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An Intelligent Framework for Sustainable Horticulture: A Systematic Literature Review

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Abstract – The source of income and livelihood of around 70% of the Indian population depends on agriculture. Agriculture plays a significant role in the Indian economy. However, an exploding global population, a changing climate, global warming, soil pollution, rapid urbanization, and the exhaustion of arable land, among other issues, have harmed agriculture production and its dependents in India. Available cultivable land is decreasing

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yearly, and current food production using traditional farming practices will not be enough to feed millions of people in the coming days. There is a pressing need to revolutionize our agricultural and horticultural practices using advanced technologies like IoT, AI, cloud computing, data analytics, blockchain, etc.

In this study, we have presented a three-layered Internet of Things (IoT) architecture appropriate for horticulture production and conducted a Systematic Literature Review (SLR) to demonstrate the extensive research accomplished in various application domains of IoT and Artificial Intelligence (AI) concerning horticulture production cycle. In addition, we have discussed challenges and open issues in deploying IoT to horticulture from a three-layered perspective. Further, we differentiated existing research accomplished in the key application areas of IoT and AI concerning the horticulture production cycle. This article identifies key research areas that should be investigated, thereby assisting researchers, industry experts, and academicians in investigating open issues.

Keywords: IoT and AI in horticulture; IoT in horticulture; AI in horticulture; smart farming.

1. INTRODUCTION

Agriculture is one of the primary livelihood sources for most of India's population [1]. The agriculture/horticulture system includes irrigation, the main issue faced by developing countries like India. Due to the lack of proper irrigation facilities, farmers rely entirely on a good monsoon. India has an isotropic climatic condition, but climate change due to global warming results in erratic monsoons, and hence, the use of agricultural resources remains halfway in its implementation [2]. India's agriculture system is facing massive loss of nearly 15% due to heavy industrialization and other service sectors [3].

The agriculture sector in India is facing losses due to many reasons. The natural causes of crop loss are floods, droughts, calamities, bad weather, etc. Apart from the natural causes, one of the primary causes is traditional and inadequate irrigation practices. Only 22% of the Indian farms have regular irrigation sources, and others depend on monsoon rains. Poor irrigation and water management techniques, lack of permanent irrigation facilities, and underutilization of resources have led to low productivity. The second major cause of the loss is low productivity due to the degradation of soil quality. Soil degradation can be natural or human-caused. The natural causes are soil erosion, floods, famine, landslides, wildfires, earthquakes, etc. Human-induced causes are outdated agricultural practices, poor irrigation, over usage of chemical fertilizers, excessive use of pesticides and herbicides, deforestation, poor crop residual management, improper crop cycles, etc. The third major cause is loss due to the structure of land holdings. According to the agriculture census, 85% of the land holdings are less than 2 hectares and are scattered (not at one location). Only 5% of

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landholdings are more than 4 hectares. These smaller and scattered fragments cannot facilitate modern machinery for cultivation besides the traditional farming practices, which has led to low productivity [4].

Recently, Indian farmers are showing interest in horticulture, which is the art of growing fruits, nuts, and flowers. India has emerged as the world leader in the production of a wide range of fruits, including mango, banana, guava, papaya, sapota (Chikoo), pomegranate, lime, and amla (Indian gooseberry), and stands second amongst the world's major producers of fruits and vegetables [5]. The land of rich cultural heritage and diversity has also dominated the production of spices, coconut, and cashew nuts. Ever since the farmers drifted towards horticulture, they have been successful in adopting the cultivation of new crops. Some promising crops that can benefit the farming community are kiwi, gherkins, kinnow, date palm, oil palm, etc. [5] However, climate change brings unexpected obstacles to horticulture such as droughts and floods. Apart from climatic changes, horticulture has numerous other challenges such as a shortage of arable or cultivable land due to urbanization, lack of investment, labor shortage, water scarcity, rising global temperatures, plant diseases, weeds, postharvest loss, and so on. The forecasted demand for food can only be met only if farming methods become smarter using cutting-edge technologies [6].

In this context, for a significant improvement in agriculture or horticulture production in smaller farmlands with available irrigation sources and to keep the soil health at the optimum level, there is a pressing need to use AI-integrated IoT in farming [7]. The prime advantages of smart agriculture are increased productivity, cost efficiency, sustainability, waste reduction, low production risks, and operational automation [8]. Fig. 1 shows prime technologies used in the automation of agriculture or horticulture, such as IoT, AI, Cloud Computing, Big Data Analytics, and Blockchain.

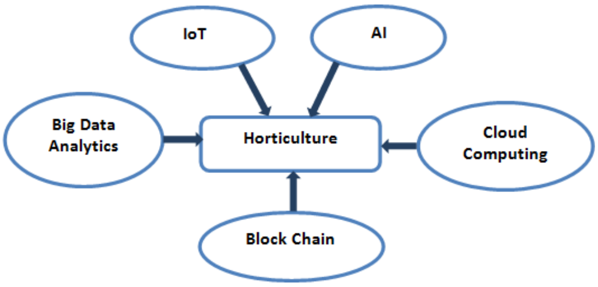

Figure 1. Key Technologies in horticulture

AI is an effective tool in modern agriculture that can be used at various stages. Some of them are, deciding the right time to sow and harvest, knowing soil type and amount of fertilizer to be applied, yield prediction, disease detection at the early stages, market analysis, etc. AI-enabled robotics combined with computer vision helps in precision crop harvesting with minimal damage to the yield. The robotic sprayers reduce the herbicide and pesticide volume

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needed for herb or pest control as they target only unwanted herbs and infected plants, not affecting healthy crops, thereby reducing overall cost and labor problems. AI's predictive analytics determines the exact time to sow the seeds and harvest the yield based on market demands, to fetch better profits for the farmers. Computer vision coupled with AI helps detect plant diseases at the early stages so timely measures can be taken to prevent crop loss. The harvest quality checks on a large-scale benefit farmers and retailers fix crop prices.

