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| How artificial intelligence uses to achieve the agriculture sustainability: Systematic review | |  |

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| a r t i c l e | i n f o | a b s t r a c t |
| Article history:  Received 3 February 2022  Received in revised form 20 April 2023 Accepted 25 April 2023  Available online 28 April 2023 | | The generation of food production that meets the rising demand for food and ecosystem security is a big challenge. With the development of Artificial Intelligence (AI) models, there is a growing need to use them to achieve sustainable agriculture. The continuous enhancement of AI in agriculture, researchers have proposed many models in agriculture functions such as prediction,weed control, resource management, advance care of crops, and so on. This article evaluates on a systematic review of AI models in agriculture functions. It also reviews |
| Keywords:  AI  Agriculture  Sustainability | | how AI models are used in identified sustainable objectives. Through this extensive review, this paper discusses considerations and limitations for building the next generation of sustainable agriculture using AI.  © 2023 The Authors. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co., Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>). |

Review   
Robotics   
Deep learning

|  |  |
| --- | --- |
| 1. Introduction | and mitigating atmospheric changes is the biggest global challenge in |

the 21st century (Di Vaio et al., 2020). The terms “sustainability” and

The agricultural sector in any nation plays a key role to address the one of universal challenges, provide sufficient foods to survive people. As estimated (Alexandratos and Bruinsma, 2012), in 2050, there is a re-quirement to increase global food supply by 60% in order to feed nearly 9 billion people (Padilla and Hudson, 2019). Growing population leads continuous farming with limited arable land (Jayne et al., 2014). This issue is further aligning with the 17 Sustainable Development Goals (SDGs) which has been focused to eliminate poverty and eradicate hun-ger and malnutrition by 2030 and 2025 respectively. Growing popula-tion leads continuous farming with limited arable land (Padilla and Hudson, 2019). It has been argued that food production process creates a foremost universal environmental degradation created through fertil-izer utilization, greenhouse gas emissions and biodiversity (Tilman et al., 2011). Though intensive agriculture (known as intensive farming) and industrial agriculture have led to an increase in food production and easing of food shortages, now bring disadvantages due to utilization of high input of fertilizers, pesticides and fresh water (Tian et al., 2021). In particular, climate changes such as global warming, aggravating flooding and drought will in turn influence the food security (Wheeler and Von Braun, 2013). Consequently, how to feed the increasing popu-lation while decreasing the negative consequences on the environment

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“sustainable” has gained substantial attention applied in varies contex-tual aspects (Bolis et al., 2014). Sustainability is defined as a balanced combination of social, environmental and economic performance to benefit current and future generations (Geissdoerfer et al., 2017). To safeguard food and ecological security, the sustaining of performing more of the same thing is commonly indicated as sustainable agricul-ture (Gaffney et al., 2019). Thus, to achieve sustainable growth in the ag-riculture sector has received greatest attention (Castro and Swart, 2017), and there is an emerging consumer demand for sustainable qual-ity food products (Mangla et al., 2019). Sustainability lays in three pillars economic, social and environmental performance. Social performance focuses on social troubles namely human rights, ethics in doing business, environmental activities, identical opportunities concerns on waste generation, greenhouse gas emission; economic performance quantifies operational efficiency, shareholder value and transaction costs (Ala-Harja and Helo, 2015; Panda, 2014). Subsequently, Sayer and Cassman Sayer and Cassman (2013) opined that agricultural firms/farms require to obtain four objectives, which are often to be competing each other, to be considered sustainable growth namely 1) Ensure production of an adequate food supply; 2) Alleviate poverty; 3) Achieve better health and nutrition for a growing population; and 4) Conserve natural resources. These objectives are highly relevant to the sustainable pillars, and they are aligned properly with the SDGs. To certify the sufficient food productions to the growing population, technologically advanced inputs, cultivation techniques and soil

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management approaches become the vital sources (Gaffney et al., 2019). High-yielding cropping systems must be concerned to convert resources to economic yield. Increasing protein obtainability of food sources of food (beans, vegetables, wheat, rice), and of availability of vi-tamins and minerals through poise diet should require to ensure healthy and affluence over 9 billion people people to be fed by 2050. Soil degradation, low irrigation management, and a less productivity sludge farmers in poverty (Tittonell and Giller, 2013). To eradicate pov-erty, agricultural sector must be move forwarded the modernized and productive agricultural transition where farmers are equipped with highly resourceful and resilient. Conserving natural resources consists of wide range of soil nutrient, quality of water, green-house gas, confrontation of pest and weed and reduction of aquifer. Preserving bio-diversity of natural settings, flora and fauna are conservation challenges. Further, when underpinning technologies are infantile or improperly used, agricultural expansion causes a serious environmental damage. This is why Mellor (Mellor, 2017) insisted that identifying and utilizing vigorous pattern of technology improvements and efforts should focus not on just one aspect of sustainability objective, but rather on activa-tion of the whole system that representing the prevailing agricultural enterprises. Yet, many firms/farms in the agricultural sector are stressed with squat profit and low productivity (Barth et al., 2021), hinders efforts to sustainable agriculture (McGuire, 2017). Gaffney et al. (Gaffney et al., 2019) further stressed that growth in emerging and recently emerged markets (Asia and Africa) creates the definitive re-straints to meet sustainability objectives. Regardless of the complexity to meet all four objectives simultaneously, agriculture sector is moving towards sustainable agriculture (Tian et al., 2021). Realizing and utiliz-ing technological advancements, the commitment derive to agriculture sustainability must be accompanied with technological improvement (Mellor, 2017). Thus, to meet Sayer and Cassman's sustainable objec-tives and face the global food security challenges ahead, wider applica-tion of existing technologies and utilization of advanced technological tools and techniques soon would be the straightforward strategies (Franco, 2021). What we observed from present panorama is that that Covid-19 pandemic emerges as a great crisis, leading to widen global food security issue. Although the generation of food production that meet the rising demand for food and ecosystem security is a big challenge, rapid developments in technology are making it possible. Re-searchers applied artificial intelligence (AI) to make sustainable agricul-ture (Li et al. 2021b; Mohapatra and Lenka, 2016). The recent application of the technologies of AI support to provide solutions to problems in agricultural domain. These technologies are used to reduce the cost as well as increase the effectiveness and efficiency. There are surveys which conducted to find what people did to make sustainable agriculture using AI. However, investigations on how AI used to achieve sustainable objectives are still under research-able area. Specifically, this research aims to map and create an understanding of the various technologies implement in agriculture sector with a special focus on the sustainability growth objectives. Thus, the main purposes of this systematic review are are to; 1) develop a more complete understand-ing of the enabling AI technologies currently applied in agriculture sec-tor, 2) explore a variety of AI technology initiatives to achieve sustainability growth objectives, and 3) analyse how agriculture firms/ farms improve sustainable growth through technologies which are already underway and new technologies are being developed. This systematic review would contribute to enhance the understanding of the present view of the agriculture sustainability and agriculture

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to identify the firsthand experiences on currently applied AI technolo-gies in agriculture sector and variety of AI technology initiatives to achieve sustainability growth objectives in agriculture sector. To carry out this SLR, we set up three stages namely, planning; implementing and reporting (Ferreras-Fernández et al., 2013).

