Modeling Competency Questions-Based Ontology for the Domain of Maize Crop: SIMcOnto

Enesi Femi Aminu, Ishaq Oyebisi Oyefolahan, Muhammad Bashir Abdullahi, and Muhammadu Tajudeen Salaudeen

Abstract In this present time, there is rapid increase of various forms and structures of information across different domains of real world; for instance, agriculture. Because of this development, information is readily available; however, to retrieve the relevant information becomes a research issue to contend with. This identified research issue is, on the one hand, attributed to the unstructured representation of data, and on the other hand, attributed to the problem of word mismatch. Consequently, and in lieu of this, to retrieve relevant soils and irrigations data for maize crop in a more efficient structure becomes a challenge. Therefore, this research work aims to model soils and irrigations data for maize crop ontologically, which is christened as SIMcOnto. In order to achieve this objective, ontology which is a data modeling technique for complex knowledge representation is exploited. At the end, rule-based ontology is developed using the combined methodologies approach and written using Web Ontology Language (OWL2) in the syntax of RDF/XML. The rules leverage on the validated competency questions (CQs) which are modeled in first-order logic (FOL). During the course of the ontology development, the terminologies and the semantic rules are validated and verified by the domain experts and evaluation techniques. Therefore, the proposed SIMcOnto provides a machine represented knowledge-based modeling for soils and irrigations knowledge of maize crop. It is promising in retrieving a more precise and efficient information.

E. F. Aminu (✉) · M. B. Abdullahi
Department of Computer Science, Federal University of Technology, Minna, Nigeria
e-mail: enesifa@futminna.edu.ng

M. B. Abdullahi
e-mail: el.bashir02@futminna.edu.ng

I. O. Oyefolahan
Department of Information & Media Technology, Federal University of Technology, Minna, Nigeria
e-mail: o.ishaq@futminna.edu.ng

M. T. Salaudeen
Department of Crop Production, Federal University of Technology, Minna, Nigeria
e-mail: mtsalaudeen@futminna.edu.ng

J. K. Mandal et al. (eds.), *Proceedings of International Conference on Advanced Computing Applications*, Advances in Intelligent Systems and Computing 1406,
https://doi.org/10.1007/978-981-16-5207-3_61

Keywords Maize ontology · Soils and irrigations knowledge · Competency questions · Semantic Web Rule Language · OWL properties

1 Introduction

Maize (*Zea mays* L.), also referred to as corn, is undoubtedly an economic viable crop alongside with rice and soybeans [1]. It remains a key food crop in Africa, Asia, and Latin America where it is largely used as human food, and in developed nations, maize is one of the most vital raw materials for animal feed production and biofuels [2]. Therefore, the need to advance research on essential agricultural knowledge such as soils, irrigations, and fertilizers is essential as they have influence on maize yields [3].

Soils and irrigations are very important agricultural inputs and are interoperable with each other as amount of irrigation's water or methods to apply on maize would be determined by the soils type [4]. When moisture or rainfall is not adequate, the plants require additional water from irrigation. However, an increasing or decreasing level of appropriate irrigation water to maize crop will inadvertently has implication on the crop yield Hazman [5]. More so, precision irrigation knowledge forms a significant factor in terms of crop yields [6]. But retrieving these heterogeneous agricultural knowledge from the existing information retrieval systems, and the ambiguities of natural language become a challenge. Thus, the need to implore a top-notch data modeling technique is inevitable. Consequently, ontology as a data modeling approach is exploited in this research because of its potentiality to adequately represent complex knowledge. This would inadvertently make the knowledge more meaning to researchers and other agro-allied stakeholders [7, 8].

Several literature proves ontology as a reliable mechanism in providing solutions to the ambiguities of natural languages. Ontologies largely utilize semantic Web's technologies for modeling [9]. Ontology is an explicit and formal specification of shared conceptualizations [10]. The definition is key because it portrays ontology as a semantic data modeling technique for developing knowledge systems in the area of information system, information management, and natural language processing [11, 12]. Gruber categorized ontology into four types considering the scale of details. These are: upper-level ontology, domain ontology, task ontology, and application ontology [11]. Thus, this research focuses on application ontology [12], which is the combination of domain and task ontologies. Domain ontology models a given knowledge area taken its semantic expressivity into consideration. Task ontology models the define activities in form of competency questions (CQs) in addition to the modeled concepts of domain ontology in axioms and rules.

