Ontology Case Study Review

by Maria Ingold

INTRODUCTION

'Ontology Development for Agriculture Domain' by Malik et al. (2015) highlights the importance of semantic relationships and contextual understanding in information retrieval. It identifies deficiencies in resources like AGROVOC, the multilingual thesaurus from the Food and Agriculture Organization (FAO) of the United Nations, particularly in mapping entity relationships, such as plant-disease or soil-fertiliser. To address, Malik et al. propose ontologies—machine-readable structured models that define concepts, relationships, and constraints for clearer comprehension. This essay examines their approach to creating a generic agriculture-specific ontology and analyses two application areas: fertiliser and cash crop.

ONTOLOGY DEVELOPMENT APPROACHES

Malik et al. (2015) follow Noy and McGuinness' (2001) rules and approach to create a generic ontology for the agriculture domain from scratch using Protégé, Stanford's open-source ontology platform (Musen, 2015). The rules specify that the optimal ontology model depends on its application and envisioned extensions, that ontology development is iterative, and that concepts are the objects (nouns) and relationships (verbs) best reflecting the domain. For clarity, the approach (Table 1), described in the now-discontinued Protégé-2000's frame language, is mapped to Debellis' (2021) contemporary Protégé 5.5's Web Ontology Language Description Logic (OWL-DL), and related terms and synonyms.

TABLE 1 | Noy & McGuinness' (2001) ontology development approach and vernacular mappings

	Step (Protégé 2000 Frame)	OWL-DL	Related / synonyms
1.	Determine *domain* and *scope*	*domain* and *range*	
2.	Reuse existing ontologies	same	
3.	Enumerate important terms	same	
4.	Define *classes* and hierarchy	*classes*	concepts
5.	Define class *slots*	*properties*	roles, relations
6.	Define slot *facets*	*property restrictions*	role restrictions, axioms
7.	Create *instances* (of classes)	*individuals*	

Noy and McGuinness propose three equal iterative development approaches: *top-down*, *bottom-up*, or a *combination* of both, depending on the preference for starting at general or specific. Alternatively, Grüninger's (1996) middle-out approach identifies key concepts, then selects abstract or specific.

Malik et al. (2015) restrict the agriculture domain and scope to five superclasses: 'Plant', 'Disease', 'Pest', 'Pesticide' and 'Fertilizer'. 'Disease', for instance, has subclasses 'Infectious' and 'Non-infectious', with 'Infectious' having subclasses 'Fungal', 'Bacterial' and 'Viral'. Starting from the superclass is a *top-down approach*.

While a general agriculture ontology is useful, this broad scope requires expansion. Expert-driven competency questions would refine the scope and enable verification (Monfardini et al., 2023).

FERTILISER

Business Context

Malik et al. (2021)—the same team—return to focus on fertiliser data, which they deem underrepresented and inconsistent because fertilisers are dependent on new targeted crop ontologies, rather than being a generic ontology. Furthermore, primary data sources, like AGROVOC, lack a full ontology, leading to incomplete fertiliser type and usage data adversely affecting crop yields.

Approach Summary

Malik et al. (2021) more thoroughly follow Noy and McGuinness' (2001) approach. Competency questions on basic fertiliser knowledge and use, both refine scope, and, when answered correctly, demonstrate feasibility of the approach using the ontology's structured framework and knowledge base. Information is gathered using expert advice and knowledge repositories, including AGROVOC. As there are no reusable complete ontologies, FertOnt is built from scratch, using a *combination* of *top-down* and *bottom-up* approaches and Protégé 4.3.

Application Area

FertOnt is aimed at various agricultural stakeholders, including farmers, researchers, scientists, academics, and policymakers. The justification is that it centralises access to fertiliser information, addressing real-time queries about types, properties, and usage guidelines, so farmers can knowledgably select and use fertiliser to boost crop yields. The scope is defined by competency questions, including nitrogen content in Amide fertilisers, optimal mixes for chemical fertilisers, suitability of phosphatic fertilisers for acidic soil, application methods for nitrogenous fertilisers, and distinctions among phosphatic fertiliser types.

Approach Rationale

Noy and McGuinness' iterative method is essential to developing a complex ontology for diverse stakeholders, including refining both competency questions and the ontology itself (Monfardini et al., 2023). The use of a *combined approach* in designing competency questions informs the structure. *Top-down*, 'Fertilizer' encompasses 'ChemicalFertilizer', which includes 'StraightFertilizer', which divides into 'NitrogenousFertilizer', 'PhosphaticFertilizer' and 'PotassicFertilizer'. Nitrogenous fertiliser is a subclass rather than a nutrient property because distinguishing between fertiliser types is key to answering competency questions. Similarly, competency questions around compounds like amide drive a *bottom-up approach*, where ‘NitrogenousFertilizer’ is a superclass of ‘AmideFertilizer’.

Approach Analysis

Aminu et al. (2020) review six ontology development methods in agriculture, including a cash crop using Noy and McGuinness. They speak positively of Noy and McGuinness as iterative, generic (with an applicable example domain of wine), simple, enabling the popular top-down approach, disambiguating the domain, and utilising Grüninger and Fox’s (1995) competency questions to define the scope.

