Unveiling Knowledge Organization Systems' Artifacts for Digital Agriculture with Lexical Network Analysis

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Abstract. This article presents a bibliometric and terminological study of a corpus composed of abstracts and titles of 278 articles retrieved by a review protocol planned for surveying initiatives on building artifacts for modeling knowledge related to agricultural production systems. The original corpus comprised a 53,379-word linguistic extract filtered to 111 interconnected major terminologies by combining AntConc and VOSViewer tools. The reduced data were imported into the Gephi tool for analysis of lexical network graphs. Emergent clusters and their central terms underscore the thematic areas that prominently shape the landscape of agricultural Knowledge Organization Systems (KOS) and highlight the interplay between technological advancements, semantic enrichment, and domain-specific challenges. Our analysis of term occurrences and clusters contributes to a broader understanding of these concepts, inferring their significance, roles, and interconnections within the agricultural landscape. It also sheds light on the roles played by KOS in Digital Agriculture.

Keywords: Corpus Linguistics · KOS · Semantic artifacts · Ontologies · Thesaurus · Metadata · Knowledge graph

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1 Introduction

Agricultural production sustains life on Earth and, as human population increases and climate changes, there is a growing effort to make productive systems more resilient and sustainable, in order to assure food security and nutrition to all. At the same time, agriculture production systems, agricultural sciences, and digital agriculture technologies tightly bound with computer science are generating a growing amount of valuable data that can drive decision-making toward a sustainable future.

However, to make sense of the data deluge in agriculture, it is imperative to adequately model agricultural knowledge using Knowledge Organization Systems (KOS) [20,22]. KOS encompass several types of artifacts with different vocabulary control (terminology) levels that seek to minimize the ambiguities of natural language. KOS represent the knowledge of a domain (scientific, educational, professional) based on an agreement accepted among peers. In general, KOS are composed of a set of terms representing concepts, delimited by their meanings and linked by semantic relationships. Each type of KOS support a specific function, although there may be some overlap of functions between them. Computationally, KOS can support the indexing of document resources, search (as an extension of semantic search), and information retrieval (as a browsing mechanism).

There are several efforts to represent agricultural knowledge, such as AGROVOC Multilingual Thesaurus (https://agrovoc.fao.org/browse/agrovoc/en/), NAL Agricultural Thesaurus (NALT) (https://data.nal.usda.gov/dataset/nal-agricultural-thesaurus-and-glossary), Chinese Agricultural Thesaurus (CAT) (https://bartoc.org/en/node/18606), CAB Thesaurus (Centre for Agricultural Bioscience International (https://www.cabi.org/cabithesaurus/) and the ones aggregated by Agroportal (https://agroportal.lirmm.fr/). Finding and mapping existing semantic artifacts is essential to understand their structure and representation models to better apply such resources to agricultural systems and products. Furthermore, within the scope of the GO FAIR initiative (https://www.go-fair.org/), the regional office in Brazil supports the implementation of the FAIR principles (Findable, Accessible, Interoperable and Reusable) [39]. In this context, the GO FAIR Agro Brazil network convened experts in the Ontology Working Group (WG) [15].

The WG aims to explore and propose methods and standards for constructing, adapting, or incorporating existing ontologies into data-centric agronomic systems with a tropical agriculture focus. The primary emphasis is on achieving improved semantic data descriptions and enhancing software interoperability.

In this paper, we describe the WG's efforts to map existing semantic artifacts for the Agriculture field, in whichever form. Particularly, we describe a bibliometric and terminological analysis of the articles' abstracts found with a literature scoping review protocol.

The next sections are structured as follows: Sect. 2 analyses related literature review initiatives concerning the use of technology on Digital Agriculture, focusing on Semantic Web models for Knowledge management. Section 3 provides information on the literature review protocol and bibliometric analysis strategies. Section 4 discusses the main findings. Final remarks are presented in Sect. 5.

2 Related Work

The use of Information and Communication Technologies (ICTs) in agricultural and livestock systems has been the subject of several reviews in the literature. For example, [16] provides a comprehensive review of semantic web technologies for agriculture, finding 13 resources by the end of 2018. It is the only article directly related to our work focusing on the type of artifacts.

