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# Harnessing the dynamic potential of Sensors, Technology, AI and Internet of Things (IoT) in soil health management and sustainable agriculture

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## ABSTRACT

By 21st century, the technology had started reaching every corners including agriculture sectors. It had made an impression of significant milestone in achieving better crop production and sustainable agriculture. Though the land availability of farming getting decreases day by day, water availability getting reduces due to adverse climate changing pattern, changes observed in weather pattern and other factors contributing in detoriation of production in agriculture. To evaluate optimisation and good precision, modern technology had a pivotal role. These include IoT (Internet of things), AI (Artificial Intelligence), GIS, GPS, unmanned aerial surveillance (drone technology) and field level sensors etc. which determines exact and accurate data in interpretation and critical thinking which also provide good yield calculation, plant protection measures and surveillance, thematic map preparation and adoption of climate smart cropping practices. It will helps resolve present constrains in farming practices. This short communication briefs the importance, ideology and better application broadcast in application of technology in farming practices which will provide better accuracy and the community of farmers gets benefitted.

***Keywords:*** *GIS, precision farming, prediction technology, sustainability, software*

## Introduction

1. The surge of growing population all around the world results in need of demanding food production. FAO demanded by in 2050, the global population will raise to 9.73 billion and it will continue till the population attains 11.2 billion in the year of 2100 FAO (2017).

The world is vast. Technology has grown more and more and plays a crucial role in every science part. Present scenario explicit that there are many external factors which diminishes agriculture production includes salinity, suitability of land and most importantly soil health is getting reduced

(Muhilan *et al*., 2024) etc. In addition to this, climate a major phenomenon which affects the crop production. ((Mohamed *et al*. (2013); Mohamed *et al*. (2014); El-Zeiny *et al*. (2017) and Abdel-Fattah *et al*. (2021)). At 20$^{th}$ century, and also after the emergence of green revolution, the crops become high fertilizer feeding crops and the land gets minimised thus production is aim to increase to satisfy the growing population. Similarly, following the fourth agricultural revolution over the past two decades, there has been considerable progress in ICT (Information Communication Technology) and AI (Artificial Intelligence). These technologies operated with components such as robotics, sensors, and chips, which enhance agricultural operations efficiently. Although the present agriculture is incomplete without the involvement of smart farming. Here are some of the most important aspects for GIS, AI and IoT in precision farming.

### 2.1. Sensors in Agriculture

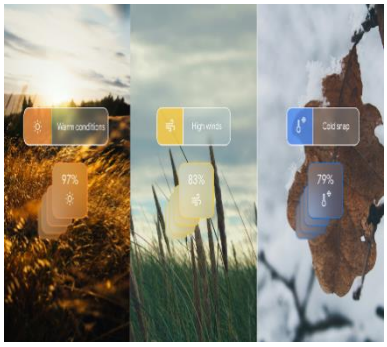
Many sensors are the primary source of information in agricultural IoT. Sensors are primarily used in agriculture for ensuring quality safety and traceability, detecting animal and plant life, and monitoring environmental information. At present scenario, every aspects were enveloped with cutting-edge technologies and advancement which involve aspects like remote sensing (Liu *et al*., 2021; Segarra *et al*., 2020), GIS - Geographic Information System (Grammatikis *et al*., 2020; Zhang & Cao, 2019; Leroux *et al*., 2018), GPS (Mavridou *et al*., 2019; Tamirat *et al*., 2018; Guo *et al*., 2018) and data analysis (Coble *et al*., 2018; Wolfert *et al*., 2017). Currently, the three types of sensors that are most commonly used in agriculture are physical property sensors, biosensors, and micro electro-mechanical sensors (You and Tang, 2013). Physical attributes Biosensors use biologically sensitive components to send information based on the response to the external environment, while sensors use sensor-sensitive physical changes to realize signal conversion; new technology has produced miniature electromechanical sensors, which have great qualities including high dependability and low power consumption Li *et al*. (2015). The wide variant of sensor mechanisms which includes electrochemical, electrical, optical and remote sensing. The effect of fluorescence quenching under the optical mechanism and principal of spectrophotometer, aids in inspection of soil and determination of leaf chlorophyll content Li *et al*. (2017).

