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MaCOnto: A robust maize crop ontology based on soils, fertilizers and irrigation knowledge

Enesi Femi Aminu [a,*], Ishaq Oyebisi Oyefolahan [b], Muhammad Bashir Abdullahi [a], Muhammadu Tajudeen Salaudeen [c]

[a] Department of Computer Science, Federal University of Technology Minna, Nigeria
[b] Department of Information & Media Technology, Federal University of Technology Minna, Nigeria
[c] Department of Crop Production, Federal University of Technology Minna, Nigeria

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ABSTRACT

The demand for relevant information in a timely manner portrays the significance of knowledge management in all areas of lives; for instance, agriculture. To this end, soils, fertilizers and irrigation as agronomic concepts are essential knowledge inputs for any crops, such as maize. Conversely, there is always difficulty in timely retrieval of these relevant information owing to the unstructured nature of data in repositories, and complexity of concepts mismatch. Sequel to this development, ontology, a semantic data modeling technique is promising as it has been recently employed to deal with these challenges across different domains. However, the robustness of ontology, in terms of semantic expressivity of hidden knowledge, and autonomous growth of ontology leave some gaps to contend with. In view of this development, this research aims to design a robust OWL Rule based ontology for maize crop domain by considering primarily soils, fertilizers and irrigation agronomic concepts capable to evolve autonomously. The proposed ontology herein christened *MaCOnto*, is developed using the adapted six steps ontology-engineering principle. Over 1,430 entities are encoded in OWL; eighty Competency Questions (CQs) validated by domain experts are modeled in FOL, and implemented as rules via SWRL. Thus, the ontology is queried by SQWRL. Besides, the novel algorithmic design for the ontology to autonomously evolve is implemented in Java environment by employing WordNet. The results obtained from structural based evaluation show an outstanding performance across the eight metrics. Similarly, the results of the competency-based evaluation are also promising. Therefore, the proposed *MaCOnto* is a robust application based ontology capable to infer and responds to user's query based on its contextual information.

1. Introduction

Maize (*Zea mays* L.), widely referred to as corn is arguably one of the economic viable cereal crops. While, in most developing nations, maize serves as staple food like rice or wheat (Badmus & Ariyo, 2011); in developed climes, it serves as feed for animals and also a significant raw materials for production industries; such as biofuels energy (Šarauskis et al., 2014). Therefore, considering these aforementioned importance of the crop, the rationale for its choice as knowledge domain in this research is justified. More so, according to Food and Agriculture Organization of United Nations (FAO), Soils, Fertilizers and Irrigation knowledge are essential agricultural inputs for any crop, and specifically, maize. Soils type for maize crop may determine the choice of irrigation's method; as amount of moisture or irrigation water affects the growth of maize (Fang & Su, 2019; Hazman, 2015; Mohanraj et al., 2018). Similarly, the nature of nutrient presence in soil also determines the volume and ingredient of fertilizers to apply (Ding et al., 2010). These scenarios partly formed the competency questions considered in this research. The Consultative Group on International Agriculture Research (CGIAR)' proposal of 2017 – 2022 carried on maize crop, reported the important of soils on the crop's growth. Similarly, fertilizer as an essential input of crop is described according to FAO as next to water. It is mostly available in various contents and ingredients for example, nitrogen, phosphorus and potassium. More so, when there is inadequacy of rainfall or moisture, an alternative water source – irrigation becomes indispensable; more importantly, precision irrigation is required for the crop (Goumopoulos et al., 2014).

No doubt that in this present age, the availability of all these

* Corresponding author.
E-mail address: enesifa@futminna.edu.ng (E.F. Aminu).

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knowledge about maize crop is not a challenge any longer; but to retrieve the relevant information in a timely and easier manner forms the challenge. This research problem is attributed to the unstructured nature of repositories and heterogeneous forms of data (Agyapong-Kodua et al., 2013; Bonacin et al., 2016; Walisadeera et al., 2015). Besides, the ambiguity nature of natural languages in terms of synonyms and polysemy contributed to the problem of concepts mismatch (Fawei et al., 2019). Hence, based on literature, ontology as a top-notch technology has proven to proffer solution across different knowledge areas. Ontology, a semantic data modeling technique is defined according to Gruber (1993) as an explicit and formal specification of shared conceptualizations. Gruber also described ontology in four different forms. An ontology design based on a particular domain is described as domain based ontology. However, such ontology can be further modeled to perform certain defined activities via set of complex or technical questions called Competency Questions (CQs). Thus, such modified domain ontology is regarded as task ontology (Li et al., 2013); which may be otherwise known as application ontology (Park et al., 2012). Top-level ontology is generic in nature, because it does not necessarily conform to a particular knowledge area.

To design a deep represented ontology, Web Ontology Language (OWL) (Alkhammash, 2020), which is a knowledge representation language with high power of semantic expressivity is required. Besides, making ontology to be rule based by way of using Semantic Web Rule Language (SWRL) (Tang et al., 2018), significantly contributes to a huge effort desired for robust ontology. Consequently, OWL Rule (González et al., 2021) based ontology would be achieved. More importantly, the robustness of ontology could be further defined based on the level of Competency Questions (CQs) formulated and appropriately modeled by First-Order-Logic (FOL) (Alvez et al., 2017). In the end, Protégé (5.5.0) (Nandhinidevi et al., 2021), an ontology development application and editor has the required capacity to develop such level of ontology.

More so, the use of WordNet, a lexical database similar in structure with ontologies (Jarrar, 2021), is promising. This is to achieve robustness of the proposed ontology in terms of providing mechanism for the autonomous evolution. It is a lexical resource considered to be one of the global largest word collection corpuses that offers hierarchical structure of Synset (set of one or more synonyms), and semantic properties of every word (Chakravarthi et al., 2018; Uthayan & Mala, 2015). Thus, synonymy, antonymy, meronyms, hypernyms and hyponyms are examples of WordNet's semantic relations (Alobed et al., 2021).

Therefore, this research aims to design an OWL Rule based application ontology for maize crop considering primarily soils, fertilizers and irrigation knowledge christened herein as MaCOnto. Other knowledge partly considered as validated by the domain experts include climatic conditions, maize's pest and weeds treatments. This research is an extension of an earlier published works on ontology designed for soils and fertilizers knowledge of maize crop (Aminu et al., 2019); and SIMCOnto: an ontology designed for soils and irrigation knowledge of maize crop (Aminu et al., 2021b). The domain part of the proposed MaCOnto is represented in OWL DL using protégé 5.5.0 based on the adapted six steps iterative ontology engineering principle (Aminu et al., 2020). The tasks part consists of eighty (80) CQs validated by experts, modeled using First-Order-Logic (FOL) and implemented via Semantic Web Rule Language (SWRL). In addition, the robustness of the ontology equally lies on the novel algorithmic design for its autonomous evolution leverages on WordNet. Similarly, robustness of ontology can be determined based on its performance level of evaluation. One of the promising evaluation techniques to validate the robustness is the structural based evaluation with its eight metrics (Sicilia et al., 2012). Therefore, MaCOnto is adjudged to be robust owing to the results from the evaluation.

The remaining sections of this paper are organized as follows: Section 2 presents some related literature of the domain under consideration; and Section 3 presents the ontology engineering process. The proposed MaCOnto framework, and development of the ontology are accounted for in both Sections 4 and 5 respectively. While Section 6 discusses the results; conclusion and suggested future work are presented in section 7.

2. Related studies

The research proposal of CGIAR on maize, which described the crop as C4 (Abdelgawad et al., 2021) crop hypothetically said that maize has a higher yield potential than rice and wheat. This is because it can grow across all seasons; it was projected to be the leading crop in year 2020. However, similar to any other knowledge areas, to retrieve relevant knowledge related to maize poses challenges as a result of unstructured data representation and the deficiency of retrieval mechanisms (Aminu et al., 2021a; Fawei et al., 2019; Tulasi et al., 2017). In view of this, this section accounts for how ontology has been explored for knowledge representation and retrieval system; the challenges and future.

Wimalanathan et al. (2018) implored a sequence based methods to produce a functional annotation of maize protein coding genes based on Gene Ontology (GO) (Ontology Gene Consortium, 2019) entities allocation. Primarily, the study aimed at improving maize annotation of the existing phytozome and Gramene maize GO annotation set (Wimalanathan et al., 2018). However, the maize protein coding genes are structured as taxonomy classification system with metadata. It lacks semantic knowledge representation techniques; that is, no aspect of ontology modeling is considered in the classification system.