Furthermore, ontology design is premised on methodology [13] and implemented using knowledge representation tools of languages and editors [14]. The importance of soils and irrigation knowledge to any crop and more importantly, to a foremost leading cereal crop such as maize cannot be over estimated. However, lack of structured repositories affects the quality of information retrieval. Therefore, this research work is motivated to ontologically model a repository for the crop but considering soils and irrigations data based on the adopted revised six-step iterative ontology methodology [15]. The methodology is implemented using Web Ontology Language (OWL2)'s RDF/XML syntax on protege5.5.0 edition. In addition, the total CQs collected via questionnaire were studied and 44 CQs finally validated by the domain experts; 24 soils knowledge and 20 for irrigation knowledge. First-order logic (FOL) was exploited to model the CQs, and Semantic Web Rule Language (SWRL) formally encoded the rules in machine represented formats. The remaining sections of this paper are organized as follows: Sect. 2 presents the related studies and Sect. 3 presents the adopted ontology engineering process for SIMcOnto. The modeling of the ontology is contained in Sect. 4. While Sect. 5 discusses the results, Sect. 6 concluded the work along with some suggestions for further work.

2 Related Works

As earlier stated, this research work concentrates on model soils and irrigations knowledge of maize crop ontologically. This is because maize is a sensitive crop to both moisture stress and extreme moisture. The importance of irrigation water generally in agriculture is key, for instance, in China, irrigation forms the main source of water for agricultural advancement [15]. This is because appropriate irrigation water to appropriate crop and soil increases the crop yields [16]. This section partly considered similar subject area as related studies along with their methodologies and tools. In the quest for an improved decision support system, the research work of [17] examined three different decision modeling systems which include Decision Modeling Ontology. The work acknowledges the strengths of ontology-based decision support systems in providing excellent data structures, for encoding complex decisions. However, the work submitted that none of the three different systems reviewed suitable for improved irrigation decision making. In order to improve on their limitations, suggested requirements for future studies include concise definitions of ontological concepts' relationships and improvement on logical representations of the systems. Incidentally, these suggestions form the core goals of this paper.

The research work of [18] aimed to semantically model knowledge from the given heterogeneous dataset. The work specifically designed hilly citrus ontology considering three thematic areas, which include fertilizers and irrigations. TopBraid-Composer editor was used to encode the ontology in RDF triple representation. The ontology developed is a decision support because competency questions which serve as input strings were query via SPARQL. However, ambiguities of natural languages (especially, synonyms) still create a research gap. The work of Hazman [5] proposed an ontology-based expert system for crop irrigation schedules. However, it is not encoded in machine represented language. Therefore, the semantic strengths of the proposed system cannot be ascertained. In furtherance to literature, the work of [19] developed irrigation-based ontology with the goal to serve as educational guide for assisting small-scale farmers on the essential values of irrigation. The ontology was created using a graph-based ObjectEditor following the Noy-McGuiness methodology. However, the ontology representation editor is highly limited in terms of knowledge representation capacity. Consequently, the proposed system is limited in terms of reasoning capability.

More so, the literature of [20] similarly presents ontology as efficient technique for data modeling. The work is motivated to provide solution to the complex data as that of agricultural entities for effective retrieval of information. Nevertheless, in order to achieve a better result, semantic similarity algorithm is required to interface with lexical database, such as WordNet. Thus, this research work takes into consideration concise definitions of ontological concepts' relationships encoded in a more expressive machine represented language. Besides, word mismatch issues of synonyms and polysemy would also be given attention on the aspect of information retrieval algorithm.

3 The Iterative Ontology Engineering Process

In every ontology design whether from scratch or reuse practice, a set of lay down procedures is expected to follow by developers. Therefore, as earlier stated, the proposed SIMcOnto is designed based on the six-step iterative engineering principle. They are as follows: collection of domain knowledge, specification of ontology's terminologies, defining competency questions based on domain, ontology formalization, ontology evaluation, and ontology evolution.

In this research, the domain knowledge include *maize/corn* along its relationship with *irrigations* and its methods (*surface, drip, and sprinkler*). Besides, soil condition and soil factors with the relationship to *maize* and *PreciseIrrigation* were part of knowledge collected and duly validated by domain specialists. The knowledge was collected from authoritative research articles and trusted online sources and relevant institutions. Then, to the next step (terms specification), the collected and validated terms from the initial step are specified into the three building blocks of OWL by leverages on the middle-out strategy of identifying terms. That is, the terms are specified into classes, properties (object and data), and individuals. A total number of 114 competency questions (CQs) was initially collected via questionnaire. In the end, after much validation by the team of the domain experts, it was reduced to 44 CQs. This is a very key step in this work in that, spontaneous validation of ontology even in the process of design is achieved. Table 1 presents some sample of CQs designed by domain experts and modeled by the developers using FOL-based axioms.

