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ONTOGRAZING: A Semantic Monitoring and Decision-Support Framework for Sustainable Grazing Management

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Abstract: Sustainable grazing management requires balancing livestock productivity with ecosystem preservation, yet existing monitoring systems integrate heterogeneous data from IoT sensors, satellite imagery, and field surveys without a unified semantic layer, limiting holistic decision support. This paper proposes ONTOGRAZING, an ontology-based monitoring architecture for sustainable grazing management. Using the Uschold and King ontology engineering framework, domain knowledge was collected through surveys involving 23 livestock farmers and 4 agro-pastoral institutions in Cameroon, complemented by a systematic literature review. Seven core concepts and fourteen semantic relationships were modeled in OWL using Protégé. A five-module monitoring architecture composed of Query Reformulator, Data Integrator, Source Monitoring, Alert, and Storage modules was designed around the ontology. ONTOGRAZING was evaluated using the HermiT 1.4.3.456 reasoner and SPARQL queries. The ontology contains 47 classes, 14 object properties, and 9 data properties, and passed all consistency checks. Comparative analysis demonstrates that ONTOGRAZING is the first ontology to jointly cover forage management, dietary preferences, pasture composition, ecological–economic trade-offs, and land-use regulations. These results highlight the potential of ontology-based integration to improve interoperability and semantic decision support in agro-pastoral systems, while future work will focus on full prototype implementation and integration with real-world IoT platforms and agricultural databa.

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Index Terms: Grazing Ontology, Semantic Web, OWL, Sustainable Agriculture, Iot, Pasture Management, Knowledge Representation, Agro-Pastoral Systems

1. Introduction

Livestock breeding accounts for a significant share of agricultural GDP in Sub-Saharan Africa and plays a critical role in food security, rural livelihoods, and ecosystem services [1]. Sustainable grazing management requires continuously balancing competing objectives: maximising animal productivity while preserving pasture biodiversity, soil health, and water resources—objectives that depend on a large number of interacting and heterogeneous variables, including forage availability, climate conditions, animal health, market prices, and regulatory constraints. The emergence of precision livestock farming has produced a wide variety of monitoring tools: IoT sensors for soil and animal physiology [2,6], unmanned aerial vehicles (UAVs) for pasture mapping [4,5], RFID tracking for individual animal identification [7], and web platforms for information dissemination [8,10]. Despite this technological wealth, existing systems share a fundamental weakness: each collects data in its own proprietary format from its own source, with no shared semantic layer to integrate information across systems, creating data silos that prevent holistic, cross-cutting analysis and impede evidence-based decision-making.

Semantic Web technologies, and ontologies in particular, offer a principled solution to this integration problem. Several ontology-based monitoring architectures have been proposed in adjacent fields [13,14,15,16], and a number of livestock-related ontologies exist [17,18,19,20,21]; however, as our analysis in Section II shows, none covers the full breadth of the grazing domain. This paper addresses three research questions: (RQ1) What concepts and relationships are necessary to formally represent the grazing domain in a way that supports monitoring? (RQ2) How can an ontology be integrated into an intelligent monitoring architecture to unify heterogeneous data sources and facilitate decision-making? (RQ3) To what extent does the proposed ontology cover the grazing domain more completely than existing ontologies?

To answer these questions, we make three contributions: (C1) ONTOGRAZING, a novel OWL domain ontology comprising 47 classes, 14 object properties, 9 data properties, 7 inference rules in FOL and SWRL, and instances of cattle breeds, diseases, and dietary preferences collected through field surveys; (C2) a five-module intelligent monitoring architecture—currently partially implemented, with the Query Reformulator and Source Monitoring modules operationally specified and the Data Integrator and Alert modules at the design stage—that uses ONTOGRAZING as a semantic backbone; and (C3) a systematic comparative analysis against five existing pastoral ontologies (CDO, ACO, ATOL, EOL, AHOL) demonstrating its broader domain coverage.

2. Related Work

This section surveys three bodies of literature that directly motivate the present work: (i) precision livestock monitoring systems, (ii) ontologies for the pastoral and livestock domain, and (iii) ontology-based monitoring systems in adjacent fields. For each body of literature, we critically assess key limitations in terms of scalability, interoperability, reasoning performance, and deployment constraints.

2.1. Precision Livestock Monitoring Systems

A first line of research focuses on hardware and software systems for real-time livestock and pasture monitoring. Markov et al. [1] provide a comprehensive review of digital management platforms for cattle farms, showing that current systems rely on isolated data pipelines without semantic interoperability—a scalability bottleneck that prevents cross-farm knowledge reuse. Barber and Ochsner [2] demonstrate the utility of soil moisture sensors for irrigation scheduling. Clark [4] and Wang [5] explore UAV-based aerial monitoring. Kappes et al. [6] evaluate an electronic system for monitoring dairy cow rumination. Information dissemination platforms—AgFunder News [8], Ag-Web [9], Pasture.io [10], FarmBeats [11], and AgriWebb [12]—complement sensor-based monitoring.

Comparative assessment: While these systems collectively address sensing, tracking, and dissemination needs, none provides a shared semantic layer. Their proprietary data formats prevent interoperability, and their inability to represent domain relationships formally limits reasoning and holistic decision support.

2.2. Ontologies for the Livestock and Pastoral Domain

A second line of research has produced domain ontologies for specific aspects of livestock management. Table 1 summarises the main proposals. Guarino and Giaretta [24] provide the foundational distinction between top-level, domain, and application ontologies. Gruber [23] establishes principles for ontology reuse and sharing. Borst [26] and Neches et al. [22] further define ontology as a formal specification of a shared conceptualisation.

Table 1. Existing pastoral/livestock ontologies and their coverage.

Ontology	Purpose	Coverage	Missing aspects
CDO [17]	Common Dairy Ontology	Dairy production, milk management, animal feed	Pasture composition, ecological/economic factors, grazing management
ACO [18]	Animal Context Ontology	Animal phenotype, classification of livestock	Forage, dietary preferences, land-use regulations
ATOL [19]	Animal Trait Ontology for Livestock	Phenotypic traits of livestock	Pasture management, ecological aspects, economics
EOL [20]	Environment Ontology for Livestock	Breeding environment, farming systems	Forage management, dietary preferences, policy and regulations
AHOL [21]	Animal Health Ontology for Livestock	Animal diseases, symptoms, treatments	Pasture composition, economic aspects, grazing management
ONTOGRAZING	Grazing domain ontology (this work)	All of the above + forage management, dietary preferences, ecological & economic factors, policies & regulations	—

Existing pastoral ontologies each cover a narrow slice of the grazing domain. No single ontology integrates forage management, dietary preferences, pasture composition, ecological–economic trade-offs, and land-use regulations within a unified model designed to support monitoring.