The research work of Vincent et al. (2003) designed *zea mays* plant structure ontology database with the aid of Directed Acyclic Graph (DAG) Edits (Landgrebe, 2022) to aid knowledge sharing in terms of botanical terms classification along with abbreviated synonyms of terms. The plant ontology designed by the researchers (Vincent et al., 2003) may be described as database for terms classification. In other words, concepts relationship were not explored based on inference. In the crop ontology of Shrestha et al. (2016) whose aim is to collect validated terms on anatomy, structure and phenotype of crops also with their relationship concepts; developed maize trait ontology as one of the crops using OBO-Edit (Karray et al., 2021). The research reported the significance of ontology to depict agronomic phenotypes terms as it offer structured data and thus enhance the retrieval of information. However, the ontology editor is no doubt limited in semantic expressivity; since the OBO-Edit version does not supports OWL knowledge representation. Therefore, the ontology output is deficient of formal computational definitions to other semantic based knowledge representations for effective information retrieval. Also concepts on soils formed less than five entities; knowledge on irrigations was not modeled. Similarly, the work of (Green et al., 2011) designed ontology by considering the retrieval of mutant phenotype information of maize gene only.

Furthermore, the research of Ma et al. (2013) developed reasoning based ontology to diagnose maize diseases with the aid of OWL DL and Semantic Web Rule Language as maize diseases knowledge representation language and rule language respectively. However, the ontology developed is not pivoted on any defined methodology; and the maize information is limited to disease only. Similarly, Cao et al. (2013) equally developed maize's diseases diagnostic model based on ontology and algorithm for diagnosis. It is solely a domain-based ontology.

The knowledge of appropriate soils, fertilizers, irrigation or any agricultural inputs to an appropriate crop has been giving research attentions in a recent time by employing ontology, semantic data modeling technique to develop decision based system (Chougule et al., 2019). Similarly, Car (2018) equally modeled a decision based ontology for irrigation knowledge. The researcher aimed to improve the decision system by paying attention to the concise relationship among the entities of the ontology. Malik et al. (2018) developed ontology for the domain of agriculture but considering fertilizer knowledge. The researchers anticipate in future integrating the knowledge with other related domain such as soils. More so, owing to the significance of soils knowledge in agriculture, the research work of (Heeptaisong &

Shivihok, 2012) designed an ontology based on soils domain to assist users in processing relevant information.

In furtherance to the literature, the work of Cornejo et al. (2005) developed irrigation-based ontology aims to serve as learning guide for subsistence farmers. Following the Noy-McGuiness approach, the ontology was designed using a graph based ObjectEditor (Tsiakmaki & Hartonas, 2013). However, the editor for the ontology is highly restricted for complex knowledge representation. Consequently, the proposed system is limited in terms of inference capability. The hilly citrus ontology designed by Wang & Wang (2018) focuses on three heterogeneous knowledge which include irrigation and fertilizers. It was developed using TopBraidComposer editor (Khondoker & Mueller, 2010) in the syntax of RDF and query in SPARQL. Considering the RDF technology, the ontology is limited to make detail semantic inferences.

Finally, the research work of Aminu et al. (2019) modeled soils and fertilizers knowledge of maize crop ontologically based on the adopted methodology. However, the ontology developed did not consider verified CQs of the knowledge; and even though Hermit reasoner (Romero et al., 2012) validated the ontology, the overall performance was not evaluated. Similarly, Aminu et al. (2021b) equally designed an OWL Rule based ontology dubbed *SIMcOnto* by considering soils and irrigation knowledge for the same crop. The same ontology development approach was explored considering it potentials to address complex questions and ontology evolution. However, the ontology was not evaluated to show its efficacy against the set standard of ontology content and construction evaluations. In conclusion, ontology can be adjudged as an effective semantic data modeling technique for complex knowledge representation such as agriculture domain Song et al. (2012).

Hence, the proposed application based ontology (MaCOnto) considered maize crop along with the essential agricultural inputs such as soils, fertilizers and irrigations, which are interoperable agronomic concepts. Similarly, unlike other review works in this section, the ontology is developed based on hybridized methodology, which uniquely includes the autonomous growth of the ontology. More so, the ontology is adjudged to be robust based on the satisfactory results of the evaluations.

3. The MACOnto's ontology engineering process: the methodology

Every standard ontology is developed based on a given engineering processes called methodology, which is similar to the iterative software development approaches. There are numbers of ontology development methodologies, but there is no standard or single correct methodology for ontology design (Kapoor & Kapoor, 2014; Noy & Mcguinness, 2001; Walisadeera et al., 2015). Consequently, this research adopted the hybridized six steps iterative ontology design process shown in Fig. 1. The steps are collection of domain knowledge, terms specification of ontology, setting out competency questions, ontology formalisation, ontology evaluation, and ontology evolution (Aminu et al., 2020).

The six activities (or steps) of harmonized Gruninger–Fox,

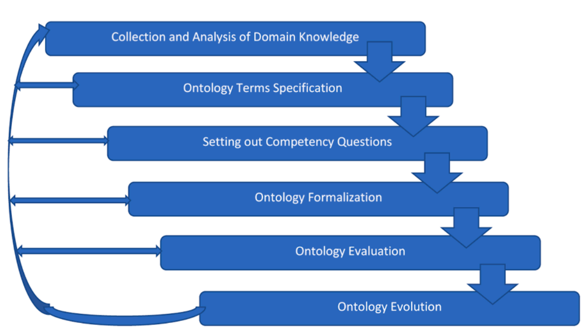

Fig. 1. Ontology Development Methodology.

Methontology and FAO based methodologies in Fig. 1 are described as an iterative ontology engineering process. This is because developer can easily loop back to any earlier implemented step if defect is noticed at any step. Therefore, the methodology for the development of the ontology (MaCOnto) is explained by the following steps. i. The first step in the development of MACOnto is the collection and analysis of domain knowledge; in this case, knowledge about maize crop itself, soils, fertilizers and irrigation. Other related knowledge of maize collected as suggested by domain experts include climatic condition, farm implement, pest/insects and weed treatment. Terminological concepts were collected from various reliable information sources. This include research articles, authoritative online data sources, and published books from institutions such as International Maize and Wheat Improvement Center (CIMMYT), International Institute of Tropical Agriculture (IITA). Others are School of Agriculture and Agricultural Technology (SAAT), Federal University of Technology, Minna and Institute for Agricultural Research (IAR), Zaria. More so, hundreds of CQs were collected via questionnaire however, after series of validation exercise by the team of domain experts, eighty CQs were satisfactorily used. The analysis of the knowledge is carried out manually following the middle-out-approach. The rationale behind the manual process is to ensure adequate involvement and participation of domain specialists. Besides, manual approach of ontology development is more reliable in terms of accuracy and precision when compare to available automatic processes, which have been proven inaccurate (Fawei et al., 2018). ii. The next step is specification of the knowledge terminologies analyzed from the previous step in accordance to OWL knowledge representation strategy. That is, the ontology's terms are specified as classes, properties (object and data) and individuals. The statistics of these OWL components starting from component classes, which include the default class of owl: Thing stands at 309. The total properties that is, object properties for relations and data properties for entity description stand at 619. Lastly, the individual component has a total number of 502 entities. In order to simplify the terms specified for domain experts, a knowledge modeling software called CMap tool (version 6.04) (Bonacin et al., 2016; Novak & Cañas, 2008) is employed in this research. It helps to stimulate the knowledge of the terms, and understanding between ontology developers and domain specialists. Each of the knowledge considered in this work has their terminologies specified. For example, sample of soils knowledge is presented in this paper using the CMap tool as shown in Fig. 2.

Fig. 2 presents sample terms of some specified soils knowledge. The terms in oval shapes represent classes but the bolded terms represent individual's concepts. In this paper, the forward slash (/) in some of the oval shapes indicates that the terms are synonymous (for example, the term *Soils* is synonymous to *SoilCondition* and *Edaphic_Requirements*) as additional attributes. Also the arrow stands for object properties. For instance, *Loamy has SiltLoamSoil* and *Soil requiresFertilier Fertilizers*. iii. Competency Questions (CQs) evidently distinguish ontology from other related knowledge representation models. The semantic contents of ontology largely have to do with its ability to handle the user query; in other word, to infer contextual knowledge of a given CQ. This step of the ontology development gives room for enforcement of logic and rules. In this research, there are 24, 23, 20 and 13 numbers of validated CQs for soils, fertilizers, irrigation and other supportive knowledge respectively. The supportive knowledge include but not limited to climatic condition and pest/insects. The reduction to the initial number of CQs is necessitated because of repetitions of some questions by almost all the respondents. Similarly, subject granularity is another factor that led to the reduction during CQs validation by experts; this is to revolve the ontology within its scope and purpose. First Order Logic (FOL) is exploited to model the questions in order to adequately represent the hidden contextual information. Table 1 presents the modeling of four sample CQs of the knowledge considered in this research.