The literature reviews highlight that reliable and secure data repositories, metadata, semantic analysis, and systems interoperability are essential for the objectives of Digital Agriculture. Another article concerned with the FAIR principles in Agriculture is [5], which discusses precision livestock farming technologies in relation to their use of public data, open standards, interoperability, and tools. The authors did not follow any literature review protocol. Several initiatives towards standardization of metadata are presented, including ISO standards for agriculture machinery. Ontologies appear as a means to give semantics for gathered data, without discussing specific research/initiatives in that direction. It is mainly concerned with decision support tools aiming at smart livestock farming.

The other papers we are aware of do not focus on semantic web technologies *per se*. However, such papers lay on how technology is used in agricultural settings, and on what are the obstacles to achieving full. Particularly, [12] uses a systematic literature review protocol to uncover term definitions, technologies, barriers, advantages, and disadvantages of Digital Agriculture. [38] uses a systematic literature review protocol to survey the main features and obstacles to the use of Farm Management Information Systems. [1] reviews the literature related to crop farming regarding the extent of digital technology adoption in the context of service type, technology readiness level, and farm type. [30] surveys the technologies used in smart livestock farming, focusing on biometric and biological sensors, big data analytics, data science, machine learning, and blockchain.

The need for compatibility between technological artifacts is considered a barrier to Digital Agriculture to develop. However, no discussion about conceptual models or data integration was issued in [12]. [4] focus their review on research activities related to smart farming within the EU, with sensing techniques, robotics, IoT, and decision support systems being the most frequent themes. [34] uses a literature review protocol to analyze 378 articles concerning technological advances in smart farming. It states that the most agriculture work is still performed manually by the farmers, mainly due to the high maintenance and deployment cost. Finally, [31] surveys articles related to data-driven decision support systems in livestock farming.

Despite ongoing efforts and existing results to achieving the objectives of Digital Agriculture, there remains the need in improving standardized data/metadata formats [1,30,34,38], data and system integration [4,31,38], data security [31,34], language regionalisms [38], reusable models [31], availability [31,38], semantic analyzes [4,30], lack of provenance metadata [10] and system interoperability [1,4,30,34,38].

3 Material and Methods

We used the literature scope review described in [2] to identify and analyze different types of artifacts produced to structure KOS and terminologies in Agriculture. Scoping methods aim to identify the nature and extent of research evidence, including ongoing research. The working method was collaborative, supported by the cloud-based software Parsifal (https://parsif.al/).

We are mainly interested in knowing how these artifacts were produced, that is, the methods, their use, their main technological characteristics and for what purpose they were developed. These are the reasons why we conducted our review rather than searching for artifact repositories, which do not directly provide this information.

The literature review protocol was collaboratively developed and refined from February to July 2023 and establishes the following research questions:

1. What are the artifacts that structure knowledge and terminology in the field of agriculture and are available for use?
2. What are the main characteristics of the artifacts found and analyzed?

The search strings were derived from a set of terms considered relevant. Table 1 presents the search terms and related terms used to search the articles.

Table 1. Search terms and related terms

Keyword	Related terms
Agriculture	Agricultural, Agronomy, Livestock
Literature review	Literature mapping, Scope review, Survey
Ontology	Conceptual model, Controlled vocabulary, Data description, Data integration, Dictionary, Glossary, Metadata, Thesaurus

The search strings development aimed to organize the authors' work. Each author was responsible for applying one of the strings to the chosen search sources. Several strings had their format modified to meet the selected bibliographic databases requirements regarding syntax or the number of operators' restrictions. The list of generic search strings is as follows:

- ((Ontolog* OR Taxonom*) AND (Agricult* OR Agronom* OR Livestock))
- ((Ontolog*) AND (Agricult* OR Agronom* OR Livestock))
- ((Metadata OR Data descriptor*) AND (Agricult* OR Agronom* OR Livestock))

