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A Systematic Review of Knowledge Representation Techniques in Smart Agriculture (Urban)

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Abstract: Urban agriculture is the practice of growing food inside the city limits. Due to the exponential amount of data generated by information and technology-based farm management systems, we need proper methods to represent the data. The branch of artificial intelligence known as "knowledge representation and reasoning" is devoted to the representation of information about the environment in a way where a computer system can utilise it to accomplish difficult problems. This research is an extensive survey of the knowledge representation techniques used in smart agriculture, and specifically in the urban agricultural domain. Relevant articles on the knowledge base are extracted from the retrieved set to study the fulfillment of the criteria of the system. Various interesting findings were observed after the review. Spatial–temporal characteristics were rarely approached. A generalised representation technique to include all domains in agriculture is another issue. Finally, proper validation technique is found to be missing in such an ontology.

Keywords: knowledge representation; sustainable agriculture; smart urban agriculture; ontology; Semantic Web; artificial intelligence in agriculture

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1. Introduction

As urbanisation increases in the 21st century, the world's population is predicted to reach 9.6 billion people by 2050 [1]. The majority of these individuals, or 67.2 percent, or 6.5 billion people, will live in urban regions [2,3]. According to the United Nations, this growing and more urbanised population will need a 70 percent rise in food consumption [4]. Buildings and infrastructure that are required to support a rising population in the city centre have changed the urban landscape, rendering it unsuitable for human habitation and resulting in a dangerous environment for pedestrians. As a result of this situation, a livable city is in threat, putting the basic needs of urban people at risk of being compromised. Furthermore, as the urban population continues to rise, the need for a consistent supply of fresh, high-quality food increases. In order to meet this rising need, smart vertical farming (USVF) is a viable method that does not require any more farmland [5].

Over the last two decades, research and practical experience have shown that urban agriculture may both assist with reducing climate change while also boosting the livability of cities. For a city to develop and to maintain a supportive green infrastructure, as well as to protect the health and well-being of its citizens, land use and spatial planning are critical components of the planning process. Due to the rising number of individuals who desire to live in green and sustainable city centres where they can obtain fresh, locally produced food, cities are once again becoming regions where food may be grown for human consumption. The purpose of urban agriculture is to establish food production sites inside the city's boundaries, such as aquaponics, indoor agriculture (including aquaponics and indoor farming), vertical farming (including rooftop farming), edible walls, and urban farms, among other things. The capacity of urban agriculture to include additional resources such as water, waste, and energy into their food systems is critical to the development of sustainable and climate-friendly communities.

Almost every element of our life has been significantly impacted by automation in the modern day. Industry and transportation, as well as agriculture and utilities, are examples of such sectors. Automatic control systems may be used for power and telecommunications networks, among other things. Automation is extensively used because it saves time and effort, is easy to use, and yields better outcomes than traditional methods. Agriculture is a broad word that incorporates a wide variety of agricultural activities, such as irrigation and flow control, as well as related technologies. Also possible is the construction of an autonomous robotic vehicle or drone for herbicide application and ploughing. It is also possible to employ harvesting equipment to manage water, plant health, and agricultural production via the use of a simple-to-operate farm automation system [6–8].

Vertical farms can achieve sustainable intensification today as a result of disruptive digital technologies such as the Internet of Things (IoT), cyber-physical systems (CPS), artificial intelligence, wireless sensor networks, Big Data and Analytics (BDA), autonomous robot systems (ARS), and ubiquitous cloud computing [9]. This novel Agriculture 4.0 system makes use of a smart farming concept, as well as a variety of emerging technologies, in order to enhance the design and administration of smart urban agriculture systems, as well as to give intelligent data-driven judgments in an ever-changing, ubiquitous environment. A successful implementation of Agriculture 4.0 requires effective data integration and information exchange across a wide range of sectors. It is vital to remember that there are both human-produced data sources (such as social media and email) and machine-produced data sources to consider (such as data collected by sensors, IoT gadgets, and other online media). To solve real-world challenges such as managing complicated operations, it is necessary to store, categorise, mine, and analyse the vast amounts of data that are generated every day. The flip side of the coin is that, as digital technology continues to advance, more complicated system designs have arisen, resulting in massive amounts of data in a number of different forms. As the quantity of data continues to grow at an exponential rate, it is becoming more challenging to integrate and extract insights from that data [10].

Knowledge representation has lately been shown to play a significant role in solving the challenges of heterogeneity, interoperability, interpretation, and integration that arise from large amounts of data [11]. Various knowledge representation techniques can be found in the literature [12,13]. Ontologies are considered to be potentially useful strategies for assuring trustworthy semantic modelling, knowledge management, and data integration in the future. The use of ontologies may lead to the inference of new information, even if the new knowledge has not been explicitly incorporated in the ontologies themselves. The construction of a knowledge base via the use of these strategies is one of the fundamental building blocks of a decision support system [14]. Beyond these benefits, ontologies have emerged as a viable alternative to relational databases (RDBs) because they are easier to work with, easier to define changes, and allow for the faster inference of new knowledge from existing models using reasons, whereas RDBs require the creation of every link manually, making them more difficult to manage in the event of knowledge expansion [15].

In this paper, we discuss in brief the basic terminologies used in agriculture and knowledge representation. The methodology used in the survey is explained, a literature review is performed for the knowledge representation models built on smart agriculture.

1.1. Agriculture

Agriculture is the practice of raising plants and animals for food. Farming, which provided food surpluses that made it feasible for people to settle down in towns and cities, is credited with the development of sedentary human civilization. It is estimated that agriculture has been around for thousands of years. It is believed that wild grains have been harvested since at least 105,000 years ago, and that early farmers first cultivated them roughly 11,500 years ago. Humans domesticated pigs, sheep, and cattle in the Mediterranean area more than 10,000 years ago, according to archaeological evidence. Plants were cultivated individually in at least 11 different locations throughout the world. A total of around 2 billion people continue to depend on subsistence farming, despite the fact that industrial agriculture based on large-scale monocultures has dominated agricultural output for much of the 20th century [16].

The demand for agricultural goods is expected to rise globally as a result of population expansion, and greater meat and dairy consumption, as well as increased biofuel production, according to projections. Between 1985 and 2005, the total global agricultural production grew by just 28 percent, despite the fact that the farmland area increased by only 2.5 percent, harvesting frequency increased by 7.5 percent, and crop yields per hectare improved by an average of 20 percent. In recent years, global agricultural production has grown, yet it has not kept pace with projections [17].

It is the result of a complex interaction between seeds, water, and agrochemicals such as fertilisers and pesticides that an agricultural production system is formed. In order to maintain the long-term survival of such a complex system, it is necessary to carefully manage all of its inputs. The lack of attention for the ecological consequences of input resources has resulted in environmental degradation as a result of human activity. Our agricultural management approaches are being forced to evolve as a result of increased environmental consciousness among the general public. We must conserve natural resources such as water, air quality, and soil quality while still ensuring that our farms stay profitable [18]. It is possible to increase output without producing any difficulties, if resource input efficiency is maximised. The fact that agricultural labour will continue to be in short supply in the future is likewise an unavoidable fact. In order to enhance crop output while still remaining economically and environmentally viable, it is necessary to integrate agricultural science with information technology. Precision agriculture, also known as precision farming, was born as a result of this development [19].

1.2. Precision Agriculture

Precision farming is a vital component of the "Third Modern Agricultural Revolution", which is right around the horizon. Precision farming is becoming more popular. Between 1900 and 1930, the mechanisation of agriculture enabled each farmer to produce enough food for 26 people, a significant increase over previous generations. The Green Revolution did not begin until decades later, in the 1990s, when the United Nations General Assembly adopted the term [20]. As a consequence of technological advancement, novel genetically modified crops that are pest resistant and that use less water have been produced, enabling each farmer to feed 155 people. By 2050, there will be 9.6 billion people on the earth, which implies that food production would need to be boosted by a factor of two from current levels in order to feed everyone. Advanced analytics and the Internet of Things will allow farmers to feed 256 people during the third industrial revolution, according to the World Economic Forum [21].

Precision agriculture (PA), satellite agriculture (SA), and site-specific crop management (SSCM) are all terms used to describe a technology-enabled approach to agricultural management that observes, measures, and analyses the needs of specific fields and crops, according to popular definitions [22]. Precision agriculture is being propelled forward by Big Data and Better Analytics Capabilities [23], as well as robotics—aerial photography, sensors, and advanced local weather forecasts, which are enabling the growth of precision farming [24]. In layman's terms, the process of using plot data to manage and optimise crop yield is referred to as "predictive agriculture" [25].

Taking medication to cure a disease is analogous to employing predictive farming techniques to increase crop yields. Everything, from the kind of crop that should be produced on a certain plot to the positioning of pesticides, is meticulously researched before being put into practice [26]. Precision farming takes into account the unique requirements of each plot, resulting in less waste and cheaper production costs. Precision farming is becoming more popular. Precision farming is a technique that makes use of cutting-edge technology and analytical tools to increase the yield of a crop. Sensor-equipped devices are used to collect a large amount of information on soil testing, plot measurement, weather pattern analysis, and crop analysis, among other things [27]. A calibrated collection of approaches, as well as a very particular set of techniques, may be used to derive inferences from the data. The various stages required for precision agriculture are shown in Figure 1.

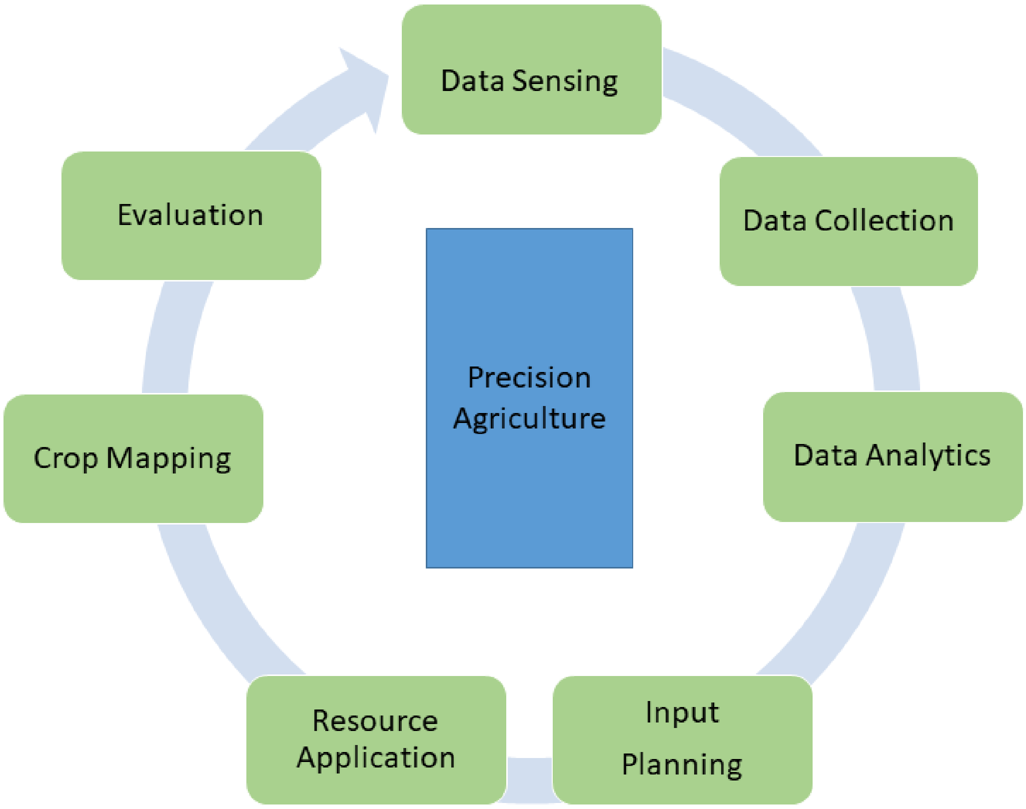

Figure 1. Stages of precision agriculture.

