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A Review of Machine Learning Applications and Their Predictive Solutions in Agriculture

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The agricultural revolution has made an innovative wave for global production systems through digital and smart technology. Modern agriculture is being connected to smart technology to improve efficiency in production. Besides, innovative technology helps farmers to understand crop insights and assist with accurate crop information. This study's aim is to survey machine learning applications and their predictive solutions in the agriculture industry. This study briefs out existing machine learning models and prediction result summaries in agricultural data. The article's findings reveal the estimated prediction model for forecasting output and predictive solutions in agricultural farming practices. The article employs previous articles to result in machine learning prediction model workflow and the main goal of this study is to find more innovative suggestions for farmers to follow in agricultural farming practices.

Keywords: Agriculture revolution; machine learning; agriculture intelligence; prediction model.

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1. INTRODUCTION

Agriculture is an important tool in livelihood, it supports humans to survive. Proper agricultural management and production developments are crucial to the current food demand and supply chain. The whole agricultural process hence needs to take digital concepts to adopt for better production and supply. Agriculture and machine learning applications are both interrelated to work fast and smoothly responding to more yield production.

Agricultural food is an economic strong pillar and the world's largest economy depends on agricultural food production. There are emerging most powerful technologies in agricultural engineering fields such as blockchain technology, cloud computing, the internet of things (IoT), machine learning (ML), and deep learning (DL) to eliminate critical issues to food production. Meshram et al., [1] described machine learning applications in agricultural domains. The authors divided general agricultural tasks into three categories i.e., pre-harvesting, harvesting, and post-harvesting. They claimed each phase needs a machine learning model to analyze bigger and can perform faster. The study [2] focuses on efficient agricultural production towards agriculture 4.0. Researchers review machine learning applications with limitations in agricultural crop yield and provide functional concepts in crop yield prediction. Soil, weather, irrigation system, fertilizer, real-time monitoring, crops, and weed management are crucial factors emphasized by the machine learning model. Another article [3] said as the population growth is high it has become more challenging to feed an increasing number of people. Advanced technology drives agriculture directly to industry developments. The authors here applied IoT and machine learning models for the farm revolution, these technologies help in farming with rapid decision-making and add innovative farming rules in agriculture science to meet food demands.

Another review article [4] described machine learning applications in agri-food supply chain management. Food-supply chain consists process chain, from land cultivation to crop production. The authors proposed a framework for proactive data-driven decision-making for agricultural food-supply chain systems. The model presented adopting machine learning can improve production planning and control processes in the agricultural industry 4.0. It also benefits environmental and social performance. Benos et al., [5] reviewed a plethora of machine learning applications in agricultural field work such as crop, water, soil, and livestock management where crop management is divided into categories i.e., yield prediction, disease detection, weed detection, crop recognition, and crop quality. This study focuses on big data analysis using ML and finding out real problems in doing smart farming. ML is used in facilitating agricultural management through supervised, semi-supervised, unsupervised, and reinforcement learning data, and claims an accurate ML model can help the farmers make informed management decisions on what to grow and how to cope in an existing food market.

The natural resources are decreasing for the time being while the food demand for increasing mouths is increasing. Therefore, automation and machine learning models can improve high agricultural production. Martinho et al., [6] researchers showed the importance of the digital transition in agricultural food chains and agricultural markets. New technologies and their application are crucial for sustainable agricultural businesses including economically, socially, and environmentally. Agricultural urbanization influenced land management and planning. For the interrelationships between machine learning and food security, this article highlights the relevance of platforms and methods, such as G-earth engines and random forest techniques for agricultural applications.

Digital agri-technology in crop field application has revealed the importance of food security worldwide, whereas the digital transition is associated with agriculture4.0 and defines the digital transmission of technology to agriculture4.0. Machine learning makes sustainable food demand in the world agricultural economy without compromising limited natural resources in agricultural development. The article [7] addressed traditional farming techniques that result in less productivity and consume a lot of farmers' time. Here authors suggested machine learning and deep learning models for smart farming. The model allows individuals to cultivate crops in smart ways in order to achieve efficiency and high productivity. The proposed model reduces cultivation costs. They described four modules such as crop recommendation, weed identification, pesticide recommendation, and crop cost estimation. A web application framework was applied for model work so that a friendly login page assists users in accessing information easily.