2.3. Ontology-Based Monitoring and Intelligence Systems

A third body of work has applied ontologies to monitoring systems in other domains. Todirascu et al. [13] propose an ontology-guided information extraction system for strategic monitoring. Maynard et al. [14] develop h-TechSight, a knowledge management portal for market and technology watch. Cao [15] exploits Semantic Web technologies for technology monitoring. Hodgson et al. [16] propose an intelligent technology watch integrating ontologies with agent-based information gathering. These architectures share a common pattern: (1) ontology defines vocabulary; (2) crawling/sensing collects raw information; (3) integration module aligns data; (4) reasoning infers new knowledge; (5) dissemination delivers alerts.

These frameworks demonstrate the feasibility of ontology-driven monitoring but address technology and financial domains only. The heterogeneous data types specific to grazing require domain-specific semantic primitives unavailable in existing monitoring ontologies. ONTOGRAZING instantiates this monitoring pattern with grazing-specific concepts.

2.4. Research Gap and Positioning

The survey above reveals a clear gap at the intersection of heterogeneous precision-farming data and ontology engineering methods. ONTOGRAZING fills this gap by (a) providing a comprehensive domain ontology beyond existing partial models, and (b) embedding it in a monitoring architecture that unifies heterogeneous data sources through semantic annotation and reasoning. Compared to technology-monitoring systems [13,14,15,16], ONTOGRAZING adds domain-specific inference rules and multi-concept coverage; compared to existing pastoral ontologies [17–21], it adds monitoring architecture, reasoning capabilities, and policy–economic dimensions.

3. Materials and Methods

3.1. Data Collection

Domain knowledge was gathered through two complementary channels. Semi-structured interviews and questionnaires were conducted with 23 livestock farmers and representatives of 4 agro-pastoral institutions in the Adamawa and Far North regions of Cameroon. Interview responses were coded using open and axial coding procedures: field notes and transcripts were systematically reviewed to identify recurring themes, which were then mapped to candidate ontology concepts. Concepts mentioned by at least three independent respondents were retained as core candidates, while singleton mentions were cross-validated against the literature review. This double triangulation ensures that ONTOGRAZING's conceptual structure reflects both practitioner knowledge and scientific consensus.

3.2. Ontology Engineering Methodology

We follow the four-step methodology of Uschold and King [27]: (1) identifying purpose and scope; (2) building the ontology by capturing domain knowledge and encoding it in OWL; (3) evaluating consistency and completeness via a description-logic reasoner and SPARQL competency-question queries; (4) producing human-readable documentation. METHONTOLOGY [29] was set aside as too prescriptive; SENSUS [25] targets large-scale reuse; and Gandon's approach [28] is oriented towards multi-agent knowledge management.

3.3. Ontology Competency Questions

Before encoding, the following competency questions (CQs) were defined to guide concept selection and serve as evaluation criteria in Section IV.C:

- CQ1: Which animal breeds are raised on a given pasture?
- CQ2: What forage species are preferred by a given livestock breed?
- CQ3: Which diseases affect animals under specific environmental conditions?
- CQ4: What management practices are recommended for a pasture with specific soil and climate characteristics?
- CQ5: Which regulations govern land use in a given region?
- CQ6: What are the economic costs associated with a specific grazing management strategy?

These competency questions cover core operational needs identified in field surveys. Development of more advanced inference-intensive CQs (e.g., multi-hop reasoning over ecological, economic, and regulatory constraints) is identified as a priority for the next iteration.

3.4. Ontology Design Tool

ONTOGRAZING was implemented in OWL 2 using Protégé 5.5 (Stanford University, open source). The HermiT 1.4.3.456 description-logic reasoner was used for consistency checking. SWRL rules were authored using the built-in SWRL editor, and SPARQL queries were executed via the SPARQL Query plug-in.

4. Results

4.1. ONTOGRAZING: The Grazing Domain Ontology

4.1.1 Main Concepts

Guided by the field surveys and competency questions, seven top-level concepts were identified. Each concept was derived from recurring interview themes and validated against the literature. The mapping from interview codes to ontology classes followed: (i) clustering of raw themes; (ii) cross-referencing with at least two published sources; (iii) discarding candidates without literature support or fewer than three survey occurrences. The seven classes are: Animal Husbandry (breeding and raising of livestock); Ecological Aspect (ecosystems and biodiversity); Economic Aspects (financial considerations); Environmental Factor (natural conditions affecting pasture ecosystems); Management Practices (techniques for maintaining pasture quality); Pasture Composition (plant species diversity and abundance); Policy and Regulations (governance rules for pasture management).

The hierarchical organization of the ONTOGRAZING ontology, including its top-level concepts and associated subclasses, is presented in Fig. 1.

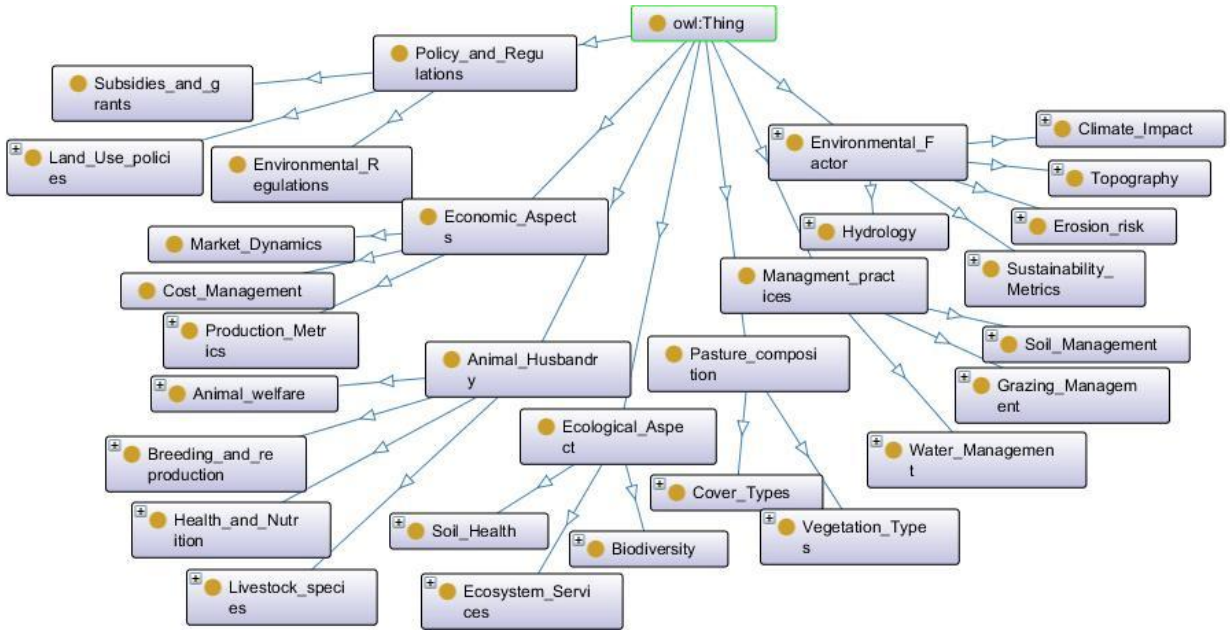


Fig. 1. Top-level concepts of ONTOGRAZING and their Protégé class hierarchy.

