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Fuzzy Methods in Smart Farming: A Systematic Review

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Abstract. Smart Farming (SF) has garnered interest from computer science researchers for its potential to address challenges in Smart Farming and Precision Agriculture (PA). This systematic review explores the application of Fuzzy Logic (FL) in these areas. Using a specific anonymous search method across five scientific web indexing databases, we identified relevant scholarly articles published from 2017 to 2024, assessed through the PRISMA methodology. Out of 830 selected papers, the review revealed four gaps in using FL to manage imprecise data in Smart Farming. This review provides valuable insights into FL for potential applications and areas needing further investigation in SF.

Key words: fuzzy logic, Smart Farming, precision agriculture, agri-food chain, Preferred Reporting Items for Systematic Reviews (PRISMA).

1. Introduction

In order to achieve global food security as outlined by the United Nations in the document "Transforming our world: the 2030 Agenda for Sustainable Development", it is necessary to innovate and potentially transform policies, distribution chains, and global agricultural models. In addition, there are various challenges in ensuring food safety, as reported by the NASA Technical Reports Server in a publication titled "Special Report on Climate Change and Land", Chapter 5: Food Safety, Mbow *et al.* (2020). Globally, 821 million people are

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undernourished, and the demand for food has surged by over 30% since 1961. Furthermore, 613 million women aged 15 to 49 are iron deficient, 151 million children under five experiencing stunted growth, and 2 billion adults classified as overweight or obese. The food supply system is also under pressure from non-climate stressors. Including population and income growth and the increasing demand for animal-sourced products. A critical component of realizing this in the agricultural sector involves the transition of traditional agricultural systems into intelligent ones. Smart farming addresses the challenge by integrating data collection, analysis, automation, connectivity, precision applications, and sustainability (Walter *et al.*, 2017b).

Smart farming technologies gather, analyse, and use data to help farmers be more productive, successful, and environmentally friendly. This is done by combining big data with new artificial intelligence technologies. Such as remote sensing, automated control, and yield monitoring. This data-driven approach is essential for effectively monitoring and tracing perishable products back to their respective origins (Monteleone *et al.*, 2019). In essence, the benefits of smart farming extend beyond the farm level because of the insights provided by intelligent decision support systems to farmers and other actors in the agri-food chains. It can help reduce resource waste (Tang *et al.*, 2002) and agricultural industries environmental footprint (Walter *et al.*, 2017a), improve food quality (Sundmaeker *et al.*, 2016), and increase food security (Ribarics, 2016).

Smart farming is characterized as a complex data system concerning agri-food safety, mainly because agri-food safety data and information are scattered across the agriculture and food sectors. Moreover, agri-food supply chains represent related events in the agricultural production of food and describe associated events in agricultural production. Various technological and methodological developments in the agri-food chain were adapted using the Internet of Things (IoT), big data, and Geographic Information System (GIS), which enhanced the agri-production rate. However, due to its complex structure, the agri-food chain is susceptible to various vulnerabilities and hazards, including operational difficulties and breakdowns caused by various uncertainty factors and circumstances (Mbow *et al.*, 2020). Uncertainty may be classified into four categories: (1) Product (shelflife, degradation rate, lack of uniformity, food quality, and food safety), (2) Process (harvesting yield, supply lead time, resource demands, production), (3) Market (demand, market pricing), and (4) Environment (weather, pests and diseases and regulations) (Esteso *et al.*, 2017).

To address this issue of uncertainty, many researchers have employed fuzzy logic to mitigate these factors that arise in the agricultural sector. Tomasiello and Alijani (2021) has conducted a review of several articles on the application of fuzzy logic as a solution for the agricultural food supply chain (AFSC) and has highlighted various aspects, including the complexity of uncertain factors in the supply chain, such as operational difficulties, credit losses, and economic losses. Nonetheless, Tomasiello and Alijani (2021) also noted that there is still a lack of research on fuzzy logic techniques specific to the data-driven model level in the AFSC. Blanco-Mesa *et al.* (2017) also made the same observation, noting that fuzzy logic is widely used by researchers as a method for Multi-Criteria Decision Making (MCDM), addressing uncertainty in various fields. However, the application of fuzzy logic to the agricultural sector was not explicitly addressed by Blanco-Mesa *et al.* (2017).

This paper was motivated by the importance of identifying the gaps in innovative agriculture research conducted by researchers, particularly when applying fuzzy logic in this sector. This will help in expediting the implementation of smart farming to support global food safety at every stage of the agricultural industry, in line with the targets set by United Nations. This paper contributes by reviewing the existing literature and offering new perspectives, emphasizing the use of fuzzy methods in agriculture and the food chain in a broader context to model the uncertain environment and what has been achieved in the field so far. It also emphasizes research potential in this field. Our current scope of work is limited to exploring operational challenges, with a specific focus on integrating data distribution within the agriculture sector. We are particularly interested in addressing quality monitoring, traceability of farm products, and uncertainty issues that utilize fuzzy logic as a tool at various levels of the agri-food chain.

To gain a deeper understanding of the significance of primary activities in the smart agriculture sector, in Section 2 we will begin by examining research activities along the agricultural chain and potential issues at storage points. This will involve exploring the relationship between applying fuzzy logic and various Multi-Criteria Decision Making (MCDM) algorithms in the agricultural sector. Following this, we will outline the methodology for selecting review papers in Section 3, and present the results in Section 4. We will then delve into the discussion and potential research opportunities in Section 5, before concluding with the identification of gaps and future work in Section 6.

2. Literature Review

2.1. *Previous Reviews*

Several reviews have been conducted concerning the application of fuzzy methods in agriculture. A study by Sannakki and Rajpurohit (2011) reviewed early papers on the use of fuzzy methods in agriculture. The study concluded that fuzzy logic effectively identifies plant diseases in various parts of the plant using image processing and soft computing techniques, particularly in handling vague image data. The paper by Makkar (2018) reviews the concept of fuzzy logic and its application in various fields such as chemical science, medical science, agriculture, and operations research. Meanwhile, Bannerjee *et al.* (2018) discusses challenges in agriculture, including disease and pest infestation, improper soil treatment, inadequate drainage, and irrigation. The paper highlights three primary artificial intelligence (AI) systems used to address these challenges, including fuzzy logic systems.

The application of fuzzy methods in agriculture has recently been reviewed by De and Singh (2021), highlighting the lack of efficient knowledge-based models in the agri-supply chain domains. The review specifically covers aspects such as land suitability, production techniques, irrigation, cold storage deficiencies, transportation, waste management, environmental and sustainability issues, and drought management.

In the paper by Tomasiello and Alijani (2021), the authors discuss papers addressing decision-making in agri-food supply chains, with a focus on green supplier selection, routing problems, and the most common fuzzy decision-making techniques employed for agri-food supply chains. Each of these reviews contributes to our understanding of the implementation of fuzzy logic in agri-food supply chains. However, they do not explicitly address the achievements in integrated and coordinated data distribution throughout the entire supply chain.

All activities within the agricultural chain are intricately linked and exert a collective influence on the final outcomes of agricultural products. Therefore, it is imperative to develop a model and conduct simulations incorporating various activities and parameters that impact the agri-chain in order to achieve optimal results. This paper intends to fill this gap and complement previous studies by focusing on papers discussing the agriculture part, specifically, farm processes such as cultivation and harvesting, which mostly has the potential to influence the mixing of products or goods.

2.2. *The Agri Chain's Complexity Features*

Agri-chains are the chains of activities within the agricultural sector that transfer crops from farms to consumers and transform raw commodities into marketable goods. They involve both fresh products, which retain their inherent qualities, and processed products, where raw materials are transformed into higher-value items like canned goods and desserts (Alemany *et al.*, 2021). The primary activities in agri-chains include cultivating, harvesting, handling, processing, storing, and transporting (distributing) (Taşkıner and Bilgen, 2021), as illustrated in Fig. 1.

The agricultural process begins with crop selection, land selection, planting, and nurturing (cultivating), which includes fertilizer application and pest and disease management (Barker, 2016). Harvesting occurs at maturity, but scheduling is challenging due to restricted time frames and resource restrictions (Johnson *et al.*, 2019), weather, and resource constraints, leading to potential losses (Kumar and Kalita, 2017). As a result, harvest yields are inherently uncertain in terms of quantity, quality, and timeliness. After harvesting, crops are delivered to preprocessing sites where they may be washed, packed, or treated according to their shelf life requirements (Paltrinieri and Staff, 2014). Semi-processed stocks then proceed to processing factories for conversion into final products with a greater added value that meets consumer demand.

The complexity of the products will affect the preprocessing and processing locations, whether they occur at the same place or in different places. For example, cocoa beans may undergo fermentation and packaging at processing sites (Saltini *et al.*, 2013). The cocoa bean can also be technically pressed into powder or liquid cocoa, which is then stored or delivered to other factories to be utilized as raw materials to produce final products (Kamphuis, 2009), meaning that preprocessing and processing are done at different locations. The complexity of end products required a different approach to preprocessing and processing facilities. Crop quality frequently degrades during storage and shipping (Kumar and Kalita, 2017). The storage of agricultural products is critical, as quality often declines during this phase, with post-harvest waste estimated at 20–60% (Lemma *et al.*, 2014). Sufficient transportation and inventory management are vital due to fresh products'

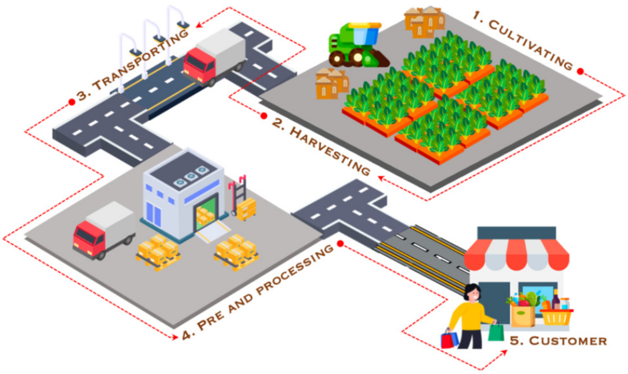


Fig. 1. Agriculture activities and potential storage areas.

perishability and processing equipment's limited capacity, as indicated in Fig. 1. The key challenges include uncertainty of weather, the effectiveness of the fertilization process, control, and resource constraints that complicate harvest planning and scheduling.

Nevertheless, ascertained high-quality products are secure and efficient in traceability while minimizing losses; an integrated approach is necessary for harvest planning, which includes harvesting planning such as scheduling, routing, and resource allocation. In particular, the complexity features of the agri-chain aformentioned are highly influenced by product mixing and perishability, yielding the importance of effective traceability from farm to consumer consumption is required. Information technology solutions such as IoT, sensors (e.g. temperature, humidity, and soil pH), networking (e.g. WSN, Long Range Wide Area Network (LoRaWAN)), and positioning systems (e.g. GIS) are essential to tackle these challenges. However, storing large datasets on cloud platforms raises security concerns (Stojkoska and Trivodaliev, 2017). Utilizing fuzzy techniques and algorithms for data processing methods and analytical systems can leverage farm management's effectiveness. A comprehensive assessment of prior research is needed to evaluate the integrated approach and available decision-making models.

2.3. *Fuzzy Decision Making In-World of Smart Farming*

The emergence of smart technologies and other advanced machinery in agriculture has led to remarkable improvements in both the quality and quantity of products. As the global population grows, the demand for efficient food production vastly increases. However, farmers are taking on this challenge and exploring innovative methods to meet the demand for agricultural products.