Considering the global crisis for food supply, [8] researchers started to think about precision agriculture. Machine learning applications are having a great impact on transforming agriculture into precision agriculture. Machine learning algorithms can analyze vast amounts of data from IoT sensors and other sources such as weather level, soil moisture, crop growth status, and weed and pest control. A noteworthy application of machine learning in agriculture is precision farming, which includes employing data and technology to optimize agricultural conducts such as fertilization, irrigation, and pest control to improve reap output and quality. Machine learning models make it easier for farmers to apply precision agricultural concepts in the farming industry. The study followed key advantages of machine learning applications in agriculture and considered machine learning challenging sites for farming i.e., addresses the issues are large data amount, cleansing data quality, difficulties in data model build in the field, limited software infrastructure, and data privacy, etc. Addressing these issues authors suggest strong collaboration between farmers and data scientists can make machine learning algorithms usable for farming. Furthermore, the study [9] focuses on developing and evaluating tree-based ensemble learning models to predict crop productivity. Article highlights machine learning prediction model food security and farmers decision-analytics in order to achieve the global agenda 'Zero Hunger by 2030'. For crop yield prediction researchers proposed multiple linear regression (MLR), artificial neural network (ANN), and a hybrid model in accurate crop yield prediction (CYP). By predicting the most suitable crop type using soil properties and environmental factors, farmers are able to make an informed decision and thus ML enhances productivity in agricultural systems.

Therefore, this study's aim is to focus on machine learning applications in agricultural production. This study highlights the machine learning model, its functional output, and predictive solutions in agriculture. The article deals with agricultural intelligence with improved production using machine learning applications and shows how the machine learning model will reflect and positively change future agricultural production needs. The author suggests through this review article that farmers must adopt machine learning farming applications to increase farm production and prepare themselves to produce more yields to satisfy more consuming demand.

The paper is organized into several sections such as an introduction briefing machine learning applications in farming, then following sections explain the function of ML and its solutions, agricultural intelligence, global market values, ML impact on the industrial revolution, farming directions of ML, study findings and lastly conclusion section concludes this article.

2. MACHINE LEARNING DEFINITION

Machine learning is called the 'subfield application' of artificial intelligence according to [10]. Machine learning (ML) has the powerful capability to act like humans can behave. Artificial intelligence (AI) applications expand their potential skill through ML systems to identify and solve complex issues that are quite impossible to complete by a human. According to Liakos et al., [11] ML algorithms process data from training data to produce predictive solutions The functions of machine learning are classified into three types. One is descriptive which accepts data and results output about happening cases. The second is predictive, applying dataset and then deciding if future cases will happen. The last one prescriptive function that not only predicts but also suggests solutions for data cases. Here it has drawn ML functions classification in Fig. 1.

Tucci, [12] said that machine learning (ML) is another similar type of artificial intelligence. It learns from data and builds a computing system to enable improved performance.ML takes historical datasets to classify information and cluster analysis, reduces data point dimensionality, and predicts data patterns into relationships. ML is a subset of artificial intelligence that makes machines just like more than humans to make judgments and decision-making [13]. Data is fed to the machine and apply ML algorithm to build the model. The algorithm depends on the data pattern used and decisions need to be automated.ML designs its program to itself which is in stark contrast to traditional model programming.

2.1 Agricultural Intelligence

Machine learning (ML) applications and artificial intelligence (AI) ensures food for all through efficient way in food industry. AI and ML play important roles in transforming food systems and helping to address food production and nutrition insecurity. Both improve AI and ML applications in agriculture through e-agriculture. Emerging AI