### 2.2. Usage of prediction of weather forecast

At today's condition and situation, weather had changed tremendously. Without prediction the weather, the farmers cannot go for cropping. Hence analysing the weather prediction acts as a key challenge for precision farming. By forecasting the meteorological data, the farmers can determine the status of weather conditions, thereby making accurate decisions regarding cropping, planting, irrigation, and harvesting of crops. This kind of act will reduce the damage of crop failure due to adverse climate change, and thus increase yield optimum. By utilizing forecasting models, every farmer can create their work plan with greater accuracy, efficiency, and ultimately minimize crop failure while enhancing overall farm management (Bendre *et al*., 2015).

Here are some of the AI models used in predicting the weather forecast given below:

**Table. 1. AI Models used in weather prediction**

| Sl. No | AI Model name | Major function | Developed authority | Imagery conceptual |
|---|---|---|---|---|
| 1 | GenCast | Identification of complex relationships between variables like temperature, humidity, and wind. It is the best among the other and it gives 97.5 % data reliable and the interval for observation takes on 15th day with a short term reading of 8 minutes to read based on AI chip processor | "Google Deepmind" |   https://klu.ai/glossary/google-deepmind |
| 2 | GraphCast | It contains historical and near real time weather data with good accuracy. the accuracy significantly beats current weather systems on 90% | "ERA5" |   https://deepmind.google/discover/blog/graphcast-ai-model-for-faster-and-more-accurate-global-weather-forecasting/ |
| 3 | Pangu-Weather | Pangu Weather is a hybrid tool in which it was developed with machine learning based model which has better performance than ECMWF IFS with lead span duration of 7d which is oriented with root mean square error and correlation coefficient. It mainly simulate height of geopotential level and temperature at 500 hPa. | "Huawei" |   https://www.huawei.com/en/news/2023/7/pangu-ai-model-nature-publish |

(Bendre *et al*., 2015)

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### 2.3. Artificial Intelligence and Machine learning program for precision farming

At current situation, these are the forerunner for advanced level precision farming. To overcome manual errors and to collect the impossible data, this would tend to help in collecting data. It offers patterns, irregularities for crop production and development, soil wellness, pest invasions and population recognition, thereby resulting in obtaining precise information. It simulates the weed growth and management aspects (through drone technology) and pesticidal residue calculation can be achieved effectively and hence making farm level operations more precise and efficient. (Ahmad and Nabi, 2021).

### 2.4. Cloud data analysis in agriculture

The linear integration and computation of cloud data in agriculture helps and modifies the pattern of farmers practices thus by helps in collecting and storing the large size data of weather, soil and crop efficiently. It offers insights into forecasting weather phenomena such as droughts, heat waves, frosts, hurricanes, torrential rains, pest infestations, and market trend analysis, as well as decision-making practices. Fig. 1. Depicts the usage of machine learning and crop modelling for yield prediction (Delgado *et al*., 2013).

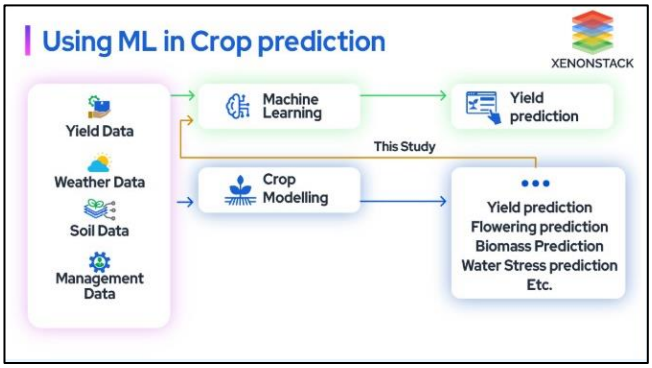


**Fig. 1. Usage of Machine learning in crop prediction**
(Xenonstack, 2024)

### 2.5. Block chain concept for Transparency and Traceability

It gives a transparent vision for farmers in precision farming. It covers a secure and traceability of precision farming. It can be maintained a linear length of unaltered record maintenance starting from planting to till post-harvest operations. It decides the price and transaction policy rate at optimal cost and helps the farmers from losses (Demestichas *et al*., 2020) and Figure. 2. Represents the flow chart of how digital system helps the farmers from sowing to harvest.