Table 1 presents samples of the formalized CQs in second column of the table against the expressed CQs in natural language as appeared in

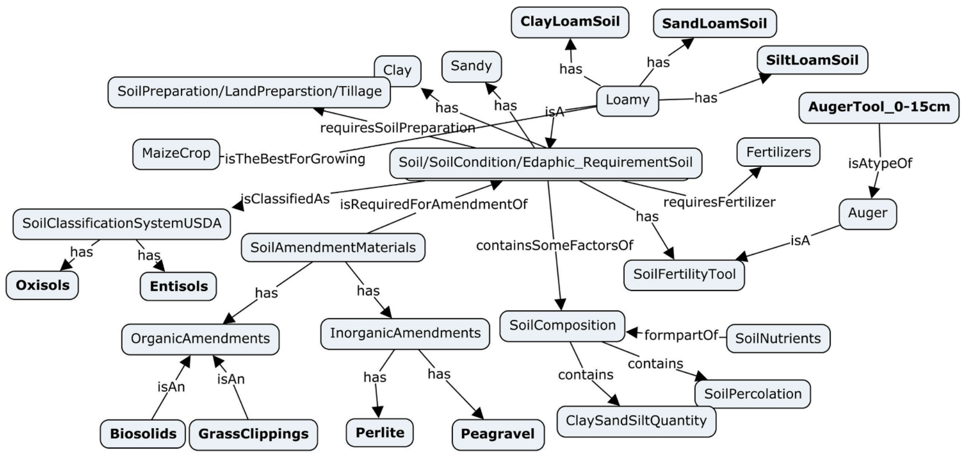

Fig. 2. Graphical Representation of Specified Terms for Soils Knowledge.

Table 1
FOL Representation of Sample CQs.

Competency Questions (Informal)	Competency Questions (Formal)
Which type of fertilizer is required for maize cultivation/ what is the best fertilizer type for maize?	∃ x ∀ y . (Fertilizer(x) ∧ MaizeCrop(y) ∧ isAheavyFeederOfNitrogen(y, Nitrogen) ∧ isA_NitrogenRich(PoultryDropping, x) ∧ isA_NitrogenRich(NPK ∨ Urea, x) → isMostlySuitableFor(PoultryDropping ∨ NPK ∨ Urea, y))
How fertility state of soil can be determined for maize crop?	∀ x . (SoilSample(x) ∧ ∃y. (0–15cm_Auger(y) ∧ isA_MaizeTest(y, Tool) → isTestedForMaizeCropUsing(x, y) ∧ isTestedInThe(x, SoilLab)))
Which type of soil can irrigation be carried out in maize cultivation?	∀ x . (Soil(x) ∧ isATypeOf(Loam ∨ Clay ∨ Sandy, x) ∧ ∃y. (Irrigation(y) ∧ forMaizeCropDependsOn(y, SoilPercolation ∨ SoilNutrient ∨ IrrigationMethods) ∧ hasGood (Loam, SoilPercolation ∧ SoilNutrient) → isAgoodSoilForMaize (SandLoam∨ClayLoam∨SiltLoam, y)))
What type of pesticide to use if earworm, stem borer or armyworm is noticed?	∃ x, y . (EarWorm (x) ∨ StemBorer (x) ∨ ArmyWorm(x) ∧ isAmaizeCropDisease(x, Disease) ∧ PesticideTreatment(y) ∧ isAmaizeCrop(y, FarmChemicalTreatment) → isUsedForTheTreatmentOf(y, x))

the first column. The FOL model enables the contextual information of every question to be expressed, in other words, allows entailment of hidden knowledge. The first row contains the sample CQ for fertilizer knowledge, which is about the suitable fertilizers for maize plant. The logic takes cognizance of the two classes of fertilizers that can be applied. However, each of the classes has the most suitable type for maize crop; that is, not all types of fertilizers can be applied. Consequently, the use of existential quantifier (∃x) has to be invoked for both classes of fertilizers. In this case, *PoultryDropping* for *OrganicFertilizer* class and *NitrogenPhosphorusPotassium (NPK) and Urea for InorganicFertilizer* class are independently suitable for maize cultivation because of their *Nitrogen* content. The hidden knowledge or contextual information of the (informal) CQ that is modelled by the logic (the formal CQ) is that maize crop is *aHeavyFeederOfNitrogen*. This concatenated word is a relation (object property) for classes *MaizeCrop* and *Nitrogen* as shown in the first row, second column of Table 1. The second row is the CQ for soil knowledge; third row is the CQ for irrigation knowledge and the last row contains sample CQ for pest/insects knowledge of maize crop. The output is at the right side of the implication symbol (→), which is the consequence of antecedent knowledge at the left side. iv. The next step formalizes the ontology using latest version of Protégé 5.5.0 edition that strongly supports the OWL2. Terms specified in steps 2 and 3 are formalized in OWL along with constraints enforcement while, the formulated CQs of step 3 are formulized using SWRL.

Next step is evaluation, which is a process of carrying out consistency checks of ontology in adherence to proper concepts. The process involves ontology validation and verification with respect to W3C semantic web vocabularies convention. In this research, the eight popular metrics of structural based evaluation is employed. In addition, HermiT version 1.3.8.413, an ontology reasoner was constantly used to verify and validates consistencies of the ontology's concepts. CQs were encoded in SQWRL to validate the correctness content of the ontology; and domain experts ascertained the level of results' accuracy. In case of any defect, the ontology developer can easily loops back to previous steps for correction.

Ontology evolution is the last step of this design methodology. The principle of ontology's scalability is an important aspect of evolution that aids ontology's self-growth and reuse. In view of this, the following novel Algorithm 1 presents design framework on how the proposed ontology can autonomously evolve.

Algorithm1: MaCOnto Evolution
Input: Q
Output: Result, MaCOnto Autonomous Update
Parameters: Query String (Q); WordNet; MaCOntoTerms (T); POSparser: CandidateTerms
(C); counter (i); numbers of terms in C (n); hypernyms (hyp); holonymy (hoy); Meronym (mer); domain (dom); object property (obProp); individual (indiv)
Procedure:
```
execute OntEvolutionThreads;
input Q
qPOS=POSparser(Q, true); //preprocess to remove stop words and tokenize
C = qPOS;
initialize T;
do
if C ∈ T then // if C is found among MaCOnto's Terms
Output Result // the appropriate C along with synonyms terms and relation
elseIf C ∉ T. then //if C is not found in MaCOnto (MaCOnto starts to evolve)
learn WordNet (C);
check SemanticRelation(hyp; hoy; mer);
encode OntStatement(dom; range; subclass; obProp);
elseIf find(WordNet; classes) then
axiom; classes = getRelatedAxiom(WordNet);
end
elseIf find(WordNet; indiv) then
axiom; indiv = getRelatedAxiom(WordNet);
end
update MaCOnto;
else Print "out of subject granularity" end
end
end
while (i = n)
return MaCOnto
```

From this algorithm, it is expected to define before engage in execution of all the necessary user define methods that aid its objective. This is collectively termed as Ontology evolution threads in this research as shown by line 1; they include SemanticRelation, OntStatement, getRelatedAxiom and load WordNet.

From lines 2 to 5, user inputs query string as competency question; and the query is immediately preprocessed to eliminate stop words like punctuations, articles (*a, an, the*) and conjunctive terms using the part of speech (POS) parser technique. The result of this process is what is referred to as candidate terms in this research. Before testing if the candidate term(s) is/are found in the ontology, the already manually built terms of MaCOnto is initialized. From line 7, the term(s) is/are being tested to know if they are matched with the existing ontology's terms. If true, results are outputted, else the objective of this algorithm starts to manifest from line 9.

From lines 10 to 12, the user defined methods activate and load WordNet to learn the terms. It also determines with the aid of SemanticRelation and OntStatement methods if such term is a super class (hypernymy), subclass (hyponymy) or relation (meronymy). Class can either serves as domain class or range class; it depends on the relation. This research is only considering the nouns POS; which are equivalent of classes and individuals in OWL ontology. Consequently, from lines 13 to 19, the terms are being validated by the methods if they are classes or individuals. Hence the ontology is autonomously updated via the mapping strategy between MaCOnto, the domain ontology and WorldNet, the lexical database. If no update takes place, it implies that the term is outside the domain consideration as represented by line 20 and the ontology returns. At line 23, the pseudocode checks by the *do…while loop* construct if the condition is satisfy. That is, the counter (*i*) checks if it has got to the last term (*n*) in the string data structure.

