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Machine Learning in Agriculture: A Primer

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ABSTRACT

Machine learning (ML) is a branch of artificial intelligence focused on using data and algorithms to simulate human evaluation. It refers to the automated detection of meaningful patterns in a given data and focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy. Some companies make use of machine learning for various processes. ML can make a real difference in agricultural productivity and profitability by reducing waste while enhancing product quality. In agriculture, it allows for more accurate disease diagnosis and crop disease prediction. This paper introduces what machine learning can do in the agriculture sector.

KEYWORDS: *Machine learning, artificial intelligence, deep learning, farming, agriculture.*

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INTRODUCTION

Food is considered a basic need of human beings which can be achieved through farming. Agriculture, an essential sector for any economy, not only fulfills humans' basic needs, but is also considered as source of employment worldwide. It is one of the most fundamental human activities. It is unfortunately an extremely challenging undertaking with some of its products being highly perishable with a volatile market when proper plans for good preservation systems are lacking. Climate change, soil erosion, and biodiversity loss can cripple the business, as well as customers' shifting tastes in food. Modern agriculture seeks ways to conserve water, use nutrients and energy more efficiently, and adapt to climate change. Without drastic changes in the agricultural industry, we will not be able to feed everyone. Since we do not have a lot of agricultural lands left, we have to do more with less to make the industry competitive and sustainable [1].

Recent development in technology has caused a great revolution in agriculture and made agricultural processes more efficient and precise. Machine learning can be applied to farming in various ways to optimize processes, increase efficiency, and improve outcomes. It is a fast-growing technology with many promising applications in various fields, including marketing, retail, finance, and agriculture. By combining reliable data and advanced technologies, machine learning helps farmers make more informed decisions, optimize resource allocation, and reduce crop loss risks. In a nutshell, ML is changing the way agriculture operates.

WHAT IS MACHINE LEARNING?

Machine learning is a subfield of artificial intelligence that uses algorithms trained on data sets to create models capable of performing tasks that would otherwise only be possible for humans, such as categorizing images, analyzing data, or predicting price fluctuations. It uses algorithms (essentially lists of rules) trained on data sets to create self-learning models capable of predicting outcomes and classifying information without human intervention. It focuses on algorithms that can "learn" the patterns of training data and, subsequently, make accurate inferences about new data. This pattern recognition ability enables machine learning models to make decisions or predictions without explicit, hard-coded instructions. To ensure such algorithms work effectively, however, they must typically be refined many times until they accumulate a comprehensive list of instructions that allow them to function correctly [2]. A symbol of machine learning is shown in Figure 1 [3].

Generally speaking, a learning problem considers a set of samples of data and then tries to predict properties of unknown data. ML builds heavily on statistics because when we train a machine to learn, we have to give it a statistically significant random sample as training data. Intelligent machines are increasingly doing incredible things: Facebook recognizes faces in photos, Siri understands voices, and Google translates websites [4].

Machine learning techniques are transforming many fields including computer science, engineering, mathematics, physics, neuroscience, and cognitive science. We are surrounded by ML-based technologies: search engines learn how to bring us the best results, digital cameras learn to detect faces, credit card transactions are secured by a software that detects fraud, and cars are equipped with accident prevention systems that are built using ML algorithms [5]. In ML, data plays an indispensable role, and the learning algorithm is used to learn from the data. ML algorithms are now easy to use. One can download packages in Python. Programming languages used in ML include C++, Java, Python.

As its name indicates, machine learning works by creating computer-based statistical models that are refined for a given purpose by evaluating training data, rather than by the classical approach where programmers develop a static algorithm that attempts to solve a problem. Because the algorithm adjusts as it evaluates training data, the process of exposure and calculation around new data trains the algorithm to become better at what it does. Algorithms are the computational part of a machine learning project. Once trained, algorithms produce models with a statistical probability of answering a question or achieving a goal. Unlike in expert systems, the logic by which a machine learning model operates is not explicitly programmed; it is learned through experience. Machine learning has come to dominate the field of AI: it provides the backbone of most modern AI systems, from forecasting models to autonomous vehicles to large language models (LLMs) and other generative AI tools. Machine learning has become a household term in recent years as the concept moved from science fiction to a key driver of how businesses and organizations process information [6].

