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Development of an ontology for Bulgarian soil types

Asya Stoyanova-Doycheva
Dept. of Computer Systems
University of Plovdiv "Paisii Hilendarski"
Plovdiv, Bulgaria
IICT, Bulgarian Academy of Sciences
Sofia, Bulgaria
astoyanova@uni-plovdiv.net

Sebiha Madanska
Dept. of Computer Systems
University of Plovdiv "Paisii Hilendarski"
Plovdiv, Bulgaria
sebimadanska@uni-plovdiv.bg

Sheban Bilyanov
Dept. of Residential Buildings,
University of Architecture, Civil Engineering and Geodesy
Sofia, Bulgaria
sh.bilqnov_far@uacg.bg

***Abstract*—The article presents the development of an ontology for the Taxonomic List of Soils in Bulgaria (according to the FAO World System). In addition to soil types, the ontology includes knowledge about the different agro-climatic regions in Bulgaria that are suitable for cultivating various agricultural crops. The ontology is part of the knowledge base of the ZEMELA platform for smart agriculture.**

***Keywords*— ontology, intelligent agriculture, ZEMELA, Bulgarian soil**

I. Introduction

Agriculture is an important sector in the economy of Bulgaria. Increasing attention is being given to the development of concepts and tools that utilize various technologies and systems for automation and optimization of agricultural processes. This process of automation, facilitation, and improvement of processes in agriculture is known as smart farming or precision agriculture. Approaches to implementing smart farming include the use of a suitable combination of sensors, data collection devices, the Internet of Things (IoT), artificial intelligence (AI), and others, aimed at enhancing the efficiency, productivity, and sustainability of agricultural operations. Sensors are used to gather information on various parameters in the agricultural process, such as soil, moisture, temperature, and plant growth. This data is analyzed to make informed decisions and take appropriate actions in crop cultivation.

The goal of this article is to present the use of ontologies in the context of intelligent agriculture. The research is part of the intelligent farming platform called ZEMELA [1]. The architecture of ZEMELA includes an intelligent assistant [2] that assists farmers in cultivating various crops by providing them with information about plant growth and any incidental events that occur during cultivation. To perform analyses on the state of agricultural crops, the assistant relies on foundational knowledge about the physiological development of crops [3], plant taxonomy [4], environmental conditions, and more. This knowledge is stored in the form of ontologies, frames, and other structures within the ADK center, which is a component of the ZEMELA architecture.

A core part of the ADK Center comprises ontologies that store fundamental knowledge about the cultivation of various agricultural crops. The ontologies in the Center are divided into three main types - domain ontologies, event ontologies, and task ontologies.

- Domain ontologies contain structured knowledge commonly accepted in the field of plant science. This includes knowledge about plant taxonomy, soil characteristics, and others.
- Event ontologies contain knowledge about the cultivation of various agricultural crops. This includes the developmental stages of plants and the conditions under which they transition from one phase to another. Each crop has its own dedicated event ontology. Additionally, these ontologies describe various emergency events that may occur during crop cultivation, such as drought, disease outbreaks, pest infestations, and others.
- Task ontologies are related to the activities that farmers need to perform in response to specific events. These activities include transitioning crops from one phase to another or carrying out necessary tasks during emergency events. Examples of such tasks include spraying with various pesticides or herbicides, irrigation, fertilization, and others.

In the article, we will focus in detail on one of the ontologies related to soil types in Bulgaria. The ontology presents knowledge about soil types as well as information about different regions with soils in Bulgaria that are suitable for cultivating various types of crops.

II. State of the Art

Different crops have varying requirements for soil in terms of texture, structure, pH value, drainage, and nutrient content. Farmers pay particular attention to the characteristics of the soil in which they will cultivate a specific crop in order to achieve optimal yields. They also focus on preserving the soil's characteristics and nutrient levels from a fertilization perspective. In this regard, numerous developments exist.

The International Union of Soil Sciences (IUSS) is an international society that brings together scholars and professionals in the field of soil science. They have resources and publications related to soil classification and characteristics [5]. The World Soil Information (ISRIC) is a global center for soil information that provides data, maps, and online services related to soils. They have online resources and databases that present soil types [6]. The European Soil

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Data Centre (ESDAC) is a soil information center established by the European Commission. They provide data, maps, and tools that aid in the analysis and understanding of soil resources in Europe [7].