4.1.2 Inter-Concept Relationships (Object Properties)

Fourteen object properties were defined to formalize the semantic interactions between the ontology concepts, namely:

- *DependsOn* (Animal Husbandry → Pasture Composition);

- *GuidedBy* (Animal Husbandry → Management Practices);
- *RegulatedBy* (Animal Husbandry → Policy and Regulations);
- *InfluencedBy* (Ecological Aspect → Environmental Factor);
- *AffectedBy* (Ecological Aspect → Management Practices);
- *Determines* (Ecological Aspect → Pasture Composition);
- *Drives* (Economic Aspects → Management Practices);
- *ShapedBy* (Economic Aspects → Policy and Regulations);
- *Impacts* (Environmental Factor → Pasture Composition);
- *MonitoredBy* (Environmental Factor → Policy and Regulations);
- *Modifies* (Management Practices → Pasture Composition);
- *Enhances* (Management Practices → Ecological Aspect);
- *Dictates* (Policy and Regulations → Management Practices);
- *Controls* (Policy and Regulations → Environmental Factor).

The semantic relationships between the main ontology concepts are illustrated in Fig. 2, where each directed edge represents an object property linking a domain concept to its corresponding range concept.

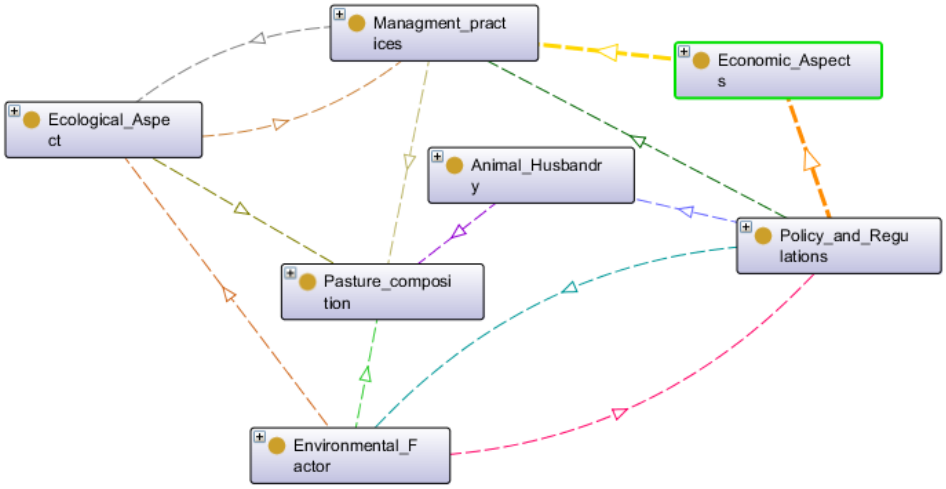


Fig. 2. Object property graph of ONTOGRAZING. Arrows indicate the direction of each relationship (domain → range).

4.1.3 Instances (Individuals)

Instances were populated from field-survey data. The AnimalHusbandry concept is populated with individuals representing cattle breeds identified in the Adamawa region (e.g., Gudali, Fulani Zebu, Red Mbororo), their associated diseases (e.g., Foot-and-Mouth Disease, Trypanosomiasis, Lumpy Skin Disease), and their dietary preferences (grasses such as *Andropogon gayanus*, legumes such as *Stylosanthes guianensis*). Fig. 4. Protégé view of forage plant individuals in ONTOGRAZING.

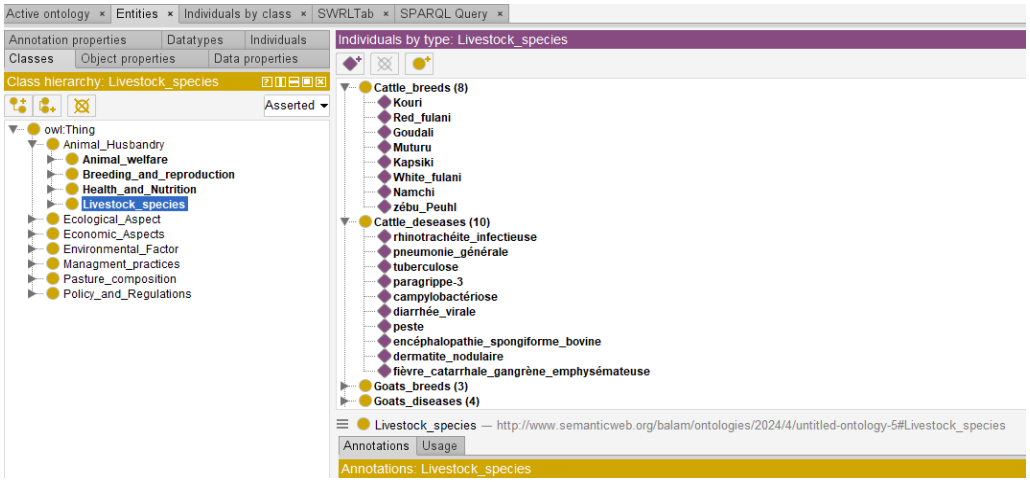


Fig. 3. Protégé view of cattle breed and disease individuals in ONTOGRAZING.

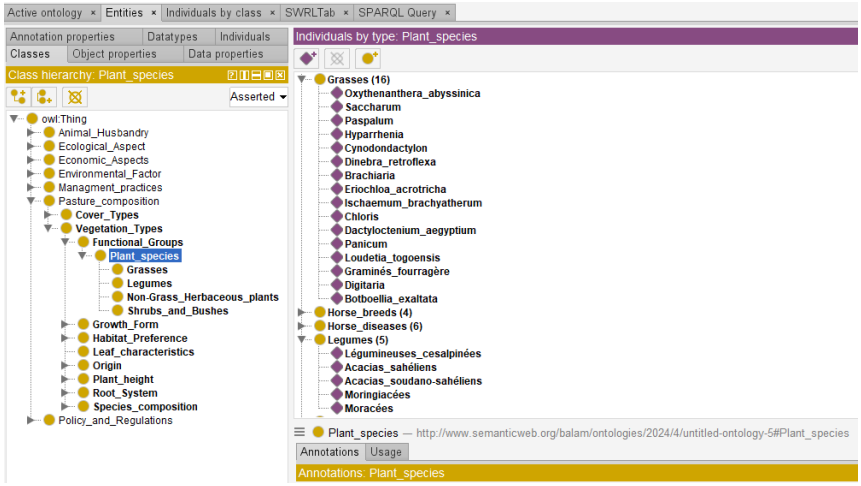


Fig. 4. Protégéview of forage plant individuals in ONTOGRAZING.