As shown in Figure 2 [3], there are different types of machine learning. The four major types of machine learning are supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning, each suited to different kinds of data and outcomes. Different types of machine learning include the following [7]:

- *Supervised Learning*: The program is "trained" on a pre-defined set of "training examples" from a "teacher," which then facilitate its ability to reach an accurate conclusion when given new data. In this case, the data comes with additional attributes that we want to predict. A common case of supervised learning is to use historical data to predict statistically likely future events. Under supervised ML, we have regression ML and classification ML.
- *Unsupervised Learning:* As their name suggests, unsupervised learning algorithms can be broadly understood as somewhat "optimizing themselves." Unsupervised algorithms do not need to be trained with desired outcome data. The program is given a bunch of data and must find patterns and relationships therein. A typical goal of unsupervised learning may be as straightforward as discovering hidden patterns within a dataset. Without being told a "correct" answer, unsupervised learning methods can look at complex data and organize it in potentially meaningful ways.
- *Reinforcement Learning:* Reinforcement learning models are trained holistically through trial and error. Reinforcement learning is a method with reward values attached to the different steps that the algorithm must go through. So, the model's goal is to accumulate as many reward points as possible and eventually reach an end goal. Reinforcement learning is an area of machine learning concerned with how software agents ought to take actions in an environment so as to maximize some notion of cumulative reward.
- *Deep Learning:* Deep learning (DL) is a specialized form of machine learning that uses artificial neural networks to mimic the human brain. It is a type of machine learning technique that is modeled after the human brain. It is an advanced technique for handling complex tasks like image and speech recognition. The way in which neural networks are trained can be described as deep learning. It is called deep because the network of neurons is arranged in

several hierarchical levels. Deep learning laid the foundation for advances in generative artificial intelligence.

MACHINE LEARNING IN AGRICULTURE

Agriculture is considered an important pillar of the world's economy and also satisfies one of the basic needs of man which is food. The major branches of agriculture are agronomy, horticulture, forestry, animal husbandry, soil science, fisheries, agriculture engineering, and agricultural economics. Figure 3 shows the general categorization of agriculture tasks [8]. Machine learning's capabilities in these activities exemplify its potential in agriculture. During pre-harvesting tasks, farmers focus on selection of crops, land preparation, seed sowing, irrigation, and crop maintenance which includes use of pesticides. While harvesting, farmers focus on maturity of crops or fruits that are of quality, able to attract high demand, post-harvesting, farmers are focused on post-harvest storage and processing systems.

Machine learning is a growing field with many potential applications in agriculture. Machine learning in agriculture can optimize the way food gets to our table and revolutionize one of the most critical sectors of the economy. It applies AI to analyze data for tasks like predicting crop yields, detecting diseases and pests, and optimizing resource use. It helps farmers make data-driven decisions to improve efficiency, increase profitability, and enhance sustainability. It has the potential to revolutionize the agriculture industry by providing farmers with valuable insights, enabling more efficient resource management, and ultimately increasing productivity and profitability while minimizing environmental impact.

The interplay of machine learning (ML) and deep learning (DL) within the agroclimatic domain is pivotal for addressing the multifaceted challenges posed by climate change on agriculture. In today's technological and data-driven landscape, DL, a specialized area within ML, holds significant promise for transforming the agriculture sector. It offers enhanced accuracy and efficiency in monitoring crop development, forecasting yields, and detecting plant diseases. Utilizing neural networks with multiple layers, DL excels at discerning complex patterns and predictions from large, unstructured datasets. ML and DL offer transformative potential in addressing agricultural challenges, ranging from crop selection to post-harvest management. Figure 4 showcases the integration of ML in agricultural research, highlighting the deployment of traditional ML and DL methods [9].

APPLICATIONS OF MACHINE LEARNING IN AGRICULTURE

There is a plethora of applications of ML in agriculture, from simple analytics to high-tech automated systems. Some of these applications are displayed in Figure 5 [10]. Machine learning is the current technology which is benefiting farmers to minimize the losses in farming by providing rich recommendations and insights about the crops. Farmers and agricultural scientists are exploring how turning to machine learning development can improve crop yields, reduce water usage, and predict pests and diseases. Common applications of ML in agriculture are explained as follows [10-14]:

- *Crop Management:* Crop management is a huge layer of pre-harvesting activities that is responsible for future yields. It involves versatile aspects that originated from the combination of farming techniques in the direction of managing the biological, chemical and physical crop environment with the aim of reaching both quantitative and qualitative targets. However, this is one of the most challenging stages of the agricultural lifecycle. Increased frequency of drought, higher temperatures, unpredictable wetting, and drying cycles can influence crop resistance. Therefore, machine learning development is widely leveraged to navigate this stage.
- *Weed Management:* Weeds are notorious enemy of every farmer. They quickly grow, take over crop territories, cause numerous plant diseases, and lower yield. Weeds compete with crops for vital nutrients, water, and sunlight, often reducing yield. Traditional weed control methods, such as manual removal can be labor-intensive and costly while spraying of herbicides, can be environmentally damaging. Machine learning offers precision weed management solutions by identifying and targeting specific weed species within fields. This targeted approach reduces chemical usage, cuts expenses, and minimizes environmental impact.
- *Livestock Management:* Animal welfare and livestock production are among salient areas for use of machine learning in agriculture applications. Animal welfare assessment, predictive modeling of animal production, as well as estimating the environmental impact of livestock operations are some of the areas where it can be used. This technology relies on a chip with a sensor that is connected to an RFID reader, and users' mobile phones or computers. This way, the software can detect and monitor most health

indicators and behavioral trends from eating to fertility.