There are also numerous ontologies developed for soil taxonomy, soil properties, and soil content, intended for various purposes and fields. In [8], the authors present an ontology for soil characteristics relevant to road construction and infrastructure. The authors of [9] present an ontology of soil taxonomy in India. In [10], an ontology is created for storing detailed information about soil composition with various minerals. The ontology provides structured and formalized knowledge that can be extracted for different models, ultimately resulting in crop recommendations and suitable soil compositions.

In this article, an ontology for soils in Bulgaria will be presented, which also includes agro-climatic regions with soils in Bulgaria suitable for cultivating different crops.

III. Bulgarian Soils ontology & agro-climatic zoning

We are not aware of the existence of another ontology focused on the study of soils regarding the location of Bulgaria and the so-called agro-climatic zoning of plant crops. The ontology itself is developed in Protégé OWL-ontology development environment [11].

It includes a total of 787 axioms, 295 logical axioms, 161 declaration axioms, 123 classes, 6 object properties, 10 data properties, 20 individuals and 5 types annotation properties used (rdfs:comment, schema:image, source, rdfs:label on Bulgarian and on English, and rdfs:seeAlso). The ontology is being developed and is still a work in progress.

A. Class hierarchy

The class hierarchy in the ontology for Bulgarian soils follows the Taxonomic List of Soils in Bulgaria (according to the FAO World System) by Professor Doctor Nino Ninov [12], and regarding the zoning of crops and their suitability – the Bulgarian National Soil Survey's studies [13].

The current state of the Bulgarian soils ontology (as metrics) is presented on Fig. 1.

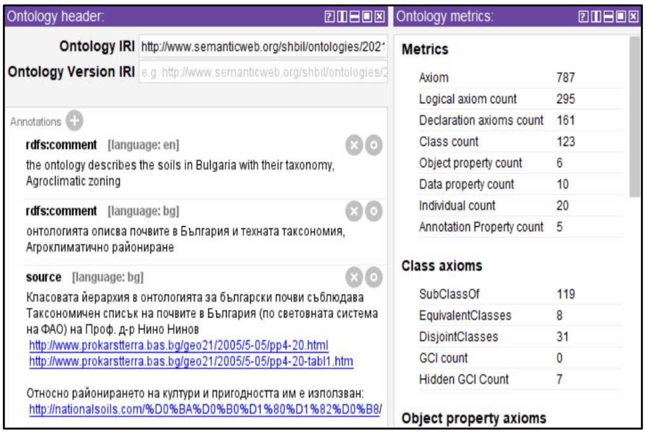

Fig. 1. Metrics of the Bulgarian soils ontology

The ontology includes a taxonomy of the soils on the territory of Bulgaria. They are used as predominant types of soils in the descriptions of the agro-climatic zoning of popular plant crops like wheat - also including humus content, level of benignity of the soil in view of the plant cultures. Soils are divided into two main types - azonal and zonal. For example, fertile chernozems belong to zonal soils. They are widespread in Northern Bulgaria, about 20% of the total area of the country [12]. An illustration of the taxonomy of all soil types represented as classes and some other classes is depicted in Fig. 2. Several classes (namely *Plant, AgroclimaticZoningOfPlantCulture, Soil, Location, Climate*) are subclasses of the base class *owl:Thing* – and some of them also have their subclasses. Each class is accompanied by additional information, which includes labels in two languages. Some classes are described with comments, pictures and links to additional sources of information. The information included as comments and pictures is presented also with *source* property.