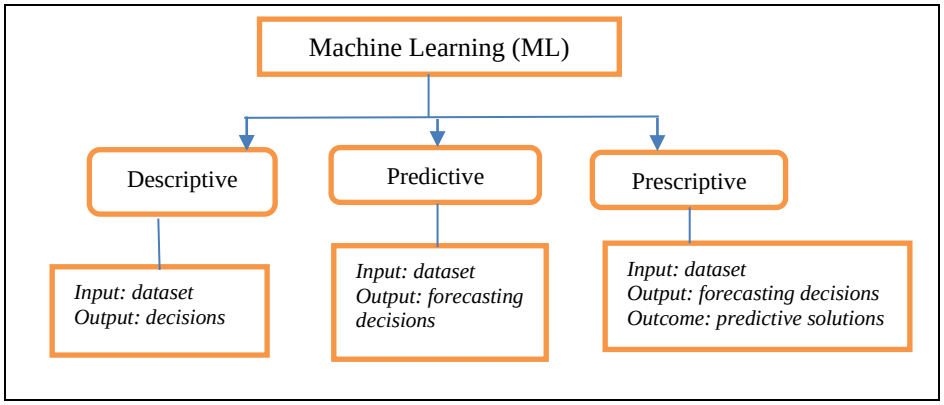

Fig. 1. ML functions classification with input, output and outcome according to agricultural data

and ML have improved smart farming in three major areas: Agricultural robotics, soil and crop monitoring, and predictive analytics. Farming automation, manpower reduction, detection of earlier disease, more yield production, and less harvesting time are crucial components of modern farming. AI applications in farming make smart farming and ML analyzes massive data to predict farming.

Machine Learning in Agriculture-new innovative concepts that bring the latest trend in the agricultural revolution. Today machine learning models and prediction algorithms are implemented into smart farming to produce quality yield. Authors Veeragandham and Santhi, [14] proposed ML model works in agriculture, and has major five components such as farm data collection, data storage, data pre-processing, training the data model, and performance output.

Different types of sensors are configured to retrieve data from crop fields. Sensors provide crop insight values using moisture, temperature, humidity, pH, rain, light, and color sensors ADC values. Farmers do not need to depend only on weather information. The machine learning model enables computer devices to read this sensor information. These data are not free of noise which reduces data quality. Sensors collected in these real-time data are inconsistent, duplication, noise, and missing values. Then machine learning has a data pre-processing step that removes the data noise, and inserts the data missing values where required thus enhancing data quality. Machine learning make agricultural intelligence in smart farming view, machine learning workflow model acts as following Fig. 2, in agricultural practices.

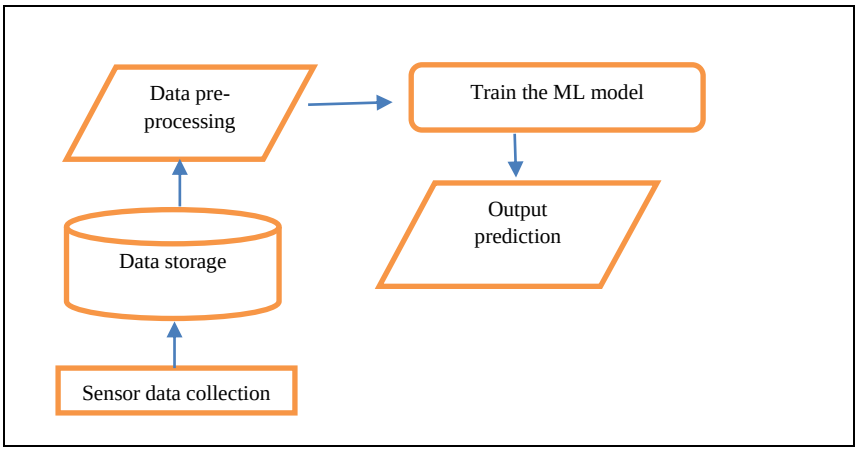

Fig. 2. Machine learning workflow model in agriculture while input retrieved from sensor data, store in database before processing to train the model and predicts result through output