The classical decision-making process helps decision-makers evaluate and choose the best course of action from a set of alternatives. These alternatives may include actions, acts, or strategies, and the decision-maker must also consider the state of nature and probability distribution to make an informed choice and utilize it to determine the most suitable course of action. Decision-making is a complex mental process that implicates problem-solving to determine a desired outcome by considering various factors.

Table 1
Various method of multi-criteria decision making (MCDM).

MCMD method	Description	Area of first introduced	References or underlying source
Analytic Hierarchy Process (AHP)	Comparing different pieces of information through hierarchical criteria in a pairwise manner.	Mathematical modelling, social problem	Saaty Saaty (1980)
Fuzzy AHP	The use of AHP in combination with fuzzy evaluation for alternative options.	Mathematical modelling	Van Laarhoven and Pedrycz (1983)
Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)	Rank alternatives and use pairwise comparison with multiple iterations to determine the best option.	Management science	Brans (1982)
Fuzzy Evaluation based on Distance from Average Solution (EDAS)	Rank alternatives based on aggregated distance scores.	Inventory and stock on industrial management	Keshavarz Ghorabaee *et al.* (2015)
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Evaluating the distance between the alternative and the ideal solution to determine its effectiveness.	Management science	Ching-Lai and Kwangsun (1981)
Fuzzy TOPSIS	TOPSIS considers fuzzy or uncertain data for decision-making.	Mathematical modelling, management science	Chen (2000) or Lai *et al.* (1994)
Tomada de Decisão Iterativa Multicritério (TODIM)	The value function calculates the dominance of one alternative over another for each criterion in a pairwise comparison.	Economic science	Kahneman and Tversky (2013)

Fuzzy logic is a highly recommended approach for decision-making when faced with situations that are uncertain, vague, imprecise or ambiguous. It provides an effective means of dealing with such complexities and can prove to be a valuable tool in a variety of contexts, especially in smart farming. Bellman and Zadeh (1970) made a significant contribution to decision-making in fuzzy environments when they introduced it in 1970. Fuzzy decision-making in smart farming improves agricultural yield and quality. It optimizes resource utilization, reduces waste, and enhances efficiency and sustainability (Erdoğan, 2022).

The MCDM methods listed in Table 1 have both advantages and disadvantages, which vary depending on the field in which they are applied. Researchers have conducted comparative studies on each MCDM method. In a survey of MCDM applications in various fields, Aruldoss *et al.* (2013) found that the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was the most widely used. In the TOPSIS methodology, the ideal solution is defined as the one that has the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). During the process of TOPSIS, the performance ratings and the criteria weights are assigned as crisp values (Chen, 2000) (sees Table 2).

Table 2
Multi criteria decision making matrix (MCDM).

MCDM	C_1	C_2	$\dots$	C_n
A_1	x_{11}	x_{12}	$\dots$	x_{1n}
A_2	x_{21}	x_{22}	$\dots$	x_{2n}
$\dots$	$\dots$	$\dots$	x_{ij}	$\dots$
A_m	x_{m1}	x_{m2}	$\dots$	x_{mn}

Various combinations of fuzzy algorithms and TOPSIS have been used in research to support the development of smart farming. For example, Ecer *et al.* (2023) utilized the TOPSIS approach combined with q-rung Orthopair fuzzy numbers (q-ROFNs) to select the most suitable Unmanned Aerial Vehicles (UAVs), commonly known as Drones, based on different features such as radar, power system, and camera capabilities. Similarly, in the fishery sector, Padma *et al.* (2022) used two Multi-Criteria Decision-Making (MCDM) methods, namely fuzzy AHP (FAHP) and TOPSIS, to compare five types of fish varieties that are popularly consumed, and provide fishermen or farmers with a vision of the optimal types of fish species to be fished or farmed.

Fuzzy techniques can also enhance traditional Multi-Criteria Decision-Making (MCDM) methods in dynamic environments. Notably, Dhumras and Bajaj (2023) introduced a picture fuzzy soft Dombi EDAS methodology that uses multiple aggregation operators and evaluates interrelationships as input arguments for traditional Evaluation based on Distance from Average Solution (EDAS) and tested in robotic farming to address various contemporary challenges.

A study conducted by Gichamo *et al.* (2020) used MCDM in the agricultural sector to select a processed wastewater control system for reuse that has a positive impact on the environment. They utilized fuzzy Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) to provide recommendations for the application of the system. However, other MCDM methods, such as TODIM, are rarely employed by researchers for development in smart farming.

3. Methodology of Selection

3.1. *Paper Selection Method*

The significance of this systematic review lies in its aim to identify and analyse works related to fuzzy methods for smart farming or precision agriculture. It emphasizes the importance of decision-making systems in managing uncertainties in the agricultural chain, influenced by factors such as environmental conditions, weather, and the economic climate (Foley *et al.*, 2011; Godfray *et al.*, 2010). The review employs a systematic literature analysis methodology to achieve its objectives (Kitchenham, 2012).

The literature analysis for this review was conducted with thoroughness and rigour. Five databases, including Scopus, Google Scholar, ACM Digital Library, Springerlink, and IEEEXplore, were utilized. The search term was carefully defined as (‘Fuzzy Smart

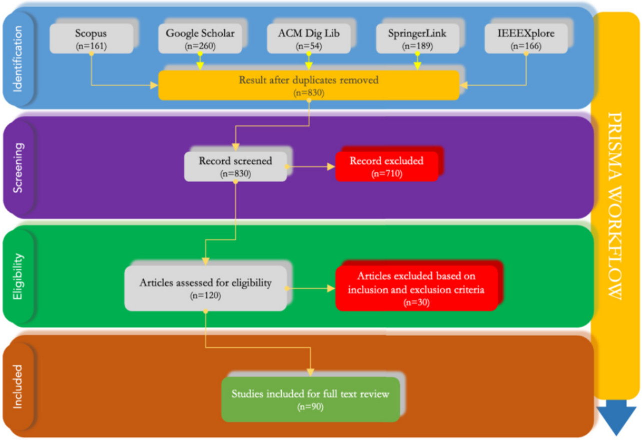


Fig. 2. PRISMA flowchart of the systematic review on cutting-edge Fuzzy Smart Farming.

Farming') AND ('Fuzzy Precision Agriculture'). The review's time frame ranges from 2017 to 2024, ensuring a comprehensive coverage of the previous seven years. The studies evaluated in this review were published in English in periodicals, with the exception of chapters of books and summaries of events and seminars.

The Preferred Reporting Items for Systematic Reviews (PRISMA) technique was carefully followed in this study, which included three stages: identification, screening, and eligibility. In the identification stage, relevant works were gathered using specific search terms, and duplicates from various databases were removed. During the screening stage, articles were assessed for relevance, while in the eligibility stage, they were evaluated for compliance with the criteria and the quality of their results and conclusions. Relevant information was then collected for each eligible study, including authors, publication year, objectives, and descriptions of the fuzzy methods used for smart farming or precision agriculture.

In the identification stage, we obtained 830 non-duplicate entries through metadata filtration. In the screening phase, we examined the titles and abstracts, leading to the selection of 710 items for a comprehensive review. In the screening phase, we examined the titles and abstracts, leading to the selection of 710 items for a comprehensive review. After assessing the eligibility criteria, we included 90 of the 120 reviewed publications in the systematic review. The selection process can be seen in the workflow depicted in Fig. 2. The selected papers, based on PRISMA criteria (see Fig. 2), were categorized by publication year and citation count from each search engine. Clustering and relationships among articles follow the methods in Waltman *et al.* (2010) and Van Eck and Waltman (2017), which outline how to create clusters and assign weighting values based on total citations. Figures 3 and 4 illustrate the resulting clusters and relationships. We used VOSviewer (Perianes-Rodriguez *et al.*, 2016) to visualize these connections, accessible through both desktop and online platforms.

The density of relationships between articles in Fig. 3 shows the total number published annually from 2017 to 2024. Fig. 4 illustrates clusters based on data from various

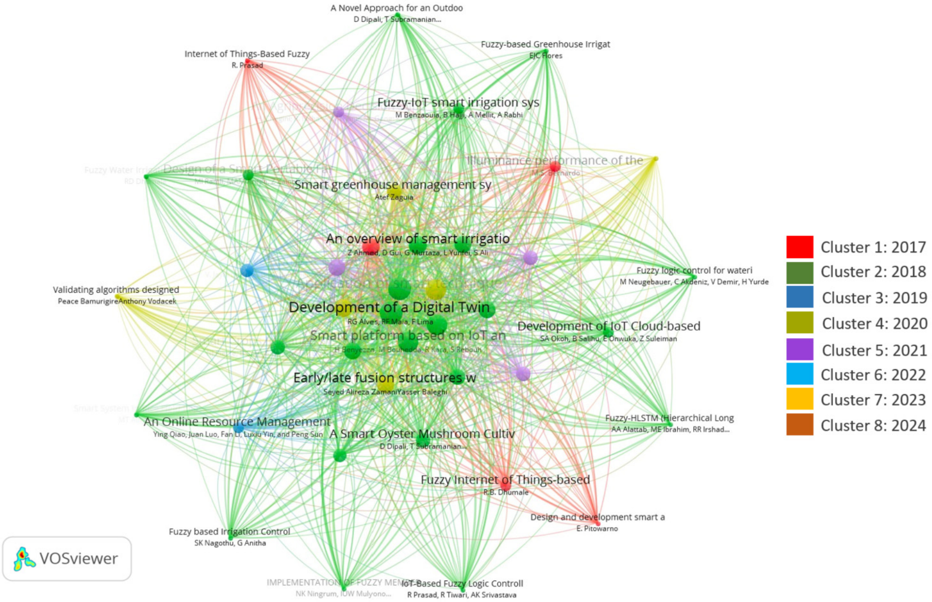


Fig. 3. Visualization of clusters of articles by publication years.

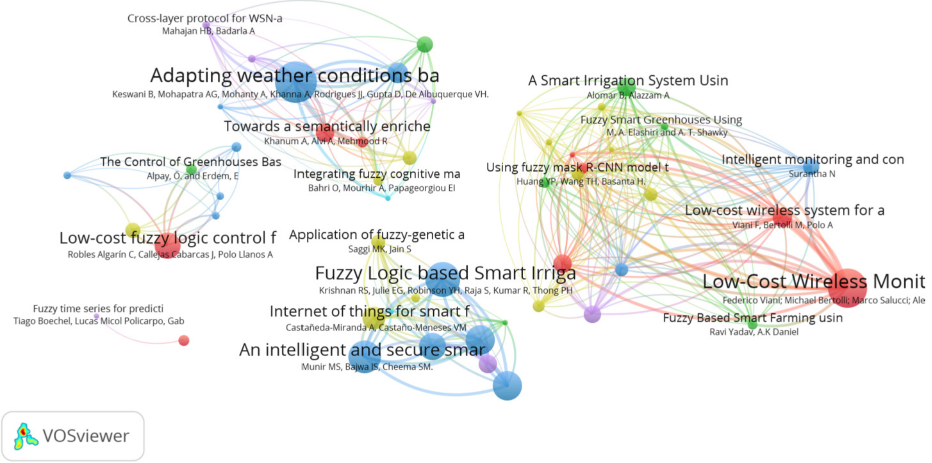
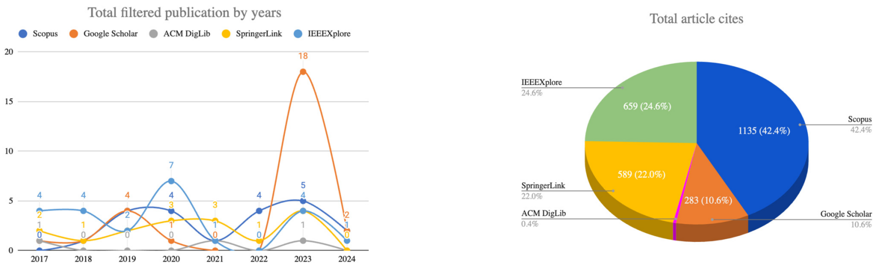


Fig. 4. Visualization of clusters of articles based on five scientific search engine.

search engine databases, with the largest circle in each cluster representing citation counts. For instance, in the Scopus cluster, the article “Fuzzy Logic Based Smart Irrigation System Using Internet of Things” by Krishnan *et al.* (2020) has the highest citation total at 236. Furthermore, Fig. 5a illustrates the number of articles published by year. From 2017 to 2021, IEEEXplore was the leading source, with 19 publications and a peak of seven



(a) The total number of selected articles by year of publication.