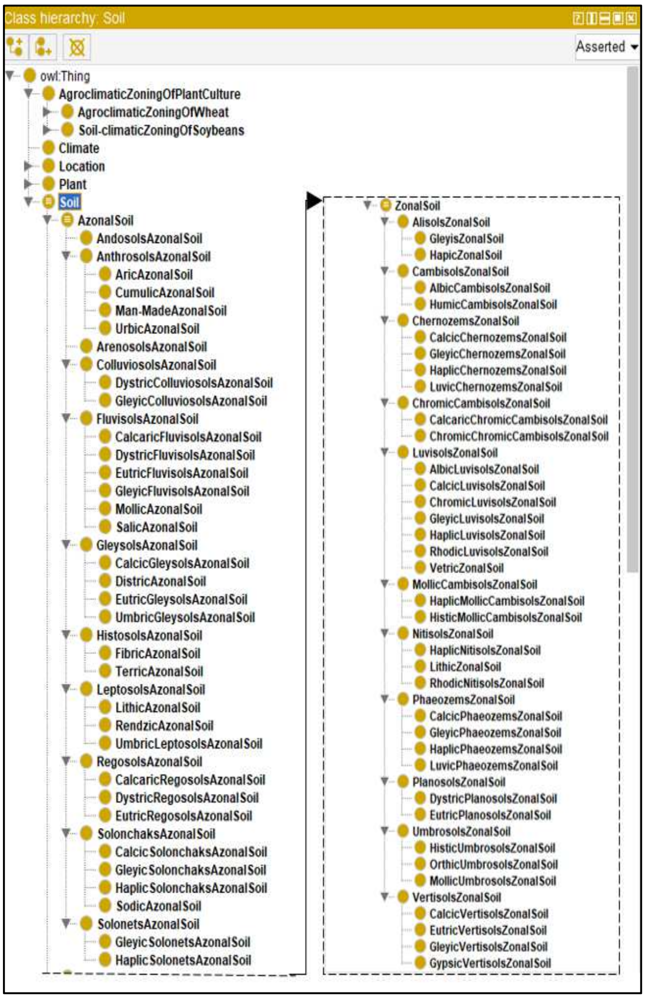

Fig. 2. Main class hierarchy

Disjointness axioms are attached, which means that two classes with no possible instance belonging to both must be clearly stated. This is because of the 'Open World Assumption', which is one of the bases of Ontology Engineering in OWL. For the same reason, in the descriptions of some of the classes (e.g. *Soil, AzonalSoil, ZonalSoil*, etc.) the so-called 'covering axioms' were used. For instance, the class *Soil* is described with axiom as being either *AzonalSoil* or *ZonalSoil*, which means that the class is defined only by a specific set of classes.

Most of the classes are primitive (e.g. *EutricGleysolsAzonalSoil*), i.e. they have only necessary conditions, while there are also defined classes - with

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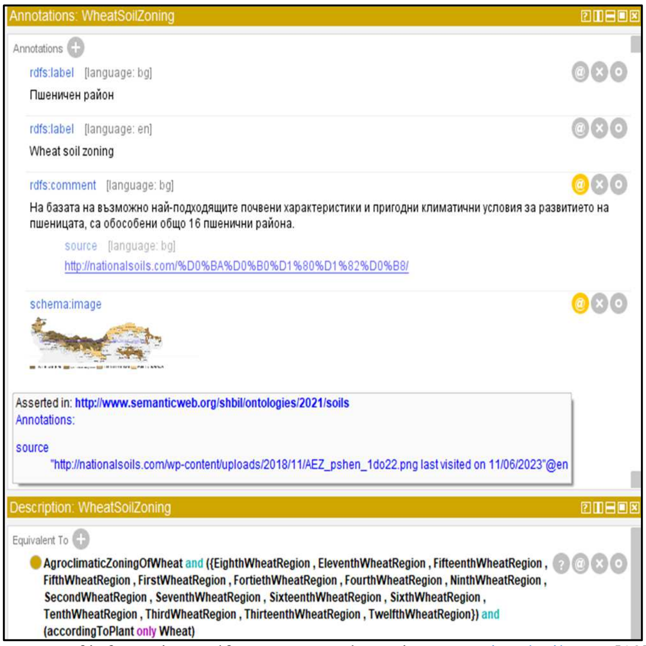
necessary and sufficient conditions, for example, *WheatSoilZoning* (Fig. 3), which is defined class and also enumerated class with a list of its possible individuals.



Source of information - rdfs:comment, schema:image: nationalsoils.com[13]

Fig. 3. WheatSoilZoning class description and annotations

B. Object properties

Object properties are these that are used to connect class of individuals with other class of individuals, or a specific individual with others. The object properties in the ontology are: *accordingToPlant, growsWellIn, hasClimate, isLocatedIn, isSuitableForGrowing and withPredominant*. They have further characteristics. For example, *growsWellIn* is irreflexive property, with domain – class *Plant*, and range – class *Soil*. Its inverse property is *isSuitableForGrowing* (also irreflexive). The *accordingToPlant* property is functional and inverse functional, with the class *AgroclimaticZoningOfPlantCulture* as domain and the class *Plant* as range.