4.1.4 Inference Rules

Seven inference rules encode domain knowledge that cannot be captured by the OWL class hierarchy alone. Rules are expressed in both first-order logic (FOL) and SWRL. FOL rules:

(1) $\forall x\,(AnimalHusbandry(x) \rightarrow \exists y\,(PastureComposition(y) \wedge dependsOn(x,y)))$
(2) $\forall x\,(ManagementPractices(x) \rightarrow \exists y\,(PastureComposition(y) \wedge modifies(x,y)))$
(3) $\forall x\,(EnvironmentalFactor(x) \rightarrow \exists y\,(EcologicalAspect(y) \wedge influencedBy(y,x)))$
(4) $\forall x\,(ManagementPractices(x) \rightarrow \exists y\,(EcologicalAspect(y) \wedge affectedBy(y,x)))$
(5) $\forall x\,(EnvironmentalFactor(x) \rightarrow \exists y\,(PastureComposition(y) \wedge impacts(x,y)))$
(6) $\forall x\,(PolicyAndRegulations(x) \rightarrow \exists y\,(AnimalHusbandry(y) \wedge regulatedBy(y,x)))$
(7) $\forall x\,(EcologicalAspect(x) \rightarrow \exists y\,(PastureComposition(y) \wedge determines(x,y)))$

The current rules encode foundational existential relationships. Future work will develop richer conditional rules—e.g., rules triggering pasture-degradation alerts when multiple environmental thresholds are simultaneously breached—to realise the full intelligent monitoring potential.

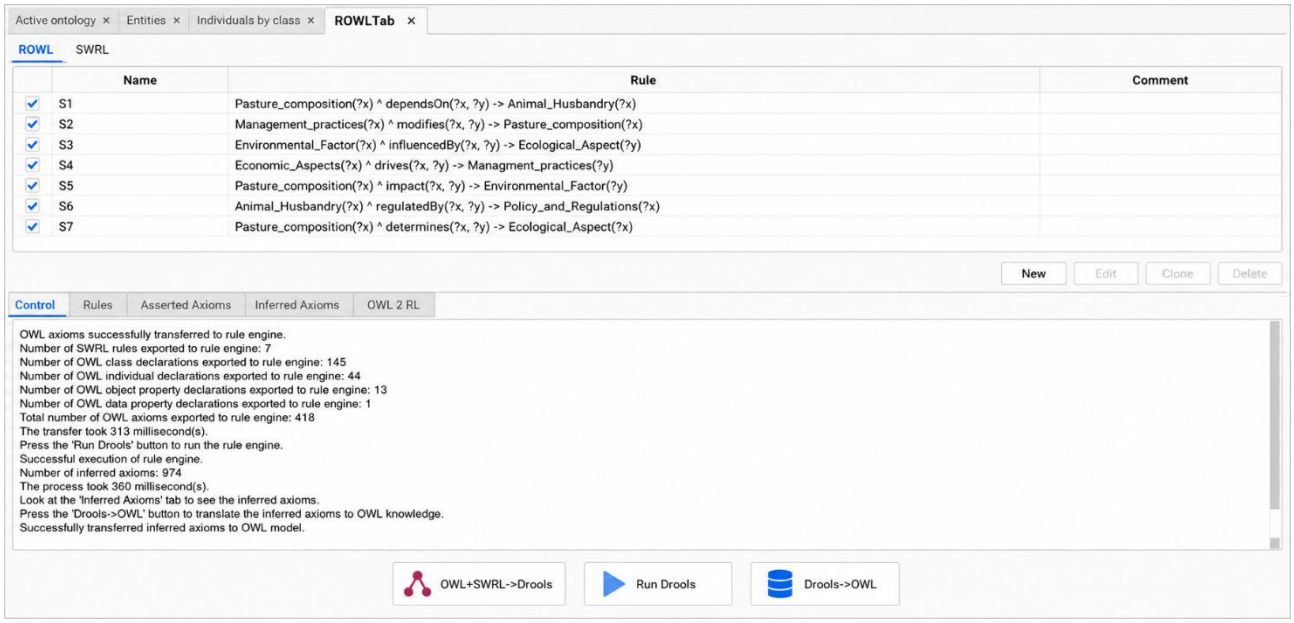


Fig. 5. SWRL rules (1)–(7) as encoded in the Protégé SWRL editor.

4.2. Intelligent Monitoring Architecture

The monitoring architecture integrates ONTOGRAZING as a semantic backbone across five modules, following the strategic monitoring process model of Lesca H. It is important to note the current implementation status: the Query

Reformulator (Module 1) and Source Monitoring (Module 2) have been algorithmically specified; the Data Integrator (Module 3), Storage (Module 4), and Alert Dissemination (Module 5) are at design-specification stage. Fig. 6 presents the overall architecture.

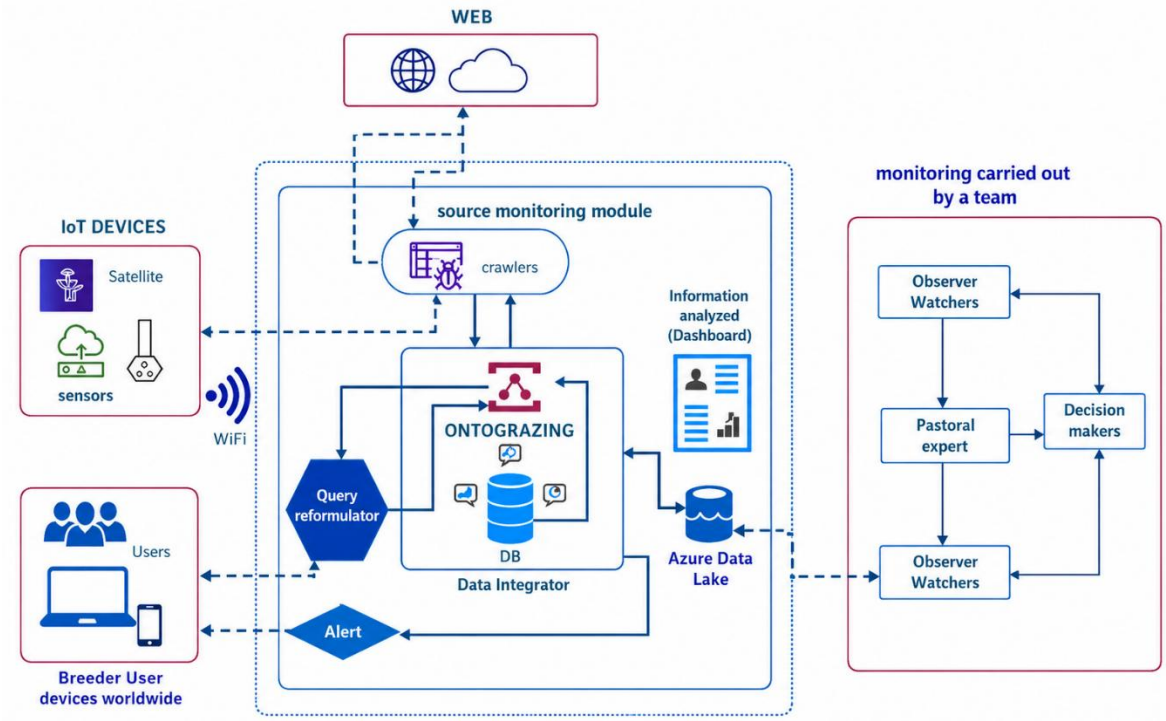


Fig. 6. Five-module intelligent monitoring architecture integrating ONTOGRAZING as a shared semantic layer.