IoT-enabled fields allow farmers to increase productivity using optimal resources. Precision irrigation using IoT sensors can determine the exact amount of water or nutrients required for the plants based on weather conditions, soil minerals, and soil health. IoT drones can assist in spraying pesticides, herbicides, and crop monitoring without human intervention, solving labor shortage problems in agriculture. Smart greenhouses produce a better yield in a controlled environment where IoT plays a crucial role in controlling, irrigating, monitoring, and managing greenhouse echo-system. The blended application of IoT and AI to agriculture will be the driving force of modern agriculture to meet the explosive food security of the modern world.

2. RESEARCH METHODOLOGY

We used a Systematic Literature Review (SLR) approach as the research methodology to investigate and depict reviews on carefully selected peer-reviewed journals, conference proceedings, and web articles from reputed industries. Fig. 2 depicts selecting journals, conference proceedings, and web articles for our review.

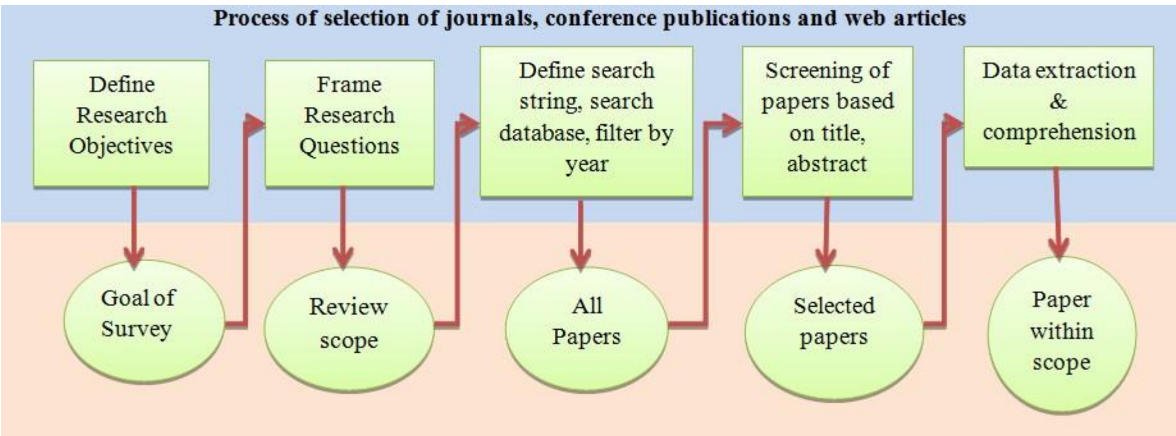

Figure 2. Research Methodology

A. *Research Objectives*

The following are the primary goals of this study

- Objective 1: To explore state-of-the-art research in IoT and AI technologies in the

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field of horticulture.

- Objective 2: To demonstrate the significance of IoT and AI technologies in horticulture to mitigate the problems in the current horticulture practices.
- Objective 3: To compare state-of-the-art research in IoT and AI concerning horticulture and their outcomes in the different application domains of the horticulture production cycle.
- Objective 4: To highlight advantages, challenges, and open issues in the implementation of IoT in horticulture.

B. Research Questions

We have framed Research Questions (RQs) that are appropriate for meeting the research objectives mentioned in section II to limit the scope of our study and avoid deviations in our current research. The SLR is carried out to answer these research questions systematically and comprehensively. Table 1 lists the research questions and the motivations for selecting them.

Table 1. RESEARCH QUESTIONS AND MOTIVATION

No.	Research Question	Motivation
RQ1	What key technologies can be used in horticulture to improve horticulture production?	To identify critical technologies which can mitigate problems and improve horticulture production using optimal resources
RQ2	What are the different sensors, communication protocols, and application areas of IoT in horticulture?	To present a comprehensive description of devices, sensors, protocols, and applications based on the Three Layered Architecture of IoT.
RQ3	What are the benefits, issues, and challenges of implementing IoT in horticulture?	To identify and project advantages, issues, and challenges associated with using IoT to automate horticultural processes and practices.
RQ4	What are the major application areas of AI in horticulture?	To study and depict research carried out in AI and related techniques for providing more innovative solutions in the major application areas of horticulture.

C. Search String

To achieve the research objectives and to answer the research questions mentioned in the previous section, we carefully selected articles from peer-reviewed journals indexed in Google Scholar, Scopus, and Web of Science databases published between 2016 and 2022

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(till January) that are relevant to our research. Table 2 lists the string used and databases searched for referring journals.

Table 2. SEARCH STRING

Databases	Search string	Domain
IEEE Elsevier MDPI IOP Springer	• IoT in horticulture • IoT in agriculture • AI in horticulture • AI in agriculture • IoT and AI in horticulture or agriculture. • ML or DL in agriculture. • Smart farming	Agriculture Horticulture Greenhouse

D. *Research Contribution*

The main contributions of our work are as follows.

1. We proposed Three-Layered Architecture of IoT for Horticulture.
2. We put forth a comprehensive description of different sensors, communication protocols, and applications of IoTbased on three-layer architecture.
3. We discussed advantages, challenges, and outstanding issues while deploying IoT in horticulture from a three-layer perspective.
4. We set forth a comparative study of AI and related techniques in the main application areas of the horticulture production cycle.

E. *Structure of the Article*

This article is organized into the following sections to meet the stated objectives and research questions. In section III we presented Indian horticulture crop production statistics and their contribution to Indian economy. In section IV we discussed the role of AI - IoT in India's horticulture, Three Layered Architecture of IoT for Horticulture, layer-wise detailed explanation focusing on sensors, communication protocols, and applications, advantages of using IoT in horticulture, challenges, and open issues while deploying IoT in horticulture. In section V we described the role of AI and its significant application domains in horticulture. In section VI, we summarized with a conclusion.