1.3. Urban Agriculture

Despite the fact that urban agriculture can be found in all major cities across the world, there is yet to be a formalised research and development effort in this area. Because of the increasing urbanisation that is occurring in Asia, Africa, and Latin America, concerns have been raised about how to employ and feed the expanding urban populations, as well as how to manage the ever-changing fringes of these cities [28].

This is already causing conceptual challenges for national statistics entities because of the distinction between rural and urban regions. Detailed information on the economic activities and manner of life in the area is lacking. Local economic activity is difficult to quantify for a variety of reasons, the most significant of which are as follows: Illegal production and smuggling are classified into three categories: (i) subterranean production, which includes registered merchants who purposefully hide their outputs, (ii) informal production, which includes "unregistered traders", who produce primarily at the household level, and (iv) production for self-consumption by households, such as food production. The investigations of livelihoods will be necessary in order to have a comprehensive picture of households and to understand the continuous structural and social changes that are taking place. In order to have a better understanding of family strategies and income portfolios, agricultural and non-agricultural activities must be considered together rather than independently from one another [29].

Urban agriculture provides food for both self-consumption and purchased food, and it also acts as a source of food for urban dwellers in general. Depending on the availability of land in the city, the nature of the main crops, and the purchasing power of urban dwellers, the proportion of self-consumption in urban agriculture may range from 10 percent to 90 percent. Increasing land pressure has been shown to result in a decrease in family consumption while simultaneously increasing market demand. Perishable items, such as vegetables, are strongly dependent on the periurban supply chain for their distribution [30].

There are significant advantages to urban agriculture over rural agriculture that cannot be explained only by geographical differences. Although it is possible that a city was established in a particular location because of the area's abundant agricultural hinterland, this is not always the case. For urban farmers, on the other hand, creating a consistent cash flow year-round from a tiny piece of land is more important than anything else in order to buy food and sustain a regular income. This explains why urban output is less seasonal than rural output, which is critical for ensuring food security in metropolitan environments [31]. The various scopes where urban agriculture is used is shown in Figure 2.

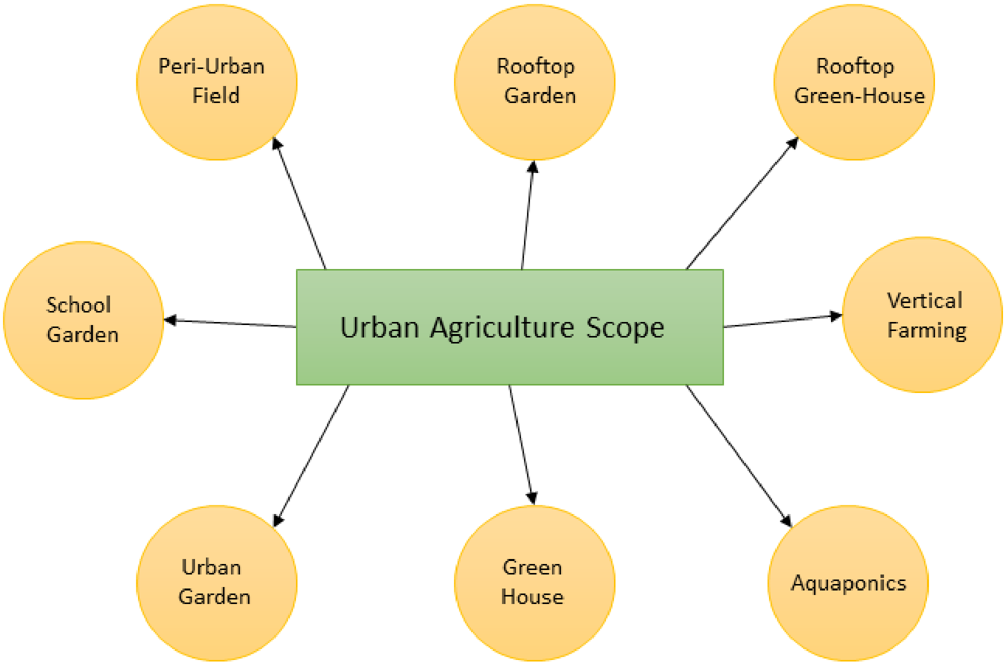

Figure 2. Scopes for urban agriculture.

Economic activities outside of agriculture, such as non-agricultural housing, transportation, and other variables, all compete with urban agriculture for resources in the city. There is fierce competition for human resources, as well as for natural resources such as water and fertiliser. A significant amount of pollution occurs in metropolitan and peri-urban regions as a result of industrial activity, household activities such as heating and cooling of the home or office, and the usage of public transit systems. Agriculture has a long history of environmental deterioration as a consequence of the use of pesticides, chemical and organic fertilisers, and other agricultural inputs. It is as a consequence of this that urban agriculture has difficulties in showing that it does not poison the urban environment, but rather that it provides nutritious food items in spite of a polluted urban environment at times.

Governments tend to tolerate rather than encourage urban agriculture, despite the fact that it provides considerably towards employment and income. This is despite the fact that there is evidence that this is beginning to change. In order to develop their agriculture and to offer a broad variety of services to the city's citizens, including landscape preservation and social integration, urban farmers must put up more efforts. The promotion of urban agriculture's diverse applications is a critical issue for the future. In order to record the efficient integration of urban agriculture into urban expansion, as well as the circumstances necessary for its social and economic sustainability, there is a growing demand for documentation in this area [32].

1.4. Knowledge Representation

A large amount of information, as well as the proper methodologies for conveying and manipulating that information, are often necessary to address the most challenging problems in artificial intelligence. One of the most significant goals of a computer-readable knowledge representation is to enable our artificial intelligence agents to perform at a high level. Even as early as 1958, John McCarthy was considering the possibility of artificial intelligence systems that make use of common knowledge [33]. As a result of this and other early work, researchers [34,35] came to the conclusion that artificial intelligence could be formalised as symbolic reasoning with explicit representations of knowledge, and that the central research challenge is to figure out how to represent knowledge in computers and to use it algorithmically to solve problems. As it turns out, the classical logic language of first-order (predicate) equations is the one that has been most widely used in the theory of knowledge representation [36]. The different types of knowledge representation are shown in Figure 3.

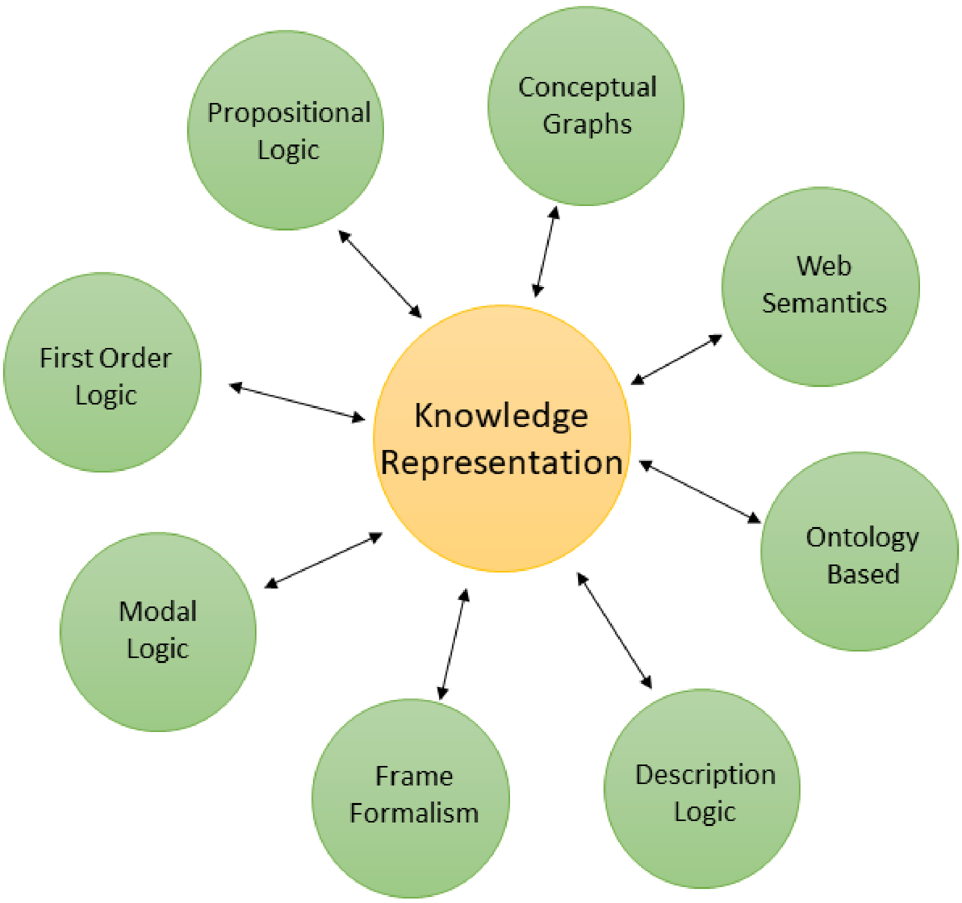

Figure 3. Types of knowledge representation techniques.

Observable objects, events, and conditions may be generalised into ideas or concepts. It is not possible to apply metaphysical notions concerning the existence of concepts (ideas). Computers, which are designed to represent knowledge, must be built from scratch. Finding hierarchies within a subject matter is a critical initial step in learning and developing conceptual frameworks. From specific apples and oranges, the idea of fruits, then meals, etc., may be created. Similarly, the conceptualisations of body-related medical occurrences, commodity-related economic conceptions, etc., are all viable [37].

According to an object-oriented approach, the object is seen as the most basic notion in the system, one that cannot be further split. Because of this, depending on the demands of the users, the definitions and reasonings that follow may start with the definition of a particular apple, the general apple notion, or even with a specific fruit. A subclass of an object is a subclass of an instance, and an instance is a subclass of a class. A thorough discussion of definitional variables has been conducted in the context of classes and objects. As part of this inheritance method, the qualities of a class are employed as vehicles for the transmission of information. Superclasses include items from many different classes that are all coherent with one another. Classes contain things that are closer together, while subclasses contain things that are even closer together, and subclasses contain things that are even closer together. All of the items in this list reflect the concept of hierarchy. On the other hand, in the discipline of knowledge representation, ontology is the formalism that is most often used today to describe a domain and is based on conceptual hierarchies to do this.

When selecting a representational formalism, it is critical to consider exactly what information needs to be represented, and how that information has to be processed. We also need to consider how the system will learn new things as it progresses. When it comes to knowledge representation systems, there is no such thing as a one-size-fits-all solution. Many different ways of knowledge representation are often used in the construction of large, complex artificial intelligence systems [38].

In order to improve agricultural information exchange and cooperation around the globe, the United Nations Food and Agriculture Organization (UNFAO) established the Agriculture Ontology Service (AOS) in the year 2000 [39]. An ontology system, which is a formally expressed representation of agricultural ideas and the linkages that connect them, comprises agricultural terminology, as well as their distinct meanings and the relationships that connect those concepts with one another. Due to the ontology's carefully constrained vocabulary, it is possible to offer semantic assistance for the definition of agricultural domain knowledge. A precise definition of ideas and their numerous conceivable forms, as well as their qualities and links to other concepts, is produced as a result of this process. Acquiring, organising, storing, and retrieving information are all aspects of agricultural knowledge management systems, which are built on ontologies to help with these tasks. When it comes to the current organisation and dissemination of agricultural information, agriculture ontology takes priority over other approaches.