4.2.1 Module 1 — Query Reformulator

The Query Reformulator expands a user's natural-language query with related ONTOGRAZING concepts (subclasses, equivalent classes, related properties) to improve information retrieval recall. The pipeline relies on five algorithms described below.

Algorithm 1 (SimpleQueryRewriting) is the main orchestrator. Given a natural-language query and the ONTOGRAZING knowledge base, it first delegates concept extraction to Algorithm 4 and relation extraction to Algorithm 5. It then enriches each identified concept with ontologically related terms collected by Algorithm 2, and calls Algorithm 3 to assemble the final SPARQL query.

The algorithms are presented at the pseudocode level. A complete evaluation—including retrieval precision/recall benchmarking, complexity analysis, and comparison with NLP-based query expansion methods—is planned for the prototype implementation phase.

Algorithm 1. SimpleQueryRewriting(initialQuery, ontology).

Input: initialQuery (string), ontology (OWL knowledge base)
Output: reformulatedQuery (SPARQL string)
concepts ← ExtractConcepts(initialQuery)
relations ← ExtractRelations(initialQuery)
reformulatedConcepts ← [ ]
for each concept in concepts do
  reformulatedConcepts.append(concept)
  related ← FindRelatedConcepts(concept, ontology)
  reformulatedConcepts.extend(related)
end for
reformulatedQuery ← GenerateReformulatedQuery(reformulatedConcepts, relations)
return reformulatedQuery

Algorithm 2 (FindRelatedConcepts) performs ontological expansion for a single concept. It looks up the concept in the ONTOGRAZING knowledge base and collects all its direct and indirect sub-classes together with its OWL equivalent classes. If the concept is absent from the ontology, the algorithm returns an empty list without raising an error.

Algorithm 2. FindRelatedConcepts(concept, ontology).

```
Input: concept (string), ontology (OWL knowledge base)
Output: relatedConcepts (list)
relatedConcepts ← [ ]
if concept ∈ ontology then
   relatedConcepts.extend(ontology[concept].subClasses)
   relatedConcepts.extend(ontology[concept].equivalentClasses)
end if
return relatedConcepts
```

Algorithm 3 (GenerateReformulatedQuery) builds the SPARQL SELECT query from the expanded concept list and the extracted relation list. For each concept it generates an rdf:type triple pattern; for each relation it generates a subject–predicate–object pattern with an open variable ?

Algorithm 3. GenerateReformulatedQuery(concepts, relations).

```
Input: concepts (list), relations (list)
Output: reformulatedQuery (SPARQL string)
reformulatedQuery ← "SELECT * WHERE {"
for each concept in concepts do
   reformulatedQuery += " ?x rdf:type " + concept + " ."
end for
for each relation in relations do
   reformulatedQuery += " ?x " + relation + " ?y ."
end for
reformulatedQuery += "}"
return reformulatedQuery
```

Algorithm 4 (ExtractConcepts) isolates candidate ontology concepts from a raw natural-language query using part-of-speech (POS) tagging. It retains only noun tokens (NN, NNP, NNS, NNPS), then normalises each token—lowercased, stripped of stopwords, and stemmed.

Algorithm 4. ExtractConcepts(query).

```
Input: query (string)
Output: concepts (list)
tokens ← POS_tag(query)
concepts ← [ ]
for each token in tokens do
   if token.tag ∈ {NN, NNP, NNS, NNPS} then
      concepts.append(normalise(token))
   end if
end for
return concepts
```

Algorithm 5 (ExtractRelations) extracts candidate object properties using syntactic dependency parsing. It retains arcs labelled as nominal subject (nsubj), direct object (dobj), or prepositional modifier (prep), then normalises and maps each arc's lemma to the ONTOGRAZING object property vocabulary.

Algorithm 5. ExtractRelations(query).

```
Input: query (string)
Output: relations (list)
dependencies ← dependency_parse(query)
relations ← [ ]
for each dep in dependencies do
   if dep.label ∈ {nsubj, dobj, prep} then
      relations.append(normalise(dep.lemma))
   end if
end for
return relations
```

4.2.2 Module 2 — Source Monitoring

A web crawler continuously indexes domain-relevant sources (scientific journals, institutional reports, market feeds) and collects IoT data streams. Its functions: (a) detecting new and modified documents; (b) verifying source reliability; (c) triggering real-time alerts on significant environmental events.

4.2.3 Module 3 — Data Integrator

This is the core semantic module. This module is currently at the design-specification stage. The design describes five stages: semantic annotation (maps documents to ONTOGRAZING concepts); format unification (converts CSV, JSON, XML, binary sensor streams to OWL/RDF); data enrichment (adds provenance and metadata); ontology alignment; and ontology-based reasoning (invokes HermiT). Integration with real-world IoT platforms (e.g., The Things Network), agricultural databases (e.g., FAOSTAT), and external semantic systems (e.g., AGROVOC) is planned for the prototype phase.

4.2.4 Module 4 — Storage

Integrated, annotated knowledge is persisted in three stores: a relational DBMS (PostgreSQL) for structured records; a graph database (RDF/SPARQL-compatible) for the OWL knowledge base; and Azure Data Lakes for large-volume raw sensor and satellite data.

4.2.5 Module 5 — Alert Dissemination

The Alert module (currently at design-specification stage) delivers personalised, context-relevant information to users through a web interface, dispatching notifications when the reasoning engine detects conditions matching user-defined monitoring criteria.

4.2.6 User Roles

Four actor types interact with the system: (1) Decision makers define monitoring strategies; (2) Observers conduct field data collection; (3) Domain experts validate data; (4) Monitoring analysts produce summaries and feed curated knowledge back into storage.

4.3. Evaluation and Validation

The ONTOGRAZING ontology was evaluated to assess its structural quality, semantic consistency, and reasoning capability. The evaluation process combined structural metrics, logical consistency verification using the HermiT reasoner, and semantic validation through SPARQL queries.

