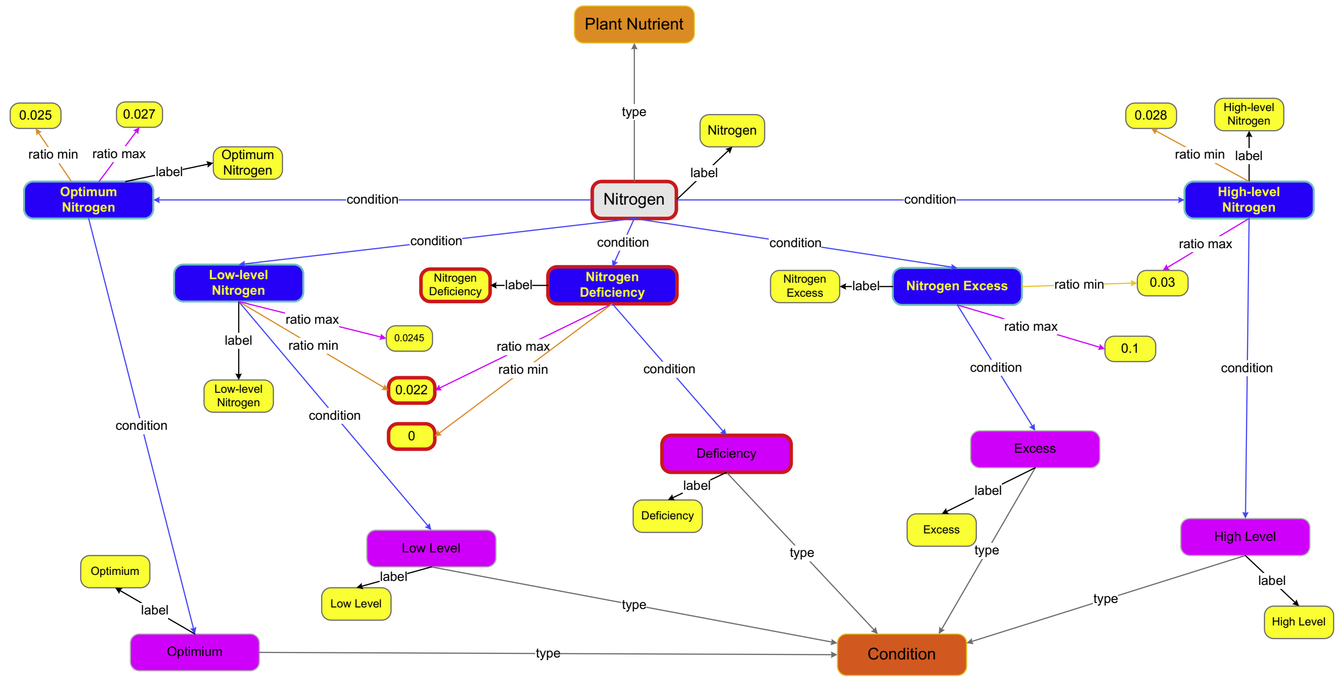
Table 1
Classification standard of nutrient levels for sweet orange leaves.[a]

Element	Concentration unit	Deficiency	Low level	Optimum	High level	Excess
Nitrogen	kg/kg	<0.022	0.022–0.024	0.025–0.027	0.028–0.03	>0.03
Phosphorus	kg/kg	<0.0009	0.0009–0.0011	0.0012–0.0016	0.0017–0.0029	>0.003
Potassium	kg/kg	<0.007	0.007–0.011	0.012–0.017	0.018–0.023	>0.024
Calcium	kg/kg	<0.015	0.015–0.029	0.03–0.045	0.046–0.06	>0.07
Magnesium	kg/kg	<0.002	0.002–0.0029	0.003–0.0049	0.005–0.007	>0.008
Sulfur	kg/kg	<0.0014	0.0014–0.0019	0.002–0.0039	0.004–0.006	>0.006
Boron	mg/kg	<20	20–35	36–100	101–200	>260
Iron	mg/kg	<35	35–49	50–120	130–200	>250?
Manganese	mg/kg	<18	18–24	25–49	50–500	>1000
Zinc	mg/kg	<18	18–24	25–49	50–200	>200
Copper	mg/kg	<3.6	3.7–4.9	5–12	13–19	>20
Molybdenum	mg/kg	<0.05	0.06–0.09	0.1–1	2–50	>100?
Sodium	kg/kg	*	–	<0.0016	0.0017–0.0024	>0.0025
Chlorine	kg/kg	?	?	<0.002	0.003–0.005	>0.007
Lithium	mg/kg	*	–	<1	1–5	>12

[a] * – Means it is not clear whether those elements are necessary for normal citrus growth. ? – Represents the lack of relevant data.



Note: Nodes represent the subjects or objects of triples. Directed edges denote properties (predicates of triples). Different resources are depicted in different colors. This figure is generated by the Gruff tool (Franz, 2013a), which is a user-friendly visualization tool that allows users to easily navigate triples and configure the layout by dragging.

Fig. 1. RDF triples related to nitrogen. *Note:* Nodes represent the subjects or objects of triples. Directed edges denote properties (predicates of triples). Different resources are depicted in different colors. This figure is generated by the Gruff tool (Franz Inc., 2013a), which is a user-friendly visualization tool that allows users to easily navigate triples and configure the layout by dragging. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Citrus growth relies on soil, terrain, and meteorological conditions such as temperature, moisture, and sunlight. Terrain is one of the most important influencing factors because for the following reasons: (i) soil nutrients distribute differently on hilltops and in valleys; (ii) there are differences in wind and sunlight between hills and plains; and (iii) water and soil loss are severe for hilly citrus compared with those planted on plains, which results in an increased amount of fertilization.

In this paper, our work involves three major aspects: First, we analyze and organize the knowledge of citrus on fertilization, nutrient imbalance, and irrigation/drainage management. The relations and hierarchies among knowledge are refined by hilly citrus experts. Second, the ontology-based approach is applied to integrate citrus knowledge. The knowledge in research reports or books is converted into the computable RDF triples used directly by computers. Third, three ontology-based citrus decision services are developed. The three services (fertilization, nutrient imbalance, and irrigation/drainage) are accessed through web browsers or smart phones. We validated our ontology and services with experiments and citrus experts. The results of the fertilization service completely agree with the expected values by experts. The accuracy of our nutrient imbalance service is 98%, and the irrigation/drainage part can achieve an accuracy of 94%.

This paper is organized as follows. First, in Section 2, a hilly citrus fertilization and irrigation ontology is created. The approach to modeling and integrating knowledge in texts, tables, and pictures as RDF triples is discussed in detail. Second, in Section 3, the system architecture and the three decision services (fertilization,