2. Methodology

This section is dedicated to the methodology of the survey executed in the domain of 'Knowledge Representation in Smart Urban Agriculture'. For the collection of relevant materials, it was essential to perform an in-depth examination of the domain's final selected works in two phases. The first step was to select relevant keywords for a search in scientific databases and scientific indexing services such as IEEE Explore and Google Scholar to find articles from related conferences and journals. We have fixed IEEE Explore and Google Scholar as the databases on which the retrieval step is performed. The second step was to conduct a search in those databases and indexing services to retrieve the relevant articles. The keywords used in this study include various combinations of strings such as 'Smart Urban Agriculture', 'Ontology', 'Knowledge Representation', 'Vertical Farming', and 'Agriculture'. More than 200 papers were extracted, and out of them, only 48 papers were in the domain of 'Knowledge Representation in Agriculture' and 27 papers were found as relevant ones specifically in the field 'Knowledge Representation in Urban Agriculture'.

The complete methodology of the article on which the various ontological knowledge representations are studied is shown in Figure 4.

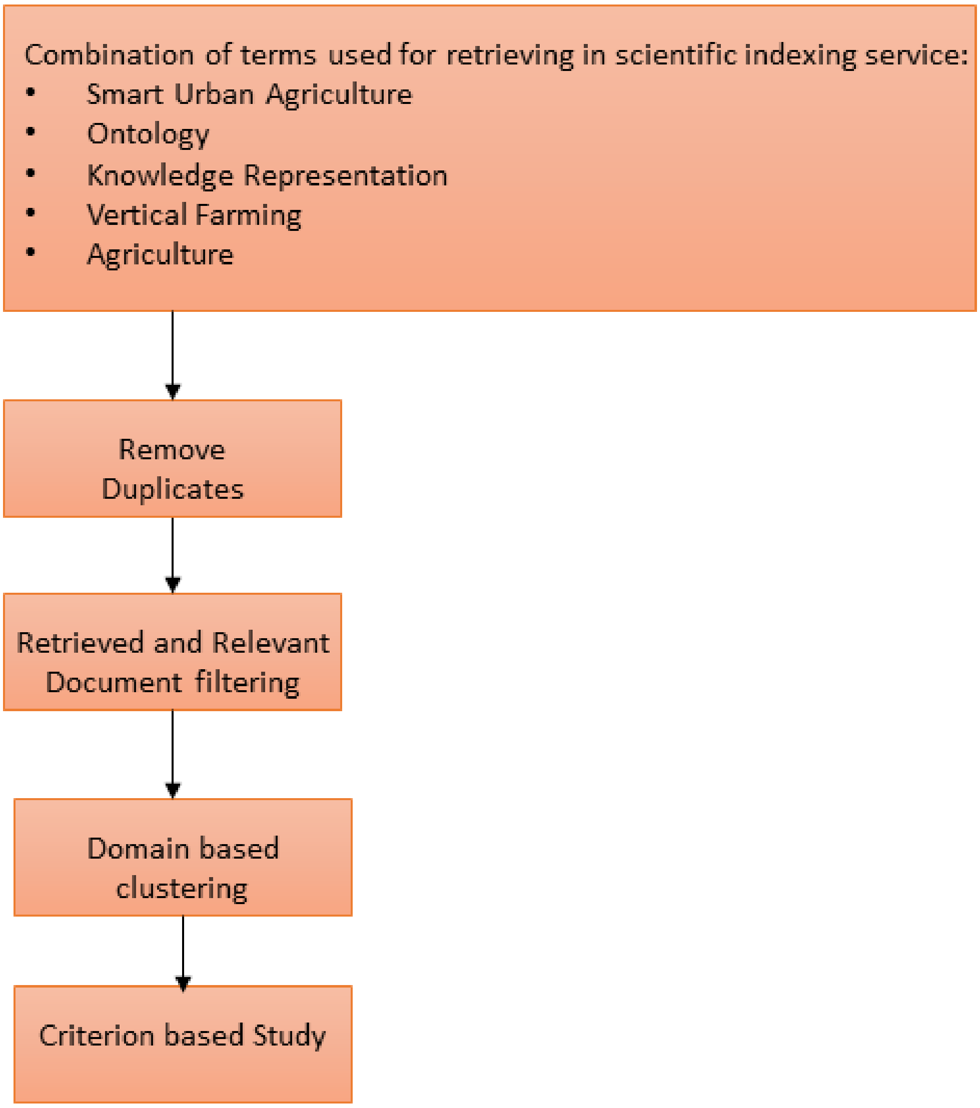

Figure 4. Methodology for the survey.

The various domains on which the current study is performed is shown in Figure 5. Finally, the different criterion on which the review is prepared is shown in Figure 6.

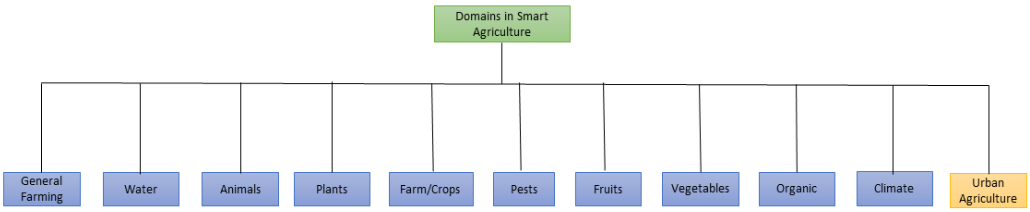

Figure 5. Domains covered in smart agriculture.

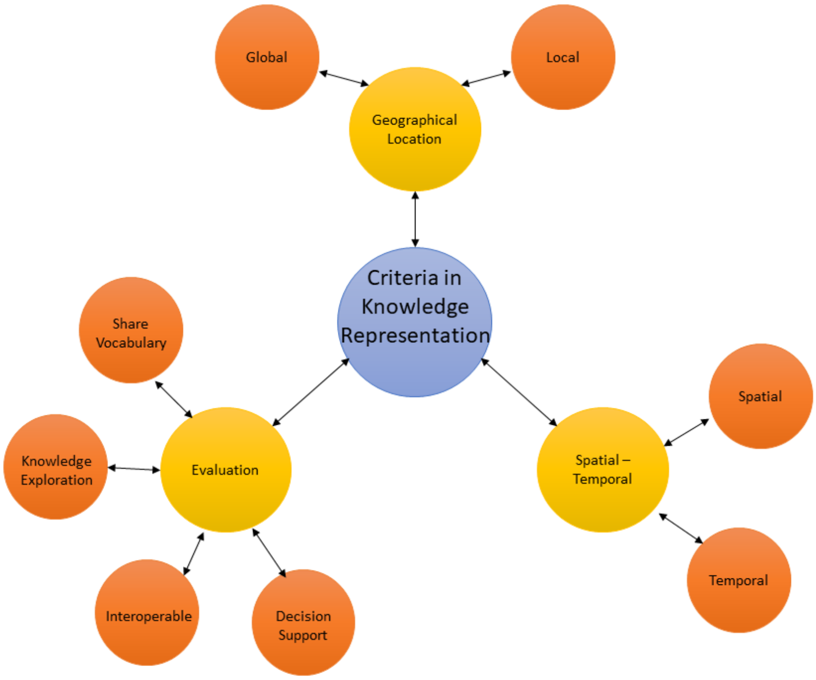

Figure 6. Criterion taken into account for the study on knowledge representation in agriculture.

Ontology-based agricultural systems are becoming more prevalent, and the Semantic Web is getting more popular. It needs the development and evaluation of ontology construction and evaluation procedures, which are now under development. Given the wide range of knowledge domains, concepts, sources, and forms that agriculture involves, it needs complex ontologies. It is true that many various techniques toward ontology creation have been proposed over the years, but these approaches tend to be either too generic or too specialised in their application to certain domains. Because of the vast variety of creation methodologies available and their inconsistencies, ontology assessment may grow increasingly difficult, increasing the need for clear guiding criteria for ontology evaluation [40,41].

Information sharing has become more important in today's business. For many commercial and administrative processes to be successful, it is necessary for several parties to work together to accomplish a common goal. Furthermore, because of the time and resources needed to obtain and maintain information, it is necessary to utilise up-to-date information wherever it is possible. When it comes to information stores, the World Wide Web, with its millions of pages, is the most renowned example of one that is currently accessible in principle. Using vocabulary sharing in ontology, it is possible to detect the mappings between classes from different vocabularies as a consequence of comparing and contrasting class structures and definitions, as well as using shared upper-level ontologies [42].

When knowledge domains are broad and complicated, ontology research and modelling become a time-consuming and demanding endeavour. The ability of a model to be reviewed and adjusted on a small scale may allow designers to obtain better results by focussing on certain subsets of the domain rather than the whole domain [43]. Tooling for software development and data management has long featured the capability of highlighting significant parts of a model (such as an architectural role or a functional facet) and displaying them in a convenient manner on the screen. For example, the introduction of user-definable subject categories into knowledge modelling tools may be advantageous to ontology builders.

The ability to transfer data that have a clear, common meaning across computer systems is referred to as "semantic interoperability" in the computer science community [44].

Semantic interoperability is essential for data federation, machine-computable reasoning, inference, and knowledge discovery, all of which are reliant on it. However, information models are meant to represent the circumstances and epistemic environments in which domain terms are used, while terminologies should explain the meanings of domain words independent of the scenario or epistemic environment in which they are used. In fact, the usage of many encodings for the same clinical data makes semantic interoperability difficult to achieve. The same meaning may be expressed using a variety of terminologies, and pre- and postcoordinated sentences in the same language, and various combinations of (partially overlapping) terminologies and information models [45].

A Decision Support System (DSS) [46] is a system that assists users in making decisions when the information is disorganised or when the problem to be solved is difficult. This has resulted in unclear dynamics of data in certain domains, semantic interoperability, and varied data sources that are inconclusive. In order to resolve the problem, it may be necessary to represent knowledge using an ontology. A range of heterogeneous data sources are used in crop production decision making, which is still mostly performed manually in many cases. Small-scale farmers and their local advisers, in particular, are being squeezed by ever-increasing expectations. It is essential to consider local circumstances and standards. A clear picture of evaluating a knowledge representation system is shown in Figure 7.

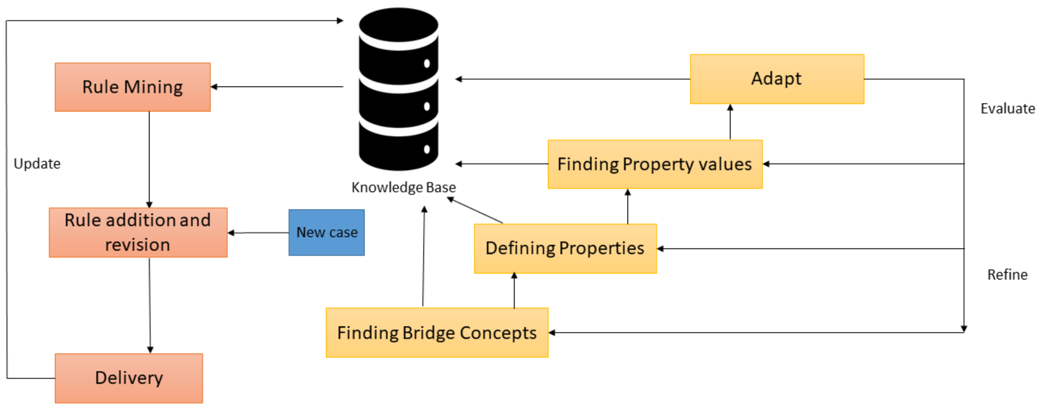

Figure 7. Evaluating criterion.