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3. HORTICULTURE IN INDIA

Horticulture production contributes 33% of the Gross Value Added (GVA) to the Indian economy. Aside from improving rural employment and providing more revenue to farmers, it also ensures food and nutritional security. The total horticulture production in India is approximately 320 million tonnes per year, surpassing total food grain production. Surprisingly, this massive output comes from a considerably smaller area of 25.66 million hectares of horticulture land (TABLE III) against 127.6 million hectares of the area used for food grains production. Horticultural production raised about 38% between 2004-05 and 2019-20 (TABLE III). A primary reason for the increased horticulture production is the growing demand for food (due to the population explosion). Few others are growing health-consciousness among people, and better profits for all those involved in the horticulture food supply-chain management like farmers, retailers, commissioning agents, etc. [5].

Table 3 summarizes horticulture crop production statistics in India (area and production-wise). According to the table data, for the year 2019-20, vegetables are the highest produced horticulture crop (188 million tonnes from 10292 hectares), fruits are the second highest produced (95.743 million tonnes from 6660 hectares), and plantation crop stands third (16.412 million tonnes from 3866 hectares). Spices (9.372 million tonnes from 3866 hectares), flowers (2.873 million tonnes from 294 hectares), aromatics-medicinal plants, and honey occupy fourth, fifth, sixth, and seventh place in horticulture production, respectively. The total horticultural land has expanded by 377 hectares or about 1.47 percent of total horticulture land, and total output has increased by 2.682 million tonnes, or about 0.86 percent of total production, from 2017-18 to 2019-20 [9].

Table 3. SUMMARY OF HORTICULTURE CROPS IN INDIA [9]

Year	2017-18		2018-19		2019-20	
Crops	**Area** ('000 Ha)	**Production** ('000 MT)	**Area** ('000 Ha)	**Production** ('000 MT)	**Area** ('000 Ha)	**Production** ('000 MT)
Fruits	6510	96447	6597	97967	6660	95743
Vegetables	10061	184041	10073	183170	10292	188009
Flowers	324	2631	303	2910	294	2873
Plantation	3744	18082	3872	16350	3866	16412
Spices	3876	8497	3957	9428	3866	9372
Honey		105		120		120
Aromatics and Medicinal	720	866	627	795	634	822
Total	**25235**	**310669**	**25429**	**310740**	**25612**	**313351**

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*Area in _000 hectare, production in _000 million tonnes

The Figure 3 shows a graphical representation of summary of total horticulture land utilized and total crop producedbetween 2017-18 and 2019-20 (Source Table 3).

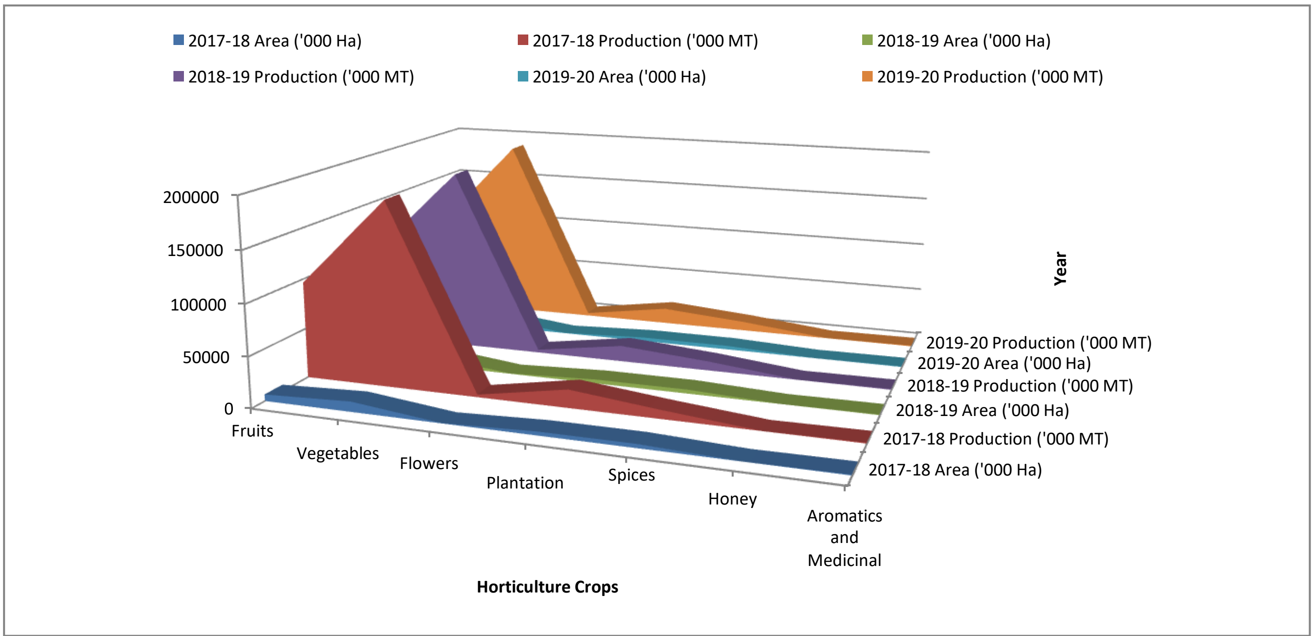

Figure 3. Graph showing summary of horticulture crops in India (source Table 3)

From the statistics depicted in Table 3 and Figure 3, we can conclude that the area-wise and production-wise horticulture crop is increasing yearly. Farmers, agro-based industries, and those involved in the horticulture food supply chain are seeing horticulture as a promising sector in terms of food security and revenue.