In the planning stage, described the key terms that could be considered relate to the study namely, agriculture, farming, protected agriculture, smart farming, Artificial Intelligence (AI), Deep Learning (DL), Machine Learning (ML), agricultural robot and robotics. The Bool-ean operators AND and OR were used to do more thorough searches, for example, “AI” AND “agriculture” AND “crops” OR “farming” AND “Smart Agriculture” AND “smart farming”. The search was performed in the four well-known data sources that encompass multidisciplinary publications, google scholar, Scopus, Science Direct and Web of Science, following the process used by similar recent studies of AI and sustain-able agriculture (Traldi, 2021; Navarro et al., 2020). The scope of the publications was limited to documents such as journal and conference articles, published in English. The past ten years considered as the time range to conform the objectives of the study.

In the implementing phase, 1421 articles were selected with the search tool. A database review of publications about the desired key-words in Web of Science found 347 records since 2012. In the case of Scopus and Science Direct, there have been 256 and 244 documents published respectively. The total number of articles published in Google scholar search engine was 574 from 2012 to 2021 December. The areas in which they have been published the most are agriculture, technology, computer and electronic, agronomy, agriengineering, computer sci-ences and sustainability. After getting the articles, they were manually reviewed through the title, keywords, abstract and text analysis adher-ent to the objectives proposed of the study. Number of record screened was 313. During this process, the list of documents was consequently sorted to eliminate the duplicate articles (Åstrand and Baerveldt, 2002). 131 articles were excluded due to irrelevant to agriculture indus-try. This analysis resulted in 115 articles deemed eligible which were incorporated as a sample for this study. Out of 115 articles, 45 identified through Web of Science, 37 Science Direct and 33 identified through other sources listed above. The article list was finalized in December 2021 (Refer Table 1 in Appendix 1).

In the reporting stage, each of the articles retrieved was analyzed according to the AI component such as DL, ML, neutral network and robotics and agriculture activities namely harvesting, plant eco-phenotyping, grading system, weed and crop classification, disease detection and monitoring and soil management. The searched articles were then listed on excel spreadsheet. The data sheet contained the de-tails of article namely name of author/s, year of published, study title, key AI technology used, main agriculture area, benefits obtained and limitations. Once the database was completed, a content analysis was performed to examine the review summary in-depth and summarise the empirical experiences on currently applied AI technologies in agri-culture sector and variety of AI technology initiatives to achieve sustain-ability growth objectives in agriculture sector. Fig. 1 illustrates the methodological chart applied in the SLR.

3. AI methods use in agriculture

AI is one of the emerging areas of research in recent generation. Today AI is used to solve the problems particularly to reduce the use of the labor force, to enhance efficient utilization of resources and to

technology. facilitate the development of sustainable business. With the rapid tech-

nological advancement,people are more intend to developed these ap-

2. Research methodology   
 Systematic Literature Review (SLR) permits identifying and obtaining relevant information on interesting subject area from the existing literature (Kitchenham and Charters, 2007). The SLR pursues

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Table 1

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Agriculture functions and sustainability growth objectives.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reference | AI technology | Technology used in agriculture function | Agriculture function | Sustainability |
| category | objective |
| (Han et al., 2018) | NN | Prediction for agricultural output value | Prediction | 1 |
| (Almomani, 2020) | ANN | Prediction model for agriculture waste | Prediction | 1 |
| (Espejo-Garcia et al., 2020) | DNN | Weeds identification | Weed control | 1 |
| (Yamaç, 2021) | KNN, SVM, RF, AB | Estimate sugar beet Etc for efficient irrigation management | Prediction | 1 |
| (Mohapatra and Lenka, | NN | Crop monitoring | Advanced care of crops | 3 |
| 2016) | ANN | Prediction of Generic Escherichia coli population based on | Prediction | 1 |
| (Buyrukoğlu et al., 2021) |

Weather Station Measurements

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Dargan et al., 2020) | Machine learning | Sustainable agriculture supply chain performance | Supply chain | 2 |

applications

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Nguyen et al., 2019) | ANN | Agricultural landscapes management | Resource management | 4 |
| (Liu et al., 2020) | ANN | Develop integrated agricultural drought index | Prediction | 1 |
| (Castro et al., 2017) | ANN | High-performance prediction of Macauba fruit biomass | Prediction | 1 |
| (Jung et al., 2021) | AI | Improve the resilience of agricultural systems Crop simulation | Prediction | 1 |

models utilize input variables such as crop management   
information, weather, and soil data to estimate crop productivity

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Camaréna, 2020) | AI | Food production system | Supply chain | 2 |
| (Zhang et al., 2021) | LSTM | Weather radar echo prediction method | Prediction | 1 |
| (Dey and Shekhawat, 2021) | AI | Blockchain for sustainable e-agriculture Data management | Supply chain | 2 |
| (Albalasmeh et al., 2020) | ANN | Predict the quality of the biochar based on operational conditions | Prediction | 1 |

of biochar production (parent biomass type, particle size,   
pyrolysis temperature)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Khan et al., 2020) | Deep Learning | Fruit Prediction | Prediction | 1 |
| (Senocak and Goren, 2021) | AI | Forecasting the biomass-based energy potential | Prediction | 1 |
| (Emmi et al., 2014) | Robotics | Integration and assessment of a real fleet | Advanced care of crops | 3 |
| (Abdullahi et al., 2017) | CNN | Plant image recognition and classification | Weed control | 3 |
| (McGuire, 2017) | ANN | Crop yield prediction Climate change impact assessment | Prediction | 1 |
| (Guillén et al., 2021) | Deep Learning | Performance evaluation of edge-computing platforms for the | Prediction | 1 |

prediction of low temperatures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Sharma et al., 2020) | Machine Learning | Applications for precision agriculture | Advanced care of crops | 3 |
| (Espejo-Garcia et al., 2020) | DNN | Improving weeds identification | Weed control | 3 |
| (Mohapatra and Lenka, | ANN, Fuzzy Logic | Pattern classification and weather dependent Fuzzy Logic Model | Resource management | 4 |
| 2016) | ANN | for irrigation control | Prediction | 1 |
| (Buyrukoğlu et al., 2021) | Prediction of Generic Escherichia coli Population in Agricultural |