C. Data properties

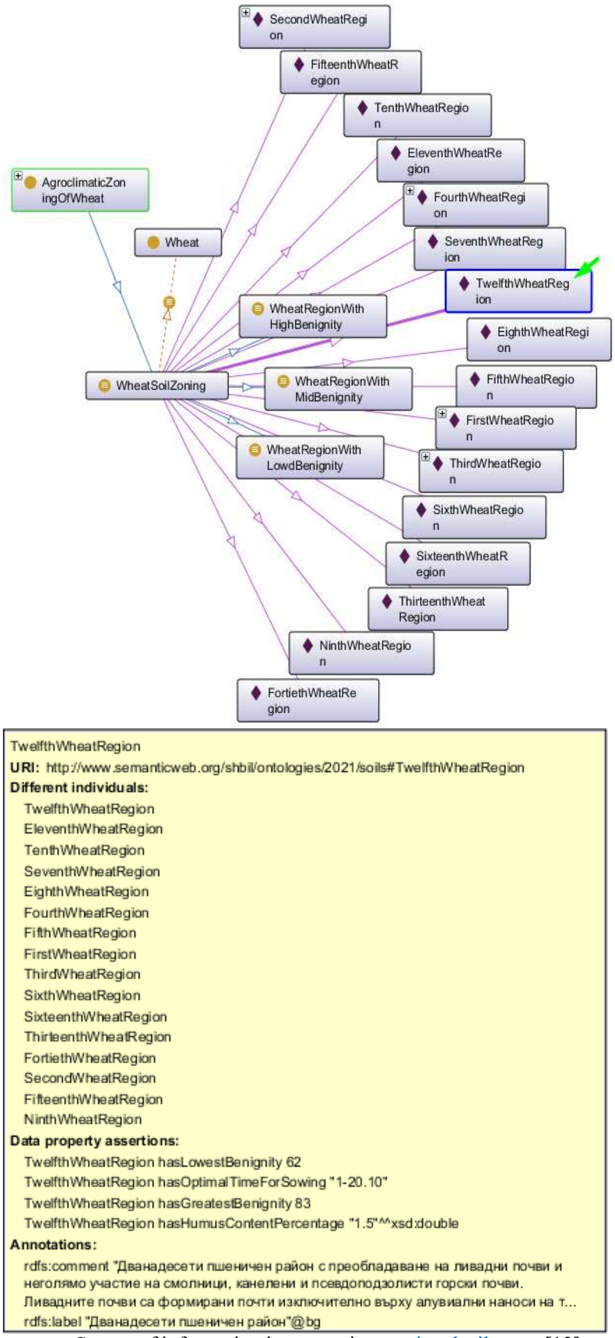
Data property's purpose is to connect a class of individuals (or individual) with value from a specific data type. The data properties in the ontology are: *hasBenignity* (with sub-properties *hasGreatestBenignity* and *hasLowestBenignity)*, *hasHumusContentPercentage* (with sub-properties *hasAtLeastHumusContentPercentage* and *hasTheBiggestHumusContentPercentage*), *hasLatitude, hasLongitude, hasOptimalTimeForSowing* and *pH.*

There are criteria which describe the most beneficial soil for concrete plant culture. Therefore, the *hasHumusContentPercentage* property is included, and annotated with metadata type 'label' on Bulgarian and English languages. Its domain is the *AgroclimaticZoningOfPlantCulture* class, but its range is the following axiom: *xsd:double[>= "0.0"^^xsd:double , <= "100.0"^^xsd:double]*.

Another important property for the concept is *hasBenignity*. Its domain is the class *AgroclimaticZoningOfPlantCulture*, and its range is the following axiom: *xsd:integer[>= 0 , <= 100]*. Some other properties in the ontology are *hasLongitude* and *hasLatitude*, with domain – the classes *Soil* and *AgroclimaticZoningOfPlantCulture,* and range – specific value from a data type decimal.

D. Individuals

The specific agro-climatic regions of plant cultures are presented as individuals. For example, the *TwelfthWheatRegion* individual (on Fig. 4, illustrated using Protégé's OntoGraf plug-in) is an instance of the *WheatSoilZoning* class. Its description corresponds to the following axiom: *WheatSoilZoning and (withPredominant some (ChromicLuvisolsZonalSoil or GleyicChernozemsZonalSoil or PlanosolsZonalSoil or VetricZonalSoil)).* Typically, they contain 1.5% humus, and the benignity from the subtypes of soil in the region varies from 62 to 83 points [13].