The population explosion has left a significant gap between demand and supply despite increased horticultural production. In the coming days, more demand for food security will be increased. The current world population is 7.9 billion (January 2022), with a projected increase to 10 billion by 2057, and food demand is anticipated to increase by 58% to 98% in the next few years. However, the amount of land available for agriculture and horticulture remains constant. Meeting global food security on limited available land presents a more significant challenge.

4. AI - IOT IN HORTICULTURE – INDIA

A. AI in Horticulture

17-18% of India's GDP is contributed by the agriculture sector, employing more than 50% of

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the total workforce [10]. India is the second largest producer and a major exporter of various agricultural commodities. However, Indian agriculture faces many challenges like low productivity due to unpredictable weather conditions, depletion of natural resources, poor supply chain efficiencies, labor shortage, and traditional farming methods. The COVID – 19 outbreak further worsened the cultivation and harvesting activities due to the unavailability of migrant laborers. Technology-driven smart farming with the aid of IoT and AI can revolutionize Indian agriculture and its allied sectors to their highest capabilities. Leveraging technology to collect real-time environmental data from the farm fields using an IoT ecosystem, analyzing raw data using AI techniques to draw insights and control the farm environment to increase productivity by addressing existing challenges is crucial. Thus IoT and AI, if adopted in the agriculture production cycle, could fetch huge benefits concerning productivity, economy, sustainability, and resource utilization [11]. Table 4 shows applications of IoT – AI in Indian agriculture.

Table 4. APPLICATIONS OF IOT – AI IN INDIAN AGRICULTURE

Sl. No.	IoT/AI Solutions Company	Application Domain	Methodology	Use Cases	Reference
1	SatSure (Data analytics based)	Crop statistics	Integrates satellite, weather, and IoT analytics	Assists farmers in knowing the right time to sow, irrigate, and fertilize	[12]
2	Qzense (IoT, Cloud, Analytics based)	Fresh Food Management	Grading of food by tracking/capturing insights of spoilage, ripeness, and shelf life.	Helps farmers to gain profits from their produce	[12]
3	Aarav Unmanned Systems	End to End Drone solutions for framing	Provides 3D geographical topography information about the field	Helps in irrigation, planning	[13]
4	Aquaconnect (AI and remote sensing technology based)	Farming of shrimp and fish.	Use deep learning and remote sensing technologies.	Farm advisory to improve water quality, and aquatic health and optimize feed consumption	[14]
5	BharatAgri	Personalized farming solutions	Weather forecasting, satellite imagery, crop	Personalized farming suggestions based on	[15]

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		from sowing till harvesting	advisory	the weather forecast, soil and water testing, crop suggestion	
6	CropIn	Farm management, Farm risk and assessment solution, supply chain traceability, seed to shelf traceability solution	AI models, deep learning, analytics, digitizing farm ecosystems	Smart agri-solutions using decision-making tools to provide consistency, sustainability, and dependability.	[16]
7	Agdhi	Automated Seed quality testing, crop disease detection, and prevention	Artificial intelligence, machine learning, cloud, IoT, and blockchain are used. Seed images are captured, and the insights about the batch, and real-time crop data are stored using blockchain	Image processing and computer vision to test and classify seeds and infected plants.	[17]
8	Intello Labs	Quality assessment of fresh fruits, vegetables, spices and nuts.	AI, ML, and computer vision are used for digitizing quality assessment of fruits, nuts, and vegetables.	Prevents food wastage, increase quality of produce, fair pricing and digitize food quality.	[18]
9	GramworkX	Decision support system, farm resource management tool	IoT, AI, Cloud computing, and machine learning are used. IoT sensors read farm parameters like temperature, pressure, humidity, rainfall, and soil moisture and send them to the backend cloud.	The app helps farmers to improve yield by 20 -30% , saves water, and provides automated remote farm control	[19]
10	Fasal	Smart and sustainable	IoT and AI is used to sense data from the	Helps farmers to make decisions and manage	[20]

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	development for horticulture crops.	environment like weather condition, soil moisture, temperature etc., and provides farm and crop-specific advisory.	crops through data-driven smart farming (weather prediction, irrigation alerts, and disease and pest prediction).

B. IoT in Horticulture

IoT is defined as a network of devices, objects, vehicles, or anything, identified by unique identifiers (UID) and capable of sensing, actuating, computing, and communicating in the network without the need for human-to-human or human-to-machine. IoT ecosystem consists of sensors, microprocessors, microcontrollers, actuators, communicating hardware, software, etc., which can collect data from the target environments, process them, transmit them and act based on collected data to provide intelligent solutions. Since the birth of this technology, it has revolutionized how businesses operate, industries function, improved sales, and changed people's lifestyles. Smart cities, smart homes, smart farms, smart health care, and smart transportation systems are some smart solutions built using IoT. Figure 4 depicts the IoT ecosystem for several industries.

i.Three Layered Architecture of IoT for Horticulture

As shown in Figure 4, the IoT architecture for horticulture comprises three critical layers: Environmental Data Acquisition Layer, Data Analysis and Communication Layer, and Application Layer.