(b) The total number of citations of selected articles and categorized according to search engines.

Fig. 5. Graph and pie chart of clustered articles.

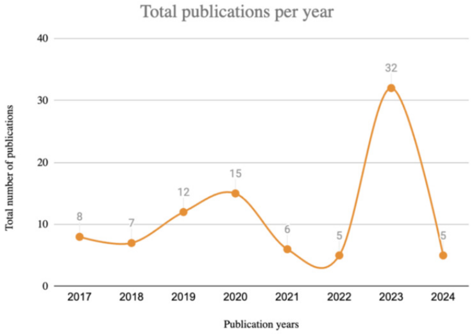


Fig. 6. Total publication per year.

in 2020. In 2023, Google Scholar saw a significant rise, adding 18 qualifying publications. In contrast, the ACM Digital Library produced only three publications from 2017 to 2024. Figure 6 shows the total articles published from 2017 to 2024 across five indexing platforms.

Our findings are significant, particularly when considering the total number of citations, as shown in Fig. 5b. Publications published on Scopus have a higher number of citations than IEEEXplore, reaching almost 40% of the total citations of articles. Across the board of search results that have been carried out in this research, individually, the article written by Keswani *et al.* (2019), published by SpringerLink, is the article that has the highest number of citations, which has been cited 120 times. Several things underlie why many other researchers cited the article. More about the substance of the discussion of each article can be seen in the Section 5.

3.2. *Anonymous Search Method*

When gathering information on the Internet, users rely on the used search engines to find what they are searching for. Different search engines cater to various needs and use distinct algorithms (Ulloa *et al.*, 2022; The free encyclopedia, 2024). Their main function is to gather and organize information in a results table, a process called indexing. For academic

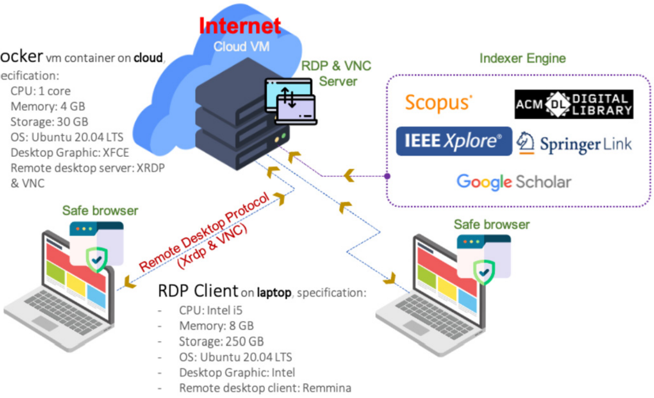


Fig. 7. Anonymous search method.

searches—such as scientific journals, research articles, patents, and abstracts—specific algorithms are employed for each type of indexed work.

This study utilized five scientific search engines. When users first visit a search engine, cookies are stored by their browsers to enhance the experience. Cookies play an essential role in indexing keywords and search results (Moz.com, 2024). However, these cookies are also widely used to provide feedback to third parties who work with search engine providers, which generally produce advertisements for any product correlated with frequently used keywords by users.

Search engines track user behaviour, impacting search results. To counteract this personalization and maintain the integrity of searches, we use an anonymous browsing method for default users, as shown in Fig. 7. We also established a closed cloud environment accessible via Remote Desktop Protocol (RDP). Virtual machines provide remote desktop services using XRDP and VNC, allowing multiple RDP clients to connect simultaneously. We choose the Brave browser as one of the best browsers that support good security and privacy controls, based on a review by Jennifer Simonson. Its Security and Privacy option cleans history, cookies, and cache upon closing, ensuring consistent default search conditions.

4. Review on Smart Farming Based Fuzzification Operations and Features

In this section, a literature review of the selected papers covers agriculture cultivation, harvesting, and minor preprocessing/processing. We have classified the reviewed articles into four categories of fuzzy approaches: basic fuzzy logic, fuzzy logic controller, fuzzy inference system, and advanced fuzzy algorithm, as outlined in Table 4 Appendix A. We then proceed to expound on the primary objective, modelling approach, and results of each reviewed article. We next indicate a categorization aspect that we state to understand the scope and limitations of this study.

First and foremost, articles are classified according to the scope of their problem. Since agri-chain activities might vary, three categories of decision variables are determined.

Cultivation operations, harvest operations, and processing facilities are all decision variables. Second, model characteristics are presented. Agri-chain concerns are evaluated using many criteria based on the nature of the problem. Time window, resource limitations, uncertainty, and sustainability are all considered model features, followed by the modelling approaches used are explained, as shown in Table 3. Last is the actuator, variables that perform as decision-making control.

4.1. *Types of Problems Covered*

All papers in this category are mainly concerned with cultivation operations. Fifty-six papers focus on smart farming cultivation operations such as irrigation systems, watering

Table 3
Farming activities with types of problems covered.

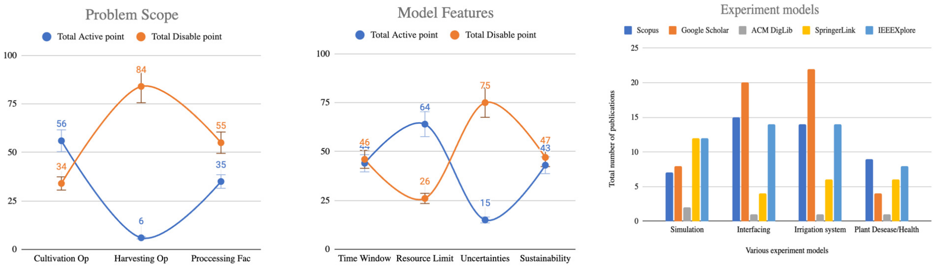
Farming activities categories	Authors	Types of problems covered			
		Time windows	Resource limit	Uncertainties	Sustainability
Cultivation (CU)	Robles Algarín *et al.* (2017)	✓			
	Cruz *et al.* (2017)	✓	✓		✓
	Viani *et al.* (2017)	✓	✓		
	dela Cruz *et al.* (2017)	✓	✓		
	Kokkonis *et al.* (2017)	✓	✓		
	Abouzahir *et al.* (2017)	✓			✓
	Culibrina and Dadios (2018)	✓	✓		
	Alpay and Erdem (2018)	✓	✓		
	Badr *et al.* (2018)	✓			
	Munir *et al.* (2019)	✓	✓		
	Anter *et al.* (2019)				
	Mendes *et al.* (2019)	✓	✓		
	Al-Ali *et al.* (2019)	✓	✓		
	Wiangsamut *et al.* (2019)	✓			
	Karimah *et al.* (2019)	✓	✓		
	Bryan *et al.* (2019)	✓	✓		✓
	Cai *et al.* (2019)	✓	✓		
	Keswani *et al.* (2019)	✓	✓	✓	
	Mohapatra *et al.* (2019)	✓			
	Çelikbilek and Tüysüz (2020b)	✓			
	Pandiyaraju *et al.* (2020)	✓			
	Alaviyan *et al.* (2020)	✓	✓		
	Jamroen *et al.* (2020)	✓	✓		
	Khudoyberdiev *et al.* (2020)	✓	✓		
	Krishnan *et al.* (2020)	✓	✓		
	Jaiswal and Ballal (2020)	✓	✓		
	Castañeda-Miranda and Castaño-Meneses (2020)	✓	✓		
	Saggi and Jain (2020)	✓	✓		
	Benyezza *et al.* (2021)	✓	✓		
	Boechel *et al.* (2021)	✓			
	Mahajan and Badarla (2021)	✓	✓		
	Acharjya and Rathi (2021)		✓	✓	✓
	Nandi and Mahmood (2021)	✓	✓		✓

(*continued on next page*)

Table 3
(*continued*)

Farming activities categories	Authors	Types of problems covered			
		Time windows	Resource limit	Uncertainties	Sustainability
Harvesting (HA)	Dimatira *et al.* (2016)	✓		✓	
	Huang *et al.* (2020)			✓	✓
	Deepanayaki and Vidyaathulasiraman (2024)			✓	
Processing facilities (PF)	Jamil *et al.* (2022)				✓
	Khanum *et al.* (2018)		✓		
	Chouhan *et al.* (2021)				
	Lal *et al.* (2022)		✓		✓
	Kavitha and Sujaritha (2022)		✓		✓
	Remya (2022)	✓	✓		✓
	Al-Mutairi and Al-Aubidy (2023)		✓		✓
	Prasad *et al.* (2023a)		✓		✓
	Pitowarno *et al.* (2023)		✓		✓
	Alves *et al.* (2023)		✓	✓	✓
	Sharma *et al.* (2023)	✓	✓		✓
	Okoh *et al.* (2023)		✓		✓
	Nagothu and Anitha (2023)		✓		✓
	Benyezza *et al.* (2023)		✓		✓
	Flores (2023)		✓		✓
	Fahim *et al.* (2023)		✓	✓	✓
	Prasad *et al.* (2023b)		✓		✓
	Pierre *et al.* (2023)	✓	✓		✓
	Dhumale *et al.* (2023)		✓		✓
	Zaguia (2023)		✓		✓
	Jayakumar *et al.* (2023)				
	Chegini *et al.* (2023)				✓
	Araújo *et al.* (2023)		✓		✓
	Ahmed *et al.* (2024)		✓		✓
	Amertet Finecomess *et al.* (2024)		✓		✓
CU + HA	Bahri *et al.* (2020)	✓	✓		
	Tobias *et al.* (2020)	✓		✓	
CU + PF	Dhumale *et al.* (2023)		✓		✓
	Bernardo *et al.* (2023)		✓		✓
	Dipali *et al.* (2023)		✓		✓
	Ramli *et al.* (2023)		✓		✓
	Umam *et al.* (2023)		✓		✓
	Florea *et al.* (2023)		✓		✓
	Benzaouia *et al.* (2023)		✓	✓	✓
	Manikandan *et al.* (2023)		✓		✓
	Widura *et al.* (2023)	✓	✓	✓	
	Manikandan *et al.* (2023)		✓		✓
	Irwanto *et al.* (2024)		✓		✓
CU + HA + PF	He *et al.* (2024)			✓	✓

monitoring, fertilizer controlling, crop monitoring, soil monitoring, and crop condition monitoring, as depicted in Fig. 8a. In contrast, six papers examine harvesting operations,



(a) Problems covered. (b) Features covered. (c) Experiment model.

Fig. 8. Paper contribution.

such as crop maturity decisions. Three papers cover both cultivating and harvesting operations, while thirty-six papers focus on processing facilities. In the following section, we will delineate numerous factors that encompass the primary endeavours of agriculture overall, encompassing cultivation operations, harvesting procedures, processing facilities, and amalgamations of these undertakings.