- ((Thesaurus OR Data descriptor* OR controlled vocabular*) AND (Agricult* OR Agronom* OR Livestock))
- ((Glossar* OR vocabular* OR dictionar*) AND (Agricult* OR Agronom* OR Livestock))
- ((Conceptual map*) AND (Agricult* OR Agronom* OR Livestock))
- ((Subject headings list*) AND (Agricult* OR Agronom* OR Livestock))
- ((Data model*) AND (Agricult* OR Agronom* OR Livestock))
- ((Conceptual scheme for agro thesaurus integration) AND (Agricult* OR Agronom* OR Livestock))

The digital bibliographic databases used as search sources were: Dimensions (https://www.dimensions.ai/), ISI Web of Science (http://www.isiknowledge.com) and Scopus (http://www.scopus.com). We chose these bibliographic databases because of their interdisciplinary character, mirroring the diverse nature of the domain we examined.

The selection criteria consider both inclusion and exclusion sub-criteria. The inclusion sub-criteria define what are the obligatory subjects of an article to be included in the analysis, while the exclusion sub-criteria disqualify prospective subjects for an article not to be included, provided that it meets at least one of them. Table 2 shows the selection criteria defined within the protocol.

Table 2. Selection (inclusion and exclusion) criteria

Selection Criterion	
Inclusion Criterion	Exclusion Criterion
. Articles written in PT, EN, ES, or FR	.Strictly theoretical review articles
.Articles published between 2002 and 2022	.Articles that mention polysemous terms in other domains of knowledge
.Articles that answer at least one of the research questions	.Articles without full-text digital access
.Articles that present artifacts that structure knowledge and terminology of some domain of agriculture	.Duplicated texts

The data extraction form organizes the articles' reading objectives, focusing on the analysis' main aspects. We have defined a set of information to be extracted, including artifact type, building methods, modeling language, serialization/exchange formats, used license, specific application domain within Agriculture, building tools, used objectives, semantic formalization degree, as well as a qualitative analysis to capture aspects not presented in the form. This data will be used in future analyses since the myriad of answer possibilities showed us that a prior, automatized analysis would be beneficial, so we conducted first a bibliometric and terminological analysis, as described below.

The lexical network metrics for graph analysis were computed using a linguistic corpus [33] composed of abstracts and titles of the selected articles, totaling 53,379 words. In order to extract the lexical-conceptual knowledge [13], i.e., the terms and their semantic meaning and relations, to have a first analysis of the distribution of how the searched artifacts appear in the retrieved texts, the corpus was processed using AntConc (https://www.laurenceanthony.net/software/antconc/) with the minimum frequency of occurrence, i.e., all terms that occur at least one time were collected, and a preliminary inspection of full terms' frequencies and occurrences was obtained. Further, VOSviewer (https://www.vosviewer.com/) was used for the visualization and analysis of the occurrence and co-occurrence of concepts.

In Antconc, to optimize the results and reduce the wordlists, a stoplist was used and a list of terms composed of 1 to 5 words was generated to verify the main terms mentioned in the literature. Each term was searched in its singular and plural forms. The frequencies of the singular and plural forms of the same term were added, considering each pair as a synset, reaching the absolute frequency of each term.

Following the inspection of the file, the default settings of the VOSViewer application were then employed and 6,605 terms were first identified and further arrived in 111 network nodes. The data was then exported to the latest version of Gephi (https://gephi.org/) via a .gml file, which enabled calculating order degree distributions, betweenness centrality [8], and clustering nodes according to modularity classes [25].

Graphs were produced using the ForceAtlas2 algorithm [23]. Node sizes are related to order degree, whereas link sizes are proportional to the strength between nodes' connections. Colors are associated with classes created by means of modularity, while node label size is associated with betweenness centrality, which is responsible for shortening the path between nodes.