3. Knowledge Representation in Agriculture

In order to improve agricultural information exchange and cooperation around the globe, the United Nations Food and Agriculture Organization (UNFAO) established the Agriculture Ontology Service (AOS) in the year 2000 [39]. An ontology system, which is a formally expressed representation of agricultural ideas and the linkages that connect them, comprises agricultural terminology, as well as their distinct meanings and the relationships that connect those concepts with one another. Due to the ontology's carefully constrained vocabulary, it is possible to offer semantic assistance for the definition of agricultural domain knowledge. A precise definition of ideas and their numerous conceivable forms, as well as their qualities and links to other concepts, is produced as a result of this process. Acquiring, organising, storing, and retrieving information are all aspects of agricultural knowledge management systems, which are built on ontologies to help with these tasks. When it comes to the current organisation and dissemination of agricultural information, agriculture ontology takes priority over other approaches. The organised survey is shown in Table 1.

Table 1. Summary of agricultural KR papers with Geography, Domains, Spatio-Temporal Factors, and Evaluation Criteria, where Go = Global, Co = Country Specific, G = General Farming, W = Water, A = Animals, P = Plants, F = Farm, Pe = Pests, Fr = Fruits, V = Vegetables, O = Organic, C = Climate, SV = Share Vocabulary, KE = Knowledge Exploration, I = Interoperable, DS = Decision Support, S = Spatial Factor, and T = Temporal Factor.

Papers	Geo		Domain										Method				Space–Time	
	Go	Co	G	W	A	P	F	Pe	Fr	V	O	C	SV	KE	I	DS	S	T
AGROVOC [47]	x		x										x	x	x		x	
CAT [48]		x	x											x			x	
AGROVOC + CAT [49,50]	x		x										x	x	x		x	
AgOnt [51]	x		x												x	x	x	x
ONTAgri [52]	x		x				x								x		x	x
Agroportal [53]	x		x			x	x								x		x	
Crop Ontology [54]	x											x			x		x	
AgTrials [55]	x											x			x		x	
AgriOn [56]		x				x	x					x			x		x	
AOS [57]	x		x											x	x			
Alfred et al. [58]	x		x													x		
Kang et al. [59]	x		x											x				
Naidoo et al. [60]	x											x		x				
Roy et al. [61]	x					x								x		x		
Samarasinghe et al. [62]		x				x	x		x					x		x		
Hirakawa et al. [63]	x					x	x		x					x				
SemantEco [64]	x											x			x	x		
Ma et al. [65]		x										x			x	x		
OntoAgroHidro [66]	x			x								x			x	x	x	x
PLANTS [67]	x					x								x		x	x	
Wang et al. [68]	x					x								x				
Lin et al. [69]		x				x								x				
Zheng et al. [70]	x						x							x				
EDIS [71]	x						x	x						x				
Beck et al. [72]	x						x	x						x	x			
Damos et al. [73]	x							x						x	x	x		
Chougule et al. [74]		x						x						x				
CropPestO [75]	x							x						x				
PCT-O [76]	x							x								x		
AgriEnt [77]	x							x						x		x		
Jha et al. [78]		x						x	x							x	x	
Kumar et al. [79]	x							x	x							x		
Wilson et al. [80]		x					x	x	x					x		x	x	
Yue et al. [81]	x									x				x				

Table 1. *Cont.*

Papers	Geo		Domain											Method			Space–Time	
	Go	Co	G	W	A	P	F	Pe	Fr	V	O	C	SV	KE	I	DS	S	T
TAO et al. [82]	x									x				x		x		
FTTO [83]	x									x				x				
Samarasinghe et al. [62]		x								x				x				
AgriGO [84]		x				x				x				x				
Campbell et al. [85]		x									x							
Sicilia et al. [86]	x										x			x			x	
Abayomi et al. [87]	x										x			x		x	x	
Alonso et al. [88]	x										x							
Manouselis et al. [89]	x										x					x		
Pakdeetrakul et al. [90]		x									x					x		
Pouteau et al. [91]		x				x					x							
Bhuyan et al. [92]	x		x											x		x	x	x
Titiya et al. [93]		x				x										x	x	
SAGRO-Lite [94]		x	x											x			x	

3.1. Global Geographical KR

The Food and Agriculture Organization of the United Nations (FAO) produced AGROVOC [47], which is the largest and most comprehensive semantic resource accessible on the Semantic Web. AGROVOC, with its early development in 1980s is being maintained by the FAO. AGROVOC is a collection of 40,000 concepts and 931,700 words, all of which are part of a standardised vocabulary. There are several areas addressed by AGROVOC in addition to agricultural words and concepts. These topics include: food and nutrition, forestry, and fisheries, to name a few. This transmission of information encompasses the whole extent of the FAO's operations. Apart from English, Arabic, and Chinese, AGROVOC is available in a total of 41 other languages. Although it is used in many case studies, AGROVOC suffers from certain limitations. For example, it cannot identify the type of fertilizers, neither can it declare the disease in crops nor the type of soil; thus, it cannot cover all domains [86]. In addition, it is a vocabulary system or thesaurus by itself, but not an ontology [95].

When it comes to sensor-transmitted data vocabulary, the AgOnt ontology [51] is the best option available. In this hierarchy, a product, phase, time, location, and condition are all included at the very top level of the pyramid. Every one of these agricultural ideas has subclasses that include the terms seed, seedling, plant, crop, and processed food, among others. By using the ontology, it is feasible to transfer data from a wide range of sensors. The purpose of this ontology for the global agribusiness clouds computer system is to provide a foundation for semantic interoperability across a variety of different systems and applications (clouds). In order to integrate varied agricultural information systems, ontology-based semantic integration is used. This method provides a strong basis for the integration of disparate agricultural information systems. However, the run-time building of query processing is still a challenge.

The ONTAgri ontology [52] has been developed in order to aid those working in the agricultural area. Services such as irrigation, fertilisation, pesticide application, and other agricultural practices are provided to assist with agricultural practices. This kind of service may be used for a number of purposes. In order to conduct a complete investigation of these concerns, exact measurements of cropland are required. Sensing networks are utilised to collect this information, which is then combined and inferred to offer insight into a specific service demand and how it is being used over time. The only method to express the different knowledge required to perform any kind of service is via the use of a service-oriented ontology. ONTAgri provides the same with the help of System and Domain ontology, which is farther divided into various concepts. Many semantic resources exist for agriculture; however, academics may wish to develop additional specialised resources outside of the collaborative editing platforms of AgroPortal [53] that define not only where food comes from, but also how it is packaged and preserved, among other meta-properties, as well as other metadata. Ontologies with a greater degree of abstraction are unlikely to have this level of precision.

Crop Ontology (CO) [54], an earlier ontology developed by the Consultative Group for International Agricultural Research (CGIAR) and used in combination with the Gene Ontology and the Trait Ontology, is still in use today. Members of the CGIAR breeding community collaborated in 2008 to produce an important source of characteristics and variables for the CGIAR breeding platforms, including the Integrated Breeding Platform and databases for roots, tubers, and bananas. These data were used to improve the efficiency of CGIAR breeding platforms.

Each of the CGIAR Centers has a CO for one of its mandate crops. A variety of collaborators, including Cornell University, INRA, CIRAD, and the National Agricultural Research and Development Institute (NacRI), have worked together to develop Crop Ontology Template content. Because it provides descriptions of agronomic, morphological, physiological, quality, post-harvest, abiotic, and biotic stress elements in different projects and localities, the CO makes it feasible to combine and compare digital data across projects and locales.

The properties of the CO have been linked to a reference and species-neutral Trait Ontology maintained by Oregon State University, which has been utilised in the process (TO). The Planteome website offers mappings that enable users to search for a trait without having to worry about the species they are looking for. It is possible that studies in comparative genomes and cladistic categorisation will benefit from this (e.g., legumes). Searching for CO features is possible using the EMBL/European Bioinformatics Institute (EBI) Ontology Look Up Service. The CO is also available via Agroportal.

The primary goal is to describe characteristics that are critical for communities while also enabling scientists to exploit these characteristics in breeding goods. Farmers' crop trait preferences are incorporated in the ontologies for roots, tubers, and bananas, and a specific field book format is provided in order to collect farmers' opinions on each of these ontologies. Achieving this was made feasible via the use of customised scoring systems and the counting of votes from the general public. Breeders have a difficult time defining traits and rating them in a way that is acceptable to farmers and other stakeholders. Furthermore, the CO takes into account the preferences of different genders for different crop traits. There has been much research on women's preferences for certain crop characteristics, and the outcomes of the Participatory Varietal Selection study may be reliably analysed in light of this knowledge. The main purpose is to establish characteristics that are important to communities while also providing scientists with the ability to include those characteristics into a breeding product profiling.

AgTrials [55] depends on the Crop Ontology initiative to standardise and to interoperate data in order to deliver open trial data. This work is critical for allowing open trial data driven by breakthroughs in molecular biology and site-specific agriculture. This research builds on decades of evaluation trials, largely of varieties, and integrates any agricultural technology for global farmers in AgTrials sites around the poor world. AgTrials is the world's first multi-crop platform for freely storing, organising, and enabling access to crop trial data from all around the world, and it does so for the first time. AgTrials aims to build an agricultural technology assessment database for climate change analysis, as well as a multi-site agricultural trial database and file repository, as part of a larger agricultural technology assessment project.

Agro-informatics platforms with the organisation of agricultural data are necessary for the identification, hosting, and exploitation of these crops, among other things. In order to facilitate the development of ontologies for the agronomy domain, the NCBO BioPortal [96] technology was used. One of the aims of the AgroPortal [53] effort is to repurpose biomedical research in sectors such as agriculture, food, and biodiversity, among other things. A few of the functions of an ontology portal that we offer include hosting, search, versioning, and visualisation. The portal also enables semantic annotation and the storage of ontology alignments, among other features. Every one of these features is included inside a framework that is completely Semantic Web-compliant. Additional to this, AgroPortal gives particular consideration to ontology formats, as well as supporting features that are crucial to agriculturalists in their work.

The Agricultural Ontology Service (AOS) [57] was established with the goal of organising and supplying agricultural vocabulary, nomenclature, and information transfer standards in many languages for use by a variety of systems. AOS makes agricultural resource descriptions and connections more efficient and consistent, and less random, as they are less random now. As a bonus, they are simpler to use, making it easier for members of the agricultural community to communicate common descriptions, definitions, and connections with one another. The AOS's ability to communicate in a variety of languages is one of its greatest assets. For individuals from all over the world who demand access to resources, we must be able to index and locate material in any language that they require. For the FAO's five official languages - English, French, Spanish, Arabic, and Chinese—the AOS is required for the collection and management of terminologies, meanings, and links between them. In the course of developing ontologies, it may be necessary to include other languages if working in the original language of the country is helpful.

Ontology-based query expansion is a more ad hoc method of query expansion. The article [58] examines a wide range of research on query extension and ontologies for agricultural applications, as well as their implications. Inputting a few key phrases into the search box leads to a big list of results, giving the impression that locating the information is easy and straightforward. The ability of a search engine to comprehend and to respond to users' brief and basic queries, as well as to give appropriate lists of publications that fulfil their informational demands, is critical to its success. For people who are seeking for information, finding relevant results may prove to be a challenging task. The difficulty of retrieving information is exacerbated by term mismatches. An instance of term mismatch happens when a user puts words into a database that do not match the indexers that are already there. In situations when there are a large number of data sources of varied sizes, polysemy increases, and synonymy becomes more difficult to cope with in situations where there are fewer query terms accessible. In order to provide a comprehensive collection of key works, it is necessary to settle issues of terminology and linguistics. By combining information from several sources and defining it as an ontology, domain knowledge may be further enhanced. Making one's way through a massive amount of agricultural data is a demanding task in and of itself. Ontology-based information retrieval is an alternate approach of retrieving information from a database. The query's scope is enlarged by the use of ontology-derived words that are included in the ontology. Ontology for non-textual resources has extensive idea mapping properties in addition to words matching, which makes it a more comprehensive resource than a textual resource alone. This aspect has a significant impact on the speed with which information may be obtained.