The terms specified and CQs represented in FOL are formalized using the most expressive ontology representation language OWL2 DL based on RDF/XML syntax and SWRL, respectively, of protégé 5.5.0 full version. The likely errors of ontology's contents and construction are detected and corrected at the validation/evaluation activity. While a Java-based reasoner, HermiT 1.4.3.456 was implored to check the consistency of the ontology, domain experts were equally involved in validating

Table 1 Machine represented CQs

Competency Questions (Informal CQs)	Semantic Web Rule Language (SWRL)—Formal	Semantic Query-Enhanced Web Rule Language (SQWRL) of the CQs	Output
What are the appropriate soils can maize irrigation be carried out?	Soils(?s)^MaizeCrop(?c)^ withHigher NutrientAndMoistureHoldingAre BetterIrrigatedFor(?s, ?c) ->areMore AppropriateToBeIrrigatedFor(?s, ?c)	Soils(?s)^MaizeCrop(?c)^ with HigherNutrientAndMoisture HoldingAreBetterIrrigatedFor(?s, ?c) ->areMoreAppropriateToBeIrrigated For(?s, ?c)^ sqwrl:select(?s)	Clay Loam soil Loamy soil
Which soil is required for maize cultivation?/What is the best soil recommended for maize?	Soils(?s)^SoilOrganicMatter(?o)^Soil Nutrient(?n)^ClaySandSiltQuantity(?q)^Loamy(?l)^Maize(?m)^Maize Growth(?g)^MaizeYield(?y)^thatIs VeryRichInHumus(?s, ?o)^ thatHas AdequateNutrient(?s, ?n)^ thatHas BalanceProportionOf(?s, ?q) ->may BeDescribedAs(?s, ?l) ^ guarantee More(?l, ?y) ^ guaranteeMore(?l, ?g)^ isRequiredToGrow(?l, ?m) ^ isTheBestSoilToGrow(?l, ?m)	Soils(?s). sqwrl:makeSet(?s1, ?s). sqwrl:size(?dd, ?s1)^SoilOrganic Matter(?o)^SoilNutrient(?n)^ClaySandSiltQuantity(?q)^Loamy(?l)^Maize(?m). sqwrl:makeSet(?s2, ?m). sqwrl:size(?ddd, ?s2)^thatIs VeryRichInHumus(?s, ?o)^ thatHasAdequateNutrient(?s, ?n)^ thatHasBalanceProportionOf(?s, ?q) - > isTheBestSoilToGrow(?s, ?m) ^ sqwrl:select(?s)	Loam
What are the climatic conditions that can affects the numbers of irrigation on maize crop?	Irrigation_Numbers(?i)^ Climatic Condition(?c)^ mayDetermineThe NumbersOf(?c, ?i) ->affectsThe NumbersOfIrrigation(?c, ?i)	Irrigation_Numbers(?i)^ Climatic Condition(?c)^ mayDeter mineTheNumbersOf(?c, ?i) -> sqwrl:select(?c)	Windspeed Sunlight Humidity Moisture

the results roll out by the ontology. Besides, some assume synonyms entities of hyponymy and hypernymy along with relation concepts such as meronymy and holonymy which were theoretically evaluated to ascertain the semantic correctness of ontology's content. However, the research is still work in progress, when completed experimental evaluation based on ontology's structure and CQs serving as input string would be carried out. Finally, since reusability forms a salient principle of ontology, it implies that ontology's contents must be evolved and dynamic. That is, the last activity of this process is proposed to autonomously recognize and add relevant term(s) of CQs input string to the ontology file which is/are presupposed not in the initial file. Therefore, this novel idea would be achieved at the completion of this entire research work based on the proposed intelligent algorithm.