4 Results and Discussion

This first approach to analyzing the corpus using the absolute frequency of the searched artifacts highlighted ontological and thesauri artifacts, while the analysis of terms relations by graphs analysis provided a comprehensive portrait of semantic relations around the possible concepts. The absolute frequencies of the terms of interest are: *ontology* = 956; *agriculture* = 326; *thesaurus* = 156; *controlled vocabulary* = 28; *livestock* = 24; *taxonomy* = 21; *data model* = 17; *agronomy* = 12; *dictionary* = 9; *subject headings* = 7; *conceptual map* = 2; *glossary* = 1; *conceptual scheme* = 0; and *data descriptor* = 0.

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The graph with the 111 terms selected by the method is displayed in Fig. 1. It evidences a greater degree of centrality of terms *vocabulary*, *analysis*, *farmer*, and

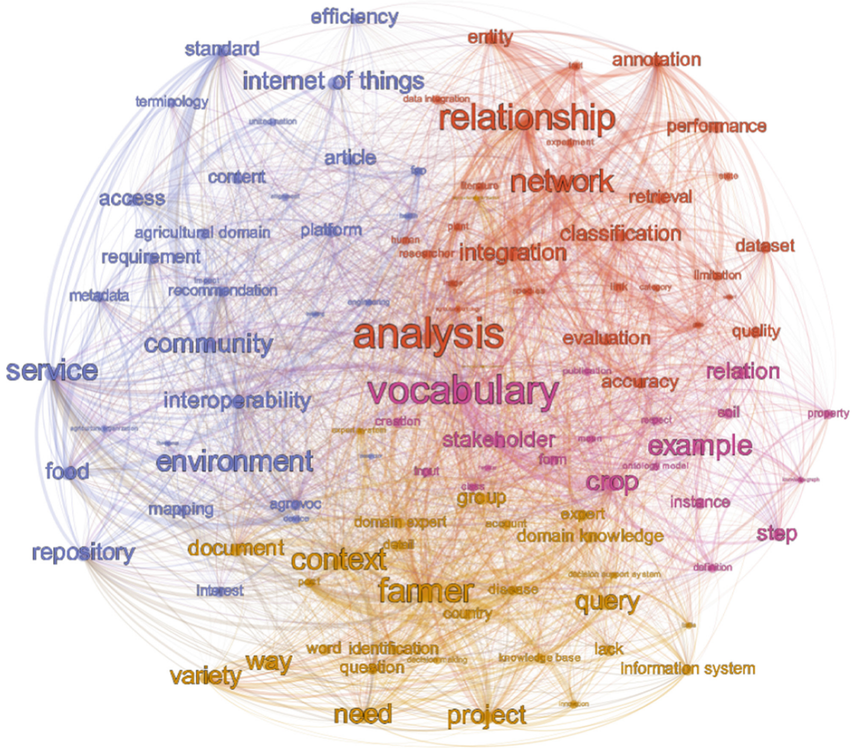

Fig. 1. Network graph of selected terms colored by modularity, nodes sized by order degree and labels sized by betweenness centrality. Link thickness is related to the strength between two adjacent nodes.

relationship, while important terms responsible for shortening the path between nodes are *network*, *context*, *service*, and *environment*.

Node distributions segregated by clusters are illustrated in Fig. 2. The four networks were filtered according with the attribute modularity [25]. Within the blue cluster highlighted in Fig. 2, in the first level, notable recurring terms include *environment* and *service*. That observation likely reflects the increasing utilization of these terms within the context of environmentally-oriented KOS in Agriculture – e.g., [29] –, and the extensive application of KOS in agricultural web services, such as in [19]. The convergence of these terms signaled a thematic intersection that resonates with the imperative of sustainable agricultural practices in the face of environmental challenges.

Within the second tier, there is a notable resurgence of key terms, which encompass *food*, *interoperability*, *metadata*, *repository*, *community*, *content*, *access*, and *Internet of Things (IoT)*. The term *food* emerges with heightened frequency as a pivotal domain of application within KOS, extending its influence across a spectrum of domains. This encompasses its relevance to food supply chains [26], nutritional dimensions [32], as well as its intricate interplay with environmental considerations and the sustainability of food production [29]. This cluster mirrored the technical dimensions of KOS application and development, signifying the pivotal role that KOS play in enhancing data interoperability, accessibility, and the utilization of emerging technology like the IoT in agriculture.