4. The proposed MaCOnto's framework

The proposed MaCOnto is defined based on the Maize Crop Knowledge Framework (MCKF) primarily consist of MaizeCrop (Mo) itself, Soils (So), Fertilizers (Fo) and Irrigation (Io) knowledge. Other Supportive Knowledge (SKo) are Climatic Conditions (Windspeed, Humidity, Sunlight, and Temperature), Farm Implements, Pest/Insects and Diseases. Therefore, the ontology is formulized as follows:

$$MaCOnto = < C, P, I, \alpha > \tag{1}$$

where C stands for set of nonterminal Concepts or Classes for the domain. In this research work, C comprises set of classes for Soils, Fertilizers, Irrigation and other considered knowledge of Maize Crop. That is,

$$C = C_{Mo} \cup C_{So} \cup C_{Fo} \cup C_{Io} \cup C_{SKo} \tag{2}$$

P is set of Properties. Typically, property may be defined as set of relationship (R) that exists between concepts. That is,

$$R \subseteq C \times C.Ontheotherhand, \forall r \in R : r = \{(c_1, c_2) : c_1, c_2 \in C\} \tag{3}$$

However, in this research work the definition of Eq. (3) only hold for object property, which implies relationship (R). This is because Data Property (P_d) of (nonterminal or terminal) concept is also an essential component to consider for robust ontology. OWL based ontology is robust when developer equally harvests all required concepts from collection sources strictly in accordance to classes, individuals and (object and data) properties. However, in many cases, data property component is not considered, which inadvertently affect the correctness of ontology in terms of annotation.

$$P_d = (c_d, i_d) \tag{4}$$

that is, (class data property (c_d), individual data property (i_d)). For example, class MaizeCrop *hasRoot*; therefore, *hasRoot* is P_d specifically, it is c_d. Because the data property belong to a class. Conclusively, property component of OWL is expressed in this research as:

$$P = R \cup P_d \tag{5}$$

Symbol I stands for Individual which is/are terminal(s) set of c. that is,

$$c_x = \{i_0, i_1, i_2, \ldots i_n\} n \geq 0 \tag{6}$$

α represents rules and constraints of concept, which is expressed as follow

$$\alpha = (C_{inf}, C_{con}) \tag{7}$$

Where C_{inf} stands for Contextual information derived from competency questions that form the rules. C_{con} denotes Concept's constraints such as transitive and functional characteristics of object property.

Furthermore, the development of MaCOnto is analogously described by the conceptual framework of Fig. 3. As stated by Eq. (1), the development of the application-based ontology consists of taxonomy and semantic components' implementation.

The framework of Fig. 3 is described as three-tier architectural design. They are:

i **Knowledge Collection:** this is the first tier of the architecture where the required knowledge in textual forms are collected from reliable and trusted information sources. The domain experts constantly validate the (soils, fertilizers and irrigations) knowledge based on the defined domain of maize crop. Middle-out-approach is employed in this work as concept identifying technique owing to its ability to first identify most important concepts and then generalized and specialized into other concepts.

ii **Ontology Design:** the second tier illustrates how the domain ontology is designed. The domain ontology at this level primarily consist of Eqs. (2) to 6; that is, ⟨ C, P, I,⟩ without contextual information derived from the set of CQs (α). The entities of 309 classes, 443 object properties, 176 data properties and 502 individuals based on OWL representation model defined the domain ontology at this point. From Fig. 3, *classes, prop and ind* denote the Classes, Properties and Individuals respectively. The entities are encoded via Protégé editor. At this level of the design, the ontology cannot performed a robust competency tasks; hence, the need for the last tier.

iii **Inference Design:** This research goes beyond development of lightweight ontology or typical domain ontology that cannot perform competency tasks. It is extended by enforcing high-level constraints on concepts for example, properties are designed to be

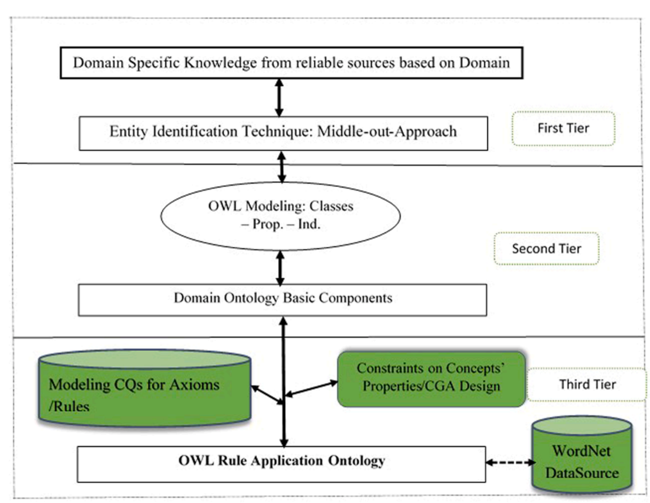

Fig. 3. Conceptual Framework of MaCOnto.

transitive, functional and symmetric. Besides, class component of the domain ontology from second tier are furthered encoded by considering Classes General Axiom (CGA) mechanism of Protégé to minimize the challenge of synonyms. More importantly, the validated CQs are modeled using FOL as shown by the samples of Table 1. Consequently, the logics are encoded into rules and axioms with the aid of SWRL of Protégé; so that the ontology can perform robust competency tasks. That is, to infer contextual knowledge based on the informal query in CQs form. In the end, an OWL Rule based application ontology that autonomously evolves is developed. The aspect of ontology evolution is achieved via the adoption of WordNet as ontology to ontology mapping strategy as earlier shown by algorithm 1. Table 2 shows the SWRL representation of the CQs already modeled in FOL of Table 1 and their corresponding query format: SQWRL.

Table 2 presents samples of implemented CQs using SWRL as shown by the second column of the Table. The first CQ in first row of the Table, which is on fertilizers knowledge, formulized the modeled CQ in FOL into SWRL using the notations. Concepts such as *Fertilizers, InorganicFertilizers* and *NPK_Fertilizer* are defined using letter as atom or variable, which is normally preceded by question mark (?) symbol in parenthesis. For example, the concept *Fertilizers* is coded in SWRL as *Fertilizers(?f)*; and the concepts are separated with the exponential symbol (ˆ). The knowledge that precede the implication symbol (->) such as *containsAlotOf(PoultryDropping, Nitrogen)* is termed as antecedent knowledge. While the knowledge after the symbol is termed as the consequent that represents the output of the knowledge. Thus, the OWL axioms and the SWRL in the Table 2 are transferred to the rule engine (Drools). Consequently, execution take place and the inferred axioms were successfully transferred back to the OWL model.

Similarly, the corresponding representation of the rule but in query form is the SQWRL shown by the third column of Table 2. Ontology query language that complies with the OWL evolution in terms of in-depth supports for semantic expressivity of axioms and rules is required; hence, the motivation for SQWRL. This query language works by using the antecedent and consequent parts of the SWRL as pattern specification and retrieval specification respectively. However, in order to avoid duplication of results during query, some special functions such as *sqwrl:makeSet(?s1, ?f)* is used. In this example, the atom *(?s1)* makes a union set of the concept *Fertilizer (?f)* regardless of the numbers of time it appears in the ontology file. The second row of the Table 2 shows the corresponding SWRL and SQWRL of the FOL model for soils. While, the third column is for irrigation knowledge, the last row is for knowledge on pest and insects. Therefore, the results are discussed in the next section of this research.

5. MaCOnto's results and discussion

This section firstly, presents and discusses the results of the developed MaCOnto based on the terminological construct of OWL and the competency questions. Similarly, the result of how the ontology autonomously evolve is equally discussed. Secondly, the results of the ontology's different forms of evaluations are also discussed in this section of the paper.

The ontology is developed using the java based Protégé editor, and the summary result is graphically presented by Fig. 4.

Fig. 4 shows the summary representation of the ontology graphically, using OntoGraf of Protégé by considering only the core classes. The rectangular boxes of the Figure represent the core classes and the plus (+) signs signify that they are all super classes. As clearly shown by the Figure, every other classes span out from the root (default) class *owl: Thing*. As such, each of the classes contain numbers of classes among which are also super classes to some other classes. For examples, Figs. 5 and 6 demonstrate fragmented results of the implemented soils and supportive knowledge respectively for terminological aspect of the ontology, semantically.