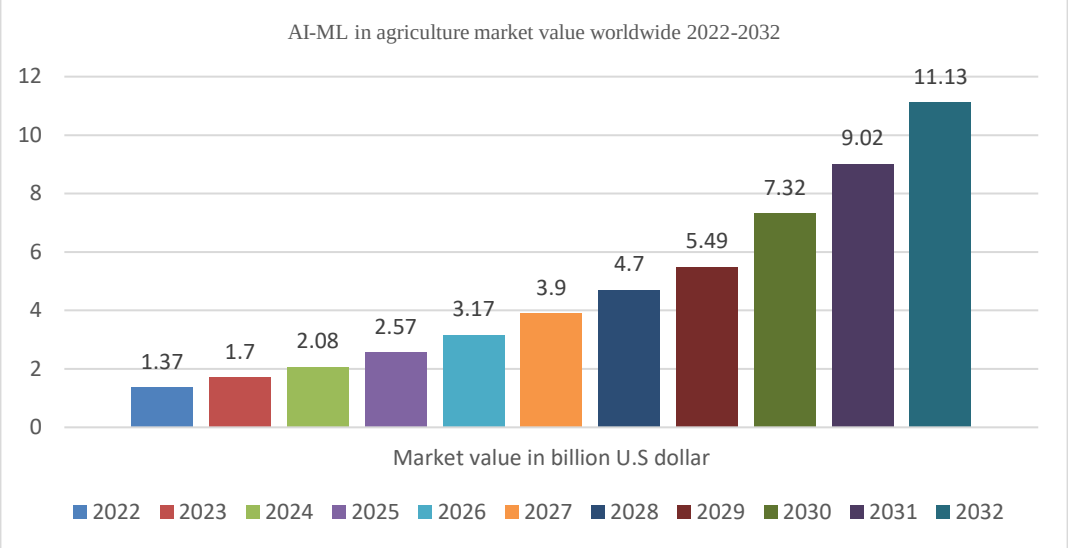

Fig. 3. AI and ML -agricultural market data,data designed in graphical view from earlier year 2022 to 2032 in future

2.1.1 AI and ML-agricultural market

This statistic report is shown in Fig. 3 says 'AI-ML in agriculture market value worldwide 2022-2032'. The global artificial intelligence and machine learning in agriculture market size was estimated at USD while market size values were depicted from the years 2022 and 2032, and growing at a CAGR of 23.3% from 2023 to 2032 according to data [15]. The agriculture market size using AI-ML was estimated at USD 1.37 billion in 2022 and moderately increased up to 1.7 U.S. billion in 2023. Two years later in the future, the graph shows prediction results in the year 2026 while the market size value will be added up to 3.17 billion U.S. dollars. Globally innovative AI and ML applications are used in smart agricultural production so we can see a forward progress line including market size values that reflect 7.32 billion U.S. dollars in 2030 using data [16]. The highest market values over previous years from 2022 to 2030, 11.13 billion U.S. dollars will be reached in the year 2032 by applying these techniques in agricultural production. Statistical infographic results show that applying artificial intelligence including machine learning will lead future agriculture to produce more yields and automation intelligence will occur in the future agricultural revolution.

2.1.1.1 Machine learning impact on the fourth industrial revolution

Emerging technology is shifting agriculture practices through revolution i.e., first industrial revolution, second industrial revolution, third industrial revolution, and fourth industrial revolution [17]. The farm industry began to produce large quantities of food using machines and equipment. It tended to transform the agricultural economy into a manufacturing economy and production was no longer made by individual farmers, machine manufacturing was the innovative concept to help farming production. The second industrial revolution led agricultural factories to produce mass foods in the economy. Due to technological growth, rapid farm industry, and developments farm science led the agriculture sector to face traditional challenges through this period. The period when agriculture was driven by the third industrial revolution. New innovations and innovative technology transformed farming practices into digital farming practices by using personal computers, portable devices, internet connections, and digital mobile communication. Huge changes were made in agriculture at the time fourth industrial revolution. Automation, smart decision-making, real-time data monitoring, and more quality yields are initial concepts built in agriculture production units. IoT (Internet of things), IIoT (Industrial internet of things), cloud computing, edge computing, AI (Artificial intelligence), and ML (Machine learning) applications add new innovative and smart dimensions to agriculture whereas authors [18] reviewed IoT structure for advanced steps in precision and micro precision monitoring.