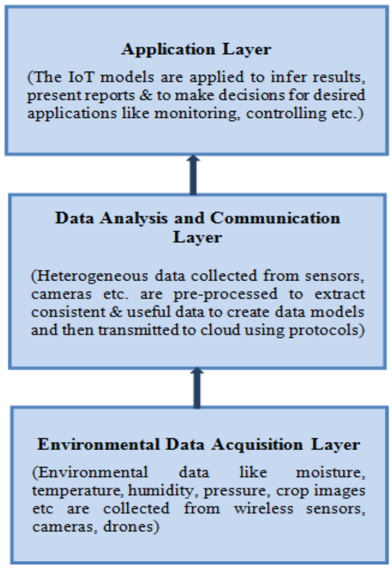

Figure 4. Three Layered Architecture of IoT for Horticulture

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1. *Environmental Data Acquisition Layer*

Data from the target environment can be fetched using different wireless sensors and cameras mounted in robots, Unmanned Aerial Vehicles (UAV), or drones [21].

a) *Wireless Sensors*

Wireless sensors are crucial in driving the IoT ecosystem. They sense or perceive specific parameters from the surrounding physical environment and produce output through signals, voltages, etc. The sensor output is gathered and processed further to act depending on the application need (irrigation, fertigation, etc.). The input parameters (like soil moisture, atmospheric temperature, pressure, light, humidity, etc.) trigger specific properties of the sensor (like conductivity, capacitance, resistance, magnetic field, etc.), by which output is generated (like the voltage, current, etc.) and then transmitted to the cloud through a base-station or gateway. The real-time data stored in the cloud are processed and used for controlling or monitoring IoT deployed environments. IoT sensors are miniature electrical/optical devices with limited functionality. They operate on low power sources, which make them, sustain for more extended periods without changing or replacing batteries. Table 5 gives a comprehensive list of sensor types, their operation, and their applications in agriculture and horticulture.

Table 5. SENSOR TYPES AND OPERATION

Sensor Type	Parameter	Operation	Applications in Horticulture/Agriculture
Accelerometer sensors	Transport, livestock monitoring, hand pump	Measures acceleration of an object by converting mechanical energy into an electrical signal	Livestock monitoring is used to detect acceleration or vibration during transportation (helps in preventing damage) [22] [23]
Acoustic sensors	Weed detection, fruit detection, grain harvesting, water level, grain silo level	Measures water level, and grain level in steel containers, and detects animals and plant genomes by emitting ultra-sonic waves	Used to detect plants and soil, thus helping in cultivation. Also used in fruit detection, weed detection, and herbicide application [24]
Airflow Sensors	Air permeability	Measures air penetration and permeability of the soil	It helps in knowing soil type, texture, and force required in plowing the soil
Dielectric Soil Moisture Sensors	Soil moisture	Measures the dielectric permittivity (an electrical	Used precision irrigation by measuring moisture content of the soil

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		property) by generating a voltageproportional to it	[25] [26] [21]
Electrical capacitance/ Electrical conductivity Sensors	Soil moisture, humidity, water pH	Measure moisture level, humidity, and fluid level based on electrical conductivity or capacitance	Used to detect essential agricultural characteristics such as temperature, humidity (vapours in the air), and pH [27] [25] [26]
Electro-chemical	Soil pH, soil minerals	Measures pH by detecting specific ions in the soil	Used to evaluate soil pH and mineral levels, allowing more precise fertilising [28] [29]
Gas sensors	CO_2, CO, toxic/hazardous gases	Measures concentration of gasespresent in the atmosphere as output voltage	Helps in prevention of food/livestock spoilage [29] [24]
Gyroscope and image sensors	Drone, UAV control	Measures angular velocity or gyration	Used in drones and robots for soil healthand land analytics
Thermocouple andThermistor	Temperature	Measures temperature indicatedby the change in output voltage or Resistance	Helps in precision irrigation [25] [21] [24]
Mass flow sensors /Load cell	Yield/harvest weight, waste weight, irrigation, Fertigation	Weighs the harvested yield, loaded containers, or agriculturalwaste	Used to weigh harvested yield or agricultural waste, irrigation, fertigation. [30]
Mechanical sensors	Soil mechanical resistance	Measures mechanical resistanceof the soil or soil compaction	Helps in helps in plowing or tilling the field by measuring the force required for plowing tools or cultivators to plow fields
Magnetic flux	Electrical current, Power	Measures power consumption, magnetic flux leakage	Used to detect leakage in pipelines [25]
Optical Sensors	Crop growth rate, harvest volume, solar radiation, disease detection, soil quality	Detects light and solar radiation. Use near-infrared, mid-infrared,and polarised light spectrums tomonitor distinct frequencies	Used in determining soil type, texture, plant growth, harvest volume etc. [24] [31]

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.Optoelectronic sensors	Weed control	Detects based on LED	Identifying and classifying plants helps in weed detection [32]
Pressure sensor	Pressure level, irrigation, water Level	Measure pressure indicating electrical signal when pressure Applied	Useful in irrigation [24]
Passive Infrared (PIR) Sensors	Motion detection, object tracking	Detects movement of an object based on infrared energy or heat, indicating as an electrical signal	Helps in livestock tracking and monitoring.[32]
Ultrasonic sensors/proximity	Distance, water/liquid level, spray coverage	Measures distance or liquid levelby emitting ultra-sonic waves	Helps find water level in tank, spray coverage and distance detection, crop canopy measurement, crop monitoring [26] [33]
Ultra Violet (UV) Sensor	Growth of plants	The photodiode generates current when exposed to UV rays, the current is converted into voltage to indicate the plant growth	Used in monitoring the effective growth of plants [27] [34] [24]

2. *Data Analysis and Communication Layer*

Huge data collected from target environments like agricultural fields, greenhouses, and indoor farms are heterogeneous, incomplete, inconsistent, and tend to beunclean. Hence, this data must be made consistent and valuable with the help of data mining methods like data-pre-processing,data reduction, and data modeling [21] [27].

a) Data Analysis

- **Data Pre-processing:** In this step, raw data (likesoil moisture, temperature, humidity, pressure etc.) are processed to remove noise (errors/inconsistent data) [25] [26].
- **Data Reduction:** Here, the large data is reduced intoshort meaningful representations keeping original-data’s integrity intact.
- **Data Modeling:** Here, the knowledge mining (patterns) from the previous step‘s data representations is done to create data models. Usually, the data modeling techniques combine techniques like classification, clustering, and association rules to establish a meaningful relationship from the heterogeneous data [35].