Fig. 5 presents the snapshot of the implemented results of some classes of the soils knowledge. The arrows that precede some classes of the Figure for instance, *Soil_Organisms, SoilAmendment and Soils* signify that the entities are super classes. *SoilAmendment* has

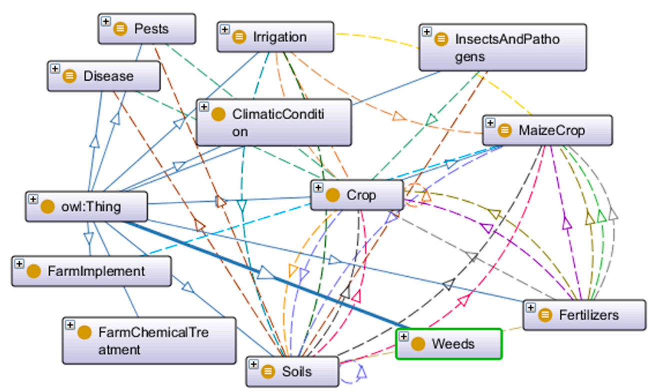

Fig. 4. General Concepts of MaCOnto.

Table 2
Implementation of Modeled CQs using SWRL.

CQs	SWRL	SQWRL
What is the best fertilizer type for maize?	Fertilizers(?f)ˆOrganicFertilizers(?o)InorganicFertilizers(?i) ˆMaizeCrop(?m)ˆUrea(?u)ˆNPK_Fertilizer(?n)ˆisAheavyFeederOf(?m, Nitrogen)ˆstrictlyContains(?u,Nitrogen)ˆcontainsGoodProportionOf(?n, Nitrogen) isAveryRichFormsOf(PoultryDropping, ?o) ˆcontainsAlotOf(PoultryDropping, Nitrogen) -> isTheMostSuitable (PoultryDropping, ?o) ˆ isTheMostSuitableForCultivating(?n, ?m) ˆ isTheMostSuitableForCultivating (?u, ?m)	Fertilizers(?f) . sqwrl:makeSet(?s1, ?f) ˆ MaizeCrop(?m) ˆ sqwrl:makeSet(?s2, ?m) ˆ Urea(?u) ˆ NPK_Fertilizer(?n) ˆ isAheavyFeederOf(?m, Nitrogen) ˆ containsMainlyNitrogen(?u, Nitrogen) ˆ containsGoodProportionOf(?n, Nitrogen) ˆ containsAlotOfNitrogen(?a, Nitrogen) ˆ AnimalManures(?a) ˆ containsAlotOfNitrogen(PoultryDropping, Nitrogen) -> isA_SuitableFertilizerToGrow(?a, ?m) ˆ isA_SuitableFertilizerToGrow(?n, ?m) ˆ isA_SuitableFertilizerToGrow(?u, ?m) ˆ sqwrl:select(?n) ˆ sqwrl:select(?u) ˆ sqwrl:select(?a)
How fertility state of soil can be determined for maize crop?	SoilFertilityTest(?f)ˆSoilSample(?s) ˆSoilLaboratory(?l) ˆAuger(?a) ˆMaizeCrop(?c)-> isDeterminedFor(?f, ?c) ˆ isCarriedOutInThe(?f, ?l) ˆ isCarriedOutOnThe(?f, ?s) ˆisConductedUsing(?f,0–15cmTool)	Soils(?s)ˆSoilTestTools(?t)ˆSoilFertility(?y)ˆSoilFertilityTest(?f)ˆMaize(?m) ˆsqwrl:makeSet(?s1, ?t). sqwrl:size(?d, ?s1)ˆMaize(?m) . sqwrl:makeSet(?s2, ?f). sqwrl:size(?z, ?s2)ˆcanBeDeterminedByTest(?y, ?f) ˆ canBeDeterminedByTool(?y, ?t) ->stateOfFertilitycanBeDeterminedByTest(?s, ?f)ˆstateOfFertilitycanBeDeterminedByTool(?s,?t)ˆsqwrl:select(?f)ˆsqwrl:select(?t)
Which type of soil can irrigation be carried out in maize cultivation?	Soils(?s)ˆIrrigation(?i)ˆMaizeCrop(?m)ˆrequiresModerateIrrigation(?m, ?i) -> canBeCarriedOutInAnySoil(?i, ?s) ˆ sqwrl:select(?s)	Soils(?s) . sqwrl:makeSet(?s1, ?s) ˆIrrigation(?i) ˆMaizeCrop(?m) ->requiresModerateIrrigation(?m, ?i) ˆcanBeCarriedOutInAnySoil(?i, ?s) ˆ sqwrl:select(?s)
What type of pesticide to use if earworm, stem borer or armyworm is noticed?	Insecticides_Treatment(?i) ˆ Pests(?p)ˆisUsedForTheTreatmentOfPest (?i, ?p)-> sqwrl:select(?i)OR sqwrl:select(?i, ?p)	Insecticides_Treatment(?i) ˆ Pests(?p) ˆisUsedForTheTreatmentOfPest(?i, ?p) -> sqwrl:select(?i)OR sqwrl:select(?i, ?p)

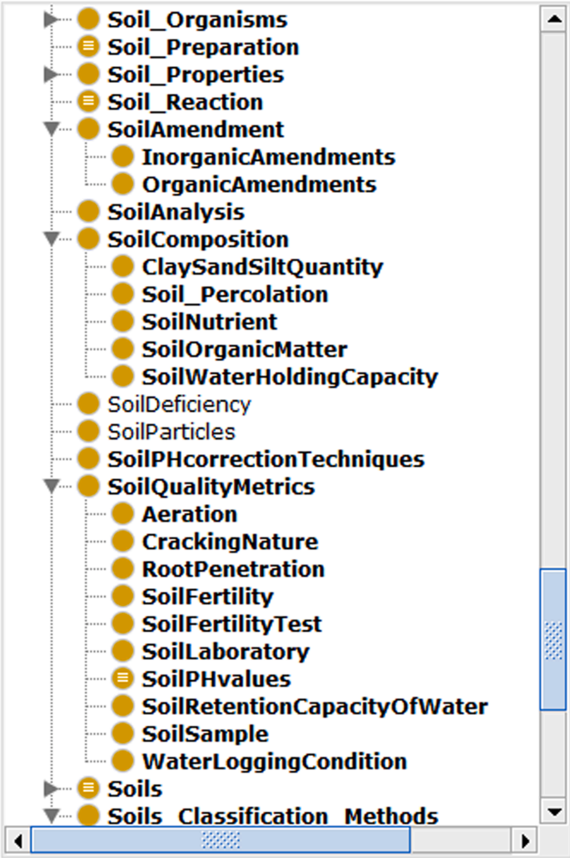

Fig. 5. Soils Knowledge Classes.

InorganicAmendments and *OrganicAmendments* as subclasses. This is the same implementation and operational methods with the super classes of the knowledge. Similarly, Fig. 6 presents other supportive knowledge such as *ClimaticCondition* along with subclasses, *FarmChemicalTreatment* and *Pest/Insects*. Pests or Insects is a similar class to Disease. Figs. 7 and 8 also partly present the implemented classes for fertilizer and irrigation knowledge respectively.

From Fig. 7, class *Fertilizer_Application_Methods* has *BandingApplicationMethod, BroadcastingApplicationMethod* and others directly appeared under it as subclasses. Similarly, different categories of fertilizers are encoded along with their examples. Fig. 8 also partly presents the irrigation concepts such as *Surface_Irrigation, Sprinkler_Irrigation* and *Drip_Irrigation*.

As stated earlier, CGA is employed to provide similar metadata to the agronomic concepts; therefore, Fig. 9 presents an implemented example for soil concept.

The class *Soils* has *Edaphic_Requirement* and *Soil_Conditions* as equivalent concepts. However, beyond this effort, the developers of the ontology provide a metadata mechanism to easily identify concepts. As shown by Fig. 9, this is an annotation mechanism such that when document in the ontology contain concepts like *compositionOfOrganicMatter* or *mixtureOfSandClaySilt*, it can be ascribed to the class *Soils*.

Summarily, all the 309 classes along with 443 object properties, 176 data properties and 502 individuals are duly implemented. The OWL file of the ontology can be accessed via https://github.com/enesifa/Enesi/blob/main/MaCOnto_OWL%20File.owl.

More so, Figs. 10 and 11 present the results of querying the first and last CQs as earlier shown by Table 2 using the SQWRL of SWRL.