4.1.1. *Types of Problems Covered: Cultivation Operations*

The irrigation systems are essential in agricultural activities in the cultivation operation, and can be categorized into three classifications based on our analysis: (1) systems that focus on the effectiveness and efficiency of simple control, (2) systems focused on enhancing crop quality, and (3) systems that utilize advanced remote control and monitoring technologies. These innovations aim to optimize resource use, including electricity and water conservation.

1. Cruz *et al.* (2017) developed an automated organic irrigation system to efficiently manage water resources and pump electricity. dela Cruz *et al.* (2017) introduced a fuzzy logic-based decision support system (DSS) for monitoring water tanks in automated irrigation. Alomar and Alazzam (2018) created an intelligent irrigation method to enhance water conservation in high-water-stress areas. Florea *et al.* (2023) designed a scalable IoT system to adjust sprinkler irrigation according to weather changes. Puri *et al.* (2020) integrated IoT and fuzzy logic to improve the water irrigation motor's valve control for better accuracy and lower energy use. Al-Ali *et al.* (2019) focused on an IoT-based solar energy system for smart irrigation, using a single-board controller with WiFi and solar power. Benyezza *et al.* (2021) created a low-cost, zoned irrigation system to reduce water and energy use. Keswani *et al.* (2019) implemented a water valve management system based on structural similarity (SSIM) to locate water-deficient farm areas. Nevertheless, Abdullah *et al.* (2020) designed a pump controller that adjusts based on user-defined variables and sensor data to decrease water consumption and watering time.
2. Multiple studies have explored fuzzy logic for crop monitoring and irrigation efficiency. Yadav and Daniel (2018) developed a fuzzy system to optimize water use in irrigation for better crop quantity and quality. Umam *et al.* (2023) implemented a drip

irrigation system for chili plants using fuzzy logic, while (Pezol *et al.*, 2020) designed a smart irrigation and fertilization system for the same purpose to improve upon traditional methods. Nandi and Mahmood (2021) focused on irrigation and fertilization management using soil moisture and pH levels to boost crop productivity. Additionally, Mendes *et al.* (2019) created a smart irrigation system that uses fuzzy inference to manage central pivot speeds based on crop growth phases. Innovations included an intelligent motor speed controller with a variable frequency driver (VFD) to improve the accuracy of crop's water demand from Culibrina and Dadios (2018), a multilevel model for estimating crop coefficients (Kc) and reference evapotranspiration (ETc) using Fuzzy-Genetic (FG) and Regularization Random Forest (RRF) models from Saggi and Jain (2020), and an automated irrigation controller using sensor data from Jaiswal and Ballal (2020) to reduce water loss. Research on water monitoring includes Elashiri and Shawky (2018)'s IoT-based fuzzy algorithm for greenhouses, Bryan *et al.* (2019)'s fuzzy based decision support system for resource allocation, and Khudoyberdiev *et al.* (2020)'s scheme for optimal humidity and water level control. Other significant works involve a low-cost WSAN-based system for irrigation from Viani *et al.* (2017) and Herman and Surantha (2019)'s combination of hydroponics, IoT, and fuzzy logic for controlling plant nutrition and water needs. Finally, Widura *et al.* (2023) designed a vertical smart farming system incorporating fuzzy control and IoT for hydroponics swamp cabbage plants.

3. A sensor-based intelligent control system using IoT sensors gathers data on ultraviolet range, humidity, temperature, light intensity, and soil moisture for irrigation systems (Manikandan *et al.*, 2023). Benzaouia *et al.* (2023) proposed a weather-soil irrigation strategy with a long-range IoT communication unit, while (Jamroen *et al.*, 2020) developed a fuzzy-based irrigation scheduling system utilizing a low-cost wireless sensor network for precision irrigation and energy efficiency. Krishnan *et al.* (2020) created a smart irrigation system using GSM for plant growth monitoring, and Mohapatra *et al.* (2019) integrated weather-dependent irrigation control with a DSS for SMS notifications via a GSM modem. Kokkonis *et al.* (2017) embedded a neuro-fuzzy algorithm for automatic irrigation adjustment in changing environmental conditions. Munir *et al.* (2019) established a secure blockchain IoT watering control system using fuzzy logic, while (Karimah *et al.*, 2019) designed an automated plant watering system with a fuzzy algorithm. Wiangsamut *et al.* (2019) introduced a chat interaction model for orchid plants, and Irwanto *et al.* (2024) implemented real-time monitoring for mushroom farms with a fuzzy logic controller. Additionally, Alaviyan *et al.* (2020) created a greenhouse monitoring controller for remote adjustments via internet, and Alpay and Erdem (2018) utilized sensor nodes to control climate parameters for optimized greenhouse yield and resource conservation. Robles Algarín *et al.* (2017) developed a low-cost remote control system for efficient greenhouse water and electricity use of different types of crops.

The papers on fertilizer control include Viani *et al.* (2017), which developed a decision support system for pesticide dosage distribution using a low-cost wireless sensor network. Pezol *et al.* (2020) examined a fertilization system for chili plants with fuzzy logic compared to traditional methods. Nandi and Mahmood (2021) focused on fertilization management using soil moisture and pH to enhance crop productivity. Bryan *et al.* (2019) investigated fertilizer use in relation to plant age to optimize yield quality.

Several studies have focused on plant health and monitoring. For instance, Khummanee *et al.* (2018) developed an automatic growth control system for orchids inflorescences using sensors to optimize growth rates. Cagri Tolga and Basar (2022) evaluated different vertical farm models (basic, IoT, and automated) through MCDM in hydroponics, considering land availability. Anter *et al.* (2019) used the Crow Search Optimization Algorithm (CSA) with Fast Fuzzy C-Means (FFCM) to identify the greenness of agricultural images and generated an alternative approach based on optimization of green plants segmentation. Meanwhile, Khanum *et al.* (2017) modelled a fuzzy logic-based Semantically Enriched Computational Intelligence (SECI) for managing the complex tasks of smart farming, such as smart sensing and crop monitoring to respond to a natural condition. In terms of weed and yield monitoring, Abouzahir *et al.* (2017) assessed legacy algorithms for segmentation problems. Acharjya and Rathi (2021) optimized crop identification using fuzzy-rough set and RCGA to enhance prediction performance on prediction by comparing six different methodologies in terms of accuracy, average time, and success rate. An automatic control system for pH and humidity in hydroponics was designed by Fakhrurroja *et al.* (2019) using fuzzy logic. Additionally, Castañeda-Miranda and Castaño-Meneses (2020) developed a smart frost forecast system with an anti-frost intelligent control for greenhouses. Chouhan *et al.* (2021) focused on disease detection in plants using an IoT-Fuzzy Based Function Network with Raspberry Pi. Çelikbilek and Tüysüz (2020b) evaluated a model plant with sensors for intelligent farming, while Cai *et al.* (2019) created a smart greenhouse temperature control system with a fuzzy adaptive PID algorithm. Boechel *et al.* (2021) examined various Fuzzy Time Series methods to predict apple tree phenological stages based on temperature, in particular, univariate and multivariate methods. Ramli *et al.* (2023) introduced a portable farming kit for indoor mushroom cultivation in urban areas with minimal user attention. Additionally, soil monitoring received attention from Remya (2022), who developed a fuzzy logic model to predict soil quality based on organic carbon and C:N ratio.

4.1.2. *Types of Problems Covered: Harvesting Operations*

There are three papers dealing with harvesting-related operations. The study of Dimatira *et al.* (2016) evaluated the tomato's level of maturity by visual recognition using the colour, size, and shape of tomato fruit. Huang *et al.* (2020) focused on identifying the maturity stages of tomatoes that minimize the loss of quality. A lightweight deep network for classifying and predicting sugarcane yield by utilizing steps from the segmentation process and classification process using various algorithms proposed by Deepanayaki and Vidyaathulasiraman (2024).

4.1.3. *Types of Problems Covered: Cultivation and Harvesting Operations*

For cultivation and harvesting operations, Bahri *et al.* (2020) developed a multi-agent smart farm platform that leverages FCM modelling to make recommendations to farmers on using fertilizers that limit their environmental footprint without compromising crop yields with JADE framework. Tobias *et al.* (2020) developed a predicting and identifying the lettuce growth stages classification with low percentage error and correct classifications.

4.1.4. *Types of Problems Covered: Processing Facilities*

Processing facility constraints were considered in several papers—particularly suitable areas for the crops and farm monitoring applications such as WSN routing protocol design. Mahajan and Badarla (2021) proposed a BFO (bacterial foraging optimization) algorithm to select the optimal sensor node for clustering and routing problems based on cross-layer parameters-based fitness value computation including network layer, physical layer, and Medium Access Control (MAC) in the farming area. The study compared clustering techniques on the energy efficiency of WSNs with fuzzy logic techniques. On the other hand, Badr *et al.* (2018) developed a comprehensive system to aid in selecting suitable areas for grapevine cultivation, including several bioclimatic indices and soil and topographical data. While Pandiyaraju *et al.* (2020) modelled a new intelligent routing protocol called Terrain Based Routing Protocol for Wireless Sensors Network communication using fuzzy rules for precision agriculture. Al-Mutairi and Al-Aubidy (2023) focused on designing and implementing quality water for fish farming by performing smart monitoring to control the water quality of the ponds for fish farming. Dhumale *et al.* (2023) considered intelligent control of fuzzy water irrigation systems for four different types of crops: cotton, wheat, sugarcane, and rice. A fuzzy classifier to categorize the real-time data coming from NPK sensors to monitor the content of nitrogen, phosphorus, and potassium in the soil conditions proposed by Prasad *et al.* (2023a). Several papers also focus on irrigation control systems, among others, (Alves *et al.*, 2023) discuss a complex irrigation system that evaluates sensor data before employing the watering strategies to the farm area, Okoh *et al.* (2023) focuses on a platform for the irrigation system to control water usage compare to the traditional control system, while (Nagothu and Anitha, 2023) proposed an automated intelligent watering system that uses weather data coupled with various sensors to control watering mechanism.

4.2. *Model Features*

As agri-chains had a complex activity constrained by natural problems, such as weather conditions and resource availability, this section examines model features, including time window, resource limitations, uncertainty, and sustainability, as seen in Fig. 8b.

4.2.1. *Model Features: Time Window*

Several studies have explored the use of time window restrictions. Time windows were considered to limit the time periods for planting and harvesting decisions to ensure high-quality crop yields. For instance, Viani *et al.* (2017) developed a decision support strategy that integrates crop monitoring data and weather conditions in organizing multiple steps to estimate when, how much, and how irrigation might enable effective irrigation planning. Krishnan *et al.* (2020) focused on automating irrigation control with sensors that measure soil moisture, temperature, and humidity while optimizing solar energy usage. Munir *et al.* (2019) examined efficient water usage for various plants, including green chili, cucumber, mint, coriander, onion, garlic, radish, carrot, and tomato, for maximum time without being affected by watering quantity in day and night time, winter or summer seasons. Bryan *et al.* (2019) proposed a system to optimize resource use in vegetable production by adjusting water, fertilizer, and sunlight based on plant age and environmental conditions. Additionally, one study analysed tomato harvesting by assessing fruit maturity through visual cues like colour, shape, and size (Dimatira *et al.*, 2016), while (Huang *et al.*, 2020) emphasized automation for identifying the maturity of tomato production for optimizing the quality, flavour, juiciness, texture, and ripeness. Additionally, Badr *et al.* (2018) highlighted the importance of selecting appropriate areas for grapevine cultivation to enhance wine grape yield.