4 Modeling the SIMcOnto Ontology

The soils and irrigation knowledge of Maize Crop Ontology which is dubbed as SIMCOnto ontology in this research is formally expressed as

SIMcOnto = (owl:Thing $\cup S_k \cup I_k \cup M_k$) where owl:Thing is the default class, S_k stands for the soils knowledge, I_k represents the irrigation knowledge, and M_k denotes knowledge about the maize crop itself. Each of these knowledge is further expressed as S_k, I_k, or $M_k = \{T_C \cup S_C\}$where T_C and S_C denote taxonomy and semantic components, respectively. Consequently, SIMcOnto is expressed as {owl:Thing $\cup$ $T_C \cup S_C\}$. T_C is defined as $\{C, I, P\}$ note $P = (P_o, P_d)$. C is set of classes as $\{c_1, c_2, c_3,$ $\ldots c_{n,}$ $c_{n+1}\}$, I stands for Individual which is/are terminal(s) set of c. that is, $c_x = \{i_0,$ $i_1, i_2, \ldots i_n\}$ $n \geq 0$. P denotes Property both Object Property (P_o) and Data Property (P_d). $P_o = (c, r, c,)$ or $(i, r, i,)$ that is, (class, relation, class) or (individual, relation, individual). For example, *MaizeCrop requiresIrrigation Irrigation* where *MaizeCrop* and *Irrigation* are classes, and *requiresIrrigation* is a relation (P_o). $P_d = (c_d, i_d)$ that is, (class data property, individual data property). For example, class *MaizeCrop hasRoot*; therefore, *hasRoot* is P_d specifically, c_d. Similarly, S_C is defined as S_C = {CI, CC}, where CI stands for contextual information derived from competency questions that form the axioms and rules. CC denotes Concept's Constraints such as transitive and functional characteristics of object property. Figure 1 shows the conceptual framework of the application-based ontology SIMcOnto which consist of $\{T_C \cup S_C\}$.

The processes of modeling the taxonomical components of the ontology ranges from collection of the domain knowledge to the design of domain ontology as shown in Fig. 1. Data were collected from consistent research materials, trusted institutes such as CMMYT and IITA. In order to specify the required terminologies, middle-out approach is exploited; it identifies the most important concepts first and then generalized or specialized into other entities. The specification of the terms is classified into three categories such as classes, properties (Prop), and individuals (Ind) considering the OWL knowledge representation used in this research. Thus, T_C which is the domain ontology is modeled. However, to make the ontology a task based, *S*c

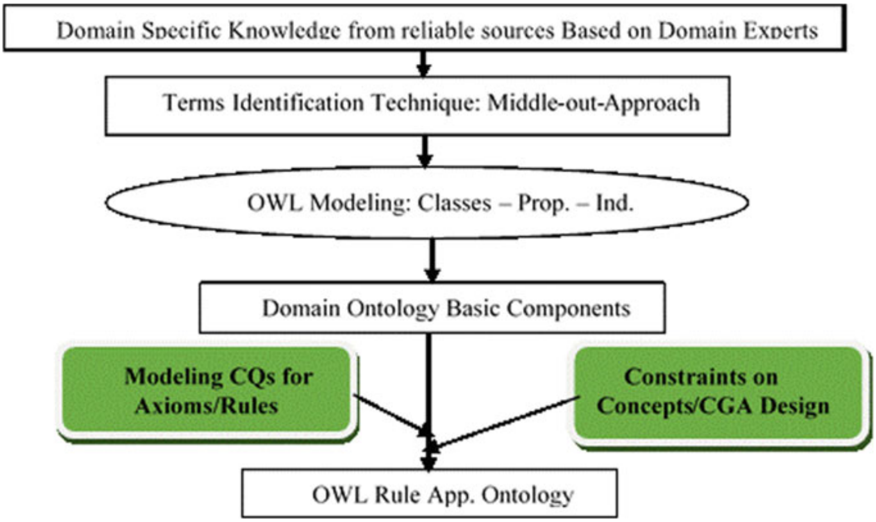

Fig. 1 Conceptual framework of the ontology design

which consists of contextual information from competency questions that form the axioms and rules, and Concept's Constraints such as transitive characteristics of object property were modeled to finally yield the application-based ontology.