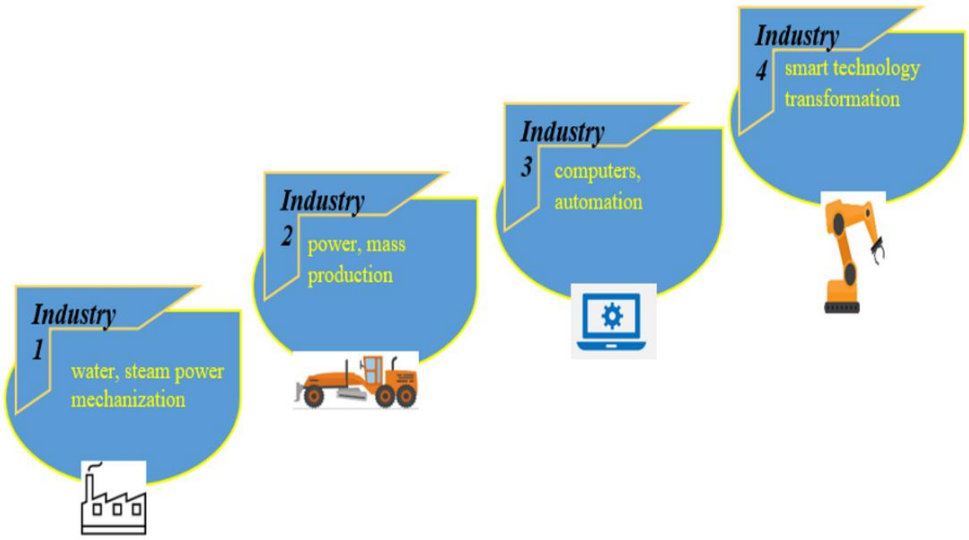

Fig. 4. Industrial revolution in agriculture e.g., industry1 depends on water and steam, industry2 improved production, industry3 applied automation and industry4 enhanced technology transformation in agricultural farms

The agriculture field is connected to the internet, robots work in the absence of farmers, irrigation systems satisfy water level in fields when needed, and drones are flying into the field to capture images which is difficult for humans [19]. The fourth industrial revolution has already made smart agriculture using machine learning and artificial intelligence models and algorithms. The agriculture industrial revolution scenario is shown in Fig. 4.

3. FARMING DIRECTIONS OF ML IN AGRICULTURE

3.1 Crop Analysis

Agricultural drones: are designed as unmanned system, they can avoid any obstacles and automatically perform complex task without operator interventions. Drones are available in using agricultural field to retrieve images or pick a portion of unreachable data. After analyzing complex data Machine learning model predict final output of crops growth. Drone applications in machine learning just like 'crops medicine after disease diagnosis'. Using DJI Mavic 2 Pro drone, a comprehensive guide in [20], shows its mapping and scanning time requires less than 30 minutes to fly over 30 acres land. Survey used total station with local coordinates or used GPS (Global Positioning System) devices such as a GNSS (Global Navigation Satellite System) receiver with RTK (Real-Time Kinematic) and able to take fast scanning.

3.2 Identifying and Eradicating Weeds

Deep learning (DL) is subset applications of machine learning algorithms. DL model has the ability to weed detection from image processing. Modern farming has been strongly connected to machine learning and its deep-learning algorithm in rapid weed detection management. Very fast detection of weeds in crops enables the farmer to identify the correct weeds and then decide on accurate doses of herbicide in crop fields thus enhancing more yields. Smart farming provides an automatic weed detection formula through a machine-learning algorithm. A review article [21] conducted deep learning techniques to detect weeds on farms. The study applied two approaches such as localized plant crops and classified crops or weeds, and then mapped weed density in the crop field. In dataset preparation raw data are not suitable for weed detection so it applied different techniques of image processing, data labelling, and image augmentation to appropriately select datasets. Supervised learning model detection passed datasets in the DL model and model results output based on the labelled dataset. DL elaborate ML functions with more data transforming functions so that data can be easily extracted from raw features and thus it reduces data regression issues said in [22].