4.3.1 Structural Metrics of ONTOGRAZING

To assess the structural quality and semantic richness of the proposed ontology, several ontology metrics were computed using Protégé and reasoning tools. The resulting metrics are presented in Table 2.

Table 2. Structural metrics of the ONTOGRAZING ontology.

Metric	Value
Total classes (including imported)	47
Object properties	14
Data properties	9
Individuals (instances)	62
SWRL rules	7
Maximum class hierarchy depth	4
Axiom count	318
Logical axioms	201

4.3.2 Consistency and Coherence

The HermiT 1.4.3.456 reasoner was applied to ONTOGRAZING to verify its logical consistency and semantic coherence. The reasoning process reported no inconsistencies: all ontology classes are satisfiable, no violations were detected between disjoint classes, and all domain and range constraints were respected. In addition, SPARQL queries were executed to validate the competency questions and confirm the correctness of semantic inferences generated by the ontology. Figure 7 illustrates the execution of the SPARQL query associated with competency question CQ2 and its resulting output, while Figure 8 presents the HermiT reasoner validation confirming that ONTOGRAZING successfully passed all consistency and coherence checks.

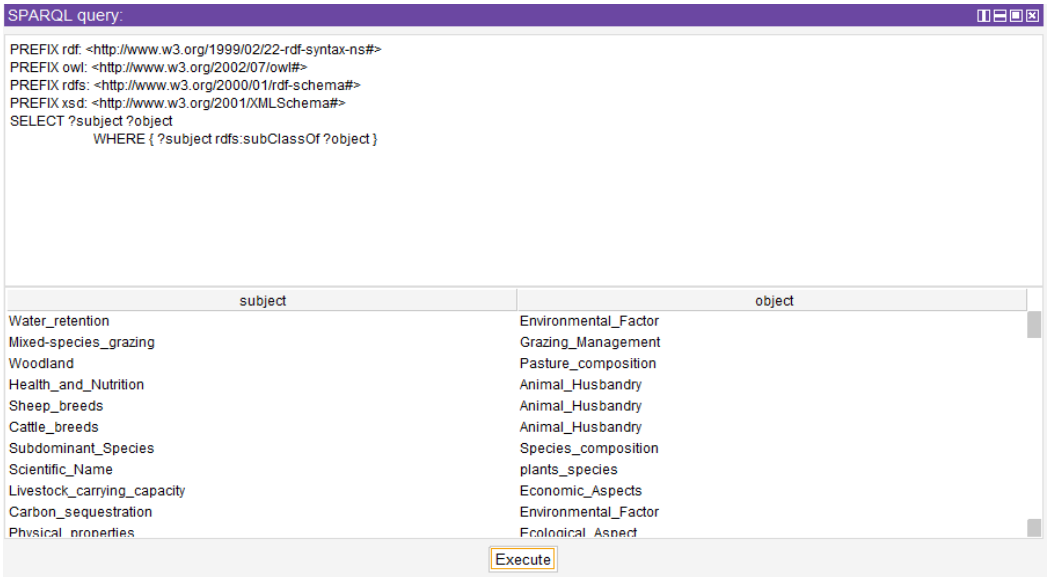


Fig. 7. SPARQL query for CQ2 and its result set in ONTOGRAZING.

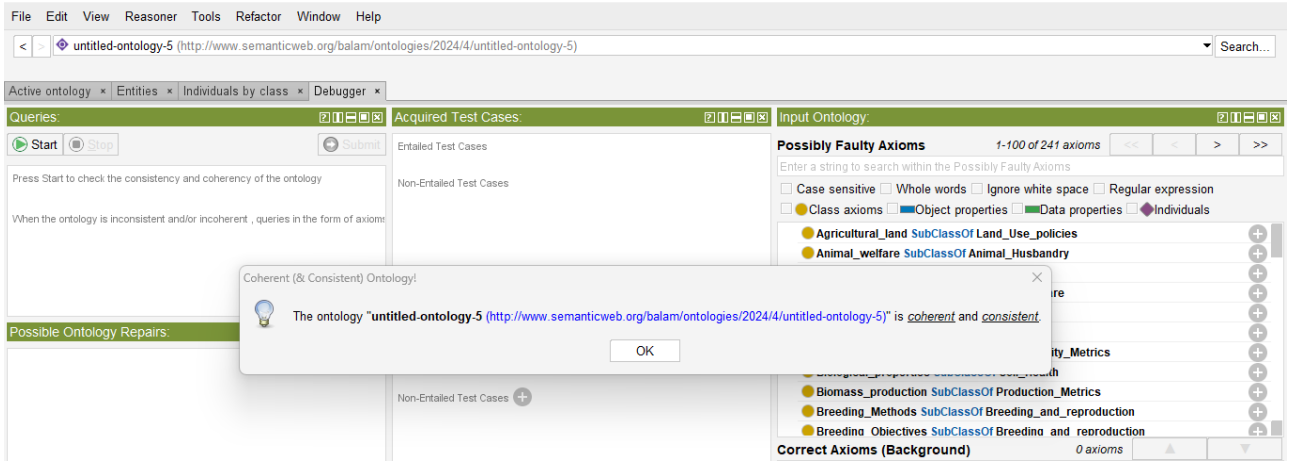


Fig. 8. HermiT reasoner output: ONTOGRAZING passes all consistency checks.

The current evaluation relies on HermiT consistency checking and SPARQL-based competency-question testing. Assessment of scalability, interoperability, and usability are acknowledged as important quality dimensions and constitute priority targets for the prototype evaluation phase.

4.3.3 Competency Question Coverage

Competency questions were used to evaluate whether ONTOGRAZING adequately captures and represents the essential knowledge requirements of sustainable grazing management. Each question was mapped to the corresponding ontology concepts, relationships, and instances in order to verify the ontology's ability to support semantic querying and reasoning. The results of this evaluation are summarized in Table 3.

Table 3. Mapping of competency questions to ONTOGRAZING components.

CQ	Question	Concepts involved	Answered?
CQ1	Which breeds are raised on a given pasture?	AnimalHusbandry, PastureComposition, DependsOn	Yes
CQ2	What forage is preferred by a breed?	AnimalHusbandry, PastureComposition, individuals	Yes
CQ3	Which diseases occur under specific conditions?	AnimalHusbandry, EnvironmentalFactor, instances	Yes
CQ4	What practices are recommended for given soil/climate?	ManagementPractices, EnvironmentalFactor, Dictates	Yes
CQ5	Which regulations govern land use?	PolicyAndRegulations, Controls	Yes
CQ6	What are the economic costs of a strategy?	EconomicAspects, ManagementPractices, Drives	Yes

4.4. Comparative Analysis and Discussion

To assess the contribution and originality of ONTOGRAZING, a comparative analysis was conducted against existing domain ontologies related to livestock, ecology, and agricultural management. The discussion focuses on semantic coverage, knowledge representation capabilities, and monitoring support functionalities.