4.2.2. *Model Features: Resource Limitation*

Resource limitations, in terms of capacity or productivity, such as available land for cultivation, resource availability due to depletion sources, climate changes, and machinery, are considered in several papers. A few papers such as Elashiri and Shawky (2018), Alaviyan *et al.* (2020), Castañeda-Miranda and Castaño-Meneses (2020), Herman and Surantha (2019), Fakhrurroja *et al.* (2019), Cagri Tolga and Basar (2022) further used available land size as a limitation for planting crops. Jamroen *et al.* (2020), Benyezza *et al.* (2021) do specifically develop a model to solve water scarcity with an irrigation scheduling system by utilizing low-cost WSN that is efficient regarding water use and energy consumption. Badr *et al.* (2018) consider the topography of the agricultural area to select suitable sites for wine grapes plants that affect the practical use of machinery while Pitowarno *et al.* (2023) take into account limitations of monitors and manages ponds done in a conventional way on aquaculture or fish farming in Indonesia, and Irwanto *et al.* (2024) also include the high labour requirement in their decision support system for improved substrate environment management in mushroom cultivation.

4.2.3. *Model Features: Uncertainty*

Uncertainties are considered in less than half of the studies. Weather is considered to induce uncertainty in maturity time for those who do. Harvest season duration of the production of tomato fruit is made feasible by Dimatira *et al.* (2016) in season or not. Huang *et al.* (2020) consider uncertain harvest yield of tomato fruits that affected agroclimatic conditions such as climate change and natural calamities by modelling automation to identify tomato ripeness. Mohapatra *et al.* (2019), Keswani *et al.* (2019) specifically consider the irrigation system's efficiency and uniformity uncertainty by assuming the weather, soil, water, and crop data.

4.2.4. *Model Features: Sustainability*

In this subsection, we address the growing concern about sustainability, which has gained significant attention in recent years. Several articles have discussed the sustainability of the environment through various constraints. Cruz *et al.* (2017) provided a model for the automation of turning on the electric pump through the power management system based on the reservoir and water storage situation. Viani *et al.* (2017) considered forty-seven percent of pesticide reduction for organic cultivation. Pezol *et al.* (2020) modelled a smart fertilization system for chili plants under a controlled environment, while Nandi and Mahmood (2021) determined a controlling fertilization management to increase crop productivity. Badr *et al.* (2018) proposed a model for selecting suitable areas for grapevine cultivation. Economic and environmental sustainability were considered by Huang *et al.* (2020) with maximization of world's annual production of tomato fruits.

4.3. *Modelling Approach*

Regarding the modelling approach (see Fig. 9), most studies utilize fuzzy logic for decision-making. For example, Cruz *et al.* (2017) used fuzzy control to optimize the distribution of water and electrical resources on farms. Dimatira *et al.* (2016) applied fuzzy logic to assess tomato maturity, whether the tomato is matured, half-matured, or immature, based on colour, size, and shape. Herman and Surantha (2019) implemented a Mamdani fuzzy controller for managing water and nutrients in hydroponics plants, e.g. bok choy and lettuce, while Tobias *et al.* (2020) classified lettuce growth stages using a Mamdani fuzzy inference system. Additionally, Alaviyan *et al.* (2020) employed a fuzzy controller to regulate temperature, light, and soil moisture for production optimization and cost efficiency.

Nevertheless, several studies have utilized fuzzy inference systems for agricultural innovations. Munir *et al.* (2019) implemented a Mamdani fuzzy model in their Smart Watering System (SWS) to control irrigation. Mendes *et al.* (2019) created prescriptive maps for central pivot speed control using fuzzy inference. Cagri Tolga and Basar (2022) developed fuzzy MCDM methods to assess vertical farm options. Castañeda-Miranda and

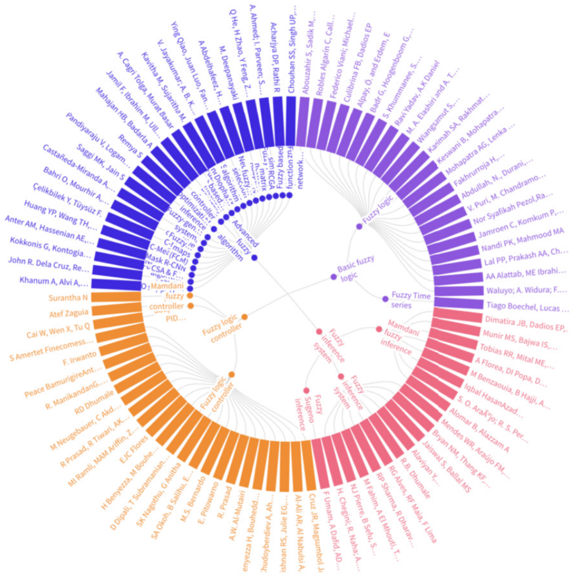


Fig. 9. Categorizing of fuzzy application.

Castaño-Meneses (2020) employed various fuzzy systems to manage water pumps, predict greenhouse temperatures, and activate anti-frost irrigation. Saggi and Jain (2020) applied fuzzy-genetic algorithms for estimating crop coefficients and evapotranspiration in wheat and maize. Anter *et al.* (2019) combined the Crow Search Algorithm and Fast Fuzzy C-Means (FFCM) for identifying greenness in agricultural images and generated an accurate alternative approach based on optimization for the segmentation of green plants. Chouhan *et al.* (2021) used a Fuzzy Based Function Network (FBFN) with IoT to detect plant leaf diseases.

Furthermore, Bahri *et al.* (2020) developed a multi-agent smart farm platform using fuzzy cognitive maps for fertilization. Acharjya and Rathi (2021) applied a fuzzy rough set and real-coded genetic algorithm (RCGA) for optimal crop identification prediction. Remya (2022) utilized neuro-fuzzy inference to assess soil quality based on limited inputs like organic carbon. Cai *et al.* (2019) employed a fuzzy adaptive PID control algorithm for managing greenhouse parameters such as temperature and moisture. Kokkonis *et al.* (2017) introduced a neuro-fuzzy algorithm for controlling irrigation water valves.

4.4. *Actuator*

This section discusses the actuators as variables that perform decision-making control. Actuators are responsible for performing specific actions based on instructions given by a control system. These variables are crucial in decision-making, allowing farmers to automate and efficiently complete tasks. The actuators should ideally take into account, i.e. data source, acquisition, controller, and effects.

4.4.1. *Actuator: Data Source*

Data sources, for instance, in terms of agriculture sensors that provide environmental information directly retrieved from the parameters measured from the crop, soil, or ambient, pH meters, humidity, GPS trackers, drones, and cameras. Over 40 articles have highlighted data collection through sensors, and 13 articles specify using WSNs, with many studies focusing on monitoring and controlling farming systems through sensor devices as seen in Fig. 10. Meanwhile, some researchers who offer concepts and methods that can be said to be new approaches mostly use datasets as proof of the effectiveness and efficiency of the concept or method proposed, such as Saggi and Jain (2020), Alattab *et al.* (2023), Hasan *et al.* (2023), Jayakumar *et al.* (2023) and Ahmed *et al.* (2024). Additionally, nine articles and eight papers have utilized datasets or alternative media, such as RGB cameras (Anter *et al.*, 2019), Raspberry Pi Camera (Abouzahir *et al.*, 2017), and NS2 IoT device simulation (Khanum *et al.*, 2017).

Figure 11 visualizes the intensity of use of various data sources. The visualization of data sources is divided into six clusters. The cluster with the highest intensity is shown in Cluster 1, which is indicated by the red cluster. Nevertheless, Cluster 6, with a light blue cluster, shows the minor intensity of the clusters.

4.4.2. *Actuator: Acquisition*

Acquisition within the sub-section pertains explicitly to data and information collection from nearby farms through a range of sensors and devices where acquired data is essen-

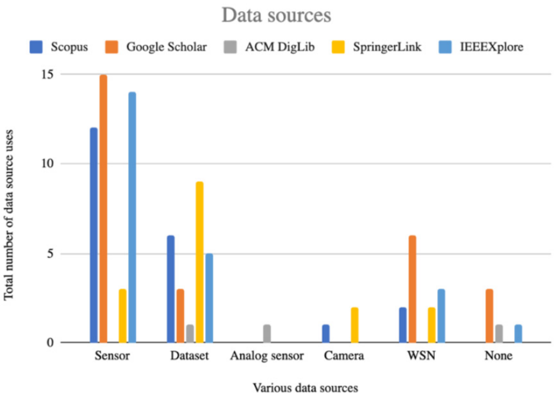


Fig. 10. Various data sources.

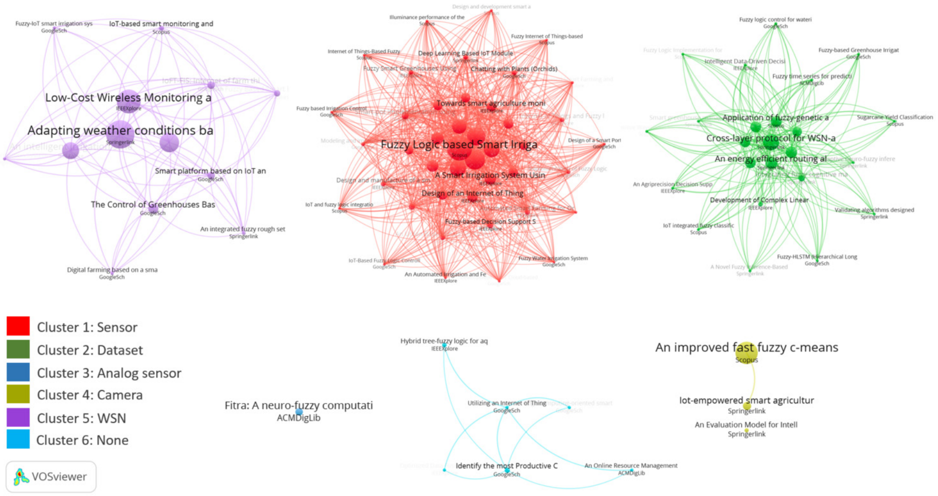


Fig. 11. Cluster based data sources.

tial for making informed decisions to optimize agricultural operations and enhance overall efficiency. Most of the related papers highlighted the significance of farming sensors that continually monitor soil conditions, allowing farmers to determine when to irrigate, for instance, promptly, Yadav and Daniel (2018), Mendes *et al.* (2019), Mohapatra *et al.* (2019), Kokkonis *et al.* (2017), focus mainly on irrigation control systems. Other papers focus more on improving planting patterns and accurately applying resources like fertilizers and pesticides to the precise locations where they are needed, such as Viani *et al.* (2017), Nandi and Mahmood (2021), Bryan *et al.* (2019). Furthermore, Abouzahir *et al.* (2017), Anter *et al.* (2019), Wiangsamut *et al.* (2019) consider agricultural sensors as fundamental tools for data acquisition, e.g. decision support systems such as optimal planting times, disease risk assessments, and yield predictions, help in gaining a thorough understanding of the farm's conditions and trends.

4.4.3. *Actuator: Controller*

The controller, for instance, like acquisition elements, is a variable that converts decisions based on data into actionable outcomes. It is indeed contributed in most papers, for example, for the irrigation scheduling system in Jamroen *et al.* (2020), which automatically triggers efficient water use. For the application of resources such as water consumption, as highlighted in Abdullah *et al.* (2020), Karimah *et al.* (2019), whereby sensors control crops' watering system. In contrast, Anter *et al.* (2019), Acharjya and Rathi (2021), and Remya (2022) employ algorithms in various farming operations control systems.