This study [59] presents the field of agricultural ontology and information retrieval research, as well as the research object, which is agricultural domain knowledge. A framework for agriculture knowledge is then created by using the agricultural ontology, which is then used to establish an agriculture-related knowledge ontology and database that allows for intelligent searching of the agricultural information. The researchers were able to improve both the accuracy and the reliability of the information they were able to obtain by incorporating agricultural ontology technology into agricultural information retrieval.

Efforts in ontology engineering, the conceptual modelling of metadata, and semantic representation in computer systems have resulted in ontologies for medical, legal, engineering, and biological terms. The same cannot be said for general task vocabulary used in agricultural field activities. Combined with the domain ontology, the model in [63] may be used to build an agricultural application ontology, which is the topic of this work. The research revealed who the task agents were, their roles, and the input resources required to execute the tasks. Finally, using UML class and activity diagrams, a conceptual model of agricultural field activities was built. A case study was utilised to evaluate the model's consistency for sugar cane harvesting. It might be used for precision agriculture, field operations control, decision support, and other computer-based applications.

It was decided to modularise the SemantEco [64] site in order to assist resource managers in making better choices and to make it more widely reusable by researchers. Adding new components to an existing system is straightforward with this approach since it does not need a thorough understanding of which components perform what queries. It is possible for data managers to add or to remove modules to fit their individual data requirements, which means that the system may expand and adapt as their requirements change. It includes extensions that support wildlife monitoring enhancing provenance support through the incorporation of rationale, and performance comparisons between a tableau-based description logic reasoner and an OBOE-based description logic reasoner.

In this study [70], an ontology-based agricultural information management system was introduced, and a number of important technologies were studied. Ontology is used in this system, as opposed to other agricultural information management platforms and websites, to improve intelligence and efficiency, as well as to enable for the exchange and administration of knowledge. Aside from that, more theoretical research is planned in order to materialise knowledge services in the areas of business intelligence and simulation, and more prototype systems will be needed in order to develop specialised domain applications.

As described in this paper [92], the use of a lattice structure for the knowledge representation of data acquired from Internet of Things devices is being considered. Spatial–temporal data are utilised to construct a lattice structure, after which rules are constructed based on the features of the lattice structure. A summary of the geographically global knowledge representation systems for smart agriculture is shown in Table 2.

Table 2. Summary of geographically global knowledge representation systems for smart agriculture.

Authors (Ref.)	Year	Results
AGROVOC [47]	1995	Produced by FAO, it is the largest semantic resource, with a collection of 40,000 concepts and 931,700 words available in a total of 41 other languages.
AGROVOC + CAT [49,50]	2006	Combination of the two resulted in creating 40 classes for crop classification decision making procedures, with more than 63,000 concepts created in the process.
AgOnt [51]	2010	Sensor-transmitted data vocabulary, which provides a strong basis for the integration of disparate agricultural information systems.
ONTAgri [52]	2011	Service-oriented ontology with the help of System and Domain ontologies, which are farther divided into various concepts.

Table 2. *Cont.*

Authors (Ref.)	Year	Results
Agroportal [53]	2017	Defines not only where food comes from, but also how it is packaged and preserved, among other meta- properties.
Crop Ontology [54]	2013	Developed by CGIAR, used in combination with the Gene Ontology and the Trait Ontology.
AgTrials [55]	2015	Depends on the Crop Ontology initiative to standardise and interoperate data in order to deliver open trial data. World's first multi-crop platform for freely storing, organising, and enabling access to crop trial data.
AOS [57]	2010	Organising and supplying agricultural vocabulary, nomenclature, and information transfer standards in many languages for use by a variety of systems.
Alfred et al. [58]	2014	Examines a wide range of research on query extension and ontologies for agricultural applications, as well as their implications.
Kang et al. [59]	2013	Presents the field of agricultural ontology and information retrieval research, as well as the research object, which is agricultural domain knowledge.
Naidoo et al. [60]	2021	Climate-smart agriculture to reduce the effect of global warming on the environment.
Roy et al. [61]	2020	Collect semantically connected information that matches the expectations of the user while assisting in dealing with a variety of data sources and addressing the information retrieval concerns.
Hirakawa et al. [63]	2017	Combined with the domain ontology, the model is used to build an agricultural application ontology. A case study was utilised to evaluate the model's consistency for sugar cane harvesting.
SemantEco [64]	2014	Possible for data managers to add or remove modules to fit their individual data requirements, which means that the system may expand and adapt as their requirements change.
OntoAgroHidro [66]	2016	This study is concerned with the establishment of a network for the sharing and retrieval of information on the impact of climate change and agriculture on water resources.
PLANTS [67]	2009	Presented an ontology-driven framework for creating precision agriculture applications. It employs ontology alignment to make the system more accessible and flexible to other systems created for different environments and needs.
Wang et al. [68]	2018	Based on the Chinese Eight-Point Charter of Agriculture. The ontology is validated using the 110-question competency test, which was 88% accurate.
Zheng et al. [70]	2012	Ontology-based agricultural information management system to enable the exchange and administration of knowledge in the areas of business intelligence and simulation.
EDIS [71]	2002	Developing, distributing, and preserving an extensive library of extension publications using an automated method.

Table 2. *Cont.*

Authors (Ref.)	Year	Results
Beck et al. [72]	2005	Used to provide a classification mechanism for articles inside the EDIS system.
Damos et al. [73]	2015	Integrated pest management is being investigated for web-based decision support systems.
CropPestO [75]	2020	Describes the processes that must be followed when developing an ontology in the area of plant pests and diseases applications.
PCT-O [76]	2018	In order to make pest detection and treatment selection information more accessible, recommendation systems for pest detection and treatment selection are being developed.
AgriEnt [77]	2020	Knowledge-based Web platform designed to assist farmers in the identification and control of agricultural insect pests.
Kumar et al. [79]	2019	Recommendation system for crop identification and pest control.
Yue et al. [81]	2005	Ontology as a technique of representing information in the vegetable supply chain, as well as a data representation framework for expressing data.
TAO et al. [82]	2012	Information retrieval model based on the veggies e-commerce ontology that may be utilised to improve the recall ratio and precision radio of information retrieval engines that are used in online vegetable sales.
FTTO [83]	2013	Food ontology developed for the traceability domain. In order to examine and validate ontologies, it has been feasible to utilise the Pellet reasoner from Protégé as an external plug-in.
Sicilia et al. [86]	2009	With the help of AGROVOC, the authors tried to give an ontological structure to cases in organic agriculture, namely fertilisers.
Abayomi et al. [87]	2021	Using the protégé editor, a knowledge base of ontologies was created, as well as a high-level application programming language for developing a web-based ontology language application programme interface. The ontology knowledge base was created using the Java programming language (OWL API).
Alonso et al. [88]	2008	Organic agriculture and agroecology are handled, which address the ontology needs of the Organic project for these fields.
Manouselis et al. [89]	2009	This research looks at the use of Semantic Web technologies to aid the sharing and reuse of learning materials for organic use case.
Bhuyan et al. [92]	2021	Use of a lattice structure for knowledge representation of data acquired from Internet of Things devices is being considered. Spatial–temporal data are utilised to construct a lattice structure.

3.2. Country/Location-Specific Geographical KR

The usage of ontologies has had a significant positive impact on agriculture. Agricultural science involves a diverse variety of concepts and interactions, resulting in a discipline that is very multidisciplinary in its nature. Ontologies have been utilised in a variety of ways in different countries to express and connect these difficult concepts and relationships.

The Chinese Agricultural Thesaurus is a thesaurus for agricultural terms in Chinese (CAT) [48]. There were a number of international and national standards followed during the design and construction process. In addition to agricultural and forestry subjects, biological themes are also covered by CAT. The 40 primary categories are further subdivided into subcategories, with the majority of the ideas being expressed in English. Different languages and civilizations have developed conceptual frameworks that are distinct from one another. When it comes to all of the agricultural subdomains that it handles, AGROVOC takes a very Western and scientific viewpoint. However, notions from Chinese cosmology, such as the elements of Earth, Water, Fire, and Metal are included into CAT as well. Rather than the real material, these ideas relate to categories that are utilised to interpret occurrences and to organise vital operations, as opposed to the actual material itself. Furthermore, because of the variety of dialects in the target language, translations into the target language might create difficulties in terms of integration. AGROVOC was translated from English into Chinese, despite the fact that it was not the core emphasis of the project [50]. The combination of both of the models (AGROVOC + CAT) has resulted in creating 40 classes for a crop classification decision making procedure, with more than 63,000 concepts created in the process [49].

AgriOn [56] was developed in the context of building up agricultural knowledge via the concept of reuse for a particular region. Ontologies for agriculture comprise taxonomies, such as AGROVOC, which define common terms, or ontologies designed for smart farming but not published for reuse, which together comprise the existing ontology for agriculture. If we are working with grain or food lifecycle terms, AgriOn may help with defining the environment in which a product is produced, and describing the recall relationship between succeeding forms such as cultivated varieties, wheat and ponders, and so on, to capture the semantics.

Given the importance of agriculture as a dynamic economic sector in Sri Lanka, a community-maintained knowledge repository would be very valuable to the country's agricultural industry. For their part, today's techniques of ontology maintenance are sophisticated and necessitate the use of ontology engineering skills. Agriculture is hindered in its acceptance and dissemination by farmers who lack an understanding of ontologies, despite the clear benefits of ontology-based knowledge systems. The purpose of the study in [62] is to offer a simple approach for adding new information into ontologies in order to give a solution to this challenge. Initially, the technique's major purpose is to update the ontology structure while still retaining its real-time consistency. An additional method of gathering input from users and pinpointing areas for development was via the use of a statistical analysis based on a questionnaire. In light of these data, the authors stated that their approach outperforms the currently available standard tools in terms of effectiveness and usability, respectively.

This study's [62] purpose is to enable Sri Lankan agriculture domain users who are not acquainted with ontology to better manage their ontological knowledge base. They devised a mechanism to shield the user from the ontology framework while analysing the need. The model's design permitted ontology T-Box updates and reasoning-based knowledge inferences. The authors presented a unique way to deal with inconsistencies in real time to address the inference stage's difficulties. This approach included three levels of architecture: display, semantic framework, and in-memory database. The recommended method was evaluated using task-based user evaluation techniques with an ontology for the Sri Lankan agriculture domain. A questionnaire-based statistical analysis was also performed to obtain user input and to suggest improvement areas. The method outperforms the existing standard tools in terms of effectiveness and usability.

The summary of the country- or location-specific geographical techniques are shown in Table 3.

Table 3. Summary of geographically country/location-specific knowledge representation systems for smart agriculture.