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b) *Communication in IoT*

The data models created from the acquisition methods must be sent to the cloud to store, infer and present to the users. The data can be fetched using a web interface or mobile applications to monitor or control the target environment. The IoT communication interface provides many protocols TABLE VI gives a comparative understanding of IoT communication protocols and technical specifications like frequency, approximate range, data rate, power consumption, etc. [36].

Table 6. IOT COMMUNICATION PROTOCOLS AND SPECIFICATIONS [37]

Protocol	Standard	Approximate Range	Frequency	Data rate	Power Consumption
LoRA	LoRaWAN	2.5 km (Urban), 15 km (Suburban)	Various	0.3 to 50 Kbps	Low
MQTT	ISO/IEC 20922	NA	NA	<256 Mbps	Low
Sigfox	Sigfox	30-50 km (rural), 3-10 km (urban)	900Mhz	10- 1000 bps	Low
Z Wave	Z-wave Alliance	30 meters	Various	0.3 to 50 Kbps	Low
ZigBee	IEEE 802.15.4	10–100m	2.4 GHz	250 kbps	Low
Bluetooth	Bluetooth 4.2 core Specification	50 – 150 m (Smart/BLE)	2.4 GHz (ISM)	1 Mbps (Smart/BLE)	Low
WiFi	IEEE 802.11n	50 to 100 m	2.4 GHz and 5 GHz bands	<600 Mbps	High
Cellular	GSM/GPRS/EDGE(2G), UMTS/HSPA(3G), LTE(4G)	<35 km (GSM), <200 km (HSPA)	900/1800/1900/2 100 MHz	35-170 kbps	High
NFC	ISO/IEC 18000-3	10cm	13.56 MHz (ISM)	100-420 kbps	Low

*BLE-Bluetooth Low Energy, GPRS-General Packet Radio Service, GSM-Global System for Mobiles, LoRA-Low Range, LTE-Long Term Evolution, MQTT-Message Queue Telemetry Transport, NA-Not Applicable, NFC- Near Field Communication

3. *Application Layer*

The data collected was pre-processed and sent to the cloud using communication protocols listed in the above table. Furthermore, data saved in the cloud can be used for various

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applications. The primary application domains of IoT in horticulture are monitoring, controlling, and tracking. These domains are further classified into the following types.

a) Soil and Fertilizer Monitoring
b) Irrigation Monitoring, Controlling and Precision Farming
c) Temperature and humidity monitoring
d) Disease Monitoring and pest control

a) Soil and Fertilizer Monitoring

Soil is the mother of the plant. The food we eat comes from the soil's nutrients (soil minerals). Soil analysis determines the soil type and the amount of nutrients present in a particular area. The suitability for a specific crop or mineral deficiency, fertilizer recommendation can be determined by sensing specific parameters like soil chemicals, moisture, pH, air permeability, mechanical resistance, etc. [38]. Soil type, irrigation level, manures and fertilizers, topography, and crop history are crucial in determining soil nutrient levels. The perception and calibration of such soil parameters help in better yield by determining and recommending specific fertilizer, land suitability checking, and mapping, and avoiding soil pollution through unwanted or excessive fertilization [32] [28] [39].

b) Irrigation Monitoring, Controlling and Precision Farming

Availability of freshwater plays a major role in farming, as water is a critical resource. Many plant and animal species and people all over this planet could survive because of freshwater availability. Today's world is facing a water shortage for drinking and irrigation. Traditional agricultural and horticultural practices waste 90% of the available freshwater as they rely on flood irrigation or furrow irrigation. Even though many techniques and tools like drip irrigation, sprinkler irrigation, rainwater harvesting, etc., are in use, they cannot optimize the existing water resources for sustainable agriculture or horticulture. These erroneous practices impair crop production and reduce soil fertility by interfering with microbial processes [29] [25].

The adoption of IoT for irrigation monitoring and controlling prevents water wastage and results in better yield. Therefore, it helps determine the exact need and supply of water accordingly. The data collected from sensors like soil moisture, temperature, humidity, etc., and their calibrations, can determine thirsty plants and the quantity of irrigation, and fertigation. The sensors can be used to sense the water level in the tanks, and irrigation ponds, and hence, outlets/inlets of motors and tanks can be controlled automatically [28] [35].

c) Temperature monitoring and humidity monitoring

Temperature and humidity are critical parameters for agriculture and horticulture throughout the production cycle. Measuring and evaluating them could determine the plant's health,

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amount of irrigation required, post-harvest storage, andprevention of spoilage [27] [23] [22].

d) Disease Monitoring and pest controlling

Plant diseases affect crop yield and incur losses to farmers. The crop loss affects the financial security of the farmers and increases debts, resulting in suicides. Detecting and treating plant disease during the early stages is a significant phase in the horticulture or agriculture production cycle. The traditional methods fail to accurately determine the type of disease and specific treatment methods before it goes out of control [38] .

Several techniques, like image processing combined with AI- techniques, could forecast diseases [40]. The raw images captured from UAVs, RGB cameras, field sensors, and remote sensing satellites are processed to identify and classify pests and diseases accurately [41]. IoT technologies like robotic devices, UAVs (drones) for spraying pesticides and weedicides by spotting them with high precision prevent crop loss. Table 7 presents future IoT and AI devices used in India.