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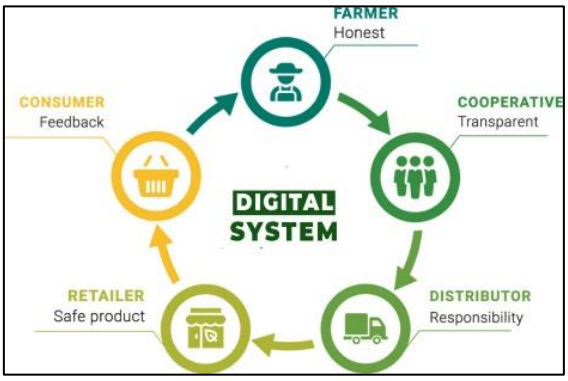


**Fig. 2. Digital traceability of farmers produce from sowing to harvest**
(Viet, 2023)

## 2.6. Pest monitoring and pathogens through Artificial Intelligence

Through the AI process, based on its functionality, there are two tasks. One is narrow AI which will be dealing with the specific task and limited range of task. For example: It includes image recognition system, virtual assistants and recommendation algorithms (Zhang *et al*., 2018). Another one is Strong AI, which will be exhibiting humanoid intellectual visualisation and learning process (Russell and Norvig, 2022).

## 2.7. Role of AI in agriculture

**2.7.1. Field level Artificial Intelligence usage:** Deep learning methods and computer vision are utilized by farmers to examine fields and create a field map for additional analysis. Microsoft is partnering with farmers on the FarmBeats initiative to reduce costs and enhance productivity.

- **Soil Health:** AI effectively monitors soil health and provides data on the soil's moisture content, pH level, and nutritional deficits. Trace Genomics, a company based in California, is utilizing machine learning to deliver comprehensive soil analysis to agricultural producers.
- **Water management strategies** - Now a days, agronomist and soil scientist are employing the tool of AI in addressing the system of irrigation and dew point level temperature prediction.

**2.7.2. Crop management under Artificial Intelligence:** By choosing the right crops, seeds, and resources, artificial intelligence (AI) technologies help farmers produce copious yields.

- **Crop monitoring –** Farmers are using drones and artificial intelligence (AI) to monitor and evaluate crop health. AI algorithm based company namely "SkySquirrel" technologies Inc. which provide detailed report on health report over vineyard farm.
- **Detection Pathogens in field level approaches** – A Raleigh-based start-up called FarmShots seeks to identify pests, illnesses, and plant nutrition levels on farms. Growers can learn from its software where and how much fertilizer is required.
- **Controlling weed growth** – Artificial intelligence (AI) based models which identifies and distinguish growth pattern of weed among field crops which facilitates easier and prompt action from farmers to take suitable measures.

**2.7.3. Livestock management under AI**: Artificial intelligence facilitates early disease and injury detection and aids farmers in keeping an eye on the wellbeing of farm

animals. To evaluate the quality of cow milk, farmers use advancement in utilizing machine-based milking tool and sensors on AI involvement.

- **"Cainthus**" a leading techno-cattle based industry who had designed facial expression of cow and its behaviour on 24/7 monitoring. The major advantage were it increases production through reduction in stress level among the cattles.

**2.7.4.** Enveloping artificial Intelligence in precision agriculture: On of the recent emerging trend is utilisation of artificial intelligence and is strengthening agribusiness by effectively utilizing AI. To get advice on crop rotation, fertilizer management, the best times to sow and harvest, and other topics, precision farming makes use of important AI-powered technology.

- Improvement of shortage of labour: Increased in global population is a big concern, rather than not fruitful in labour assist towards farming practices. Cost of cultivation involving workforce by men and women labour levels up and it affect B: C ratio for farmers. In turn, using AI based robots which can efficiently utilized in field of farm practices thereby reducing involvement of labourers. China, Japan and USA are pioneer in utilising robotics in farming practices. In India's situation, it is currently under development in both design based approach and robotically screening (i.e. primitive stage)

**2.7.5. Utilising Artificial Intelligence in forecast of weather:** Now a days, models simulated in AI are helpful in predicting weather forecast and are more useful for farmers in understanding climate change, which facilitates usage of artificial intelligence models and interpretation of data from satellite for weather forecasting and crop observation.

- The real time monitoring of agricultural fields are currently played by Artificial intelligence based machine and thus aiding in collection of data and proper land management practices. It has a better potential to revolutionize the agriculture in future.

### 2.8. Artificial Intelligence (AI) in agriculture pest identification

After the year of 2010, the evolution of artificial intelligence has started ruling agriculture sector and it has become more powerful and impactful over precision agriculture and crop monitoring system. AL includes utilisation of advanced technologies like computer software, machine learning programme, etc. Future prediction and evaluation programmes can be taken into account by utilisation of various data collected from the farmers through semi-automation programme. The various techniques or keys in AI application are given below. The process of flow diagram representing the Basic principle of model representing of Artificial intelligence in pest detection was given in Fig. 3.