Authors (Ref.)	Year	Results
CAT [48]	1994	Thesaurus for agricultural terms in Chinese.
AgriOn [56]	2020	Developed in context to building up agricultural knowledge via the concept of reuse for a particular region.
Samarasinghe et al. [62]	2016	Purpose is to update the ontology structure while still retaining its real-time consistency in Sri Lankan agriculture.
Ma et al. [65]	2014	Increase understanding, credibility, and trust in climate change research.
Lin et al. [69]	2020	Collects data from a number of sources in order to aid farmers in making better irrigation choices
Chougule et al. [74]	2017	Extract keywords from text files by using keyphrase extraction procedures and AGROVOC thesaurus comparisons, among other techniques.
Jha et al. [78]	2016	Current weather conditions at a grape field are extracted, preserving it as an OWL document results in the creation of a knowledge base for pests and illnesses.
Wilson et al. [80]	2021	User-centred ontology for Sri Lanka, which represented domain knowledge such as crop types and pests, diseases, and fertilisers was developed with accompanying meta-information such as images, videos, and notes included.
Samarasinghe et al. [62]	2016	Simple approach for adding new information into ontologies.
AgriGO [84]	2017	Analysis toolkit for the agricultural community.
Campbell et al. [85]	2011	Using two New Zealand research programmes' expanding understandings of commercial organic agriculture, three problematic claims and framings supporting the study of commercial organic agriculture are examined.
Pakdeetrakul et al. [90]	2018	Ontology-based knowledge management approach used in the agricultural sector in order to facilitate the integration of heterogeneous data on organic agriculture in Nakhon Pathom Province.
Pouteau et al. [91]	2021	Principles of plant labour as an effective method to establish a shared vocabulary and to include community participation into an overarching organic agriculture.
Titiya et al. [93]	2018	These are the three key components: Cotton Ontology, Web services, and mobile application development.
SAGRO-Lite [94]	2021	Low-weight ontology created for particular agricultural traits in disadvantaged countries

3.3. General Farming KR

Ontologies covering all the aspects without any specific purpose are termed as "General Farming Ontology" [97]. As we do not keep any specific applications in mind while designing these ontologies, we have both pros and cons for the same. As an advantage, we can say that the ontology designed is for all use, and we can share the concepts designed as a result. Along with the sharing ontologies, we might be able to explore the knowledge within and understand the relationship between the domains. The disadvantages of the general architecture lie within the advantages listed, as we have to take proper care of the ontology developed, as discrepancies might take place.

3.4. Specific Farming KR

Apart from covering all aspects of farming, an ontology can be designed for specific usage, such as:

3.4.1. Water-Based KR

There are several advantages to hydroponics, including lower water use, increased output, and the absence of the need for pesticides or weed killers. Hydroponics must be made more efficient by using the most recent technological advances. A smart hydroponics greenhouse growing system that is enabled by the Internet of Things (IoT) is shown in [98]. Another study [99] simulates a soft computing-based control system for a hydroponic fertiliser solution in a hydroponic system. It is possible that hydroponics farms will respond differently to the same set of conditions as soil-based farms. This is well shown in [100]. Only a few of the areas that need predictive analysis and timely control in hydroponics farming include nutrient solution management, pathogen management, weed management, environmental management, and other aspects of hydroponics farming. Among these characteristics, the nutrient solution is one of the most important determinants of high-quality yield. Nutrient intake and pH modification have an impact on the productivity and output of hydroponic farms [100]. It is possible that the presence of insoluble and inaccessible salts in solution with a higher pH value would restrict the amount of nutrients available for plant uptake. When determining the osmotic pressure [101], electrical conductivity (EC) may be utilised. Osmotic pressure refers to the pressure that salt ions exert in a nutritive solution.

EC is unique to each crop, and it is impacted by the surrounding environment [102], to determine what the best EC is. The pH and EC of a hydroponic farm may be predicted with the use of a model that is established by the authors of [103]. The EC value is a measure of osmotic pressure, and a lower value may have negative consequences for the health and production of the plant. The application of a nutritious solution on a daily basis is not suggested. According to the research [104], the use of highly concentrated nutrient solutions is associated with an increase in nutrient intake. Producers who want to minimise the negative repercussions of nutrient abuse can benefit from an accurate prediction model that tells them how much nutrients to apply to a certain crop at a specific time. More accurate and predictive models are necessary in order to make full advantage of hydroponic farms' capacities to modify a wide range of parameters including pH, EC, and temperature, among other things.

3.4.2. Animal-Based KR

Most sophisticated experimental and commercial dairy barns now collect data from contemporary farm equipment and farmers, such as automated milking and feeding systems, concentrate feeders, feed mixers, pedometers, weather sensors, and animal health monitoring devices such as ear tags or rumination collars. Data are accessible from specific sources such as control organisation and association information systems, animal breeding registrations, milk quality databases, and decision support programmes offering advice on various areas of dairying such as breeding and feeding. The conventional model representation techniques cannot provide efficient model expansion, whereas ISOagriNET Data Dictionaries [105] capture a wide range of livestock and dairy agricultural ideas using Dairy Farming Ontology. A graph of knowledge links to an external body of agricultural knowledge that already exists in the linked data format, making it useable for decision support applications, which may help to further develop DFO. According to the paper [97], mapping the entity, identity, and code sets into an ontology, as well as developing and deploying a translation tool, will allow for existing cattle and dairy farming knowledge to be used. It is the right size for cattle, dairy, and pig production, as well as for future expansions, and it is affordable.

3.4.3. Plants-Based KR

Precision agriculture researchers have been focusing on plant-based crop management. Using a decision support system to monitor the soil, crop, and climate in a field allows for proactive treatment choices including irrigation, fertiliser, and pesticide applications. This study [67] presented an ontology-driven framework for creating precision agriculture applications. Different ontology-based systems may use various vocabularies and follow different rules to convey the same concept. For example, plant names vary according to area, and even language. As a consequence, certain programmes and services may not operate on all platforms. However, uniformity may be difficult to achieve. Aligning ontology-based systems involves identifying and constructing mappings and linkages. The correspondences between two ontologies' discrete elements (classes, attributes, rules, predicates, or even formulas) need to be identified. The work employs ontology alignment to make the system more accessible and flexible to other systems created for different environments and needs.

To build large-scale agricultural ontologies, agricultural specialists and ontology developers must collaborate. The model and tool [68] are based on the Chinese Eight-Point Charter of Agriculture [106]. Citrus domain knowledge is divided into eight groups. The relationships between the categories are established. The citrus knowledge framework has eight categories and their relationships. The authors propose strategies for constructing citrus ontology using this knowledge architecture. The Fertilization ontology has 866 ontology entities and 12,583 RDF triples. The Fertilization ontology's structural evaluation results outperform the Web ontologies studied in this research. The ontology is validated by the 110-question competency test, which was 88% accurate. This technique can model complex agricultural knowledge and transform it into computer-usable resources.

Traditional agricultural irrigation relies on a variety of data, including plant, soil, and meteorological information. The irrigation infrastructure in Nebraska is one of the most essential infrastructures in the state since it ensures that agricultural businesses have access to sufficient water. Even though the overwatering of plants is widespread practice in large-scale farming, the marginal economic benefits of irrigation decline significantly as the amount of water used grows. The WaterSmart system [69] collects data from a number of sources in order to aid farmers in making better irrigation choices. The data are then analysed. In order to understand this Agro-Geoinformatics data with local planting knowledge such as water consumption during different crop stages, a semantic irrigation ontology is being developed to supplement the WaterSmart system and to be used in conjunction with the WaterSmart system. The ontology was developed using Webprotégé [107], while the reasoning engine is implemented using HermiT [108]. Nebraska's most significant crops are corn and soybeans, which are both grown in large quantities.

Plant ontology is a critical issue in the 21st century, since it will have a worldwide influence on agriculture in the next decades. When it comes to organic agriculture (OA), there is an opportunity to place plant ontology at the forefront of discussion and to untangle terms such as organicity, nature, and livingness from one another. OA has mostly focused on soil ontology, with little attention being paid to crop ontology. Being able to grasp why plantness is still considered a grey area in science is vital for understanding organicity and plant embodiment, and passing over. The need to expose the contradictions and paradoxes of information collecting that misses major aesthetic and relational value while encouraging a utilitarian mindset toward plants as materials and resources is one example. Another purpose is to increase public awareness of the intrinsic value of plants, and to contribute to the continuing discussion on plant agentivity and integrity, both of which are now underway. It is necessary to include the notion of "plant labour", as well as the necessity of plant–human interactions in the workplace, while discussing organic sustainability. Finally, discussing the fundamental principles of plant labour is an effective method to establish a shared vocabulary and to include community participation into an overarching OA philosophy [91].

Large amounts of agriculture-related data are collected by web services, satellites, and a network of sensors, including meteorological data, soil health records, disease and pest records, and more. Farmers and agricultural domain professionals will benefit from this new ontology-based system for agro-advisory services, which will allow them to better interact with one another. These are the three key components: Cotton Ontology, Web services, and mobile application development [93]. Ontologies are created with the help of a programme called Protégé [109]. The web services are hosted on a cloud-based application server, which is built in Java and runs on a virtual machine. The farmers use Android devices to access an app that is available on Google Play.

In the horticultural industry, IoT has already established itself as a viable tool for obtaining self-satisfaction, hybrid and advanced decision making, and computerisation. Underdeveloped nations cannot instantly adopt IoT agricultural solutions due to illiteracy, an aversion to technology, and smaller farm sizes. Farmers in poor countries such as India may increase yields by using a lightweight Internet of Things (IoT) adapted to local farming practices. In this regard, the authors created SAGRO-Lite [94], a low-weight ontology that they created for particular agricultural traits in disadvantaged countries. IoT-Lite and CESO are two additional ontologies utilised in the system for semantic sensing, and event detection and processing.

3.4.4. Farm- or Crop-Based KR

Ontologies in the crop–pest domain have been developed to represent concepts and relationships relating to crops, associated pests (insects, diseases, weeds, and nematodes), and pest management issues, among other things (integrated pest management, chemical control methods, and biological control). The ontology in [72] was used to provide a classification mechanism for articles inside the EDIS system (Extension Digital Information Source) [71]. It is an online library with more than 7000 articles that have been established by the University of Florida's Cooperative Extension Service, and which is being maintained by the university. The EDIS includes information on agriculture, natural resources, youth/families, and consumer products and services. The crop–pest ontology has 700 concepts, which accounts for about one-third of the subjects covered by the EDIS ontology. EDIS, which includes over 2000 topics and a standard full-text search engine, was originally intended to serve as a loosely organised index of material, but it has now evolved into much more. Examples include the crop–pest ontology, which was developed to demonstrate the utility of an ontology while searching a very modest and manageable set of data when compared to several alternative search strategies. The ontology was constructed by starting with the original index and manually extracting crop–pest concepts. An ontology database was constructed in order to keep track of the links between different concepts (Lyra). This comparison was made in order to highlight the advantages of using a more formalised ontology in comparison with the original topic index.

In this study's pilot experiment [110], Thai rice was used to establish prototype ontologies for plant production. The Thai Rice Production Ontology has 2322 concepts and 5603 words, organised into hierarchical connections with 57 associative linkages and 12 equivalence relations. The query expansion and reasoning components of the rice-production ontology resulted in improvement of the retrieval performance. Based on the same ontology, another work was carried on [111,112], where the Jess rule engine [113] was used to generate rules to infer knowledge in this case. This work has 63 rules that reason on 101 classes and their connected properties, allowing for many innovative conclusions, including the control of water and nutrients in yield at each stage of rice crop growth. The pesticide spray is maintained throughout the crop's life cycle, and the seed is recognised. As a consequence, farmers obtain help in making daily and phase-by-phase choices about their rice crops.

3.4.5. Pests-Based KR

To practise pest control that is more ecologically friendly, it is necessary to use fewer pesticides and to replace them with less toxic alternatives. Because of this, the use of decision aids for rational pest management is required. Success in decision making is dependent on the availability of integrated, high-quality information in the actual world, rather than in a theoretical environment. As a result of computer-aided forecasting and decision support technologies, pest control may become more ecologically friendly in the near future. Integrated pest management is being investigated for web-based decision support systems, according to the findings of this study [73]. To summarise, the ideas of sustainable agriculture and those of integrated pest management are mutually supportive of one another. Pest models, which can predict the exact date of individual pest phenological development and undertake suitable control operations in advance, assist in decision-making in pest management. The climate has an impact on the majority of models. Fourth and last, advances in hardware technology have made it feasible to take automated recordings of meteorological data in real time. In order to develop a pest management programme, it is necessary to combine these data with pest models via the use of logical processes and forecasting algorithms. It is feasible to utilise web interfaces as decision support systems, providing real-time pest alarms and management recommendations to the user using online interfaces. To classify and to describe agrodata, knowledge representations and ontology web programming may be used in conjunction with networked systems to ensure that it can be shared and utilised by many systems. A decision support system cannot accommodate the great majority of the pest management information that is presently available on static web pages, which is why static web pages are no longer used. Certain decision support systems allow users to interact with the content while also receiving real-time pest forecasts.