Another new weed detection method was proposed [23]. Traditionally farmers identified the crops' weeds manually but weeds have many

varieties so rapid weed detection by farmers is quite difficult and consumes more time. Automatic weed detection techniques are an urgent need in farming areas. This strategy used color index-based segmentation applied to image processing. The weed detection model followed Genetic Algorithms (GAs), Bayesian classification error, and CenterNet model on the training dataset. Deep learning model indexed as color boxes around the crops and image processing detects the area of the weed thus crops falling outside in the boundary box are detected as weeds. Therefore, deep learning algorithm along with a machine learning model recognizes weeds in crop fields and assist farmers in spraying herbicides where needed.

3.3 Real-time Weather Forecasting

Climate variability in agriculture year- to-year leads highly vulnerable situations. It also influences low food security and economic loss. Climate variability hampered in agricultural production and accurate forecasting real-time weather can assist farmers to avoid unwanted food loss. A study [24] focuses on potential advantages of climate forecasting in agriculture. Farmers are unprepared about the weather and make decisions on their general understanding basis. Machine learning model help the farming production units to predict weather forecasting. In order to make the farmers prepared of devastating weather risk and they can update decision-making towards crops growth in next time.

Sensors are designed to collect insights of crops data [25] including soil moisture, temperature, humidity, and rain. Sensor devices are useful to retrieve crops data from environments directly and then transmit cloud server through the channel. Machine learning models analyze these sensor data and make informed decisions for potential actions. The study [26] proposed that sensors primarily detect weather parameters that processed data using a machine learning model to predict weather and forecast real-time weather data that inform farmers to take actions regarding sensor data. Temperature and humidity sensors are configured to monitor the temperature and relative humidity on crop fields, soil moisture sensors are utilized for sensing the water level, and rain sensor is used to check the rain in the environment, if the sensor detects rain occurs then results stop all irrigation systems.

Climate change is the biggest challenge for farmers in future agriculture. Machine learning models identify proper planting and irrigation schedules as well as predict ideal crop growth conditions. Machine learning models design rapid warning systems that alert farmers about unwanted environmental effects. Farmers can use current weather data to make accurate prediction knowledge based on machine learning models about weather forecasting and farmers are able to evaluate possible farming outcomes.

3.4 Production Level Prediction

Fourth industrial revolution (*as discussed on ML impact on the fourth industrial revolution subsection)* trends to agricultural farming production into smart and industrial production units. Since farming industrialization, agricultural factory needs to estimate production time and control production planning. Machine learning model applied on manufacturing techniques to improve farming production management system. The authors [27] researched on machine learning approaches in industrialization on production system to predict production time. Here authors applied KDD framework, the cross-industry standard process model for data mining (CRISP-DM), Oracle's architecture for development process, regression supervised learning task, linear regression (LR), k-nearest neighbor (KNN), random forest (RF), and neural networks (NN) and able to accurately predict manufacturing production cycle time. Kang et al., [28] proposed production lines for automation in manufacturing industry using machine learning model. In this study, authors suggested assembly process where materials are sequentially processed in manufacturing process to make final product through a number of working stations. Production lines like food processing in manufacturing process have a high throughput for production units and can work with very high speed also reduces huge manual workers. It consists multi server workstation, buffering system, and discrete or continuous processing cycle.

Another study [29] proposed smart and intelligent strategy for agricultural crop production where farmers applied association rules and data mining knowledge. This data mining knowledge-based decision help farmers to predict production level in next year about flower plant data. Automatic prediction strategy assists farmers to decide on which variety can meet consumers demand in local market. Therefore, consumers

demand identification and then utilize production in according to present criteria using prediction algorithm. A case study [30] offers data-driven decision-making in a production company. That is designed to decrease the production delay. The study used a dataset of several periods for production records for two types of machines, Cross Industry Standard process for data mining (CRISP-DM) approach to build the machine learning models, a decision tree for data interpretation, neural network, and random forest to improve decision tree performance. The case study predicts potential production delays in the company's manufacturing process. Thus machine learning model predicts why company production is delayed and helps the production line to run smoothly.