Still in the second tier, the *interoperability*, *metadata*, *repository*, *community*, *content*, *access*, and *IoT* concepts pivot towards the technical dimensions of KOS development and application. The strength of those terms might be a response to the increasing environmental demand for interoperable access to standardized data for sustainable compliance in supply chains [24]. Besides, the use of metadata becomes a recurrent strategy for achieving seamless interoperability among datasets and repositories, as demonstrated in [17]. Moreover, metadata, along with ontologies and other forms of KOS, serve as frequent tools harnessed to enhance accessibility to data content, as illustrated by the insights gleaned from Bechini's study [6]. IoT has demonstrated extensive utility when coupled with ontologies, serving as a catalyst for bolstering semantic interoperability across diverse agricultural domains. This symbiotic integration finds practical manifestation in various contexts, including the descriptive encapsulation of crop sensor data [3] and the dynamics of pest management [9].

Within the scarlet-hued cluster illustrated in Fig. 2, another significant recurrence of terms emerges, encompassing *annotation*, *integration*, *classification*, *relationship*, *network*, *analysis*, *performance*, and *accuracy*. These concepts are notably intertwined with the application of KOS. For example, the term *annotation* predominantly pertains to the semantic annotation of data, involving the utilization of KOS like the crop ontology and AGROVOC for annotating data resources. This practice is exemplified in studies such as [7,18,35]. Data annotation is a commonly utilized technique aimed at facilitating the harmonization of data from diverse sources, with the ultimate goal of achieving data *integration*, such as in [14,27,37]. The study illuminated their roles in semantic annotation, data harmonization, and systematic categorization, illustrating the diverse ways KOS support information organization and retrieval in agriculture.

KOS are also extensively employed in the systematic categorization of objects based on established canonical knowledge within a specific domain. The utilization of ontologies and taxonomies is instrumental in formulating rules, often in the form of axioms, for precise object classification. Noteworthy examples include the utilization of an ontology for soil classification [21], as well as the application of ontologies for the classification of agricultural products [28].

The term *relationship* frequently emerges to delineate the modeling of interconnections between concepts within KOS. Networks find diverse applications, ranging from ontology networks (which also refers to the relationship between concepts in ontologies), exemplified by [9], to sensor networks leveraging ontologies, as demonstrated by [36].

The remaining detached terms within the cluster, namely *analysis*, *performance*, and *accuracy*, possess notably comprehensive and wide-ranging connota-