4.4.4. *Actuator: Effect*

The effect in this context is the outcome of actuator variables, which are responsible for implementing decisions based on sensor data and other sources. These effects bring about actual changes in the farming environment, promoting resource management, crop productivity, and sustainability in agricultural practices. With their precision, automation, and customization, these effects empower farmers to make informed decisions that yield significant and positive impacts, as seen in Table 4.

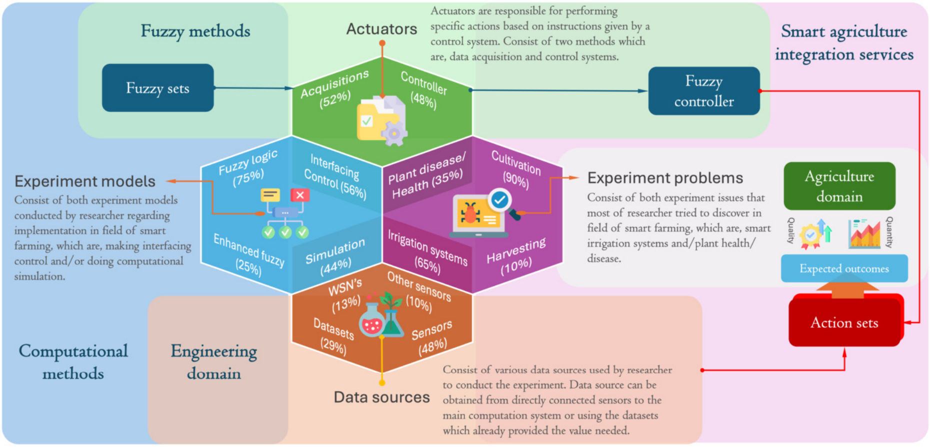
5. Discussion and Prospective Future Research

The complexity of smart farming features, as well as the broader discussion of the agricultural chain aforementioned in Section 2, offers insight into the extensive discussion about its implementation. This encompasses various stages, from land preparation, cultivation, and harvesting activities to meeting local customer demand and accessing global markets.

Our research highlights the need for an integrated approach to modelling harvesting and processing in agri-chains. Current models regard only a limited number of relevant constraints, inadequately represent real-life situations, and are typically restricted to specific areas like cultivation and irrigation systems. Nevertheless, to address these issues, we developed a comprehensive framework for understanding the challenges of deploying fuzzy logic in smart farming (Fig. 12). This framework includes four key components: the computational method, fuzzy method, smart agriculture integration service, and engineering domain. Each component is interconnected, forming a membership function that links the elements involved in fuzzy logic implementation in smart farming.

5.1. *Smart Agricultural Operations*

Each stage of the agricultural supply chain presents unique challenges that can be effectively addressed through various approaches, particularly with the aid of computer science. In Section 4, our analysis shows that majority of articles focus on challenges during the cultivation stage, as seen in Fig. 8a, where over half highlight cultivation issues with blue lines and dots. However, there's a lack of emphasis on harvesting and processing challenges. While six articles address harvesting operations—Deepanayaki and Vidyaathulasiraman (2024), He *et al.* (2024), Bahri *et al.* (2020), Dimatira *et al.* (2016), Huang *et al.* (2020), and Tobias *et al.* (2020)—they rely solely on simulations and datasets. As



Actuators are responsible for performing specific actions based on instructions given by a control system. Consist of two methods which are, data acquisition and control systems.

Consist of both experiment models conducted by researcher regarding implementation in field of smart farming, which are, making interfacing control and/or doing computational simulation.

Consist of both experiment issues that most of researcher tried to discover in field of smart farming, which are, smart irrigation systems and/plant health/ disease.

Consist of various data sources used by researcher to conduct the experiment. Data source can be obtained from directly connected sensors to the main computation system or using the datasets which already provided the value needed.

Fig. 12. A summarized framework of the reviewed articles.

Damerum *et al.* (2020) emphasize, the quality of product is highly depending to harvesting, post-harvesting, cultivation, and processing facilities. The timing of the harvest significantly affects quality, and proper storage conditions, including temperature and humidity, are essential to mitigate damage from pests and bacteria, as indicated in Liu *et al.* (2022).

5.2. *Smart Agricultural Essential Features*

The features of the agricultural chain described in Section 4 are associated with the operations shown in Fig. 8b. This figure highlights the key aspects for analysis, including time windows, resource limits, uncertainty, and sustainability. Notably, 73% of the reviewed articles focus on resource limits, followed by sustainability and time windows. Most studies provide proof of concept through experiments that implement methods in prototypes or real-world applications, as shown in Fig. 8c. In contrast, only 15 out of 90 articles examined uncertainty in farming, primarily related to natural factors such as weather and soil conditions. Furthermore, smart farming encompasses the depreciation of agricultural equipment and the crucial knowledge of farmers, in addition to devices like sensors and computing systems (Chavas and Nauges, 2020).

The other two features, sustainability, and time window, are very important as well. Smart farming effectively ensures sustainable agricultural systems that are harmonized with the quality functions of crops. It consists of using IoT devices, sensors, and edge computing to validate parameters that can induce plant growth. As shown in Fig. 8c, automated irrigation and stabilizing soil pH are crucial in crop production; also, the automation of spraying pesticides and applying fertilizers is necessary. However, it is important to perform all the stages of agriculture at appropriate time frames so that quality production and customer satisfaction requirements can meet sustainability alongside nature.

5.3. *Acquisition of Experiment Data*

Conventional farming data acquisition has been transformed into data-driven approaches since the evolution of IoT technologies has become a game changer. The upcoming advancement will incorporate more sophisticated technologies for gathering agricultural and environmental data for systematic studies. Fig. 10 indicates that the majority of articles highlight sensors as the main data acquisition tool linked to devices such as edge computing systems or microcontrollers. The data from these sensors inform control systems that implement appropriate environmental measures.

Another fact is dataset usage ranks second among researchers at 29% of total articles, followed by Wireless Sensor Networks (WSN) at 13%. Analog sensors represent the most minor portion with just one article. This trend emphasizes the strong contributions of researchers in smart farming, as they leverage various technologies to enhance agricultural quality and quantity while promoting global food safety. A wireless sensor network (WSN) is a sophisticated system comprising multiple sensors embedded in a microcontroller with a wireless communication module. In essential, WSNs are designed to gather information in remotely located areas and transmit this information wirelessly, it enable receivers to monitor remotely (Mahbub, 2020). Whereas, deploying and configuring of WSNs is a complex issue which requires huge amount energy resources.

Researchers often use datasets to investigate various dimensions of plant commodity expansion, aiming to drive innovation and improve quality. This dataset is gathered from sensors or cameras at the fields, where sowing takes place. Using datasets, researchers can simulate various scenarios to address plant issues, such as diseases or better irrigation systems.

5.4. *Integrated Smart Agriculture as a Services*

Upon comprehensive examination of global food security shows that industrial technology 4.0 has brought significant advancements, especially in the implementation of smart farming. The interconnection of agricultural activities significantly affects production effectiveness and efficiency. Therefore, establishing a system to record, monitor, and control these activities, whether through manual or automated process —is essential.

In this paper, we present a perspective on the use of fuzzy logic and control in smart farming, primarily as a control system to improve the efficiency of agricultural irrigation. Significant advancements have been made in smart farming, which is set to revolutionize traditional practices. In the future, adopting smart farming will be more accessible, with many global companies like IBM (Gomstyn and Jonker, 2023) and Microsoft (FarmBeats, 2024), along with innovative startups, showing strong interest in this field. Smart farming involves land mapping with GIS technology, global monitoring, and analytics. The resulting feedback aids decision-making and directs control systems for various agricultural tasks. Implementing smart farming will no longer be a difficult task by subscribing to a pay-per-use smart farming platform within the integration with edge computing devices. Farmers can conveniently monitor and efficiently manage their operations through various media and learn from successful crop cultivation case studies. This potential for advancement emphasizes sustainable resource use in agriculture.

6. Conclusions

In our review, we employed the PRISMA criteria to identify 90 highly relevant articles from a pool of 830 articles, excluding duplicates, across five indexing websites. Our selection criteria were based on publication year and citation count, resulting in a comprehensive and relevant selection of articles. We used a specific anonymous search method to acquire the indexing articles, ensuring that irrelevant categories based on user search behaviour were avoided.

Upon analysing the data, it was found that the highest number of articles was published in 2023, with 32 articles being published, most of which were indexed on Google Scholar, as shown in Fig. 6. Nevertheless, the graph depicted in Fig. 6 indicates a noticeable decrease in the total number of published articles between 2020 and 2022. It is plausible that the ongoing COVID-19 pandemic could be one of the contributing factors to this trend. Several researchers have shifted their attention towards discovering innovative solutions in their respective fields to combat this pandemic. Nonetheless, the trend shows an increase in the number of articles published from 2017 to 2024.

Through our comprehensive analysis, we have identified four substantial gaps that should be considered when formulating research ideas and alternatives in the realm of smart agriculture in the future; they are as follows:

1. The focus of most articles revolves around the cultivation process. According to the activity stages and features in smart farming aforementioned in Section 2, there are at least three primary processes: cultivation, harvesting, and distribution.
2. Scholars have not allocated sufficient attention to various aspects of smart farming features, such as the importance of considering uncertain factors, sustainability, and time frames within each smart farming process.
3. The majority of scholarly articles are focused on irrigation systems, with only a small fraction dedicated to the utilization of fuzzy logic for identifying or preventing plant diseases and pest incursions.
4. Researchers have not given significant attention to alternative data acquisition methods, such as cameras and WSNs, in implementing the smart farming concept.

The potential of precision agriculture remains largely untapped due to a lack of comprehensive research that explores the integration of sensor data and other sources, such as satellite-sourced weather data. Surprisingly, our study found fewer than five articles take a holistic approach to this issue. Given the significant benefits that can be gained from this integration, it is crucial that we focus on more profound research. Doing so can unlock the full potential of precision agriculture, transforming it into a more sustainable, efficient, and profitable sector.

6.1. *Study Limitations and Future Work*

Nevertheless, our study had some limitations, primarily because we were unable to use a Multi-Criteria Decision-Making (MCDM) method to analyse the survey parameters collected and yields as we may not have captured potential variations that could have been identified through the application of the MCDM method.

To address this issue, we plant to conduct further simulations using a fuzzy linguistic model and the 2-Tuple Linguistic (2-TL) MCDM approach. This will enhance our analysis of survey parameters. Furthermore, integrating a fuzzy logic controller with deep learning algorithms will improve decision-making regarding plant health issues that are not well-explored. Some other issues arise on the sustainability of smart farming systems involving various sensors, controllers and any other computing devices that needs to be addressed. A key question is whether these systems offer an economical solution for farmers who invest in equipment and software. It's important to consider how long these devices will function effectively, factoring in their depreciation. This approach will provide a clearer understanding of survey results and help identify overlooked variations in our study.

A. Appendix

Table 4

Classification parameter survey matrix.