The semantic result of the CQ: *What is the best fertilizer type for maize* is displayed as variables *n, u* and *a* at the bottom of Fig. 10. Each of these variables contains *NitrogenPhosphorusPotassium_Fertilizer, Urea_Fertilizer* and *PoultryDropping* respectively as value; they are highlighted in blue

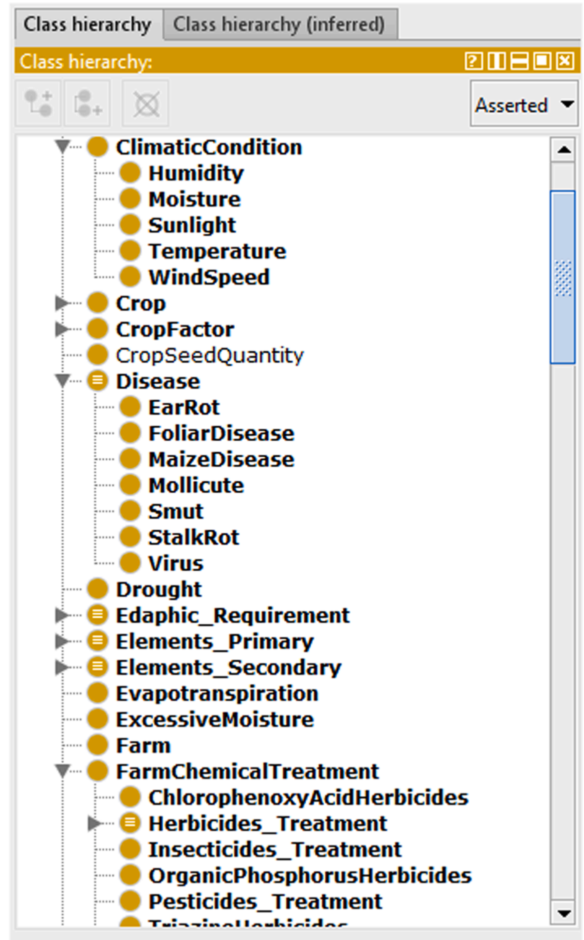

Fig. 6. Supportive Knowledge Classes.

color of Fig. 10. The query as earlier written on the third column, row one of Table 2 is successfully executed using drools engine. Similarly, Fig. 11 equally presents the result of successful execution of another sample CQ.

The CQ: *What type of pesticide to use if earworm, stem borer or armyworm is noticed* is named S72 in the SWQRL tab as shown in Fig. 11. The SQWRL is executed by the drool engine of Protégé and produces tabular results shown by the highlighted blue color at the bottom of the Figure labelled columns *i* and *p*. Column *i*, which is a coded atom for *Insecticides_Treatment* displays the corresponding treatment for the three diseases. Column *p* highlights the diseases. For example, the pesticide for treatment of *EarWorm* disease is *Cypermethrin*. However, each of the outputs has prefix of *maizeCropOntology_MODIFY3_VALIDATION:* as namespace.

Furthermore, Fig. 12 shows the implementation results of how the ontology autonomously evolves based on the given CQ.

Considering the executed CQ from Fig. 12, the only single candidate term is *tree*, a noun concept which could be superclass or subclass. However, the term is not found in the manually curated ontology file, whereas in actual sense, it could be a superclass to the term *Maize_Crop*. That is, *Maize_Crop* is part of Tree. Therefore, through the implementation of Algorithm 1 and the conceptual framework of Fig. 3, the term is autonomously added to the system. Firstly, since the term is not part of the ontology file, the WordNet is automatically activated to process the relevance of the term to the ontology by checking its semantic relations. Secondly, once the condition is satisfy, the system infer maize crop to be the only tree in this context. Therefore, the term *tree* is considered as hypernymy of the class *Maize_Crop* based on the concepts

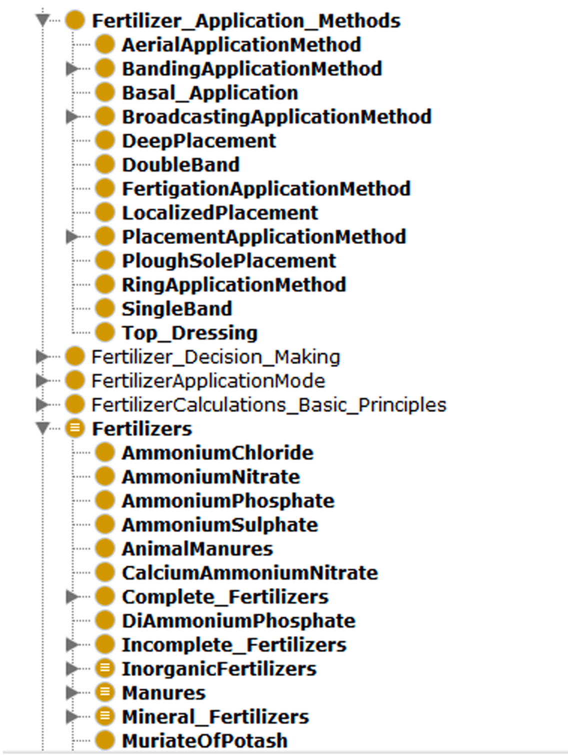

Fig. 7. Fertilizer Knowledge Classes.

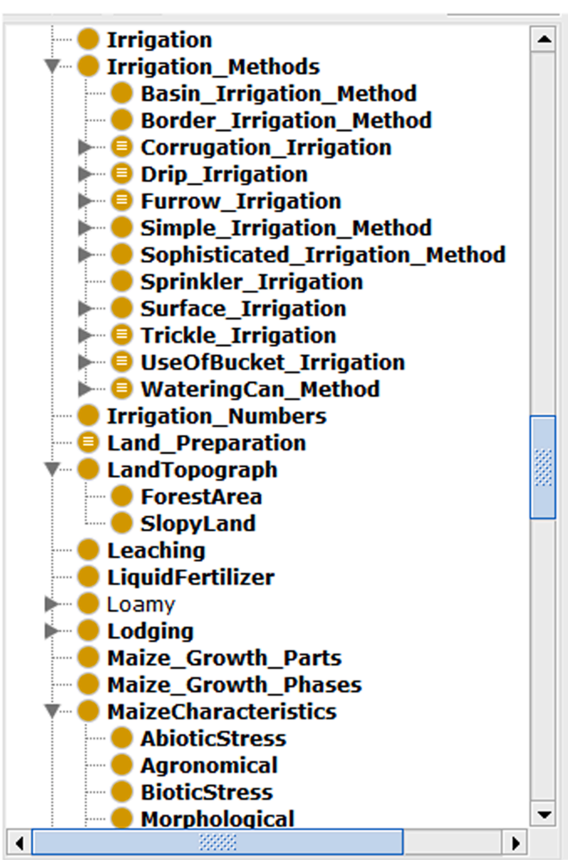

Fig. 8. Irrigation Knowledge Classes.

mapping between the MaCOnto's file and the WordNet's semantic relation.

Consequently, the semantic relations of either meronym or holonymy hold for the two concepts; and the term *Tree* is autonomously updated as class of the ontology. Similarly, the duo knowledge models also infer a user defined relation: has*VariousGrowthParts* from the ontology as a result of the existence of the term: *part* in the CQ. Thus, the semantic result, which is *Maize_Crop has VariousGrowthParts Maize_Growth_Parts* is displayed as shown by the Figure. The result is a hyperlink text upon clicking; various parts of maize crop as tree are displayed.

5.1. MaCOnto evaluations

In addition to HermiT reasoner for checking the consistency of MaCOnto ontology, structural and competency based evaluations were duly carried out to ascertain its validity. The details of the validations are as follows.

5.1.1. MaCOnto structural based evaluation

The ontology structural based evaluation is driven by the eight popular metrics (Vrandecic, 2010; Yao et al., 2005) listed in Table 3. MaCOnto is evaluated against the average and median values of 1413 existing OWL ontologies. The OWL based ontologies obtained via swoogle have become a standard of ontology's validation and verification (Sicilia et al., 2012; Wang & Wang, 2018).

Table 3 presents the results of MaCOnto's structural evaluations against the existing ontologies based on the eight metrics. The first metric is the classes' numbers (cn). While the standard average and median number of classes for OWL ontologies are 36 and 6 respectively; the proposed MaCOnto has an outstanding number of 309 classes. The second and third structural evaluation metrics are numbers of individual and object properties with expected average numbers of 28 and 24 respectively. However, the proposed MaCOnto has 502 individuals' numbers (in) and 443 number of object properties (op). Similarly, the fourth metric is the root classes' numbers (rcn), which are numbers of classes that are mainly first level super classes. In this research, there are 109 numbers of root classes against the average and median minimum numbers of 6 and 5 respectively.