First-order logic is implored to model the competency questions as rules and implemented in SWRL. For example, CQ: *Can MaizeCrop be grown in any soil*? The contextual information that enable semantic expressivity of this question include good soil nutrients and availability of suitable fertilizer. Thus, this is formally modeled in FOL as

$$\forall X \forall Y : \mathrm{Soil}\ (Y) \wedge \mathrm{Maize}(X) \Rightarrow \mathrm{Crop}(X) \Rightarrow \mathrm{can\_be\_grown\_in\_any}(X, Y) \wedge (\exists X)(\exists Y)(\mathrm{Maize\_Yields}(X)) \wedge \mathrm{Soil\_Types}(Y) \Rightarrow \mathrm{depends}\ (X, Y)(\exists Y)\ (\mathrm{Maize\_Crop}(Y)) \wedge (\forall X)(\mathrm{Soils}(X)) \wedge (\exists X)\ (\mathrm{GoodSoilFertility} \wedge \mathrm{AppropriateSoilTexture} \wedge (X)) \Leftrightarrow \mathrm{Loamy\_Soil} \Rightarrow \mathrm{guaranteeMoreYields}(X, Y)$$

Furthermore, CQs after modeled in FOL, they were similarly encoded in machine understandable language (i.e., SWRL). Table 1 presents examples of the machine represented format and as well query with SQWRL.

From Table 1, the CQs are informal because they are formulated in natural language; thus, column2 of the Table represents the sample CQs in machine understandable form (SWRL). Consequently, they were query using SQWRL and the expected results as validated by experts are shown by the fourth column as output. Evidently, the theoretical outputs are verified by the results shown in the next section.

Some of the primary concepts of the ontology modeled are *MaizeCrop* with class *Crop* as hypernym, *Irrigation, Irrigation_Methods, Soils, SoilQualityMetricss* as evidently shown in Fig. 2. All the primary concepts are subclasses to the main super class *owl*:*Thing*. Each of the core concepts has subclasses along with individuals. For example, *Irrigation_Methods* has subclasses as *Dripirrigation* or *TrickleIrrigation,*

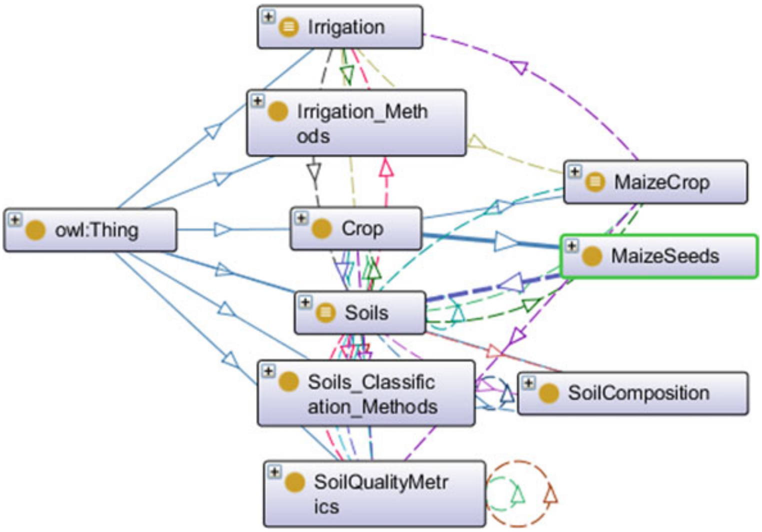

Fig. 2 Ontology's main entities

and *SurfaceIrrigation* where *Basin, Border,* and *Furrow* are equally subclasses of Surface Method. Every class has individual(s). In this ontology, class *MaizeSeeds* has *ImprovedSeed and LocalSeed* as part of its instances as shown in Fig. 3. As stated earlier, this research ensures to firmly establish rules and axioms of the ontology. For instance, the ontology's concept *MaizeCrop* forms relationship to concepts *SoilCondition* and *SoilPreparation* through the object property ***requires*** with an inverse property ***enriches***. The example is modeled as transitive in that if MaizeCrop *requires* SoilCondition and SoilCondition *requires* SoilPreparation it then implies that MaizeCrop equally *requires* SoilPreparation. Some other axioms that have been defined in the ontology are: *SoilFertility* ***influences****MaizeYields* with an inverse of ***isAffectedBy***. *Irrigation_Number* **isDeterminedBy***Maize_Growth_Phase and SoilsType.* The concept irrigation in this research work refers to *Precise_Irrigations* as class. Besides, datatype properties such as double, integer, and string were modeled for some entities of SIMcOnto. For instance, SoilTypes were declared as String, while Irrigation_Numbers were defined as Integers.

Similarly, the issues of concepts' synonyms were equally modeled. Some of the examples are as follows:

- increases $\equiv$ improve $\equiv$ boost: this is a relation (object property)
- SoilAcidity $\equiv$ Soil_PHvalues $\equiv$ Soil_Reaction: these are equivalent classes
- Drip_Irrigation $\equiv$ Trickle_Irrigation $\subseteq$ Precise_Irrigation: another equivalent classes but a subclass to class Precise_Irrigation.