Fuzzy categories	Authors	Main objective	Modelling approach	Results
Basic fuzzy logic	Robles Algarín *et al.* (2017)	Develop a low-cost system for monitoring and controlling greenhouses allows users to optimize water and electricity use for different crops.	Fuzzy logic	A prototype greenhouse environmental control using Micro-controller.
	Viani *et al.* (2017)	To develop low-cost WSAN-based decision support system for crop irrigation and water saving that maximizes the crop yield.	Fuzzy logic	Design a low-cost WSAN-based DSS system using fuzzy logic to control effectively water irrigation crops.
	Abouzahir *et al.* (2017)	Design an automated plant leaf disease detection system using IoT-Fuzzy Based Function Network (FBFN) with Raspberry Pi cameras.	Fuzzy based function network (FBFN)	An information-based image processing captured by IoT camera of plant leaf disease.
	Culibrina and Dadios (2018)	To determine the motor speed controller with variable frequency driver (VFD) for an irrigation system that improves accurate water demand amounts of crops.	Fuzzy logic	A study of power optimization on motor DC for tomatoes plant watering system.
	Alpay and Erdem (2018)	Optimize greenhouse climate using sensor nodes to enhance quality and yield while conserving time, energy, light, and water.	Fuzzy logic	Controlled greenhouse using WSN with fuzzy logic controller to monitoring the greenhouse environment in a real-time.
	Badr *et al.* (2018)	To develop a comprehensive system to aid in the selection of suitable areas for grapevine cultivation includes several bioclimatic indices.	Fuzzy logic	Potential of vineyard site using GSM dataset to help wine grape industry.
	Khummanee *et al.* (2018)	To determine automatic control growth of orchids' inflorescences using sensors that maximize the average orchid growth rate.	Fuzzy logic	Automatic control system for orchid farming using micro-controller, sensors, and actuator can be operated using mobile device.
	Yadav and Daniel (2018)	To model an efficient crop monitoring and production based on a fuzzy system by utilizing water in irrigation that maximizes the quantity and quality of crops.	Fuzzy logic	Monitoring of water-supply to crop by utilizing the WSN sensors for effective and efficient watering in irrigation.
	Elashiri and Shawky (2018)	To determine the fuzzy computational algorithm for a crop tracking system in greenhouses using IoT to improve water efficiency and productivity.	Fuzzy logic	Design system with fuzzy logic to improve watering and productivity efficiency for greenhouse.
	Wiangsamut *et al.* (2019)	To design an interaction model (chat) with plants cultivated in the automated farm system based on Internet of Things (IoT) and Fuzzy Logic.	Fuzzy logic	Design a chat application to communicate with orchid plants using NLP and fuzzy set rules.
	Karimah *et al.* (2019)	To design an automated plant watering system using a fuzzy algorithm to govern the actuator to be able to do watering automatically.	Fuzzy logic	Automate watering system in the pot for spinach plant.
	Keswani *et al.* (2019)	An irrigation control system uses a structural similarity (SSIM)-based water valve management mechanism to identify areas of water deficiency on the farm.	Fuzzy logic	Activating an irrigation valve control by specific command produced by DSS system with fuzzy logic.
	Mohapatra *et al.* (2019)	Develop a weather-based irrigation control system that integrates with the Decision Support System (DSS) to send SMS notifications via a GSM modem.	Fuzzy logic	SMS alerts for actions needed from the DSS system, integrating data from WSN devices and utilizing data learning.
	Fakhrurroja *et al.* (2019)	To design an automatic pH and humidity control system for hydroponics using fuzzy logic.	Fuzzy logic	pH and humidity control of hydroponic plants using Micro-controller based fuzzy logic rules.

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Fuzzy categories	Authors	Main objective	Modeling approach	Results
	Abdullah *et al.* (2020)	To design a pump control system that optimizes switching times using user-defined variables and sensors, reducing water consumption and watering duration.	Fuzzy logic	Mobile application for monitoring and controlling of crops watering system.
	Puri *et al.* (2020)	Integrating IoT and fuzzy logic can optimize irrigation motor valve control, improving farming efficiency.	Fuzzy logic	Comparison of fuzzy and conventional farming system with yields in minimum power consumption in fuzzy method.
	Jamroen *et al.* (2020)	To create an effective irrigation scheduling system that utilizes fuzzy logic and a low-cost wireless sensor network (WSN) to optimize water use and energy efficiency.	Fuzzy logic	Scheduling irrigation system using Low-cost WSN and take into account the cost analysis.
	Nandi and Mahmood (2021)	To determine a controlling irrigation and fertilization management using soil moisture and pH level parameters to increase crop productivity.	Fuzzy logic	Irrigation and environment control using Micro-controller.
	Boechel *et al.* (2021)	To assess different Fuzzy Time Series methods for predicting the duration of phenological stages in apple trees based on temperature, focusing on univariate and multivariate approaches.	Fuzzy time series	Proposed model of prediction of Apple trees influence factors cultivation.
	Lal *et al.* (2022)	The implementation of an innovative Internet of Things (IoT)-based solution for detecting adulterants in milk.	Fuzzy logic system	The solution utilizes pH and electrical conductivity (EC) parameters to effectively and reliably detect milk adulteration.
	Alattab *et al.* (2023)	An analysis of weather and environmental conditions for best practice of agriculture cultivation.	Fuzzy logic	An analysis of an environmental condition and prediction of the best to mature, apply fertilizers and pesticide in agriculture.
	Widura *et al.* (2023)	The study designed, implemented, tested and analysed a prototype soilles vertical smart farming systems hydroponics that involved fuzzy-based control, IoT, swamp cabbage plant.	Fuzzy logic	Fuzzy logic method for LED control contributed highest growth of swamp cabbage among the scheduled and natural methods.
Fuzzy logic controller	Cruz *et al.* (2017)	To design an automated organic irrigation system that efficiently manages water and electricity for the pump.	Fuzzy logic controller	Using MATLAB simulations, we can optimize irrigation and electrical systems with Fuzzy Inference System to improve resource distribution on the farm.
	Cai *et al.* (2019)	To design an intelligent greenhouse temperature control system based on IoT technology and fuzzy adaptive PID control algorithm.	Fuzzy adaptive PID controller	A design of automation greenhouse using fuzzy PID control was simulated using Matlab.
	Al-Ali *et al.* (2019)	Design an IoT solar energy system for smart irrigation using a WiFi-enabled system-on-a-chip controller connected to a solar cell for power.	Fuzzy logic controller	FPGA control system for solar panel power control of irrigation system.
	Herman and Surantha (2019)	To develop combination hydroponic farming methods, the IoT technology, and fuzzy logic to control plants nutrition and water needs.	Mamdani fuzzy controller	pH and humidity control of hydroponic plants using Micro-controller based fuzzy logic rules.
	Krishnan *et al.* (2020)	To create a smart irrigation system using GSM for monitoring plant growth and controlling irrigation to boost agricultural productivity.	Fuzzy logic controller	Fuzzy logic controller using GSM comms for controlling the watering system of crops from remote area.
	Khudoyberdiev *et al.* (2020)	Create an optimization scheme using fuzzy logic to control humidity and water levels for efficient crop growth and energy use.	Fuzzy logic controller	An automation of water pump actuator and sensors for hydroponic plant.
	Benyezza *et al.* (2021)	To develop a smart and low-cost irrigation system based on zoning in order to minimize the use of water and the consumption of energy.	Fuzzy logic controller	Zoning irrigation control system using fuzzy control and WSN comms for remote sensor on real tomato plants farming.
	Zaguia (2023)	The use of fuzzy adaptive PID controller to efficiently manage greenhouse temperature and humidity.	Fuzzy adaptive PID controller	Monitoring per real-time data and visualization cloud-based with mobile apps can ease farmers to revolutionize greenhouse.
	Al-Mutairi and Al-Aubidy (2023)	Design and implementation of quality water for fish farming.	Fuzzy logic controller	Performing smart monitoring to control the water quality of the ponds for fish farming.
	Prasad *et al.* (2023a)	A fuzzy classifier is used to categorize the real-time data coming from NPK sensors to monitor the content of nitrogen, phosphorus, and potassium in the soil conditions.	Fuzzy logic controller	Farmer will able to monitor soil health in real-time environment with data accuracy that has been improved and well accepted.
	Pitowarno *et al.* (2023)	Design and development of microcontroller-based for sensor readings of pH, temperature, and water turbidity of freshwater ponds and control peristaltic pump.	Fuzzy logic controller	The system successfully adjusts the control of temperature, pH, and water turbidity of ponds.
	Bernardo *et al.* (2023)	Development of LED lighting intensity controller-based powered by solar power using a fuzzy logic controller for vertical farming.	Fuzzy logic controller	The fuzzy-controlled system was tested and measured the illumination performance for indoor lettuce vertical farming.
	Okoh *et al.* (2023)	Development of IoT cloud-based platform for smart farming in the Sub-Saharan African region.	Fuzzy logic controller	Provide a platform for irrigation system which effectively controlled water usage compared to the traditional control system.
	Nagothu and Anitha (2023)	An automated intelligent watering system that uses weather data coupled with various sensors to control the watering mechanism.	Fuzzy logic controller	The system models the irrigation control with 97 percent accuracy by using weather data and sensor inputs from the robot.

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Fuzzy categories	Authors	Main objective	Modelling approach	Results
	Dipali *et al.* (2023)	An oyster mushroom environment control system using a fuzzy logic controller for sprinklers, fans, humidifiers, and heaters.	Fuzzy logic controller	Controlled environment of oyster mushroom that senses current temperature and humidity values using fuzzy logic.
	Benyezza *et al.* (2023)	An IoT-based greenhouse control and monitoring system by employing an interfacing using Raspberry Pi and WSN.	Fuzzy logic controller	Farmers can easily monitor remotely the greenhouse using a Human Machine Interface.
	Flores (2023)	An irrigation control system-based fuzzy logic controller designed using MATLAB and tested on Arduino Nano microcontroller.	Fuzzy logic controller	Simulation have been implemented to control ON/OFF water sprinkles based on the sensor reading.
	Ramli *et al.* (2023)	A smart portable farming kit for indoor mushroom cultivation in urban areas with minimal user attention.	Fuzzy logic controller	A compact design kit can easily installed in an oyster mushroom indoor environment cultivation.
	Prasad *et al.* (2023a)	A fuzzy classifier categorizes real-time data from NPK sensors to monitor soil nitrogen, phosphorus, and potassium levels.	Fuzzy logic controller	Farmer will able to monitor soil health in real-time environment with data accuracy that has been improved and well accepted.
	Neugebauer *et al.* (2023)	Build a two-dimensional model based on the finite element method to describe water propagation in soil continuously.	Fuzzy logic controller	A fuzzy logic controller irrigation system that continuously calculates input data and output variables to have better irrigation control.
	Dhumale *et al.* (2023)	Intelligent control of fuzzy water irrigation system for four different types of crops.	Fuzzy logic controller	Optimizing of water irrigation system control system of four types of crops: cotton, wheat, sugarcane, and rice.
	Manikandan *et al.* (2023)	Sensor-based intelligent control system using IoT sensor that collects information such as ultraviolet range, humidity, temperature, light intensity, and soil moisture.	Fuzzy logic controller	The irrigation system have been tested and validated against different environmental conditions.
	Bamurigire and Vodacek (2023)	Fuzzy logic controller of irrigation system for rice farming in Rwanda with simulation of different weather seasons in a year.	Fuzzy logic controller	Simulation of irrigation control system using MATLAB with fuzzy logic controller incorporated with weather prediction in different ranges of seasons in Rwanda.
	Irwanto *et al.* (2024)	Real-time monitoring and controlling system by utilizing various sensors for mushroom farm employing fuzzy logic controller.	Fuzzy logic controller	Improving mushroom crop quality involves using sensor data to manage watering, light, environmental conditions, and pest detection.
	Amertet Finecomess *et al.* (2024)	A simulation of an agricultural system that involves variable environments such as soil moisture, temperature, and humidity using MATLAB and Cisco Packet Tracer.	Fuzzy logic controller	A simulation of effective water consumption for irrigation farm.
Fuzzy inference system	Dimatira *et al.* (2016)	To evaluate the tomato's level of maturity by visual recognition uses the colour, size, and shape of tomato fruit.	Mamdani fuzzy inference	Recognizing of tomato maturity by differentiating the colour using Matlab simulation.
	Alomar and Alazzam (2018)	To develop an intelligent irrigation approach that fosters water conservation and better irrigation management in areas with high levels of water stress.	Mamdani Fuzzy Inference System	Design system with fuzzy logic to improve watering and productivity efficiency for greenhouse.
	Mendes *et al.* (2019)	To create a smart irrigation system using a fuzzy inference system that adjusts the central pivot speed based on field variability and crop phenophase.	Fuzzy Inference System	Controlled Variable rate irrigation using fuzzy inference system for different type of soils, and crops.
	Bryan *et al.* (2019)	Develop a fuzzy-based Decision Support System (DSS) to optimize water and fertilizer allocation in crop production according to plant age, enhancing yield quality.	Fuzzy inference system	Watering and fertilizing control system using Fuzzy rule-based for Spinach plants.
	Munir *et al.* (2019)	To determine a secure watering system control based on blockchain IoT automation systems and Fuzzy logic as decision making to activated and disactivated the watering system.	Mamdani fuzzy inference	Combining blockchain and Fuzzy logic based decision support system for smart watering system.
	Jaiswal and Ballal (2020)	To determine an automated irrigation controller that utilizes the data logged from the sensor network that reduces water loss and improved crop productivity.	Fuzzy inference system	An automated irrigation system using LabVIEW and GSM/GPRS for remote sensors promotes water conservation and efficient electricity use.
	Alaviyan *et al.* (2020)	To design a monitoring controller to check data and prevent plant damage in the greenhouse, allowing the user to monitor and adjust the greenhouse parameters remotely and via the internet.	Fuzzy inference controller	Controlled Green house design by implement the fuzzy set rules to control IoT devices.
	Tobias *et al.* (2020)	To develop predicting and identifying the lettuce growth stages classification with low percentage error and correct classifications.	Mamdani fuzzy inference	Using Matlab simulation to predict the lettuce plant growth using fuzzy inference system.
	Alves *et al.* (2023)	An irrigation system with two steps model which evaluate the real-time condition before applying strategies to watering system.	Fuzzy Inference Systems	A complex irrigation system that evaluates sensor data before employing the watering strategies to the farm area.
	Sharma *et al.* (2023)	To identify the lower pest breeding period and verifies a strong correlation between weather, pest breeding and crop growth.	Fuzzy inference Systems	Farmers can identify the best planting seasons with IoT services using fuzzy logic, helping to prevent pests and maximize yields.