Ponds Based on Weather Station Measurements

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Giannakis et al., 2019) | Cloud Environment | Data sharing on production, diseases and weather | Advanced care of crops | 3 |
| (Ellafi et al., 2021) | ANN | Prediction of saturated hydraulic conductivity (Ksat) in order to | Prediction | 1 |

enhance the efficacy of drainage system design in data-poor areas   
utilizing existing and currently under-utilised datasets.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Monteiro et al., 2021) | ANN | Weed control | Weed control | 3 |
| (Santin et al., 2016) | ANN | Design of performance-oriented riparian buffer strips for the | Advanced care of crops | 3 |

filtering of nitrogen in agricultural catchments

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Taghavifar et al., 2015) | ANN and Genetic | Prediction of the power provided by the agricultural tractors | Prediction | 1 |

Algorithm

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Singh et al., 2012) | ANN | WPredicting sediment yield in the Nagwa agricultural watershed | prediction | 1 |

in Jharkhand, India

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Liu et al., 2021) | ANN | Predict rice growth rate | Prediction | 1 |
| (Grimstad and From, 2017) | Robotic | Using cameras sensitive to visual and near infrared parts of the | Advanced care of crops | 3 |

electromagnetic spectrum to study plants

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Roshanianfard et al., 2021) | Robotic arms and | Seeding, watering, fertilizing, weeding, and harvesting | Advanced care of crops | 3 |

manipulation   
systems

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Ireri et al., 2019) | Machine learning | Applied in real-time tomato post-harvesting procedures Low-cost | Harvesting | 1 |

tomato grading system based

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Birrell et al., 2020) | Robotics | Achieve a consistent harvesting cutting height, high-quality cuts | Harvesting | 1 |
| (Mehta and Burks, 2016) | Robotic | Harvesting fruit detection efficiency, picking efficiency and | Harvesting | 1 |

picking rate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Navas et al., 2020) | Robotic | Suitability of the cutting tools for the plants to be harvested | Harvesting | 1 |
| (Navas et al., 2020) | Robotic | Suitability of the cutting tools for the plants to be harvested | Harvesting | 1 |
| (Booth et al., 2020) | Machine learning | 3D estimate of the plant bulb's growth direction from a triplet of | Advanced care of crops | 3 |

2D x-ray images

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Raja et al., 2020) | Robotic | Crop signaling system Weed and crop classification | Advanced care of crops, Weed | 3 |

control

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Kounalakis et al., 2019) | Deep learning | Weed visual recognition algorithms | Weed control | 1 |
| (Magalhães et al., 2021) | Deep learning, | Accurately identifying and detecting the mature fruit or fruit | Harvesting | 1 |
| (Khort et al., 2021) | Harvesting robot | bunches | Advanced care of crops | 3 |
| Robotic | 10 h of continuous operation in low-light conditions in various |

weather conditions.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Aguiar et al., 2021) | Deep Learning | Detect tree trunks is still an area quite underdeveloped | Advanced care of crops | 3 |
| (Vincent et al., 2019) | Neural networks | Agriculture land suitability analysis: Measurements of soil | Resource management | 4 |
| and Multi-Layer | moisture content, granular fragments (percentage of sand |
| Perceptron (MLP) | particles in the soil), structure of the soil, compact and |

cementation, cnternal drainage, available water content,   
porousness, organic matter, cation exchange capacity, degree

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Table 1 (continued)

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reference | AI technology | Technology used in agriculture function | Agriculture function | Sustainability |
| category | objective |

saturation, pH value, salinity, and carbonates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Hespeler et al., 2021) | Robotic | Harvesting in the evening hours or low light situations | Harvesting | 1 |
| (Buzzy et al., 2020) | Robotic | Real-time leaf detection and counting | Advanced care of crops | 3 |
| (Schor and Attwood-Charles, | Robotic | Disease detection and monitoring | Advanced care of crops | 3 |

2017)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Navas et al., 2020) | Robotic | Weed treatment with a flaming and row crop cultivator | Weed control | 3 |

implement. Weed treatment with a herbicide patch sprayer. Pest   
control with a canopy sprayer.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Zapotezny-Anderson and | Robotic | Harvesting | Harvesting | 1 |

Lehnert, 2019)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Kwon et al., 2019) | Deep convolutional | Fruit monitoring and grading systems | Advanced care of crops | 3 |

neural networks   
(DCNNs)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Zujevs et al., 2015) | Robotic | Fruit detection, localizing, gripping and picking Quality | Advanced care of crops | 3 |

measurements before picking

|  |  |  |
| --- | --- | --- |
| (Mendes et al., 2019) | Robotic path | AgRob Vineyard Detector |

planning   
Advanced care of 3   
 crops

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Paliwal et al., 2019) | Robotic | Soil data collection, disease detection, and field classification to | Resource management | 4 |

provide the best solutions for mixed cropping.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Fue et al., 2020) | Robotic | Cotton harvesting | Harvesting | 1 |
| (Linaza et al., 2021) | Machine learning | Yield prediction | Prediction | 1 |
| (Bi et al., 2021) | Slam robot | Positioning system for agricultural environment | Advanced care of crops | 3 |
| (Väljaots et al., 2018) | Robotic | Soil sampling and storage apparatus | Resource management | 3 |
| (Jez et al., 2021) | ANN, SVM, CNN | Plant growth status, pest management, water and fertilizer | Advanced care of crops | 3 |

management for plant breeders and plant physiologists

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Porsch et al., 2019) | Robotic | Gantry pneumatic robotic manipulator for greenhouse | Advanced care of crops | 3 |

automation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Zhang et al., 2021) | Robotic | Gripper developments to minimize the risk of damage to fruits, | Harvesting | 1 |

vegetables or food

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Jung et al., 2021) | AI, Deep learning | Irrigation management service Soil moisture monitoring system | Resource management | 4 |

to control irrigation, fight mildew, and deal with drought Image   
recognition application to identify potential defects and nutrient   
deficiencies in soil

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Kakani et al., 2020) | Machine Learning | Utilize the data collected from farms, irrigation, soil characteristics | Resource management | 4 |

and meteorological data to formulate field level insights as   
recommendations for farmers to improve their overall yield

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Sharma and Bisen, 2013) | Electric National | e-NAM envisages spatial market integration, reduction in | Prediction | 2 |
| Agriculture Market | transaction costs and has direct implications on price signals and |
| (e-NAM) Deep | price discovery, farmer's income and market liberalization |

learning

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Oliveira et al., 2021) | Robotic | Robotic applications for land preparation, sowing and planting, | Resource management Advanced | 2 |
| (Beloev et al., 2021) | Robotic | plant treatment, harvesting, yield estimation and phenotyping | care of crops, Harvesting | 3 |
| Map or inspect a specific farming area in accordance to the | Advanced care of crops |

situation and the surrounding environment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Isachsen et al., 2021) | Robust robot-based | Real-time speed and high registration accuracy and resolution | Prediction | 1 |
| automation in | enable the correct manipulation of food products without quality |
| primary production | degradation |

and processing

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Song et al., 2021) | Robotic | Greenhouse control system | Advanced care of crops | 3 |
| (Thomopoulos et al., 2021) | Robotic | Kiwifruit harvesting robot | Harvesting | 1 |
| (Seo and Umeda, 2021) | Unmanned aerial | UAVs are comparable to boom sprayers, showing similar | Weed control | 3 |
| (Ishii et al., 2021) | vehicles (UAVs) | pest-control costs and management efficiency | Supply chain | 2 |
| Robotic | Store, transport and relocate the boxes of tomato to the assigned |

storage area

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Peteinatos et al., 2020) | CNN | Plant and weed classifications | Weed control | 3 |
| (Fahey et al., 2021) | AI-based data fusion | Identify and quantify disease and pest epidemics accurately and at | Advanced care of crops | 3 |
| (ÖZLÜOYMAK et al. | technique | the earliest possible stage | Weed control | 3 |
| Robotic | Weed control system |