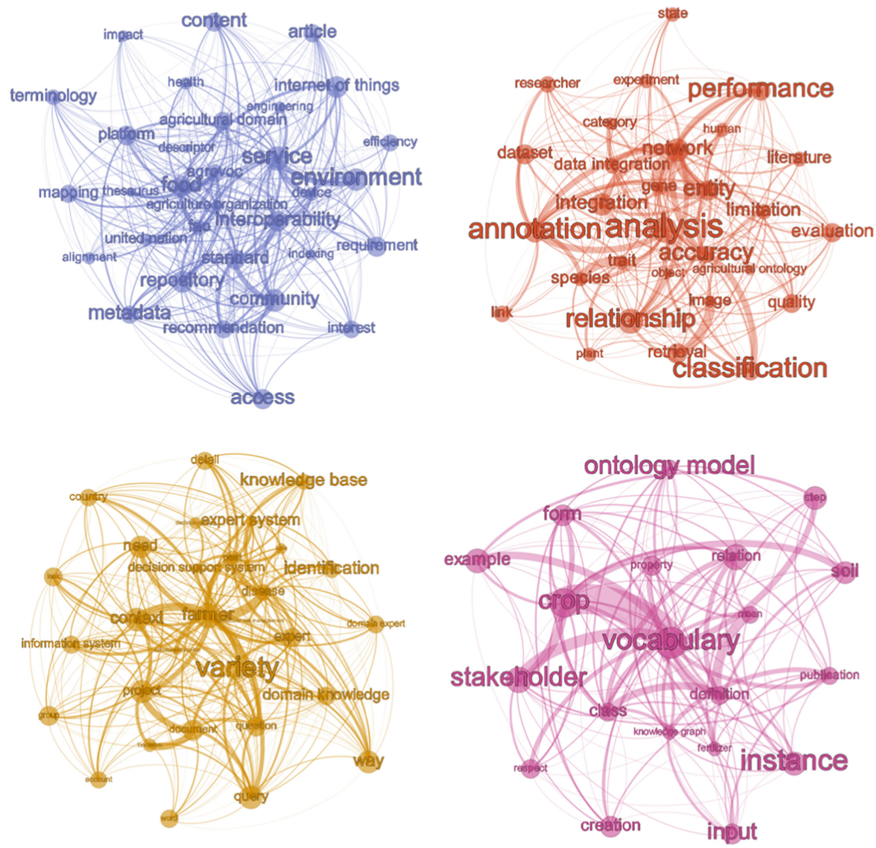

Fig. 2. Network graphs of selected terms clusterized by modularity. Measurements of centrality are recalculated for each cluster. Link thickness is related to the strength between two adjacent nodes. (Color figure online)

tions. These terms are prominently utilized as processes to scrutinize the application of KOS in specific instances or to assess the developmental trajectory of the KOS itself.

The yellowish cluster in Fig. 2 is about the application to farm data and *farmers*' needs and the related challenges of *variety* and *context*-specificity (context-specific *domain knowledge*) for supporting farmers' *decision making* (*decision support systems*, *decision making*, *expert system*). This cluster reveals needs and challenges for farmers, and therefore it does not even include technical concepts related to KOS.

The pink cluster, the last one in our analysis, draws attention to specific terms such as *vocabulary*, *crop*, *stakeholder*, *instance*, and *ontology model*. Notably, the strong connections between the first three terms hint at the significance of establishing controlled vocabularies for crops, especially concerning stakeholders within the agricultural domain. This interpretation is further supported by satellite nodes like *class*, *definition*, and *relation*, which are intricately linked to the instantiation process in ontological modeling [11]. In essence, this cluster underscores the crucial role of standardized terminology and ontological frameworks in facilitating effective communication and knowledge dissemination in agriculture.

Moreover, the pink cluster appears to reflect the landscape of international research, where ontologies and conceptual models enjoy substantial recognition and utilization. It predominantly centers around crops and soil as primary domains of application, highlighting the acknowledged importance of involving stakeholders and gaining their support in these research endeavors.

5 Final Remarks

In this bibliometric and terminological study we have focused on Knowledge Organization Systems (KOS) in the context of Digital Agriculture, unraveling the intricate web of concepts and relationships within this dynamic domain. The exploration of KOS and their interplay with ontology networks has provided insights into how these systems contribute to the advancement of agricultural knowledge, decision-making processes, and sustainable practices. Also, it would guide us to improve our data extraction form in the literature review ahead.

Our analysis of term occurrences and clusters shed light on the multifaceted roles that KOS play in agriculture. Notably, the emergent clusters and their central terms underscored the thematic areas that prominently shape the landscape of agricultural KOS. These clusters highlighted the interplay between technological advancements, semantic enrichment, and domain-specific challenges.

In the pursuit of a sustainable and innovative future for Agriculture, the synthesis of KOS and ontology networks emerges as a powerful catalyst. Our study contributes to a broader understanding of these concepts, elucidating their significance, roles, and interconnections within the agricultural landscape.

As a prospect for future research, the continuation of a systematic review of the literature is currently underway to delve deeply into diverse applications and developmental aspects of KOS within the digital agricultural domain, and their level of compliance with FAIR principles. Thus, the final results of the study should support the recommendation of semantic artifacts (KOS) by the GO FAIR Agro Brazil network to Brazilian institutions that maintain agricultural information systems to enhance the dissemination and use of the knowledge generated and managed by them. We also expect the insights gleaned from the future research can guide researchers, practitioners, and policymakers toward digital data-driven decision making based on KOS for a more transparent, efficient, sustainable and resilient agricultural ecosystem.

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