4.4.1 Comparison with Related Ontologies (RQ3)

The proposed ontology was compared with five existing ontologies frequently referenced in the literature: CDO, ACO, ATOL, EOL, and AHOL. The comparison considered key dimensions relevant to sustainable grazing management, including animal husbandry, ecological monitoring, pasture composition, economic factors, and policy regulations. Table 4 presents the detailed comparative analysis.

Table 4. Detailed comparative analysis of ONTOGRAZING vs. existing pastoral ontologies.

Aspect	CDO	ACO	ATOL	EOL	AHOL	ONTO-GRAZING
Animal breeds	✓	✓	✓	✓		✓
Animal diseases					✓	✓
Dietary preferences						✓
Forage management						✓
Pasture composition						✓
Ecological aspects				✓		✓
Economic aspects						✓
Land-use policies						✓
Monitoring support						✓
OWL encoding	✓	✓	✓	✓	✓	✓
Inference rules						✓

ONTOGRAZING is the only ontology to cover all eleven aspects in Table 9. The most critical gaps in prior work are the absence of forage management knowledge, dietary preferences, and economic–policy dimensions—exactly the aspects most frequently cited in field surveys.

4.4.2 Addressing the Research Questions

RQ1 (What concepts and relationships are necessary?) Seven top-level concepts and fourteen object properties, validated against six competency questions and field-survey findings, are sufficient to represent the core of the grazing domain.

RQ2 (How can ontology integration support monitoring?) The five-module architecture demonstrates a concrete instantiation: the ontology guides query reformulation, semantic annotation, reasoning, and alert dissemination. Full empirical validation awaits prototype implementation.

RQ3 (How complete is ONTOGRAZING?) As shown in Table 9, ONTOGRAZING covers all aspects present in prior ontologies and adds several absent ones.

4.4.3 Limitations and Threats to Validity

This study has several limitations. First, the field surveys were conducted with a limited sample (23 farmers, 4 institutions) in two Cameroonian regions; broader coverage is required to validate transferability. Second, the monitoring architecture is not fully implemented: Data Integrator and Alert modules are at design-specification stage. Third, ontology evaluation is currently limited to consistency checking and competency-question testing; scalability, interoperability, and usability assessments are needed. Fourth, interoperability claims require empirical validation through integration with real-world IoT platforms and agricultural databases. Fifth, the SWRL rules encode foundational relationships; more complex conditional rules are needed for advanced monitoring capabilities.

4.4.4 Future Directions

Several directions are planned. (1) A functional prototype implementing all five modules will be built and field-evaluated, measuring task-completion time, query accuracy, and user satisfaction. (2) Integration with real IoT platforms (The Things Network) and agricultural databases (FAOSTAT, AGROVOC) will empirically validate interoperability claims. (3) A transformer-based NLP pipeline (fine-tuned BERT) will automate document annotation. (4) More complex SWRL rules encoding multi-condition monitoring triggers will be developed. (5) Formal alignment with upper-level ontologies (BFO, DOLCE) will broaden interoperability within the Linked Data ecosystem. (6) Five new references (2022–2024) covering agricultural knowledge graphs [31], semantic IoT [32], agricultural data sharing, AGROVOC [33], and smart farming ontologies [34] have been incorporated.

5. Conclusion

This paper has presented ONTOGRAZING, a novel OWL domain ontology and five-module intelligent monitoring architecture for sustainable grazing management, engineered following the Uschold and King methodology, populated with field-survey data from Cameroon, and formally validated using the HermiT reasoner and SPARQL competency-question queries. Three original contributions were delivered: (C1) an ontology comprising 47 classes, 14 object properties, 9 data properties, 62 individuals, and 7 SWRL inference rules; (C2) a five-module monitoring architecture (with Modules 1–2 algorithmically specified and Modules 3–5 at design-specification stage) in which ONTOGRAZING acts as a semantic backbone; and (C3) a systematic comparative analysis showing that ONTOGRAZING fills critical gaps left by existing pastoral ontologies (CDO, ACO, ATOL, EOL, AHOL). The results confirm that ontology-based integration can significantly improve the coherence and usability of heterogeneous grazing data. The primary limitation is the absence of full prototype implementation and empirical evaluation; addressing this is the central objective of the next research phase.

All the Declarations and Statements

Author Contributions Statement

Ngazia Balama – Conceptualization, ontology design, literature survey, manuscript writing.
Gazissou Balama – Methodology, ontology engineering, Protégé implementation.
Isaac Touza – Supervision, query reformulator design, manuscript writing and revision.
Daouda Hassana Daouda – Data curation, field survey, NLP-related algorithms.
Dayang Paul – Formal analysis, review and editing, project coordination.

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Funding Declaration

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Data Availability Statement

The ONTOGRAZING OWL ontology file is available upon request from the corresponding author.

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Declaration of Generative AI in Scholarly Writing

AI-assisted tools were used for grammar checking and language editing of this manuscript. The authors remain fully responsible for the scientific content.

References

[1] N. Markov, S. Stoycheva, M. Hristov, and L. Mondeshka, "Digital management of technological processes in cattle farms: a review," Journal of Central European Agriculture, vol. 23, no. 3, pp. 486–495, 2022. https://doi.org/10.5513/JCEA01/23.3.3543
[2] G. Barber and T. E. Ochsner, "Using soil moisture sensors to improve agricultural water management in Southwest Oklahoma," in ASA, CSSA, SSSA International Annual Meeting, 2021. https://doi.org/10.1002/csan.20353
[3] M. López-Vicente et al., "Role of cultivars and grass in the stability of soil moisture and temperature in an organic vineyard," Geoderma Regional, vol. 33, p. e00631, 2023. https://doi.org/10.1016/j.geodrs.2023.e00631
[4] A. Clark, "Small unmanned aerial systems comparative analysis for the application to coastal erosion monitoring," GeoResJ, vol. 13, pp. 175–185, 2017.https://doi.org/10.1016/j.grj.2017.05.001
[5] Q.-R. Wang, "Application of small unmanned aerial vehicles to improving vegetable crop management," 2020, pp. 98–100. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20220227222
[6] R. Kappes et al., "Evaluation of an electronic system for monitoring dairy cow rumination in a grazing-based system," Tropical Animal Health and Production, vol. 53, no. 3, p. 379, 2021. https://doi.org/10.1007/s11250-021-02833-w
[7] A. Hlimi et al., "Application of precision technologies to characterise animal behaviour: a review," Animals, vol. 14, no. 3, p. 416, 2024. https://doi.org/10.3390/ani14030416