Özlüoymak et al., 2019)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Balafoutis et al., 2017) | Machine learning | Autonomous plant classification | Advanced care of crops | 3 |
| (Spanaki et al., 2021) | AI AgriTech drones | Collecting data from the fields, and support monitored human | Prediction | 1 |

decision making for everyday tasks (e.g. disease inspection, crop   
monitoring) and AgriFood operations (e.g. irrigation, fertilization   
etc.) of the farm

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Bi et al., 2020) | Deep Learning | Predict consumer Yogurt preferences based on sensory attributes | Prediction | 2 |
| (Kiourt et al., 2020) | Deep Learning | Automatic image-based food recognition | Advanced care of crops | 3 |
| (Dargan et al., 2020) | Deep Learning | Predict wine taste preference | Prediction | 2 |
| (Chukkapalli et al., 2020) | AI | Smart farming Cooperative ecosystem | Advanced care of crops | 3 |
| (Utstumo et al., 2018) | Robotic | Drop-on-Demand (DoD) weed control system | Weed control | 3 |
| (Lytridis et al., 2021) | Robotic | Land preparation | Resource management | 4 |
| (Hossain and Komatsuzaki, | Robotic | Weed management | Weed control | 3 |

2021)

(continued on next page)

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Table 1 (continued)

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reference | AI technology | Technology used in agriculture function | Agriculture function | Sustainability |
| category | objective |
| (Kultongkham et al., 2021) | Robotic | Tomato harvesting | Harvesting | 1 |
| (Ruigrok et al., 2020) | Robotic | Weed detection | Weed control | 3 |
| (Magomadov, 2019) | Deep Learning | Plant disease detection | Advanced care of crops | 3 |
| (Feng et al., 2018) | Robotic | robotic harvesting system for cherry tomato | Harvesting | 1 |
| (Grieve et al., 2019) | Robotic | Weed control | Weed control | 3 |
| (Midtiby et al., 2016) | Robotic | weeding application | Weed control | 3 |
| (Williams et al., 2019) | Machine Vision, | Kiwifruit Harvesting | Harvesting | 1 |

Convolutional   
Neural Networks,   
and Robotic

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Hespeler et al., 2021) | Deep learning | harvesting of chili peppers | Harvesting | 1 |
| (Gonzalez-de Santos et al., | Robotic | weed and pest control | Weed control | 3 |

2017)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Sudars et al., 2020) | Robotic computer | Annotated food crops and weed images | Weed control | 3 |
| (Ngugi et al., 2021) | Machine learning | leaf pest and disease recognition | Advanced care of crops | 3 |
| (Ghafar et al., 2021) | Robotic | Spraying fertilizers and pesticides | Weed control | 3 |
| (Azmi et al., 2021) | Robotic | Crop seeding | Harvesting | 1 |
| (Yorozu et al., 2021) | Robotic | Smooth and safe harvesting support in the field | Advanced care of crops | 3 |
| (Kim et al., 2021) | Robotic | Estimate crop height and detect the target crop region | Prediction | 1 |
| (Gai et al., 2021) | Robotic | Generating crop field maps as occupancy grids and providing | Prediction | 1 |

inter-row vehicle positioning data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Panarin and Khvorova, | Robotic | Taking into account the physical environment conditions and | Prediction | 1 |
| 2021) | Robotic | build mathematical models | Harvesting | 1 |
| (Rysz and Mehta, 2021) | Fruit harvesting |
| (Zangina et al., 2021) | Robotic | Selective and variable spray of pesticides to the plants | Weed control | 3 |
| (Mohamed et al., 2020) | Machine learning | Spatial mapping analysis of soil characteristics | Resource management | 4 |
| (Gupta et al., 2020) | Deep learning | Soil parameters analysis | Resource management | 4 |
| (Mohammed and Jassim, | Robotic | Seeding, fertilization and initial irrigation process | Harvesting, Advanced care of crops | 1,3 |

2021)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Villa-Henriksen et al., | Robotic | Harvesting | Harvesting | 1 |

2021)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Ünal et al., 2021) | Robotic | Soil penetration resistance and electrical conductivity | Resource management | 4 |
| (Li et al. 2021a) | Deep learning | Weed detection | Weed control | 3 |

Machine (SVM), Random Forest, K-nearest and Robotics. As in Fig. 2 from the selected papers the most of researchers are applied robotics which is 44%. Thereafter, NN and DL is 26% and 15%, respectively.

Robotics are used in agriculture to assist farmers. These robots are developed with many operations such as weeding application, visual detection and harvesting where they can be used to match the needs of various tasks (Zhang et al., 2020; Benos et al., 2020; Yorozu et al., 2021). Ghafar et al. (Ghafar et al., 2021) design a robot to spray pesti-cides and fertilizers in harvesting field at low operating cost and general crop monitoring. This model is used two-wheeled robot that included a a mobile base which is used a spewing mechanism with a controlling of wireless tool that is used to manage the movements of the robot. There-after, crop growth conditions and health factors are monitored using

cameras. This process assists to detect the presence of pests in the crop field. This problem is solved using low-cost agricultural robot (Azmi et al., 2021). For agricultural cyber-physical systems, researchers proposes a suggest an intelligent management deign using robotic technique(Huang et al., 2021). The robots can use in labour intensive, repetitive and physical demanding tasks in agricultural field. The recent literature reveals that robots are being used to perform several special-ized tasks which were performed by experience farmers (Marinoudi et al., 2019; Le et al., 2019; Zhang and Noguchi, 2017; Huang and Chang, 2019; Kim et al., 2021). As such, there are advantages using ro-botics in agriculture such as production increase, widening the profit and saving time for performing repetitive tasks. It is estimated that pes-ticides usage can be reduced by 80% if the farmers use robots to spray