Farmers in India are fluent in a number of different languages. Because ontologies may be translated into a multitude of languages, Indian farmers can benefit from the experience of specialists in the field. It will be difficult and time-consuming for agriculture specialists to construct an ontology of agricultural pests from the ground up from scratch. Crop pest descriptions may be put into our user-friendly interface by typing them into the text box. The system in [74] will extract keywords from text files by using keyphrase extraction procedures and AGROVOC thesaurus comparisons, among other techniques. Specifically, a Pest Keywords Extraction Algorithm is provided that may be employed for this purpose in the research. The pest ontology in OWL format will be immediately stored along with all of the information. An expert may see the pest type hierarchy at any moment in the development of agricultural pest ontology and can either add or remove a pest type and its associated data. As part of the inference engine, expert systems will be able to make use of the agricultural pest ontology after it has been developed and is complete.

Pest and disease prevention and avoidance are the primary lines of defence in organic agriculture against pests and diseases. It is necessary to provide farmers with the information they need to cope with potential threats, boost yields, and reduce insect damage. While data gathering, integration, and analysis are all important steps in the process, semantic technologies may assist by offering recommendations that are based on the data that have been acquired. It is impossible for Semantic Web apps to operate properly without ontologies serving as their basis. On the basis of this research [75], the authors describe the processes that must be followed when developing an ontology for the area of plant pests and diseases applications. The organic farming ontology may be used by farmers that are interested in organic farming practices to develop a knowledge base and a decision support system for their operations.

Crop pests are a significant source of economic loss around the world. As a precaution against causing damage to people or the environment, governments have created stringent laws and regulations controlling the commodities and methods of consumption. The guidelines for pest-related information systems must be reviewed on a regular basis in order to keep up with scientific and technological advancements. This is required to maintain pest-related information systems. When it comes to human-centred jobs such as these, we have to put in a significant amount of time. In order to make pest detection and treatment selection information more accessible, recommendation systems for pest detection and treatment selection are being developed [76]. At the centre of this system is an ontology that shows the interactions between crops, pests, and treatments.

Agricultural Ent (AgriEnt) [77] is a knowledge-based Web platform that is designed to assist farmers in the identification and control of agricultural insect pests. It is available in both English and Spanish. The data, semantics, web services, and display layers are all included in AgriEnt's four-layered functional architecture, which is divided into four categories. The data layer is considered to be the foundation of the system. It is possible to codify the skill sets of agricultural entomology practitioners in ontologies, which may subsequently be utilised to perform computer-assisted pest diagnoses. The authors endeavour to prove the validity of the AgriEnt platform comes to a close with a case study involving the discovery of an insect infestation that was causing damage to a crop. It has been shown that AgriEnt's ontology-based method may provide findings that are comparable to those provided by entomology experts who were part in the review process. Farmers may benefit from the information available on this platform in order to make better choices regarding identifying and managing agricultural insect pests.

The agricultural sector contributes to around 35% of India's gross domestic product (GDP). Decreases in India's gross agricultural production have a negative impact on the country's economy. It is estimated that pests and dieses are responsible for a considerable amount of the loss in agricultural productivity. Because grapes are grown in the majority of Indian states, they play an important role in the country's overall crop production. The use of a computerised system for pest and disease management is required in order to boost grape yields. In the future, we will be able to foresee pests and diseases that may impact grapes because of the use of an expert system. As part of its effort to provide more accurate predictions, this research [78] takes into consideration the current weather conditions at a grape field. The process of extracting information from the Internet and preserving it as an OWL document results in the creation of a knowledge base for pests and illnesses. Because it is acceptable to characterise weather conditions as fuzzy variables, the inference engine for the grape expert system is based on fuzzy logic rather than traditional logic. It is based on a set of established rules that have been developed by experts.

For Sri Lankan agriculture, a user-centred ontology that represented domain knowledge such as crop types and pests, diseases, and fertilisers was developed with accompanying meta-information such as images, videos, and notes included [80]. The management of pests and diseases was selected as the first stage in conducting this inquiry. Following field excursions and a research of the literature, the ontology representations of symptoms' occurrences were further developed. N-ary relationships are addressed by altering the ontology design rules for N-ary relationships to accommodate concepts that have more than two affiliations with each other. Using the assistance of specialists, image annotations were added to the images and annotated with photographs in order to accelerate the retrieval process. Farmers will now be able to search for information using photographs and keywords. In order to ensure the authenticity of the ontology's material, specialists and reliable sources were sought for their responses to questions regarding diseases, as well as for photographs of the conditions. The development of an ontology access system that is ontology-enhanced was performed in order to demonstrate the practicality of employing the ontology. Protégé [109] and the OWL API were used to model the ontology and connect it to the system, and the results were published online. Using Stanford CoreNLP [114], it was possible to validate that farmers' input-keywords were equivalent to ontology annotations by using WordNet APIs [115]. Eventually, a decision tree will be included into the system, which will allow it to reconcile the inconsistent responses that the ontology produces.

3.4.6. Fruits-Based KR

There are several aspects that influence citrus planting, with terrain and development stage being only two examples. When it comes to citrus planting, there are a few differences between planting on hills and planting anywhere else. For farmers in Chongqing, China, the ontology [68] is being utilised to develop three citrus decision services (fertilisation; nutrient imbalance, and irrigation/drainage). As a result, the output of the system with the reference values recommended by citrus specialists are compared to ensure that our suggestions are correct. The results of the fertilisation service were completely in line with what the experts had expected before the service began. With a 94 percent accuracy rate, the irrigation/drainage service can match farmers' demands, while the nutrient imbalance service has a 98 percent accuracy rate in matching farmers' needs. Other agricultural ontologies may be connected to and integrated into ours, resulting in the creation of AOS ontology subclasses [57].

3.4.7. Vegetable-Based KR

The authors in [81] investigated ontology as a technique of representing information in the vegetable supply chain, and they found it to be rather effective. In developing a strategy for establishing a vegetable supply network ontology for the vegetable supply chain, as well as a data representation framework for expressing data, the framework may be used to define the ideas and interactions that exist between them in order to compile a database of information about the vegetable supply chain, for example.

Modern information retrieval systems, based on keywords, fall short of consumers' expectations in terms of recall and precision in today's hyper-connected environment. This paper [82] presents an information retrieval model based on the veggies e-commerce ontology that may be utilised to improve the recall ratio and precision ratio of information retrieval engines that are used in online vegetable sales. This ontology was created using the information collected, and veggies e-commerce transactions were analysed using the Internet The vegetables e-commerce ontology is built on top of the classifications and hierarchies of vegetable classes, which are organised into categories. The usage of domain ontologies in the process of information retrieval assists in indexing and inference, as well as inference itself. An ontology-based information retrieval model is more functional than the keyword-based online information retrieval engines that are presently available on the market. The results of the experiment demonstrate that the recall and accuracy ratios of the ontology-based information retrieval model are much higher than those of the keyword-based information retrieval engine, to a certain extent.

The authors in this work [83], recommended that a food ontology be developed for the traceability domain. The authors of this article go into great depth into the ontology's design process, as well as its main qualities. They believe that the Food Track and Trace Ontology (FTTO) will serve as a central repository for the most significant concepts in the hierarchy of a supply chain. In order to codify the knowledge model and to construct the ontology in the Ontology Web Language, Protégé was used (OWL). In order to examine and validate the ontologies, it has been feasible to utilise the Pellet reasoner from Protégé as an external plug-in.

3.5. Organic KR

With the help of AGROVOC, the authors in [86] tried to give an ontological structure to cases in organic agriculture, namely fertilisers. They managed to create two subconcepts in the fertiliser concept, named general and specific fertilisers. However, no account of spatio-temporal data representation is shown. In addition, it is seen that although researchers can share the vocabulary, the exploration of knowledge and decision making arer not supported.

Using two New Zealand research programmes' expanding understandings of commercial organic agriculture, three problematic claims and framings supporting the study of commercial organic agriculture are examined in [85]. Our knowledge of commercial organic is changing, particularly when it comes to interactions between the research team and the wider organic business. The evolution of New Zealand's organic sector defies three basic political economic framings. These important exchanges show it clearly. The consequence is a great dichotomy of large-scale corporate, industrialised organic agriculture inhabited by pragmatic newcomers to the business against small-scale local, genuine remnants of the original organic social movement. The "Organic Industrial Complex" is gradually overtaking actual organic farming, according to author Michael Pollan. Second, commercialisation would ultimately "conventionalize" organic farming. This is important. Finally, it is claimed that organic farming is the only approach to improving environmental outcomes in agriculture.

There are several information systems that currently give valuable knowledge regarding organic agriculture processes, but this material is dispersed over the Internet in a variety of settings, formats, and media, making it difficult to access. In order to formalise any subject area in great detail, ontology and a conceptual framework are necessary tools to use. Research into organic farming has a specific purpose in mind: acquiring, preserving, and sharing information about organic farming to current and future software developers. By integrating information extraction and ontology building approaches, it is possible to develop an ontology-based information extraction system for organic farming applications (OBIESOF). Using the protégé editor, a knowledge base of ontologies was created in [87], as well as a high-level application programming language for developing a web-based ontology language application programme interface. The ontology knowledge base was created using the Java programming language (OWL API). In contrast to the HermiT ontology checker [108], HermiT was used to evaluate the validity of the ontology by submitting queries and analysing their consistency, rather than the other way around. The queries were expressed using the Description Logic (DL) query language (DLQL). The ontology was put to the test by presenting competency questions through the DL query interface and seeing whether or not it was able to provide responses to user enquiries. They were positive, and they point to the ontology's potential as a knowledge reservoir, according to the responses.

OA and AE (organic agriculture and agroecology) are handled in this article [88], which addresses the ontology needs of the Organic project for these fields. This process involves the participation of domain experts, ontology specialists, and other professionals, such as librarians and external consultants, among others. When developing an ontology for the OA/AE knowledge base, it is necessary to take into account a wide range of factors. The ontology experts suggested that the ontology should be built from some very basic concepts (from some publicly available, popular ontologies) such as "person", "plant", "phenomenon", and "organisation", before allowing other participants to start associating the list of concepts that they have elaborated.

In educational websites, the use of Semantic Web technologies makes it easier for users to identify, access, and retrieve information about the subject they are interested in learning. In order to achieve this aim, a variety of architectural components and services must be integrated seamlessly. A large-scale case study is described in this article [89] as a method of approaching this challenge. Organic instructional resources on agricultural concerns are available via Edunet, which is a website that gives access to a network of learning repositories that includes educational materials on the subject. In addition to providing an overview of the design, the supporting technology is described in detail. This research looks at the use of Semantic Web technologies to aid with the sharing and reuse of learning materials, with a particular emphasis on how these technologies may be used to promote ontology-facilitated sharing and reuse of learning materials.