In the like manner, the General Class Axiom (GCA) was equally exploited to proffer solution to the issue of entity synonyms. An example is shown as follows:

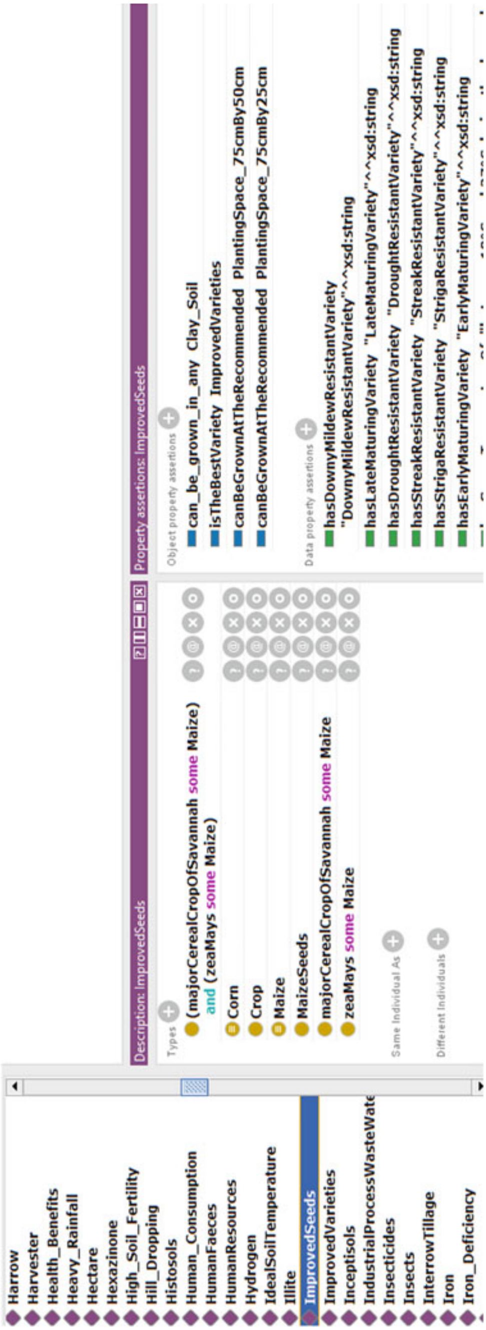

Fig. 3 OWL classes' instances and properties

((compositionOfSprinklerAndWaterSource some Irrigation) and (Watering-CanOrPumpingMachine some Irrigation)) SubClassOf Irrigation.

This axiom simply explains that, apart from entity *Soils* which is also synonymously modeled as *Edaphic_Requirement* in the SIMcOnto, any given corpus with index terms of sand, clay, silt, or organic_matter may likely be considered as document that contains soils' information. Therefore, with all these techniques, the issue of shortage to recall appropriate information is mitigated.

Figure 2 presents the graphical representation of the core classes of the ontology modeled as OntoGraf. Similarly, Fig. 3 shows instances of classes.

From Fig. 3, instance *ImprovedSeeds* highlighted in blue color is an individual of class MaizeSeeds. The class belongs to the same family of Crop as Maize/Corn/Zeamays appear at the center of the figure while the right side of the figure represents the object property and data property of the instance, respectively.

5 Results and Discussion

After the modifications to the formal CQs, that is, the antecedent and consequent of the SWRL are modified to SQWRL pattern, query executions were carried out. Drool engine is responsible for the query execution, and results were obtained from the ontology files of SIMcOnto. All the validated 44 CQs were executed, and the corresponding results were obtained. However, not without some wrong results but they are very minimal. For example, *Soil_Seprates* was displayed as part of the results of the CQ that asked for types of soils. Figures 4 and 5 present the snapshots of the results of the second and third CQs of Table 1.