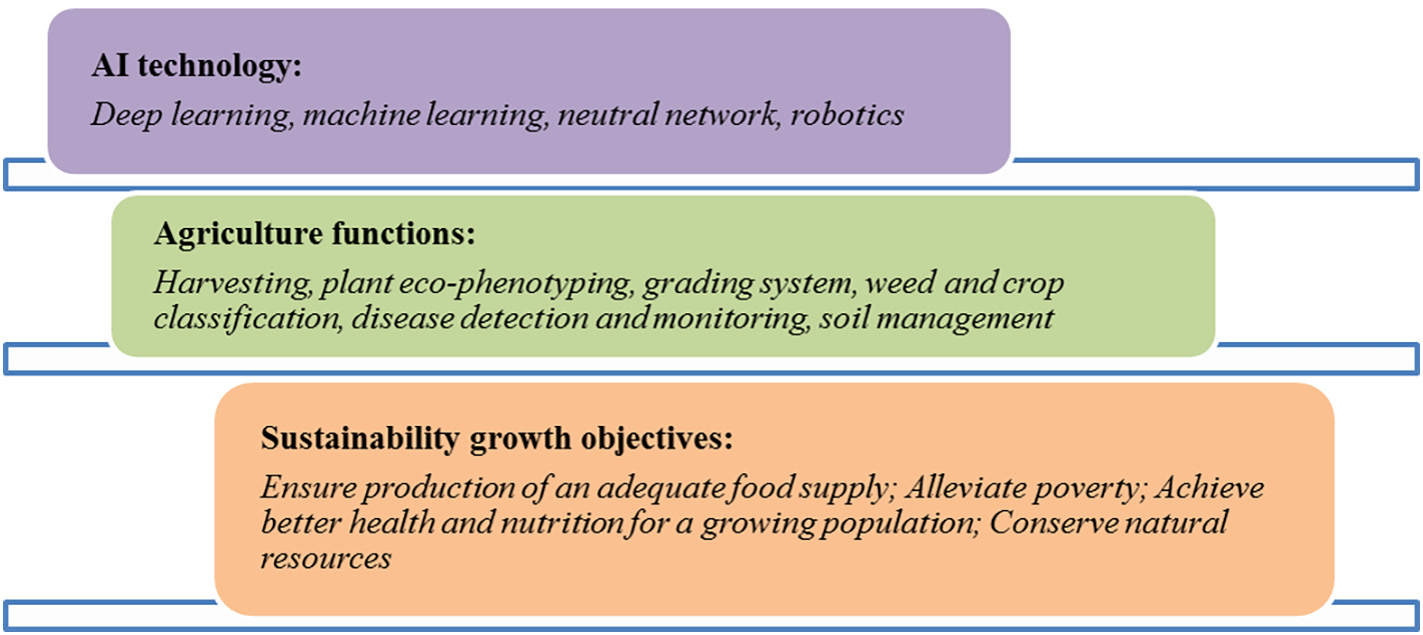


Fig. 1. Methodological chart.   
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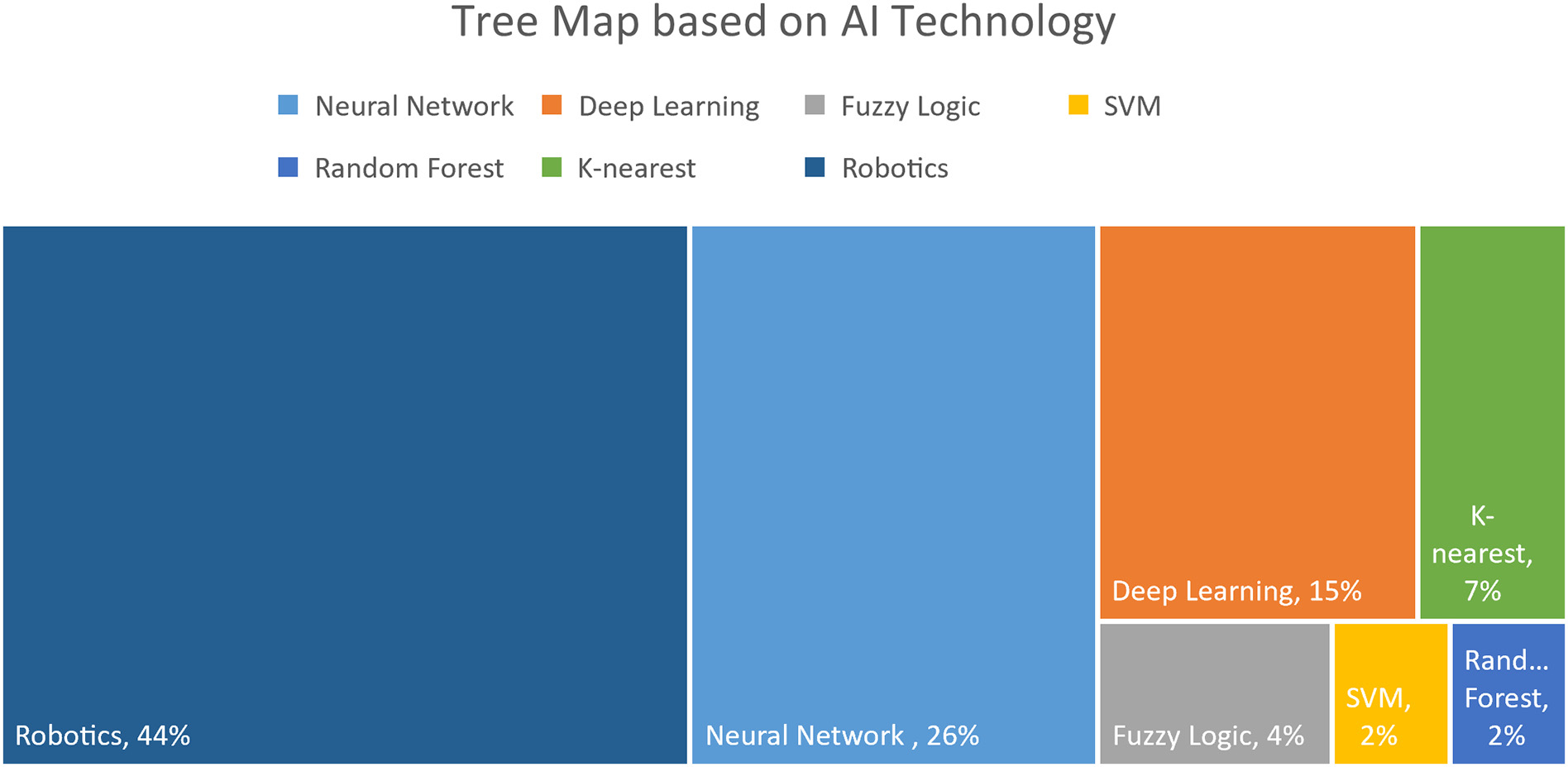


Fig. 2. AI approaches used in agriculture.

fertilizers. Moreover, since robots cab work around trees, rocks, lakes and other obstacle areas easily, crops can be cultivated more fields (Khare et al., 2021; Gai et al., 2021; Panarin and Khvorova, 2021; Rysz

nitrogen content in soil and leaf, detect irrigation and plants' water stress level, assess erosion of water, detect usage of herbicide, defects on food and damage of crop hail and monitor greenhouse (Bu and

and Mehta, 2021). Wang, 2019; Li et al. 2021c; Zhou et al., 2021; Chen et al., 2020; Xue