Source of information in annotations nationalsoils.com [13]

Fig. 4. OntoGraf view of the TwelfthWheatRegion individual

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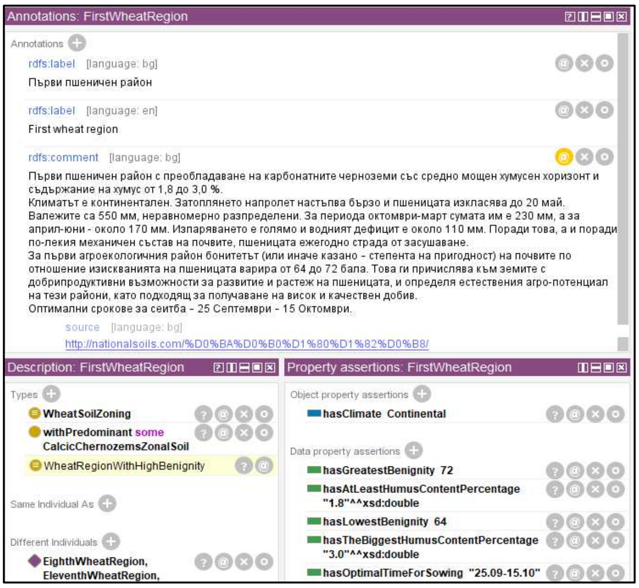
Similarly, other agro-climatic regions of plant cultures are described, using the study by the Bulgarian National Soil Survey [13] (in the ontology there are also attached assertions as rdfs:comments from the National Soil Survey's site). Illustratively, the *FirstWheatRegion* individual and its annotations, descriptions and property assertions are presented on Fig. 5.



Source of information in rdfs:comment: nationalsoils.com [13]

Fig. 5. FirstWheatRegion: description, annotations, property assertions

IV. Reasoning

The 16th wheat specific agro-climatic regions are individuals of the class *WheatSoilZoning*, but the class itself has also 3 subclasses, namely: *WheatRegionWithHighBenignity, WheatRegionWithLowdBenignity, WheatRegionWithMidBenignity,* which are described as equivalent classes with necessary and sufficient conditions – similar to the following axiom: *hasBenignity some xsd:integer[>= 64 , < 100]*. The range is conditional, according to the individual agro-climatic zoning benignity values.

After a reasoning process with the Hermit Reasoner [14] (which as mentioned in [15] is fast and accurate at ontology classification Reasoner), some individual agro-climatic regions are deduced as individuals of the defined classes (illustrated on Fig. 6).

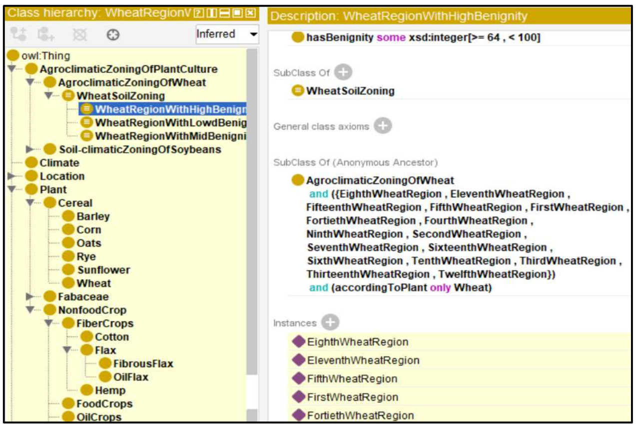


Fig. 6. WheatRegionWithHighBenignity class reasoning

This is due to the fact they are described with axioms by using the same data property, connecting the individual with value corresponding to the range in class's condition (which is not only necessary, but sufficient as mentioned). Therefore, they meet this condition and can be considered as its instances.

Conclusions

The article introduces a unique Bulgarian soil ontology designed to classify and categorize soil types within the country. This ontology is a valuable resource for farmers as it provides insights into soil suitability for various crops based on criteria such as humus content and benignity. Through reasoning processes, it allows for the classification of agro-climatic regions based on soil characteristics, facilitating precise agricultural planning.

Furthermore, the article emphasizes that the soil ontology is an ongoing project. This suggests that there are plans for future development and refinement of the ontology. This ongoing work could involve expanding the ontology to include additional soil properties, incorporating new research findings, or enhancing its usability for farmers and researchers.

In summary, the Bulgarian soil ontology not only serves as a current tool for agricultural decision-making but also signifies a commitment to its continued improvement to meet evolving agricultural needs. The soil ontology developed for agriculture could have applications beyond farming, potentially in the field of building foundations in architecture.

Acknowledgment

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