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Fuzzy categories	Authors	Main objective	Modeling approach	Results
	Fahim *et al.* (2023)	Investigating and implementing low-cost weather station service-based IoT sensors.	Fuzzy inference system	Implementation of low-cost weather station service that senses the air quality index as real-time monitoring within the IoT sensors and ESP32 board interfacing.
	Pierre *et al.* (2023)	A design and implementation of a smart irrigation system in the Eastern province of Rwanda with two consecutive seasons by employing the fuzzy logic controller.	Fuzzy inference system	Using the MATLAB fuzzy logic toolbox to enhance water and energy efficiency with control-based sensors.
	Chegini *et al.* (2023)	The study designed, implemented, evaluated a decision Support System (DSS) to detect weeds in pastures using a fuzzy inference system.	Fuzzy Inference System	Support farmers in scheduling, recommending, prohibitive tasks and storing historical data for pasture analysis.
	Umam *et al.* (2023)	A drip irrigation system for chili plants designed using fuzzy logic control.	Fuzzy Sugeno inference	Interfacing for a drip irrigation system for chili plants.
	Florea *et al.* (2023)	Design and implementation of a flexible, scalable, easy-to-use IoT embedded system to control sprinkler irrigation with varying weather conditions.	Mamdani fuzzy inference	An irrigation system with three different modes of controlling the sprinkler operation.
	Benzaouia *et al.* (2023)	An irrigation system that combines weather-soil irrigation strategies using a range of IoT communication units in the eastern region of Marocco.	Mamdani fuzzy inference	By using LoRa communication for weather monitoring and irrigation, we create a Smart Precision Irrigation System (SPIS) with remote data monitoring.
	Hasan *et al.* (2023)	The logic-based decision support system that uses a fuzzy logic controller and simulates using MATLAB for three different parameters.	Mamdani fuzzy inference	Simulation of an irrigation control system using MATLAB with fuzzy logic controller.
	Araújo *et al.* (2023)	Implementing ID3SAS integrates wireless sensors, IoT, cloud computing, and data analytics to combat water scarcity and boost agricultural productivity.	Mamdani fuzzy inference system	A cloud-based system enhances irrigation decision-making by improving fuzzy classification for water control, using machine learning and weather predictions.
Advanced fuzzy algorithm	Khanum *et al.* (2017)	A system that uses a Semantically Enriched Computational Intelligence (SECI) as based for disease classification of cotton leaf.	Ontology-based fuzzy logic	A SECI based disease classification system for cotton leaf disease using 50 images dataset and simulated using MATLAB.
	dela Cruz *et al.* (2017)	To determine decision support system (DSS) in the water tank monitoring and control subsystem of automated irrigation system based on fuzzy.	Fuzzy-based decision support system	Simulation of water and electric power optimization using MATLAB to control the irrigation and water tank filling system.
	Kokkonis *et al.* (2017)	Create an automatic irrigation system for arable land that adapts to environmental changes using a neuro-fuzzy algorithm.	Neuro-Fuzzy algorithm	Irrigation system using micro-controller and sensors with neuro-fuzzy algorithm.
	Anter *et al.* (2019)	To evaluate the Crow Search Optimization Algorithm (CSA) and Fast Fuzzy C-Means (FFCM) for accurately segmenting green plants in agricultural images.	Crow search algorithm (CSA) and Fuzzy C-means	Crop images optimization algorithm by using the Crow search optimization algorithm as an improved version of Fast Fuzzy C-Means.
	Huang *et al.* (2020)	To determine the identification of the maturity stages of tomatoes that minimizes the loss of quality.	Fuzzy C-means	Proposed new approach of classification by combining fuzzy logic and deep learning method.
	Çelikbilek and Tüysüz (2020a)	To assess the effectiveness of legacy algorithms in monitoring weed distribution and yield across farming areas.	Fuzzy C-Mean	A comparative study of both FCM and BPNN to identify the crop plants and weeds for various conditions.
	Bahri *et al.* (2020)	To develop a smart farming platform using FCM modelling and the JADE framework to recommend fertilizer use that reduces environmental impact while maintaining crop yields.	Fuzzy Cognitive Maps (FCM)	A simulation on-site monitoring scenario in one agricultural site using JADE based FCM algorithm.
	Castañeda-Miranda and Castaño-Meneses (2020)	To develop a smart frost forecast with an anti-frost intelligent control in greenhouses as a crop protection measure to reduce the frost effects on farmland.	Fuzzy Expert System, Fuzzy Associative Memory	An intelligent control in greenhouse by implement real monitoring environment from climatological station combine with ANN and Fuzzy expert system for control the water pump.
	Saggi and Jain (2020)	To create an ensemble model for accurately estimating the crop coefficient (Kc) and reference evapotranspiration using Fuzzy-Genetic (FG) and Regularization Random Forest (RRF) methods.	Fuzzy genetic	A study on estimating crop coefficients and reference evapotranspiration for three crops using fuzzy genetics and random forests.
	Pandiyaraju *et al.* (2020)	To develop a new intelligent routing protocol called Terrain Based Routing Protocol for Wireless Sensors Network communication using fuzzy rules for precision agriculture.	Neuro-Fuzzy Inference	Controller node simulation using Matlab and Routing protocol optimization for WSN in precision agriculture.
	Mahajan and Badarla (2021)	To create a bacterial foraging optimization (BFO) algorithm for selecting the best sensor node for clustering and routing, we will compute fitness values using cross-layer parameters from the network layer, physical layer, and Medium Access Control (MAC) layer in a farming area.	Bacterial foraging optimization	Optimization of cross-layer protocol for WSN IoT devices using NICC cluster-based WSN protocol.
	Acharjya and Rathi (2021)	Optimizing crop identification using fuzzy-rough sets and RCGA to compare six methodologies based on accuracy, time, and success rate.	Fuzzy-rough set and RCGA	Simulation model for crop identification using fuzzy-rough set and some stage of optimization algorithm in smart agriculture.

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Fuzzy categories	Authors	Main objective	Modeling approach	Results
	Chouhan *et al.* (2021)	To design an automated disease detection from plant leaves using Detection and classification using IoT-Fuzzy Based Function Network (FBFN) captured by Raspberry Pi cameras.	Fuzzy based function network (FBFN)	An information-based image processing captured by IoT camera of plant leaf disease.
	Jamil *et al.* (2022)	Proposed a platform that aims to develop an optimal smart contract integrated with prediction, optimization, and control for operating actuator state in a greenhouse environment.	Cascaded fuzzy controller	Balancing energy consumption with ideal greenhouse conditions, including temperature, humidity, and CO2 levels.
	Cagri Tolga and Basar (2022)	To evaluate three vertical farm alternatives (basic, IoT, Automated vertical farms) via MCDM methods for urban farming.	Fuzzy MCDM methods	A study of indoor farming for implementation of hydroponic plantation by apply the MACBETH method.
	Kavitha and Sujaritha (2022)	Development of sensing method to determine sensitive wavebands of soil macronutrients.	Supervised neuro-fuzzy based dimensionality reduction	Optimal soil wavebands are identified using Partial Least Squares Multi Variable Regression (PLS-MVR).
	Remya (2022)	To develop a fuzzy logic model for predicting soil quality, we will use two key indices: organic carbon in the soil and the carbon-to-nitrogen (C:N) ratio, both vital for maintaining soil quality.	Neuro-fuzzy inference	Soil quality prediction simulation by optimizing the four agriculture datasets using back-propagation in neural network algorithm.
	Jayakumar *et al.* (2023)	To model an optimal selection of agricultural drones for fertilizer spraying in agri-land among the various attributes using Complex Linear Diophantine Fuzzy soft set algorithm.	Complex Linear Diophantine Fuzzy set	The method helps to select a suitable agri-drone for spraying fertilizer and pesticides together with the manufacturing date in agriculture.
	Qiao *et al.* (2023)	Design a dynamic wireless communication between sensors and edge computing devices by employing the UAV as mobile computing.	Fuzzy selection algorithm	A simulation of UAV control and communication between farm sensors and the UAV computing device achieves higher network throughput than other agricultural methods.
	Abdelhafeez *et al.* (2023)	A simulation using neutrosophic mean method to analyse the best criteria in smart farming by considering of 10 parameters.	Neutrosophic Mean Method	A simulation of ten parameter on smart farming using triangular neutrosophic set of data to obtain sustainability criterion on smart farming.
	Deepanayaki and Vidyaathulasiraman (2024)	A lightweight deep network for classifying and predicting sugarcane yield by utilizing steps from the segmentation process and classification process using various algorithms.	Deep Adaptive fuzzy segmentation algorithm (DAFSA)	Sugarcane yield prediction with data mining and crop simulation models.
	He *et al.* (2024)	Proposed a framework for supply chain mechanism with auction in smart agricultural using fuzzy neural network.	Fuzzy neural network	A framework and analysis for smart agricultural supply chain mechanism with an auction.
	Ahmed *et al.* (2024)	The goal is to enhance data collection in a large-scale agricultural environment where sensors monitor and protect crops from pests.	Fuzzy similarity matrix	Edge computing for IoT data reduces the load on centralized systems, improves efficiency, and enhances security. A fuzzy logic algorithm aids data aggregation, while blockchain technology registers IoT devices with edge servers.

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