They raise, however, Zheng et al.’s (2012) concerns for AGROVOC that frame ontology methodologies (like Noy and McGuinness) are not certified and, therefore, FAO-Based should be used instead. However, FAO-Based lacks essentials like terminology specification, so they recommend hybridising with Methontology, which is IEEE standard-compliant, but needs the pre-development evaluation provided by Grüninger-Fox, which respectively requires the reusability provided by FAO-Based.

Crucially, Aminu et al. conclude that “agriculture” is too broad a domain and suggest modelling granularly—restricting domain and scope—then merging. This explains the emergence of focused domains but suggests, that while the approach is suitable, Malik et al.’s domain and scope may still be too broad.

Approach Feasibility

For feasibility, the ontology must effectively address competency questions, pass validation and evaluation, and enable evolution (Aminu et al., 2020). FertOnt identified 100 concepts and numerous properties using the Pellet reasoner to infer knowledge (Malik et al., 2021). Validation, including checking inverse relationships and concept categorisation, was performed using OOPS! and competency questions were answered using SPARQL Protocol and Resource Description Framework (RDF) Query Language (SPARQL) and DL query languages.

However, considerations like crop type, water sources, and farmer demographics suggest FertOnt may not fully support sustainable agriculture or precision farming, especially given the costs of soil analysis (Beneduzzi et al., 2022). The ontology's evolution, including integrating with soil and crop ontologies is acknowledged, as is an integration with AGROVOC, which could potentially leverage RDF to enable interoperability using SPARQL (Subirats-Coll et al., 2022).

CASH CROP

Business Context

Ekuobase and Ebietomere's (2016) Nigeria Cash Crop Farmers' Market Ontology (NOCC), more targeted than Malik et al., addresses poverty in Nigerian peasant farming. These farmers face challenges due to limited literacy, capital, land tenure, and collective bargaining power, exacerbated by a decline in agricultural exports following the 1970's oil shocks. The ontology aims to eliminate intermediaries and create a direct farmers' market to increase earnings and reduce poverty. Its global visibility of cash crop demands enables competitive pricing, while knowledge of regional crop pests and disease improves crop yield quantity and quality.

Approach Summary

Similar to Malik et al., Ekuobase and Ebietomere use Noy and McGuinness' (2001) methodology with a *top-down* approach, and Protégé OWL-DL for its popularity, expressiveness and consistency checking. Unlike Malik et al.'s "domain commitment" ontologies (agriculture or fertiliser domain), their work uses "task commitments"—a goal-oriented ontology with inputs and outputs including observations, causes and hypotheses (Visser & Bench-Capon, 1998). Competency questions, constructed from both literature and expert consultation, both define and evaluate the ontology.

Application Area

NOCC provides market and product data to consumer-buyers. The competency questions define cash crop availability and production scale, farmers' market location, and which diseases and pests affect the cash-crops. The justification is that NOCC helps Nigeria's cash crop farmers' market attain global visibility, sidestepping intermediaries to lift farmers out of poverty through direct consumer-buyer engagement, precise information, and competitive pricing.

Approach Rationale

NOCC's simplicity, with only four superclasses covering cash crop, location, pest, and disease, each with a single subclass level, justifies a *top-down* approach. This structure enables straightforward relationships, like 'is_disease' and its inverse 'has_disease' linking cash crops and diseases. While poor design, merging two concepts—crop and production type—e.g. 'Cotton_Small_Scale_Production' and 'Cotton_Large_Scale_Production', aims to keep the design at one level.

Approach Analysis

The analysis for FertOnt's use of Noy and McGuinness' methodology largely applies here, although NOCC's domain and scope are more specific (Aminu et al., 2020). With limited agricultural ontology approach examples available, NOCC contrasts with Grüninger and Fox's (1995) more formal first-order logic (FOL) approach, employed by Walisadeera et al. (2013) for a Sri Lankan farming ontology. While Malik et al. (2021) validate their competency questions using FOL, Ekuobase and Ebietomere use informal language. Grüninger and Fox mandate formal competency questions to ascertain adequacy of new ontologies and observe that simple lookups indicate poor design. This gap, along with missing reuse and term analysis suggest an incomplete design process.

Approach Feasibility

While it answers competency questions, NOCC lacks a feasibility demonstration, missing both validation to ensure content and construction accuracy, and evaluation of user satisfaction, as suggested by Walisadeera et al. (2016).

Walisadeera et al. validate content accuracy by expert feedback, and construction using a reasoner and OOPS!. These tools would have caught NOCC's naming inconsistencies, missing inverse relationships and merged concept categorisation. Combining cash-crop with production scale, and limiting each crop to one disease or pest, both restrict evolution.

Using Protégé reasoners, Walisadeera et al. provide internal evaluation. External evaluation is delivered by iterating through three field trials which provide farmers with mobile phones and the applied ontology. While NOCC seems necessary, it has not yet demonstrated feasibility, especially given the demographic challenges with literacy and poverty to both update the system and be informed of demand.

CONCLUSION

This essay explored agricultural ontology development approaches, particularly FertOnt for fertilisers and the Nigeria Cash Crop Farmers' Market Ontology (NOCC). FertOnt applied more rigor but should review scope and adaptability. NOCC, however, faces design and feasibility challenges. Walisadeera's approach seems most robust and feasible. Key themes across these studies include the importance of iterative development, expert input, formal competency questions, and thorough validation and evaluation. The effectiveness of these agricultural ontologies relies not only on rigorous development but a nuanced understanding of their domain, scope, and user requirements.

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