Artificial neural networks (ANN) are one of the most important technique of AI. These models are developed using interconnected nodes which are performed functions as our human brain. The usage of NNs application is very wide, and it also includes in agriculture (Kujawa and Niedbala, 2021). (Almomani, 2020) was applied a NN to optimize the cumulative methane production. This NN model has showed significant results in prediction. In addition, NN has employed to pattern classification and soil moisture content prediction (Mohapatra and Lenka, 2016). Scaled Conjugate Gradient and BFGS Quasi-Newton based neural network algorithms used to take various soil and environmental parameters and predict hourly requirement of soil soil moisture content. The NN has become popular as a classification method in agricultural engineering. NNs are virtuous to formulate the model using non-linear data and data represents with images. Therefore, this approach is good for crop classification using image data (Boniecki et al., 2020). The prediction of growth rate of rice is im-

et al., 2019). However, DL models need comprehensive datasets as the input to serve at the training procedure. Other than the above methods, researcher were also applied Fuzzy Logic, SVM, Random Forest and K-nearest (Kurniasih et al., 2018; Center and Verma, 1998; Pujari et al., 2016; Jez et al., 2021; Yamaç, 2021). However, Robotic models and DL models have showed significant usage in the agriculture field.

To develop a more complete understanding of the enabling AI tech-nologies currently applied in agriculture sector, Fig. 3 further illustrates main AI approaches used in agriculture functions.

Moreover, the study aligns the main agriculture functions with sustainability growth objective (Fig. 4) in order to provide contextual link with present view of the agricultural functions and sustainability. In here, the study focused on several functional areas highlighted in the selected studies. As such, the research hots-pots of AI and agriculture in the past decades comprise mainly prediction, harvesting, advanced care crops, weed control, resource management and supply

portant to obtain sustainability in agriculture. Researchers recom- chain.

mended rice growth rate modeling using NN which shows less errors

compared to regression algorithm and gene expression programming (Liu et al., 2021).

With the training limitation of NN, researchers are used DL. DL deals with recent and modern technique to process images and analyse data, which guarantees the potential results. Application of DL into agricul-tural domain is emerged instead of various domain that DL has been successfully applied (Kamilaris and Prenafeta-Boldú, 2018; Zhu et al., 2018; Santos et al., 2019; Nguyen et al., 2020). Jiang et al. (Jiang et al., 2021) suggest a method to identify the disease in fruit like Apple and

4. Agriculture functions and AI

This section elaborates the inclusive review of the literature that applied automate functions in agriculture (e.g., prediction, harvesting, advanced care crops, weed control, resource management and supply chain) using AI techniques. Within the reviewed papers it was identified that the most common applications of AI are predicting, harvesting, advanced care of crop and so on Fig. 5.

the method is useful to prevent the disease without harming the 4.1. Prediction

environment. In the method, capability of image processing and classi-

fication in DL were applied to classify the fruit image. Deep neural network with different convolution layers and different number of neu-rons are examined and evaluated. The results beat the performance of baseline models. DL stimulates multi-model approach to detect, dissem-inate and monitor the Active Fire Locations (AFL) in agricultural tasks and they are guaranteed the highly accurate results (Sharma et al., 2021). We found that DL has applied to identify seeds and pest, monitor

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Fig. 3. Main AI approaches used in agriculture functions.

optimization (Senocak and Goren, 2021; Guillén et al., 2021) and de-mand and consumer preference (Sharma and Bisen, 2013; Giannakis et al., 2019; Dargan et al., 2020; Monteiro et al., 2021). To cover these sce-narios, ANN and DL techniques are used by 95% of the reviewed papers. The ANN and DPare used to collectreal-time data about multiple agricul-tural parameters, such as production quantity, waste, climate data,

biomass, and land area to estimate yield, manage irrigation and land area and develop drought index. The fact that this AI application in pre-diction model in agriculture is so common can be justified by the com-plex and dynamic nature of the agricultural parameters, thus, it is perplexing to obtain accurate predictions. Thus, AI can be served as a method to face the complexities in the dynamic nature of agricultural



Fig. 4. Agriculture functions and Sustainability growth objectives.   
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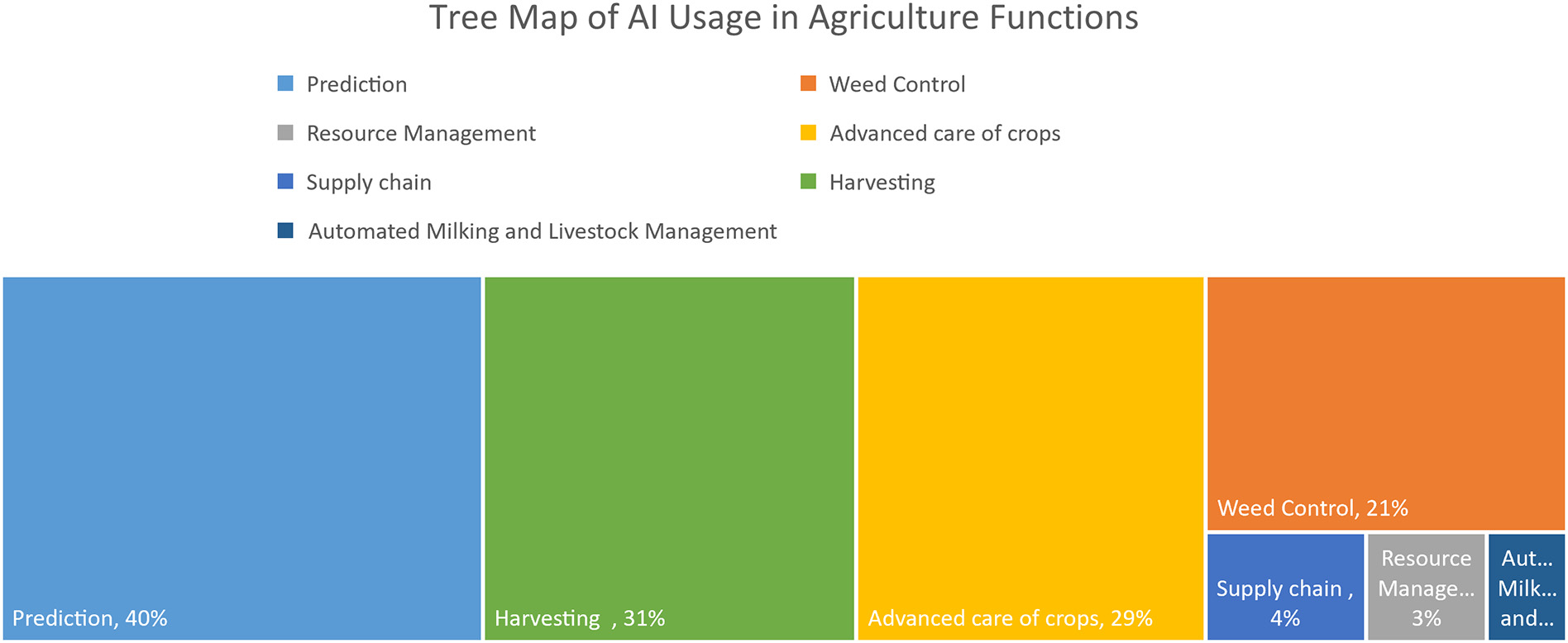