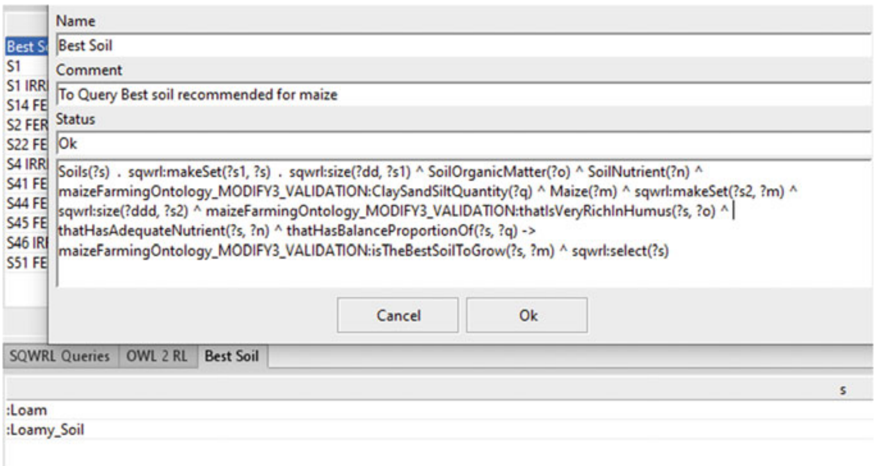

Fig. 4 SQWRL output for query named best soil

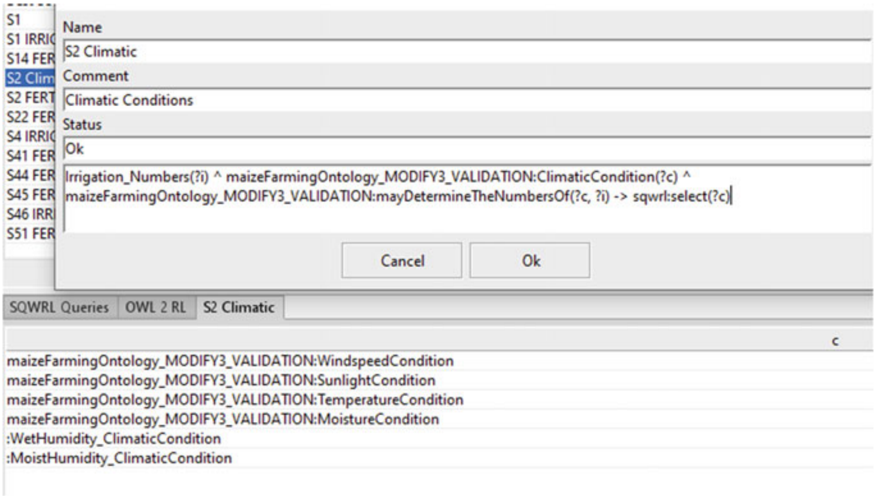

Fig. 5 SQWRL output for query named S2 climatic

The drool engine as shown at the bottom of Fig. 4 returns output *Loamy_Soil* or *Loam*. The rationale of the output is that concept *Loam* stands for type of soil, while concept *Loamy_Soil* is explicitly defined all in the ontology files. The maizeFarmingOntology_MODIFY3_VALIDATION serves as the prefix of this ontology.

Figure 5 represents the output of query code named S2 Climate which is the third CQ of Table 1. SIMcOnto returns *WindspeedCondition, SunlightCondition, Temperature, Moisture, and WetHumidity*. However, *MoistHumidity* is an equivalence of *WetHumidity* where only one is expected to return. Furthermore, SIMcOnto's structural evaluation is in progress where comparison is expected to be carried out against the 1413 OWL ontologies from swoogle based on the eight popular metrics. Besides, the effectiveness of the CQs results is also evaluated.

6 Conclusion and Future Work

In this research work, with the aid of the adopted ontology engineering principle and the conceptual framework, SIMcOnto is designed. All the entities of the ontology are hyponymy to the root class owl:Thing. SIMcOnto consists of soils and irrigation knowledge for maize crop as domain. It is an OWL rule-based application ontology in that the domain ontology is designed with OWL and the set of CQs validated by the team of the domain experts is formally represented in FOL. Consequently, SWRL was exploited to encode the formal representations as rules in protege5.5.0 full edition, and finally, query of the ontology's repository is executed with the drool engine of SQWRL. More so, the current metrics of the proposed SIMcOnto consists of 1746 axioms and 216 classes in addition to owl:Thing. Total individuals presently stood at 386, 88 object properties include the root propertyowl:topObjectProperty and 104 data properties include owl:topDataProperty. Query executions have been carried out on the validated 44 CQs in this work and results evaluation is in progress.

Therefore, SIMcOnto helps to achieve the goal of structured knowledge management for the domain. In other words, the issue of word mismatch (specifically, synonyms) for the knowledge area is fairly addressed. However, the research is still work in progress because fertilizers and other important knowledge of maize crop identified by the domain experts would be integrated into the ontology file of SIMCOnto. In the end, structural evaluation based on the eight metrics and CQs-based evaluation will be carried against the existing 1413 OWL-based ontologies from swoogle. Currently, a Java-based graphical user interface is being developed to enable end users input string query as CQ in natural language where expected results in terms of precision and recall will be outputted. Similarly, interested researchers can consider an enhanced data source (WordNet) owing to its terms inflection defect to achieve improved results as a result of ambiguity nature of natural language.