Therefore, the results of the first four metrics (that is, *cn, in, op and rcn*) for MaCOnto are far higher than their corresponding average and median values of the existing 1413 benchmark OWL ontologies. The results validate the robustness of the ontology developed in this research.

Furthermore, the fifth metric is average population (ap), which is obtained by dividing the absolute value of individuals' numbers by the classes' number. That is, $ap = |in| / |cn|$ which is equal to $|502| / |309|$ or 1.62. This is against the average value of 1.34 for this metric; this implies the proposed ontology has a promising average population. Similarly, the sixth metric, which is utilization of class (*uc*) is obtained by dividing the absolute value of the number of classes that have a minimum of one individual by the classes' numbers. That is, $uc = |c| / |cn|$ which is equal to $|309–25| / |309|$. $|c|$ is calculated by subtracting numbers of classes without individuals, which is 25 from the total number of classes. With 0.92 for *uc*, it indicates that the ontology's individuals adequately utilized the classes.

More so, schema deepness (*sd*), which is the seventh metric clearly portrays the robustness level of ontology. It is computed by dividing the number of subclasses by the total number of classes; that is, $sd = |nsc| / |cn|$ which is 200/309. Subtracting the number of root classes from number of the classes, derives the number of subclasses; that is, $|nsc| = |cn|$ - $|rcn|$. The value of *sd* clearly determine the robustness of the ontology in terms of how the classes are spread to form the ontology inheritance pattern. A higher value obtained for *sd* compared to the benchmark values shows the deepness of the ontology. Else, if the value of *sd* is less than the benchmark values, such ontology is described to be

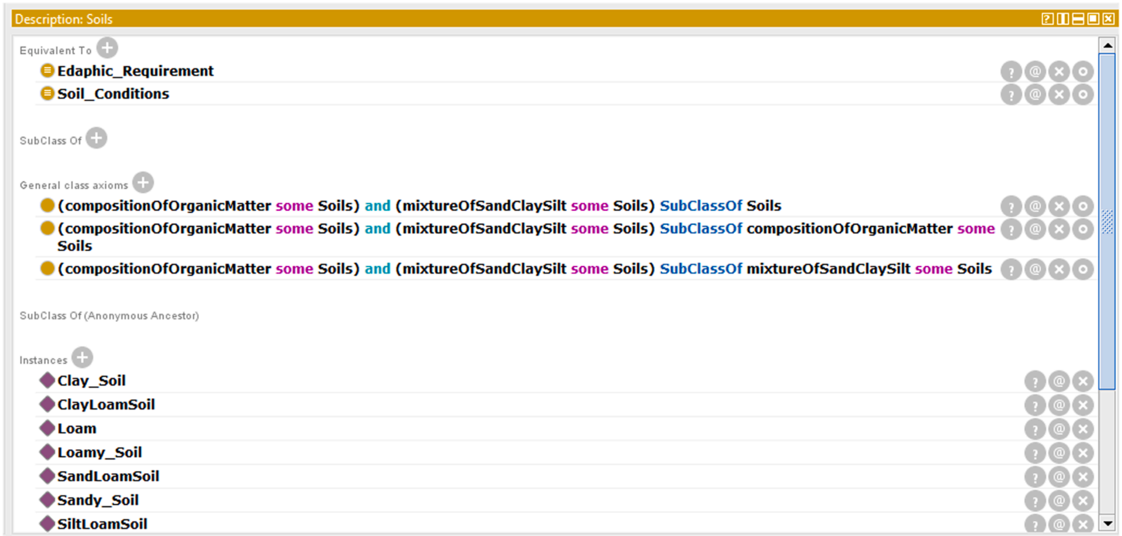

Fig. 9. General Class Axioms for Class Soils.

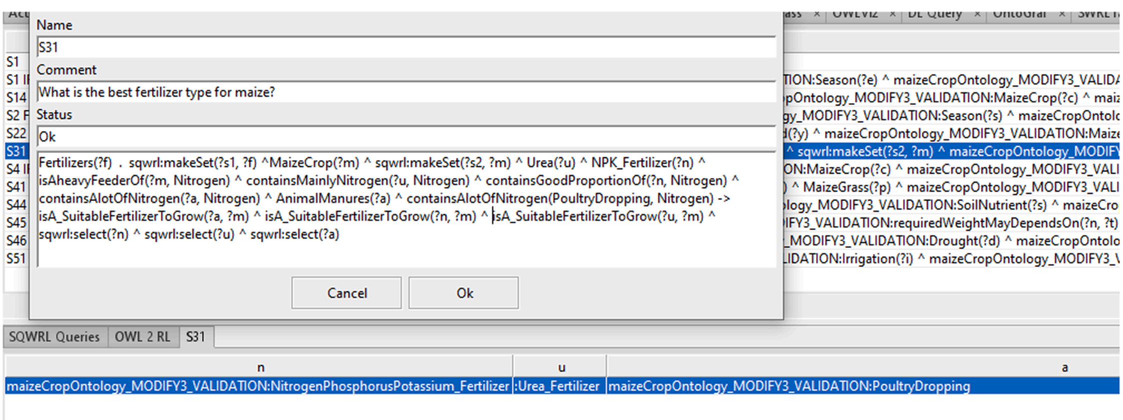

Fig. 10. Semantic Result of Fertilizer/Maize Crop CQ.

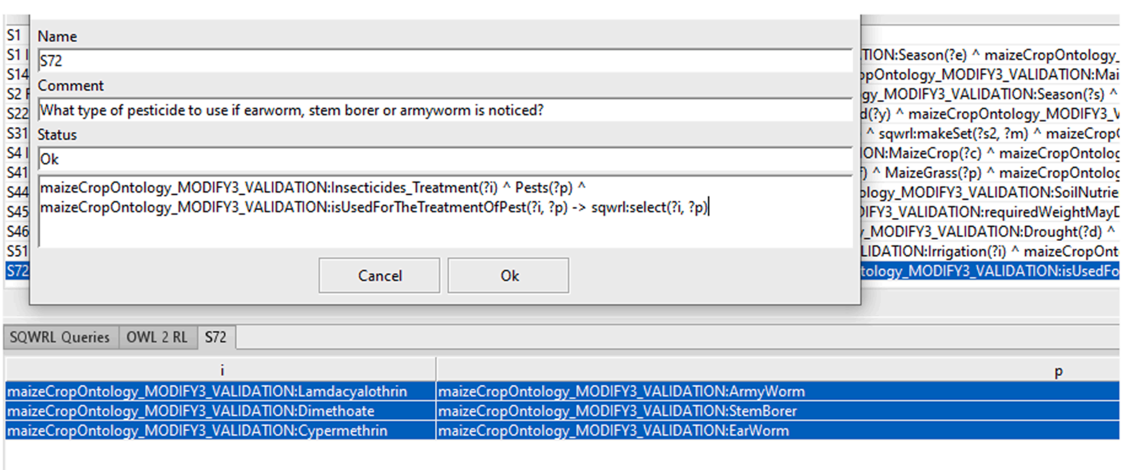

Fig. 11. Semantic Result of Pesticide/Maize Crop CQ.

flat. But, in the case of this research owing to the value of *sd*, the ontology is described to be deep.

Finally, the last metric is the diversity of relationship (*dr*), which is obtained by dividing the absolute value of object properties (*op*) by the summation of number of subclasses and object properties. That is, $dr = |op| / |nsc+op|$ ($|443| / (|200+443|)$); this translate to *dr* value of 443/

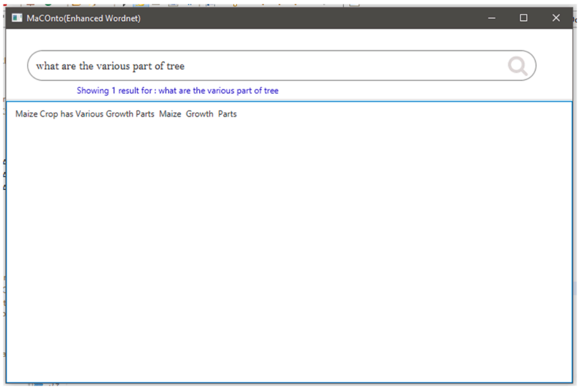

Fig. 12. Result of Ontology Evolution.

Table 3
MaCOnto Structural Evaluations.