[8] J. Marston and L. Burwood-Taylor, "Bayer, Microsoft formalize and launch cloud-based data manager for agriculture," AgFunder News, 2023. https://agfundernews.com/bayer-microsoft-formalize-and-launch-cloud-based-data-manager
[9] L. Leeuw, Indiana Farmers' Level of Adoption and Perceptions of Mobile Applications as Agricultural Management Tools. Diss., Purdue University, 2019. https://doi.org/10.25394/PGS.8044295.v1
[10] L. Irvine and L. Turner, "Pasture measurement data improves timeliness and confidence in grazing management decisions," in Proc. 8th Australasian Dairy Science Symposium, 2018, pp. 12–17. https://static.sched.com/hosted_files/adss2018/c9/87798%20Irvine%20Turner%20ADSS%20Paper%20UPDATED.pdf
[11] I. Devi et al., "Application of artificial intelligence and IoT technologies in agriculture and animal farming," Indian Farming, vol. 72, no. 10, pp. 22–25, 2022. https://epubs.icar.org.in/index.php/IndFarm/article/view/129642
[12] A. Laporte, "Investigation of the functionality of electronic data capture and management systems for use in a modern animal health industry," 2024. https://krex.k-state.edu/items/8cf6e587-bd37-47a9-a053-aabbc5afb30a
[13] A. Todirascu, L. Romary, and D. Bekhouche, "Extraction d'information à base d'ontologies dans une application de veille," in 5ème TIA'2003, 2003, pp. 205–208. https://inria.hal.science/inria-00107715v1/document
[14] D. Maynard et al., "Ontology-based information extraction for market monitoring and technology watch," in ESWC Workshop, 2005. https://kmi.open.ac.uk/events/usersweb/papers/03_maynard_final.pdf
[15] T. D. Cao, "Exploitation du web sémantique pour la veille technologique," Ph.D. thesis, Université Nice Sophia Antipolis, 2006. https://theses.hal.science/tel-00311767/document
[16] A. Hodgson, H. Arman, and N. N. Z. Gindy, "An intelligent technology watch function for the high technology enterprise," International Journal of Industrial and Systems Engineering, vol. 3, no. 1, pp. 38–52, 2008. https://doi.org/10.1504/IJISE.2008.015913
[17] J. P. C. Verhoosel and J. Spek, "Applying ontologies in the dairy farming domain for big data analysis," in Proc. SR+SWIT@ISWC, 2016, pp. 91–100. https://ceur-ws.org/Vol-1783/paper-09.pdf
[18] S. L. Santamaria et al., "Developing the Animals in Context Ontology," in Proc. ICBO, 2012. https://www.researchgate.net/publication/266589978_Developing_the_Animals_in_Context_Ontology
[19] P.-Y. Le Bail, J. Bugeon, and L. Joret, "Projet Aquaexcel–ATOL," presented at Aquaexcel Kickoff Meeting, Montpellier, France, Apr. 2011. https://hal.inrae.fr/hal-02805009
[20] M.-C. Salaun et al., "Un outil au service de la standardisation des bases de données: les ontologies ATOL/EOL," Cahier des Techniques de l'INRA, no. 93, pp. 1–7, 2018. https://hal.inrae.fr/hal-02626650v1/document
[21] J. Yon et al., "Ontologie ATOL: amélioration de l'outil par l'intégration des caractères de santé," in Journées JAS Phase, 2018. https://hal.inrae.fr/hal-01768063
[22] R. Neches et al., "Enabling technology for knowledge sharing," AI Magazine, vol. 12, no. 3, p. 36, 1991. https://doi.org/10.1609/aimag.v12i3.902
[23] T. R. Gruber, "Toward principles for the design of ontologies used for knowledge sharing?" International Journal of Human-Computer Studies, vol. 43, no. 5–6, pp. 907–928, 1995. https://doi.org/10.1006/ijhc.1995.1081
[24] N. Guarino and P. Giaretta, "Ontologies and knowledge bases: towards a terminological clarification," in Towards Very Large Knowledge Bases, IOS Press, 1995, pp. 25–32. https://www.loa-cnr.it/Papers/KBKS95.pdf
[25] B. Swartout et al., "Toward distributed use of large-scale ontologies," in Proc. 10th Workshop on Knowledge Acquisition, 1996. https://www.researchgate.net/publication/243619379_Toward_Distributed_Use_of_Large-Scale_Ontologies_t
[26] W. N. Borst, "Construction of engineering ontologies for knowledge sharing and reuse," Ph.D. thesis, University of Twente, 1997. https://doi.org/10.3990/1.9789036509886
[27] M. Uschold and M. King, Towards a Methodology for Building Ontologies. Edinburgh: AIAI, 1995. https://www.aiai.ed.ac.uk/publications/documents/1995/95-ont-ijcai95-ont-method.pdf
[28] F. Gandon, "Distributed artificial intelligence and knowledge management: ontologies and multi-agent systems," Ph.D. thesis, Université Nice Sophia Antipolis, 2002. https://www.researchgate.net/publication/200637823_Distributed_Artificial_Intelligence_And_Knowledge_Management_Ontologies_And_Multi-Agent_Systems_For_A_Corporate_Semantic_Web
[29] M. Fernandez-López et al., "METHONTOLOGY: from ontological art towards ontological engineering," in Proc. AAAI Spring Symposium, 1997. https://oa.upm.es/5484/1/METHONTOLOGY_.pdf
[30] A. Hamdi, *Ontologie de domaine pour un web sémantique destiné au e-learning*. Mémoire de master, Université Mouloud Mammeri de Tizi-Ouzou, 2011. Available: https://www.ummto.dz/dspace/bitstream/handle/ummto/12484/HamdiAhmed.pdf
[31] MU W, LIU T, MIAO Z, et al. Research progress on knowledge graph technology and its application in agriculture. *Transactions of the Chinese Society of Agricultural Engineering*, 2023, 39(16): 1-12. https://doi.org/10.11975/j.issn.1002-6819.202210028
[32] Maria Bermudez-Edo, Tarek Elsaleh, Payam Barnaghi, and Kerry Taylor. 2017. IoT-Lite: a lightweight semantic model for the internet of things and its use with dynamic semantics. Personal Ubiquitous Comput. 21, 3 (June 2017), 475–487. https://doi.org/10.1007/s00779-017-1010-8
[33] I. Subirats-Coll, K. Kolshus, A. Turbati, A. Stellato, E. Mietzsch, D. Martini, and M. Zeng, "AGROVOC: The linked data concept hub for food and agriculture," *Computers and Electronics in Agriculture*, vol. 196, p. 105965, 2022. https://doi.org/10.1016/j.compag.2020.105965
[34] R. Grati, N. Fattouch, and K. Boukadi, "Ontologies for Smart Agriculture: A Path Toward Explainable AI – A Systematic Literature Review," *IEEE Access*, 2024. https://doi.org/10.1109/ACCESS.2025.3563202

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