Table 7. FUTURE IOT AND AI DEVICES USED IN INDIA

Future Technology	Uses in Horticulture
Unmanned Aerial Vehicles (UAV)	The use of UAVs in horticulture helps in monitoring the crop. The drones can fly over the field and take high- resolution images. These images are uploaded to the cloud to be processed and stored. The high-resolution images can be analyzed for plant counting, plant height measurement, water needs, disease detection, and pest control. The drones can also be used for spraying pesticides.
Robots	The use of robotic devices can counter the major horticulture problem, a labor shortage. The adoption of robotics in horticulture helps in several ways, from sowing to till harvesting. The robotic pesticide sprayer helps in disease and pest control. Further, they can be used in crop monitoring as well as harvesting. The use of robots in the precise harvesting of horticulture crops prevents fruit damage while harvesting.

ii.Advantages of using IoT in Horticulture

There are many advantages to using IoT in horticulture at various levels. They are mentioned in the Table 8.

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Table 8. ADVANTAGES OF USING IOT IN HORTICULTURE [42]

Advantages	Description
Better and effective resource utilization	Much data collected from horticulture fields like soil moisture, temperature, humidity, air permeability of the soil, moisture content of grains, soil fertility, water level, drain level, etc. can be used to track the resources needed for horticulture crops. Thus, IoT enables better monitoring, controlling, and managing of horticulture fields with optimal resources and equipment [43].
Efficient management and control	Automating horticulture processes of the production cycle like irrigation, fertigation, weed/pest/disease control, etc. enables farmers to manage larger fields with fewer efforts and labor but more efficiently [27] [29] [33].
Accurate yield prediction and higher revenue	Harvest estimation allows farmers and the people involved in the supply chain to plan, sell and distribute the yield effectively. This not only prevents food spoilage but also fetches better profits [35] [30] [44] [23] [22] [21].
Enhanced quality and volume	Precision horticulture in controlled environments like greenhouses, and poly-houses not only results in increased volume of the product but also increases the nutritional value, size, and texture with the overall quality of the yield [45] [46].
Decreased cost and loss prevention	Early detection of anomalies like diseases, weak crop growth, and extreme weather at early stages can help mitigate them, thereby preventing crop loss [38].

iii.*Challenges and Open Issues in the Implementation of IoT in Horticulture - A Three-Layer Perspective*

Integrating IoT in agriculture or horticulture is a challenging task at every stage from the data acquisition to the application layer. From the proposed three-layer architecture of IoT outlined in section 4 (B) (i), we explore the problems and open issues in this section.

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Table 9. CHALLENGES AND OPEN ISSUES - A THREE-LAYER PERSPECTIVE

	Perspective	Challenge	Open Issue
Perspective of Environmental Data Acquisition	*Accessibility and availability of sensors, controllers, boards, and peripherals*	Standard IoT (Off-the-shelf) products are notavailable in the local markets. The customized implementation is time-consuming and relatively not affordable.	Electronic industries have a huge need and demand to produce off-the-shelf products suitable for crops.
	Design, deployment, and calibration	Small farm holders face issues in the deployment of IoT because of the location and topography. Many farms will be in remote places and hilly regions whereconnectivity may not be available.	There is much room for study in IoT regarding fool-proof designs, sensor data gathering, calibration, and communication protocols.
	Investment cost and maintenance cost of devices	For small and mid-sized farm holders the deployment of IoT incurs set-up costs, running costs, and maintenance costs and they face affordability issues. The set-up cost due to hardware, sensors, controllers, IoT gateways, etc. is not economic most of the time, considering the farm size and income generated from the farms.	However, there is still scope for creating cost- effective architectures suitable for small and mid- sized farms with long-term maintenance and without\less frequent replacements and service.
	Lack of expertise	Often farmers struggle to switch from traditional methods to technology-assisted farming due to a lack of expertise or skills to understand the technical aspects. They should rely on experts or technicians to install, use, and maintain the IoT devices for their farms.	The user interface and applications related to IoT should be made easier so that the farmers feel comfortableusing them.
Data Analysis and	*Poor connectivity and reliability*	Connectivity is a primary concern as most farms will be located in remote places. The lack of network	The infrastructure problem could be solved by setting up the required infrastructure (base

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		infrastructure leads to a poor connection which makes the IoT device unreliable, as the whole IoT architecture depends on communication technologies and protocols for data transmission.	stations, towers, gateways, and antennas).
	Data Security	This is one of the significant problems in IoT as it arises at different levels of IoT implementation. Since IoT for agriculture or horticulture will be deployed in an open environment they are prone to damage, theft, and animal attacks.	IoT comes with millions of devices connected to the internet, it is challenging to track, authorize and authenticate the devices. Hence, the identification of IoT devices is a significant issue and has to be addressed. Third, as massive data is collected, shared (through the internet), and stored in the cloud, data privacy and security is a more significant challenge.
	Data pre-processing, storage and analytics	Data calibration (extracting valuable data) from the massive volume of data produced periodically and converting them into actionable indicators is challenging.	There is a scope for creating optimized (faster and better) methods/algorithms for data analysis and processing.
	Cost of data transmission and servicing	Deploying of transmission infrastructure and protocols increases the burden on the farmers. This is a major barrier to the deployment of IoT to farms as frequent servicing technicians' visits to remote and far away farms are not feasible and affordable for the farmers.	Cost-effective infrastructure for data transmission and IoT service methods must be created and made available by respective governments or organizations.
Perspective of Applications	*Complicated business model and ecosystem*	There is no standard IoT business model when the customer does not have the affordability to technology and identifying customers of a specific service or a device is not clear.	Standard business models must be designed for all types of farmers (small, mid-sized, large) and indoor, outdoor, greenhouse, poly-house, and other ecosystems.
	Interoperabilit	The IoT is a massive collection of	Scope for design and

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	y	billions of sensors, controllers, standards, and protocols. This leads to semantic interoperability (perception and interpretation), syntactic (data formats) interoperability, and technical interoperability (hardware/software, protocols, infrastructure) issues between them. This has to be addressed.	implementation of interoperable, architecture-independent protocols, platform- independent standards.
	Integration of IoT and cloud	IoT is a heterogeneous platform connecting billions of sensors, made up of different technology (RFID or WSN), from different manufacturers, performing different operations in a distributed environment. Collecting these huge amounts of data, processing, and sending them to the cloud is challenging. The IoT devices (often running on low power) deployed in remote locations face poor connectivity, transmission impairment causes integration challenges to the cloud. Hence, this problem needs to be addressed.	Blended architecture for integration of IoT and cloud with better infrastructure and cloud services must be created.