Ontology Structural Metrics	MaCOnto	1413 OWL Ontologies Average Median	
classes' numbers (cn)	309	36.11	6
individuals' numbers (in)	502	28.13	6
object properties (op)	443	24	0
root classes' numbers (rcn)	109	6.69	5
average population (ap)	1.62	1.34	1
utilization of class (uc)	0.92	0.54	0.72
schema deepness (sd)	0.65	0.34	0
diversity of relationship (dr)	0.96	2.78	1

643 or 0.96. This last metric intends to signify the multiplicity of ontology's properties (relations). This is based on theory that ontology consist many relations other than meronyms and holonyms, which are class inheritance relations. However, the value of *dr* in this research is less than the average *dr* value but closely equal to the median value. Therefore, since the total numbers of properties in the proposed ontology are the user defined relations; it can be concluded that the value is on the fair side.

In conclusion, the structure of MaCOnto is evidently robust and stable judging from the values obtained from the eight metrics. Thus, Fig. 13 represents the results of the metrics graphically for clarity of comparisons.

The graphical representation of the results of structural evaluation of the ontology is clearly shown in percentage by Fig. 13. Obviously, except for the diversity of relationship metric, the proposed ontology is sufficiently robust. Nonetheless, the result of MaCOnto for relationship diversity is fairly satisfactory because it is very close to the median value of the existing ontologies.

5.1.2. MaCOnto's competency based evaluation

Competency Question (CQ) forms another distinctive metric for ontology's validation. This evaluation is carried out by using the formal CQs as input string. It is important to mention that the CQs are not directly dependent on the contents of the ontology's file. The total number of CQs validated for this research is eighty; Table 4 presents them in four categories considering the four knowledge sources.

The formal CQs (SWRL) are executed in their query forms that is, the SQWRL; and the results are shown by Table 4. Out of the 24 validated CQs for soils maize concepts, two (2) failed to give complete accurate results. For example, the CQ: *Which type of soil can irrigation be carried out in maize cultivation* returns *Soil_Separates* as part of results. Similar deficiencies were recorded in the other knowledge as rightly shown by the Table. The rationale behind the inaccurate results is largely traced to the multiplicity and similarity of user defined relations (object properties) between the given concepts. Consequently, this deficiency manifest on the obtained value of diversity of relationship metric of the structural based evaluation. Numbers of CQs with deficiencies results are 3, 2 and 1 for maize fertilizers, maize irrigation and maize pests/climatic condition respectively. The results displayed were studied and validated by the domain experts. At the end, the competency based evaluation achieved an overall result with accuracy of 90%. Therefore, Fig. 14 presents the summary result of the evaluation in graphical form. Nonetheless, CQs that could not return complete expected results are attributed to the diversity of relations as earlier observed in the previous structural based evaluation.

Table 4
Validation of Competency Questions.

CQs Category	Number of Validated CQs	CQs with Accurate Outputs	Percentage of Accuracy (%)	CQs with Inaccurate Outputs	Percentage of Inaccuracy (%)
Soils	24	22	92	2	8
Fertilizers	23	20	87	3	13
Irrigation	20	18	90	2	10
Others	13	12	92	1	8
Total	80	72	90	8	10

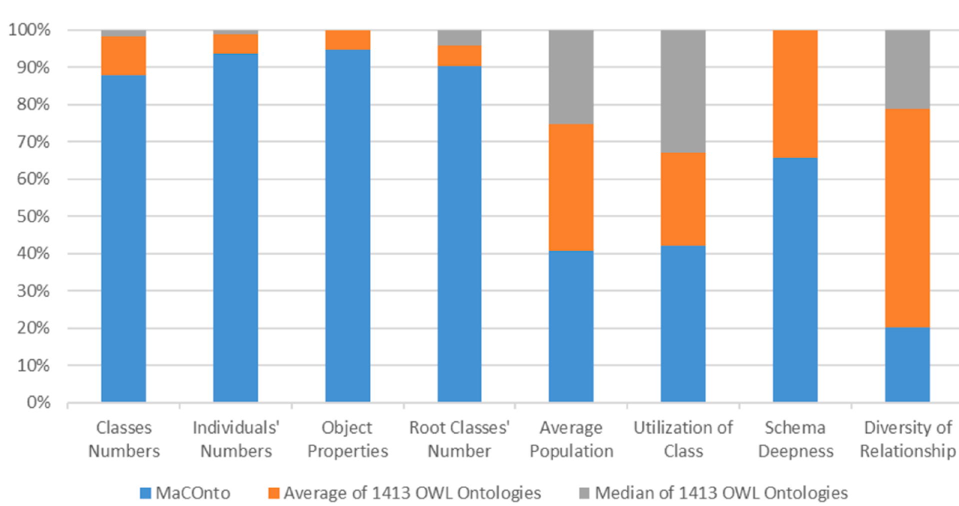

Fig. 13. MaCOnto Structural Evaluation.

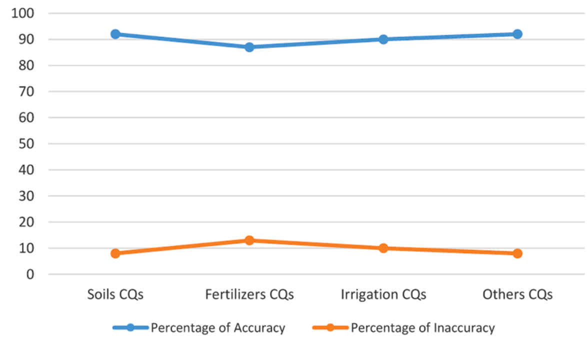

Fig. 14. Competency based Evaluation.

The formal CQs for each knowledge as presented by Table 4 are queried and tested in SQWRL formats. In the overall, the accuracy of the returned results being validated by domain experts is clearly promising as shown by Fig. 14. From the Figure, the summary accuracy of the proposed ontology based on the CQs is 90%, while the remaining 10% accounts for inaccurate results. This is tolerated because the magnitude of the inaccurate results is not total; that is, the inaccurate results contain a larger numbers of accurate results but contain one or more inaccurate concepts.

6. Conclusions and future work

In this research, a robust ontology christened MaCOnto, is developed based on the domain of maize crop but primarily considered the soils, fertilizers and irrigation agronomic concepts. MaCOnto is an extension of two earlier published literature of OWL Rule based ontology models; firstly, for soils and fertilizers' maize crop agronomic concepts; and secondly for soils and irrigation knowledge for maize crop. The development of the ontology is premised on manual top-down approach of the six steps iterative ontology engineering principle. The domain knowledge is represented using OWL2 based on RDF/XML syntax; while the CQs, which are modeled using FOL, are encoded into ontology files using the SWRL. Consequently, the ontology is queried in the format of the formal CQs as query input strings using SQWRL as query language. Hundreds of CQs initially collected via questionnaire instrument were finally scaled down to 80 after several analysis and validation by the team of domain experts. In the overall, MaCOnto has 309 classes include the root class of *owl:Thing*, 619 number of properties and 502 numbers of individuals component. Therefore, considering the sizes of the ontology's classes, properties and individuals following the results of the structural based evaluation, the proposed MaCOnto is described to be a deep ontology. In addition, efforts were equally made to exploit Class General Axiom technique of Protégé tool to provide metadata for the ontology's entities. More importantly, the robustness of the ontology leverages on the eighty (80) validated CQs by domain experts; and the new mechanism to allow the ontology to autonomously evolve.

Furthermore, in order to ascertain the validity and verification of the ontology, structural and competency based evaluations were carried out; and the results are promising. This is in addition to the consistency checks of the ontology using the HermiT reasoner of Protégé 5.5.0. Therefore, the results recall are precisely defined, which saves a lot of retrieval response time and computational cost. However, a Graphical User Interface (GUI) would be developed so that user can query the MaCOnto's files in informal CQ or natural language form. Besides, the results obtained for autonomous evolution of the ontology is practically limited; because the novel algorithm can only add a single new concept that is a class or individual from a given CQ. The algorithm could not consider or adds new concept as semantic relation; consequently, it is yet to add two classes from a given CQ. More so, the data source (WordNet) employed to autonomously update MaCOnto is limited, because it is a general lexical ontology or database. Therefore, there are contending issues of polysemy associated with the data source to carefully select an intended concept to update the ontology. In future, an alternative peculiar semantic database like AGROVOC would be considered for autonomous update of the ontology.

CRediT authorship contribution statement

Enesi Femi Aminu: Conceptualization, Formal analysis, Methodology, Data curation, Software, Validation, Writing – review & editing. **Ishaq Oyebisi Oyefolahan:** Supervision, Project administration, Writing – review & editing. **Muhammad Bashir Abdullahi:** Supervision, Data curation, Resources, Writing – review & editing. **Muhammadu Tajudeen Salaudeen:** Investigation, Formal analysis, Data curation, Validation, Resources, Writing – review & editing.

Declaration of Competing Interest

We have no known competing financial interests; and there is no any funding agency for this paper.

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