Fig. 5. AI usage in agriculture functions.

parameters. Interestedly, few papers (4) focused on predicting customer demand and preference and market integration for few agricultural products (e.g.: wine, yogurt). The studies focused on the the elements in sensory functions and reveal the associations among evaluators scor-ing and latent features. These preference predictions provide wider chances to develop food product designs in future. What we can con-clude from these literature base is that agriculture sustainability is en-sure production of an adequate food supply.

certain advantages such as minimum wastage, picking efficiency, high picking rate and flexible work force and nighttime operation. Develop-ment of timely, efficient, and careful robotic harvesting solutions lead to complete the harvesting process while generating high quality yields at minimum time consuming and at minimum unrecuperative damages in the harvesting process. Particularly, there have been significant developments of AI towards the sustainability agriculture objective of ensuring production of an adequate food supply. Besides research projects have been performed, very few have developed into the com-

4.2. Harvesting mercial world (Kiwi fruit; Tomato; Cotton; Apple; Rice).

Harvesting is a challenging task in agriculture because harvesters strongly correlate to crop detection, quality cuts, damage, picking and packaging. The labour assets utilize for harvesting is one of the main cost components in agriculture production. To overcome the high la-bour cost component, the prior studies pay wider attention to exploit commercially doable AI applications for harvesting. As presented in Fig. 5, the next most common application of AI is harvesting (28 articles; 31%). Moreover, robotic technique (robot arm) has been identified as an effective tool for assistance in the agriculture industry to harvest the fruit/vegetable while not harming the plant (Hespeler et al., 2021). As a functional model, the robot could automatically move on the rail, identify, detect and locate the mature bunch, hold and separate the tar-get and collect the crop harvested. Precisely identifying and detecting the mature crops encompass a key technique of harvesting robot. An ef-ficient object detection and inspection algorithm are necessary for a robotic platform to be used in harvesting. Different types of sensor tech-nologies use to detect and locate crop in the tree branches, determine the ripeness of the crop, determine the geometry of the tree canopy and locate the tree in orchard, and finally to pick the crop from the tree. Computer vision is used for crop ripeness estimation (Hespeler et al., 2021). In all cases, crops should be picked when they are ripe or mature without mechanical damage to the fruit. This action should take place as be as quick and as cost-effective as possible. Thus, research on harvesting robot mainly concentrations on five key areas; identifying targets under complex background; separating soft crop; level of con-suming energy to harvest, harvesting tools suitability and conformation design to fit with unshaped work fields (Navas et al., 2020). Moreover, thermal imaging for real-time harvesting robot allow to harvest in the evening hours or low light situations (Hespeler et al., 2021). Finally, vision-based crop detection is a critical component for robotic harvest-ing and it includes crop detection with dimension, mass estimation, and localization prior to pick or slice (Lee et al., 2020; Zujevs et al., 2015; Villa-Henriksen et al., 2021). Using a robotic system would enable

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(Santin et al., 2016) and measure plant growth status (Li et al. 2021b), DL to detect underdeveloped plants (Aguiar et al., 2021) and to recog-nize the plant using image-based (Kiourt et al., 2020). Therefore, it is important to recognize the AI applications that favor both disease man-agement and to provide sufficient, safe, and nutritious food to the global population. Particularly, there have been significant developments of AI towards the sustainability agriculture objective of achieving better health and nutrition for a growing population.

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reach final product the end consumers. In the process of SC also includes multiple stakeholders such as farmers, producers, processors, certifica-tion agencies, traders, government, retailers, distributors, and final consumers. Compared with other supply chains, agriculture SC is complex due to the nature of perishability and high supply-demand fluctuations of the products and high consumer awareness towards pro-duce provenance, quality, and safety. All these notes, the review insists that AI applications, especially ML, in agriculture SC enable farmers and other relevant organizations to draw valuable insights on agriculture

4.4. Weed control process, leading to increase agricultural productivity while taking

decisions via data-driven platform (Sharma et al., 2020; Camaréna,

It is necessary to control weed in the crop field to increase the produc-tion of agriculture. The review (26 articles; 29%) highlights that AANN, DNN, CNN and DL to identify and classify the plants as weed using imageprocessing.Thesetechniques includethecrop signalingcompound includes distinctive characteristics that assure the detection of crop dis-eases and ensure the classification of crop and weed (Zangina et al., 2021; Espejo-Garcia et al., 2020; Abdullahi et al., 2017; Monteiro et al., 2021; Raja et al., 2020; Kounalakis et al., 2019; Peteinatos et al., 2020). Next, the signal is transmitted to the robotic arm or Unmanned aerial ve-hicles (UAVs) toplucktheplantthroughserialcommunicationorexecute weed treatment with a flaming and row crop cultivator implement, weed treatment with a herbicide patch sprayer or canopy sprayer (Emmi et al., 2014; Seo and Umeda, 2021; Özlüoymak and Bolat, 2020; Kounalakis et al., 2019). Using AI in weed control enables to decrease unnecessary plants within fewer time frames and minimize fertilizers and herbicides utilization, which cause soil degradation and pollution.

2020). Data pays a crucial role in supply chains thus improvisation in storage, collection, visualization, privacy, security, accuracy, and access of agriculture data can impact application of AI in agriculture supply chain. The common believe in agriculture is that farmer is classified under low income group and many firms/farms in the agricultural are worried with low-profitability. AI is widely used in SC to identify hidden patterns in the data, in this line, SC stakeholders consider to accelerating AI in SC, leads to achieve the expectations of farmers as well as cus-tomers. Contextual factors that have been identified as important influencers of AI in agriculture sustainability objective: alleviate poverty of farmers through formalize products sales to certified markets and global commodity price trends, visualize the farm income prior to the intervention and the formalize the existence market structure. As re-view highlights although SC using AI platforms leads to sustainable ag-riculture objective, questions related to the mechanism of reaction and selectivity of matrices for AIs in consumer aspect are still unanswered.