5. AI IN HORTICULTURE

Artificial Intelligence is a branch of science that deals with creating and deploying intelligent algorithms for machines, so that the machines can learn and adapt dynamically to the environment. In short, it can be defined as machine intelligence that allows machines to think, act and make decisions without human intervention. Since, the inception of AI, it has revolutionized almost all sectors like automobiles, retail, health, education, supply chain, industries, agriculture etc. [29] [27].

A. AI Application Domains

AI has been penetrating the agriculture sector and is still in its infancy. There is much more scope for research and application of AI agriculture and horticulture sectors. The major applications of AI are land suitability and recommendation, fertilizer recommendation [28],

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weather forecasting [36], plant stress detection, or pest/disease detection [45] [41], weed detection, fruit maturity/quality detection and counting [46] [24] [30], yield/harvest prediction [44] [35], and profit estimation, market prediction, etc. at various stages of the horticulture production cycle.

Since the beginning of AI, many studies and models have been proposed for providing smart/intelligent solutions in each phase or area of the horticulture production cycle. The Figure 5 shows different phases in the horticulture production cycle.

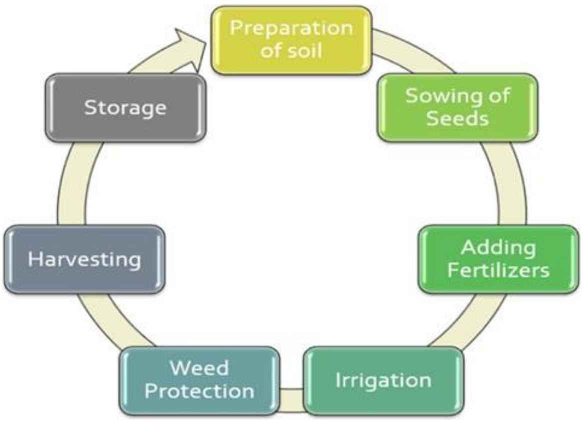

Figure 5. Horticulture Production cycle

The key application areas where AI and associated techniques can be used are broadly classified into the following,

1. Crop detection, classification, and management
2. Yield/harvest Prediction and quality checking
3. Pest/disease detection
4. Irrigation and soil management
5. Weed detection and management
6. Weather forecasting and prediction

In this section, we briefly discuss the application of AI for the first three domains viz. crop detection, classification, and management, yield/harvest prediction and quality checking, and pest/disease detection.

i. *AI in Crop detection, classification and management*

Since the manual classification of horticulture crops is time consuming and error-prone as there are nearly 200+ vegetable plants and 600+ ornamental plants and these horticulture crops mutate over a period and create multiple species. Even though automatic crop detection based on multiple features is challenging research, many attempts were made to do so.

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Priyanka Natrajan et al [40] proposed CNN based method for horticulture crop classification based on transfer learning. The model was trained using the Salinas dataset and tested on images provided by the Indian Space Research Organization (ISRO). The Supervised CNN model outperformed when compared with the unsupervised k-means clustering model.

ii. *Yield/Harvest Prediction and Quality Checking*

Yield or harvest estimation at early stages in horticulture plays a critical role in determining the volume and planning of required post-harvest storage, transportation, and selling by horticulture producers. Also, agro-based companies who buy and distribute the products can be benefitted from the yield estimation. Further, fruit quality is significant in horticulture for fetching higher revenues. Determining the quality of fruits and vegetables will allow sellers and buyers to fix reasonable prices (market value) and edibility, thereby preventing losses at either end. Fruits and vegetables are susceptible to diseases, post-harvest transportation/storage damages, and damages due to pests. As a result, quality checking using AI is one of the most important study domains with many potential. Kishan Das Menon H et al [46] developed an automated grading model for grading and sorting tomatoes. The model resulted in an accuracy of 90%, and the loss score (difference between predicted and actual output) is 0.6587.

iii. *Pest/disease detection*

The crop yield of horticulture depends on detecting and preventing pests and diseases at the early stages of the production cycle. Disease detection is a major research field in horticulture that has lot of scope for research. All most all researches published rely on image data.

6. CONCLUSION

We have conducted a systematic literature review of IoT and AI application domains in horticulture to provide automated solutions at every stage of the horticulture production cycle. To limit the scope of our research, we have formulated research objectives and questions. We have presented statistical data of horticulture crop production and the area utilized to showcase the increased demand for horticulture production in India. In this review, we have proposed a three-layered architecture of IoT for horticulture and then, demonstrated the prominent application areas of IoT, the scope for improvement, and challenges of deploying IoT from the three-layered perspective. The open issues and challenges discussed in this article help researchers to carry out further research to address the said issues. We also focused on, key application domains of AI and related techniques to provide smart solutions for crop detection, classification and management, yield/harvest prediction and quality checking, pest/disease detection, and management. Thus incorporating the latest technologies like IoT, AI, and associated techniques in various phases of horticulture

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production mitigates various problems and results in better yield utilizing optimal resources, prevents crop loss, increases farmers income, and preserves world food security.

CONFLICT OF INTERESTS
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY
Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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