4. STUDY FINDINGS

This review study explored various machine learning model and its application especially used in agricultural practices. The main goal of these studies are to produce productive yields, predict products growth, reveals that machine learning algorithm has potential ability in larger data analysis, and power of production forecasting in future agriculture. Conventional agriculture could not follow any innovative technological techniques to apply in farming land. Therefore, modern farming is being suggested to apply machine learning model by farmers to feed more people while using limited land and resources. Future farming must adopt machine learning model to meet increasing food demand and compete with 'zero hunger' policy.

This study recommended an agricultural intelligence model for farmers to apply in farming land. Here sensor devices actively retrieve data and farmers can monitor farm crops by remote access (*as discussed on real-time weather forecasting subsection*). Sensors enable the farmers to predict crop insights data to decide farming solutions.

This Study observed that smart devices on farms can assist the farmers to work more than manual labor such as using robots designed for pre-harvesting, harvesting, and post-harvesting plantation time. Machine learning model accepts crops' current data and provides the farmers' decisions about forecasting and predictive solutions (*as discussed on machine learning definition section*).

This study found that machine learning helps to build the agricultural industry in the automatic manufacturing process. (*As discussed in production level prediction subsections*), showed that machine learning makes a prediction strategy to identify production lines using manufacturing workstations to remove production delays in fast agricultural production growth. Fig. 5 shows a summarized machine learning application in agricultural practices.

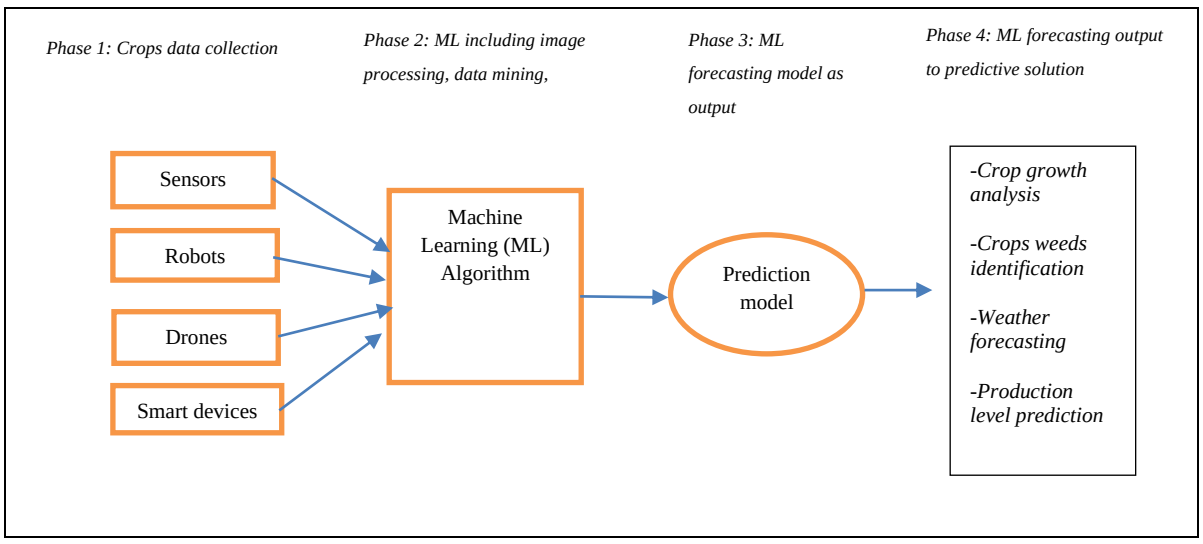

Fig. 5. Machine learning works in agricultural industry e.g., phase1: data collection, phase2: classification, phase3: forecasting and phase4: solution

5. CONCLUSION

Agriculture encompasses a broad range technology as called agri-technology to improve efficient output and meet increasing global food demand. Applying technical innovative disciplines, agriculture production has achieved milestone quality yields and transformed the traditional farming industry into a new revolution called modern agriculture through smart farming. Machine learning (ML) agri-technology helps farmers to predict crop growth and farmers get an automatic warning system to remove production loss. Farmer can use machine learning model without programming skill. Robotics, sensors, and drone devices are configured with friendly interfaces and smart model assist farmers in accessing crop insights and brings our agriculture profile to a new look as having more quality production to feed more people.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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