4.5. Resource management 5. Considerations

Agriculture is naturally bounded with the resource constraints (e.g., land, water and soil). Primarily,womb of agriculture is soil and soil management therefore serves as primal concern in agricultural re-source management. Thus, assessing the suitability of agricultural land becomes the vital task in agriculture development. Moreover, in preci-sion agriculture, irrigation management plays a crucial role. The review emphasized that AI driven agriculture is focusing on methods to opti-mize land (Nguyen et al., 2019; Oliveira et al., 2021), soil (Nguyen et al., 2019; Moya-Rico et al., 2019; Paliwal et al., 2019; Väljaots et al., 2018) and water/irrigation (Mohapatra and Lenka, 2016; Jung et al., 2021; Kakani et al., 2020) considering the benefit it brings to people linked with this profession. Moreover, the weather forecasts such as sunlight, rainfall, humidity, and moisture guide by using AI leads to the optimal use of water for scheduling and planning the crop. To cover these scenarios, ANN, DL, ML and robotic techniques are widely used by the reviewed papers. Ground robots and UAVs are more precisely used to collect soil and water sample and land preparation/ sowing. Neural networks, deep and ML techniques used to computed the normalized soil moisture index to estimate the soil moisture content and develop a model to assess the agriculture land for cultivation in terms of four decision classes, namely more suitable, suitable, moderately suitable, and unsuitable. Since irrigation management plays a critical role in quantity and quality of the crops, estimating evapotranspiration, streamflows and real-time management of reser-voir release by using ML algorithms are highlighted in the review (Sharma et al., 2020). ML helps to process all data samples to construct a heuristic model that can predict factors resulting high yields. While the use of UAVs and robots for sowing has advantages like large area coverage and speed. However, uncertainty in ground measurements and power requirements are restricting the number of task they can perform (Lytridis et al., 2021).

Fig. 6 tabulates the contextual link of usage of AI techniques that are supposed to address sustainable agriculture.

The number of studies that address sustainable agriculture is increasing; however less attention has been devoted to investigating the sustainability aspect of agriculture with regard to AI technology. Ob-viously, the sustainable agricultural is not a typical research field for AI researchers to study; the field of AI research has a historical practice to focus on the industries that involving with new products and ser-vices. Furthermore, researches related to agricultural food tend to ex-amine the way of increasing production rather that addressing sustainability issues. Moreover, most research within the agriculture food industry tends to examine production rather than sustainable is-sues. Due to the vast and increasingly expanding body of literature on agri-technology, this review has focused on how AI technology can improve the sustainability of agriculture industry. The aim of this review paper is therefore to analyse and create an understanding of the different types of AI applications in agriculture industry and how those applications align to achieve the agriculture sustainability objec-tives. A systematic and quantitative evaluation of different agricultural parameters is of vital importance to improve agriculture production and ensure sustainable food supply. Unsustainable agricultural produc-tion practices such as food wastage and production shocks due to cli-mate changes can be minimized if the sector uses AI to get accurate predictions. Our review therefore underscores the importance of AI pre-diction driving the adoption of modern agricultural innovations to en-sure adequate food production and supply. Within the context of the different concepts of sustainable agriculture objectives, AI applications in prediction specifically focus on the potential contribution towards satisfying human needs for food. However, the vast majority of agricul-ture products remain unaddressed, and almost no fully automated prediction models have been developed. Moreover, developing a specific prediction model for market demand and preference of agricul-

4.6. Supply chain ture products is insufficient. However, due to the low repeatability and

difficulties in corresponding, AI implementation in agriculture sector

Supply chain (SC) in agriculture includes several tasks such as pre-production, production, storage, processing, distribution, retail, and

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Fig. 6. AI techniques that are supposed to address sustainable agriculture.

Development of timely, efficient, and careful robotic harvesting solutions lead to obtain desired quality harvest at short-time period and more interestedly at minimum unrecoverable loss. Particularly, there have been significant developments of AI towards the sustainabil-ity agriculture objective of ensuring production of an adequate food supply. Besides research projects have been performed, very few have developed into the commercial world (Kiwi fruit; Tomato; Cotton; Apple; Rice). Moreover, the review revealed that disease detection sys-tems are mostly concerned on leaves and the lower area of leaves is not properly sensed by the camera sensor. As said, besides leaves, AI tech-niques need to be expanded for a variety of plant parts. In line with that (Li et al. 2021b) insisted that AI technologies have been counted on a dif-ferent sensors and imaging technologies to gather a variety of plant data, whereas analyzing different sensor data also relies on different hardware devices, software systems, and different platforms and different monitor-ing scales used to analyse date. Such complex operation process might slow down data acquisition and integration, leading to an information lag. This implies the need for international harmonization and standardi-zation in phenotyping data. The phenotyping data collecting and analyz-ing then could lead to manage cultivating practices, plant breeding and overall management in agricultural functions.

Weeds destructively affect agricultural crop productions by contending with crop plants for resources, including soil moisture and nutrients. Providing sufficient and healthy foods for ever growing population heavily depends on the ways we control weeds and apply fertilizers in efficient manner. For future work, the review opines (Kounalakis et al., 2019) that more robust weed recognition approaches could be extended with additional data capturing conditions (like illu-mination, grass density) and sampling techniques could be synthetized with techniques like Synthetic Minority Over-sampling Technique (SMOTE) and Adaptive Synthetic Sampling (ADASYN).

Natural resources were jeopardized and different forms of environ-mental degradation became apparent, thus conservation practices of

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6. Conclusion and further research directions

As sum in the literature consulted, we observed that AI applications are extensively adopted nowadays to enhance operational automation and performance of agricultural industry. We found that the most common applications of AI for agriculture are prediction model for total agricultural output value, followed by harvesting applications. Though agriculture is naturally bounded with the resource constraints, AI applications in natural resources management (such as water, soil, land) are presently at unsatisfactory level. We were further able to iden-tify that final consumer aspect in agriculture SC needs to be devouring extensive attention in order to achieve one of the key agriculture sus-tainability objective; alleviate poverty of farmers. Moreover, it was witnessed in this review that in recent work the use of AI and image processing techniques has become more common to improve the sus-tainable agriculture. When consider the DL models, these models are suffer from task dependent since all the models are using general word embedding vector. To overcome this problem attention-based DL models can be developed. In the future researchers can consider de-veloping attention-based DL models. Likewise, the future studies should intend to address the gaps that identified in this systematic review such as under-utilised commercial crops appraisal, data capturing conditions, natural resource standards, functional areas and geographical locations.

This study has provided useful information to understand the impli-cation of AI in agriculture sustainability. However, there can be limita-tions in this research. This work may extend by considering project costs, usability and regional challenges in AI applications. In addition, can explore how attention-based DL models are used in agriculture with the newest AI improvements. Due to the growing application of AI itself is not adequate to obtain sustainable objectives; it is required to assess the adaptability of AI together with other useful maneuvers like policy support for AI developers and programme intervention to implementations.

Credit authorship contribution statement

Vilani Sachithra: Conception and design of study, Acquisition of data, Analysis and/or interpretation of data, Writing –original draft, Writing –review & editing L.D.C.S. Subhashini: Conception and design of study, Acquisition of data, Analysis and/or interpretation of data, Writing –original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influ-ence the work reported in this paper.

Appendix 1. AI, Agriculture functions and Sustainability growth objectives

Sustainable objectives

1. Ensure production of an adequate food supply.

2. Alleviate poverty.

3. Achieve better health and nutrition for a growing population. 4. Conserve natural resources.

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