The agricultural information resources for organic farming in Nakhon Pathom Province are dispersed, difficult to find, and disorganised in their distribution. The diffusion of knowledge and the availability of information for people in need are made more difficult as a result of this. As a result, this research [90] suggests that an ontology-based knowledge management approach be used in the agricultural sector in order to facilitate the integration of heterogeneous data on organic agriculture in Nakhon Pathom Province. From the Organic and Agriculture Ontology, farmers, consumers, and government officials at the Nakhon Pathom Provincial Agricultural Extension Office and the District Agricultural Extension Office gain a better understanding of organic agriculture. It is possible that the ontology and its logical reasoning process will combine the benefits of both keyword and concept-based searches in order to further improve information retrieval.

3.6. Climate and Environmental KR

It is the goal of the SemantEco [64] to provide decision aid tools that will assist resource managers in recognising a variety of environmental circumstances. The researchers are also looking at the reuse of ontologies in order to improve the usability and interoperability of their system.

In order to provide trustworthy information to the National Climate Assessment, Semantic Web approaches were used in the research [65]. Their mission statement said that they wanted to "increase understanding, credibility, and trust in climate change research". In order to construct an ontology model of the Global Change Information System, a variety of use cases were examined in order to establish the goals and other aspects of the domain. In order to enhance communication with the general public and environmental experts, CMapTools was used. Ontologies were utilised in order to improve interoperability and system usability.

In order to make agricultural output more adaptable to the impacts of global warming, climate-smart agriculture (CSA) has been established as an objective. It involved the collaboration of a broad variety of stakeholders for CSA to be a successful initiative. It is necessary to solve information sharing and access issues in order to guarantee that each member's concerns and solutions are taken into consideration. A CSA ontology aids with this process and adds automation to a task that would otherwise be scary and time-consuming to perform manually. CSA data and solutions are accessible via the ontology created by the researchers [60], in which users will be able to consult at any time for further information. This ontology focuses on CSA efforts and processes in order to reduce the effect of global warming on the environment. Ontologies such as this one are being developed to better integrate stakeholders in the climate change, agricultural, and economic modelling communities with information technology in order to better educate them about the advantages of community-scale agriculture (CSA) practices and methods. As an added benefit, it serves as a quick and efficient technique of selecting the best practice alternatives or tactics for detecting climate change.

In order to improve the process of retrieving information, the researchers in [61] use an ontology-based knowledge representation. Additionally, by using this strategy, they are able to collect semantically connected information that matches the expectations of the user while assisting in dealing with a variety of data sources and addressing our information retrieval concerns. Using this strategy, each document is categorised according to the notions it has in common with a class. The extraction of feature words that are important to the context of each document is performed, and that may be used for indexing purposes from each document. Whenever a user submits a search query, the system first identifies the question's class, after which it matches the query against the document's metadata, and the most relevant material is shown to the user. The study have discovered that an agricultural domain ontology is a beneficial tool.

The National Climate Assessment (NCA) of the United States Global Change Research Program (USGCRP) investigates and summarises the consequences of climate change on the United States. When it comes to formulating policies and making choices, the findings of an assessment are of great importance to the general public, as well as to academics and policymakers. The researchers in [65] were able to construct data models and ontologies that properly represent the content structure and provenance of the most recent draught of the National Climate Assessment report by using a case-driven iterative approach. The ontology was put to the test by using pilot systems that provide information on the instances of chapters, scientific discoveries, images, datasets, references, people, and organisations, among other things, in the draft report. Using the results, one may track out the source of a figure in a research report, for example, by locating all of the journal publications that were used to create the figure. The "Web of Data" was utilised to maintain track of where our work came from in the first place. Additionally, in addition to the prototype systems, several other tools and services were developed that may be used to gather and utilise provenance information. The United States Global Change Research Program's Global Change Information System will eventually include all areas of global change research, including provenance information. Such a system can obtain a better understanding of global change and gain more credibility and trust in their results, as well as the capacity to duplicate scientific discoveries and conclusions.

Agribusiness and water resources are being influenced by climate change, and OntoAgroHidro [66] is a visual representation of this phenomenon. This study is concerned with the establishment of a network for the sharing and retrieval of information on the impact of climate change and agriculture on water resources. According to the engineers, ontological systems that incorporate concepts from several domains should be represented using pre-existing representations. It also looks at how to incorporate concepts from reusable representations into the design via important issues and situations, as well as looking at data sources and systems that will be combined. In partnership with subject matter experts, we used visualisation tools to study a number of different scenarios and findings. The ontology's capabilities and limitations were investigated in the context of a data recovery scenario.

4. Knowledge Representation in Smart Urban Agriculture

As opposed to just being areas where food is eaten, cities and urban centres are increasingly being considered as potential sites for the production of food as well. As a result, this study [116] re-examines earlier research on food's relational materialism and the multiple forms it may take, this time via the lens of London's "urban food foraging" activities. Fieldwork in London using a variety of methodologies is utilised to generate a series of vignettes on plants found across the city, some of which may or may not be edible. In order to determine the ontological character of "food", it is necessary to go beyond its edibleness or raw substance, and instead consider the many different types of material–cultural–legal–environmental–scientific–geographic assemblages that give birth to it.

Home gardens and family plots are among the world's oldest food production practices. A home garden's goals might vary from simple amusement to self-sufficiency, healthy output, family savings, and community inclusion. The community needs to know when harvesting, irrigation, and other operations must be undertaken. Thus, new ways involving specialised skills are definitely required to help with home garden decisions. This work [117] focuses on maintaining home gardens. This system uses semantic technologies to replicate basic garden activities, including planting, watering, transplanting, and harvesting. The intended DSS was evaluated using medicinal plants and vegetables.

An investigation of the microbial community, antibiotic resistance genes, and medically relevant parasites found in wastewater utilised for urban agriculture in Ouagadougou was carried out utilising state-of-the-art metagenomics techniques (Burkina Faso) [118]. Wastewater samples were taken from three canals near agricultural regions in three different neighbourhoods. The antibiotic resistance ontology was used to organise the markers, annotate them, and connect them to the appropriate resistance family or anticipated pathogen of interest. There were both pathogen-specific and common genes discovered in the study.

Increasingly popular in cities, urban agriculture and high-tech agriculture are the subjects of this study [119], which investigates the actor network that has evolved to facilitate public participation in local urban planning. Actors are defined as everything that performs or that has the potential to perform. In a flat ontology, actors (both social and material things) are defined by their relationships with other actors.

Urban planning influences a region's economic progress. It plans future housing, infrastructure, and service needs to improve people's quality of life. The 'Land Use Plan' is an important urban planning book (LUP). Regulatory town planning documents such as the LUP define norms for land use in their jurisdictions. To promote communication and collaboration among the various stakeholders involved in urban planning, an ontology model explaining all urban concepts and their relationships is required. The authors of this research [120] created a new ontological model for urban planning that identifies zoning, infrastructure, services, and easement.

One of the most significant emerging technologies in today's fast changing widespread environment is ubiquitous computing [121], which is quickly becoming one of the most important emerging technologies. It is still impossible to develop a context-aware system for a vertical farm without first gaining a thorough understanding of the domains, which may be defined as "a collection of objects; relations; functions; and services". The use of an ontology model based on OWL to express the links between the domain components that help us manage this issue is recommended when it comes to monitoring and regulating the services provided by the vertical farm when it comes to addressing this problem. Using a categorisation system, the authors in [122] organised the core concepts for a vertical farm setting into groups that may be further split according to unique study interests. A similar OWL-based ontology is used to describe the system and service's shared understanding and connection in [123]. Concepts such as location, user, system, context, environmental parameter, user, and network are used to build the higher level ontology. In agriculturally based smart settings, the core principles described here may be reused and developed. Another attempt to it is provided in [124], where online platforms give knowledge, making it independent of any one system. Ontologies such as this vertical farm ontology allow humans and computers alike to grasp the context in which a real-world scenario occurs. As a result, a computer is capable of recognising a scenario without the assistance of a human being. Intelligent services for optimum crop development may be supplied in a vertical farm via this article without the involvement of a person.

Urban agriculture is a vehicle for the transmission of ethnic knowledge and cultural meanings. It is an important cultural resource to have in order to advance urban agriculture innovation and development. This paper [125] describes the establishment of a digital humanistic urban agricultural resources ontology system in Beijing, which is convenient for organising, inheriting, protecting, and sharing urban agricultural cultural knowledge. It also serves as a reference for urban agriculture research and development through the summary and analysis of cases of agricultural ontology construction.

This paper [122] provides a rule-based control selector for an automated vertical farm. Choosing the right controller is critical when running an automated system. Choosing a proper controller for a large-scale agricultural operation is tricky when multiple crops are cultivated simultaneously. During the selection procedure, the weather and crop growth are analysed. Web Semantic with ontology support, and language rules are built for selecting controllers for each sector where the control selection flow identifies, matches, rates, and chooses. The Table 4 depicts the summarty of the papers discussed.

Table 4. Summary of Urban agricultural KR papers with Publication Year, Geography, Spatio-Temporal Factor, and Evaluation Criteria where Go = Global, Co = Country Specific, SV = Share Vocabulary, KE = Knowledge Exploration, I = Interoperable, DS = Decision Support, S = Spatial Factor, and T = Temporal Factor.

Papers	Year	Geography		Method				Space-Time	
		Go	Co	SV	KE	I	DS	S	T
Qianning et al. [125]	2019		x						
Nousala et al. [116]	2020	x							
Nyman et al. [116]	2019		x						
Shamshiri et al. [126]	2018	x							
Farhangi et al. [127]	2020		x			x		x	
Vergara et al. [117]	2017	x					x	x	
Bougnom et al. [118]	2019	x					x	x	
Farhangi et al. [119]	2021		x			x		x	
Barramou et al. [120]	2020		x					x	
Sivamani et al. [122]	2014	x						x	
VFO [123]	2013	x					x	x	
AquaONT [122]	2021	x					x	x	
Kim et al. [124]	2013	x			x			x	
Borghini et al. [128]	2020		x		x				
Sivamani et al. [122]	2014	x					x	x	
Afzal et al. [111]	2014	x			x		x	x	
Afzal et al. [112]	2021	x			x	x	x	x	
Wang et al. [129]	2015	x			x	x		x	
Tomic et al. [97]	2015	x		x	x	x		x	
Yang et al. [130]	2015		x						
Mazzetto et al. [131]	2019	x							
Mazac et al. [132]	2020	x							
Abbasi et al. [133]	2021	x		x		x		x	
Sreedevi et al. [134]	2021	x							
Sunguroğlu et al. [135]	2020	x							
Hosseinifarhangi et al. [136]	2019		x						
Modu et al. [137]	2020	x							

5. Conclusions

Knowledge representation in agriculture is important for the representation and proper formal reasoning of the data collected. Ontology with the Semantic Web is seen as a primary representation mechanism. Some of the inferences drawn from the paper are:

(a) It is essential that ontology evaluation methods are clear and well-organised; otherwise, an ontology cannot be regarded as a contribution to research and practice. It is becoming more vital to use ontologies and the Semantic Web in agricultural systems in order for them to be effective. It is difficult to exchange and to reuse agricultural ontologies, since as our examination of the literature has revealed, most of the studies that generate them do not disclose the creation process or even mention how the resulting ontologies were rated.

(b) Spatial–temporal knowledge representation is a challenge by itself, and so it is a rare characteristic found in the survey.
(c) Generalisation of the knowledge representation to include all domains in agriculture is also an issue by itself.
(d) A majority of the ontologies miss a proper validation technique for ensuring the correctiveness and soundness of the same.

6. Future Work

It is quite evident that knowledge representation is a requirement for better understanding and modelling agricultural data. A new knowledge representation language based on Environment Knowledge Representation Language (EKRL) [138,139] can be explored to curb the limitations found in the survey. EKRL's ability to construct complex N-ary and second-order data structures, which allow for the development of high-level reasoning methods for the purpose of deterministic inference, is particularly noteworthy [140,141]. For temporal representation and reasoning, Allan's interval calculus can be used [142].

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