References

1. Vincent, P.L.D., Coe, E.H., Jr., Polacco, M.L.: Zea mays ontology—a database of international terms. Trends Plant Sci. **8**(11), 17–520 (2003)
2. Egidijus, S., Sidona, B., Laura, M., Kestutis, R., Dovile, A., Antanas, S.: Energy balance, costs and CO_2 analysis of tillage technologies in maize cultivation. Energy, 1–9 (2014)
3. Suresh, P., Mohamed, A.S., Jens, L.: Ontology based data access and integration for improving the effectiveness of farming in Nepal. In: International Joint Conference on Web Intelligence (WI) and Intelligent Agent Technologies (IAI), vol. 02, pp. 319–326 (2014)
4. Fang, J., Su, Y.: Effects of soils and irrigation volume on maize yield, irrigation water productivity, and nitrogen uptake. Sci. Rep. **9**(1), 7740 (2019)
5. Hazman, M.: Crop irrigation schedule expert system. In: 2015 Thirteenth International Conference on ICT and Knowledge Engineering (2015)
6. Goumopoulos, C., O'Flynn, B., Kameas, A.: Automated zone-specific irrigation with wireless sensor/actuator network and adaptable decision support. Comput. Electron. Agric. **105**, 20–33 (2014)
7. Bonanci, R., Nabuco, O.F., Junior, I.P.: Ontology models of the impacts of agriculture and climate changes on water resources: scenarios on interoperability and information recovery. Future Gener. Comput. Syst. (2016)
8. Kaushik, N., Chatterjee, N.: A practical approach for term and relationship extraction for automatic ontology creation from agricultural text. In: International Conference on Information Technology (2016)
9. Li, D., Kang, L., Cheng, X., Li, D., Ji, L., Wang, K., Chen, Y.: An ontology-based knowledge representation and implement method for crop cultivation standard. Math. Comput. Model. **58**, 466–473 (2013)
10. Shadbolt, N., Berners-Lee, T., Hall, W.: The semantic web revisited. IEEE Intell. Syst. **21**(3), 96–101 (2006)
11. Gruber, T.R.: A translation approach to portable ontology specifications. Knowl. Acquis. **5**(2), 199–220 (1993)
12. Uschold, M., Grüninger, M.: Ontologies: principles methods and applications. Knowl. Eng. Rev. **11**(2), 93–137 (1996)

13. Gomez-Perez, A., Fernandez-Lopez, M., Corcho, O.: Ontological Engineering: With Examples from the Areas of Knowledge Management, e-Commerce and the Semantic Web. Springer, Berlin (2004)
14. Aminu, E.F., Oyefolahan, I.O., Abdullahi, M.B., Salaudeen, M.T.: A review on ontology development methodologies for developing ontological knowledge representation for various domains. Int. J. Inf. Eng. Electron. Bus. **2**, 28–39 (2020)
15. Allemang, D., Hendler, J.: Semantic Web for the Working Ontologist: Effective Modeling in RDFS and OWL. Elsevier (2011)
16. Feng, G., Zhang, Z., Wan, C., Lu, P., Bakour, A.: Effects of saline water irrigation on soil salinity and yield of summer maize (Zea mays L.) in subsurface drainage system. Agric. Water Manage. **193**, 205–213 (2017)
17. Tian, D., Zhang, Y., Mu, Y., Zhou, Y., Zhang, C., Liu, J.: The effect of drip irrigation and drip fertigation on N_2O and NO emissions, water saving and grain yields in a maize field in the North China Plain. Sci. Total Environ. **575**, 1034–1040 (2017)
18. Car, N.J.: USING decision models to enable better irrigation decision support systems. Comput. Electron. Agric. **152**, 290–301 (2018)
19. Wang, Y., Wang, Y., Wang, J., Yuan, Y., Zhang, Z.: An ontology-based approach to integration of hilly citrus production knowledge. Comput. Electron. Agric. **113**, 24–43 (2015)
20. Song, G., Wang, M., Ying, X., Yang, R., Zhang, B.: Study on precision agriculture knowledge presentation with ontology. AASRI Procedia **3**, 732–738 (2012)