### 2.9. Early decision practices

It is the preliminary stage to detect and identify the species in the cropping system. It detects the pest indivial or

population as a wholesome by adopting drone technology, satellite imaging and ground sensors. There are some machine learning tool used in detection of insect pest in strategies for plant protection (Chithambarathanu and Jeyakumar, 2023).

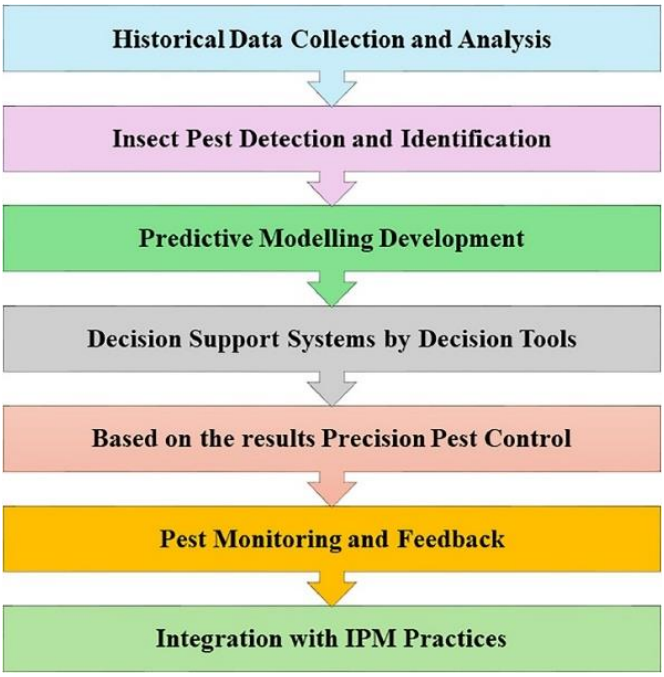


**Fig. 3. Basic principle of model representing of Artificial intelligence in pest detection**

(Kariyanna and Sowjanya, 2024)

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### 2.9.1 Precision monitoring

To precisely monitor the field crops, high resolution fixed camera were employed with in-situ sensors fixed which effectively captures the field of agriculture with better precision. To fix the problem in any part of field, assessing soil health, and to locate pest in photographs, then computer algorithm will analyse the given data hence it make a way for resource allocation and proper management. (Mohanty *et al*., 2016).

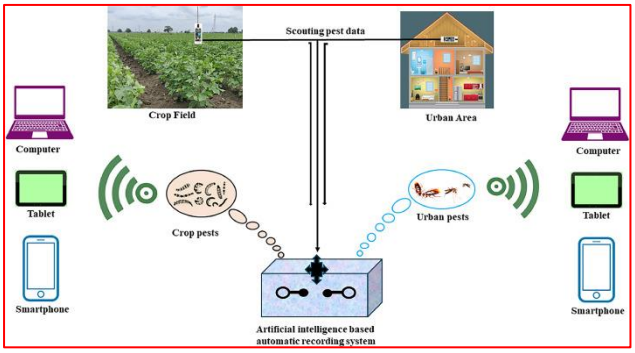


**Fig. 4. The overview lay diagram representing monitoring and surveillance of crops using IoT**

(Eliopoulos *et al*., 2018)

### 2.9.2. Data integration and Automation

It is the final stage of pest detection. Here in this, models will be used to assess meteorological patterns, pest growth pattern, pest life cycle assessment etc. (Kariyanna and Sowjanya, 2024). Hence to predict the pest outbreak, these model will be helpful.

## 3. Conclusion

To achieve global food security is one of the goal under SDG. Detoriation of soil health is observed increasing day by day which impedes the growth of the crop and results in yield reduction. Proper assessment can

only be a solution to identify health condition and to manage it effectively. AI (Artificial intelligence), and technology had made human work lesser and significantly contribute to soil health assessment. By utilization of AI driven crop simulation models, growth parameters, different farming techniques, IoT based disease and pest detection and surveillance. Also the artificial intelligence programming can be positively utilized in field of post-supply chain management and logistics approaches. Hence it was positive confirmation with AI, IoT, field based sensors, 5G spectrum had a prominent role in revolutioning the precision soil health, field based plant protection measures and finally food security thus providing environmental stability.

**Declaration of competing interest**

All the authors and Co-authors have no competing interests

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