- *Water Management:* Water is one of agriculture's most critical yet limited resources. The agricultural sector constitutes the main consumer of available fresh water on a global scale, as plant growth largely relies on water availability. Machine learning helps irrigation practices by analyzing weather data, soil moisture levels, and crop water requirements to recommend precise watering schedules. Automated irrigation systems integrated with machine learning algorithms adjust water distribution dynamically, conserving water, reducing waste, and ensuring optimal hydration for crops. Figure 6 shows a schematic representation of water management by ML and DL [15], while Figure 7 shows a mechanized irrigation system [16].
- *Soil Management:* Arable land is a crucial natural asset facilitating agricultural activities, serving as a foundation for ensuring food security and also fostering sustainable economic growth. Precise information regarding soil on a regional scale is vital, as it contributes towards better soil management consistent with land potential and, in general, sustainable agriculture. Better management of soil is also of great interest owing to issues like land degradation. Traditional soil assessment methods include soil sampling and laboratory analysis, which are normally expensive and take considerable time and effort. The use of machine learning can become a great tool in soil management.
- *Harvesting Robots:* Picking used to be manual. With increasing production rate, there is a need to develop better methods for harvesting, sorting, and eventually transporting produce to various destinations. To do so, machine learning companies are striving to build intelligent tools to automate the harvesting of agricultural produce. These technologies help make robots to be more accurate by picking out specific types of fruits or vegetables based on their shape, size, or color. The use of these robots helps minimize the harvesting time, increase speed and precision as well as reduce waste and damage to produce which ultimately boosts farmers' profit.
- *Crop Yield Prediction:* Accurately predicting crop yields is essential for meeting food production demands while minimizing waste. Machine learning enhances crop yield predictions by analyzing vast datasets, including historical yield records, weather patterns, and soil conditions. With reliable crop yield predictions, producers can reduce uncertainty, stabilize pricing strategies, and optimize distribution networks.
- *Predictive Analytics*: Being a subset of data science, predictive analytics uses historical data to predict results and improve decision-making. Machine Learning (ML) has revolutionized resource management in agriculture by analyzing vast amounts of data and creating precise predictive models. Predictive analytics can be used in agriculture to help farmers better predict crop yields, forecast demand for specific crops, and optimize irrigation and soil enrichment practices. By analyzing past data patterns, predictive analytics can provide insights that can help farmers make more informed decisions about when to plant, how to care for their crops, and what prices to charge for their produce.
- *Plant Breeding:* Plant breeders are constantly searching for improvement of crops such that they can get better yields, as the crops more efficiently use water, nutrients, and adapt to climate change. With the aid of machine learning, plant breeding is becoming more accurate and efficient.
- *Crop Disease Prediction:* Crop disease is a major cause of agriculture losses and food insecurity worldwide. It causes degradation of both quality and quantity of agricultural products. The implications crop diseases have on global food production and food security are great. When tracking any crop disease, accurate and early-stage detection is a priority for many farms. Machine learning in agriculture allows for accurate disease diagnosis than the traditional method of visual examination.

BENEFITS

The applicability of machine learning in agriculture has a lot of benefits from tilling the soil, plant and animal breeding, spraying fertilizer, crop disease detection to water usage for irrigation and harvesting. ML innovation is reshaping the future of farming by solving critical challenges and unlocking new opportunities. It revolutionizes agriculture by driving precision, efficiency, and sustainability. The integration of machine learning in agriculture enhances operational scalability and helps mitigate challenges like unpredictable weather patterns, pest outbreaks, and fluctuating market demands. Other benefits include the following [14,17,18]:

- *Automatic Weeding:* Weeds threaten yield considerably, resulting in substantial economic losses and compromised crop quality. Throughout various stages of growth, crops are susceptible to weed interference. Weeds compete with crops for basic requirements like water, sunlight, and nutrients. Weed control is a very important task for agricultural production. It is necessary to identify the weed types and then remove them so that the crop yield does not suffer. Manual weeding can take up a large chunk of time, while also being a back-breaking task. A new alternative is already on the horizon – a robot programmed with machine learning technology.

- *Automated Harvesting:* AI/ML technologies increase profits by automating repetitive tasks and using the computer to compute massive data sets. Robotics integrated with ML and advanced sensors can identify and selectively pick ripe crops, addressing labor shortages and ensuring consistent quality and reduced damage during harvest.
- *Saving Time and Labor*: ML automates field mapping, monitoring crop health, and applying fertilizers. This can save farmers' time and money and reduce their need for hired labor. ML helps farmers to optimize resources, resulting in increased crop yields. It also helps farmers save money on crucial resources like water, fertilizer, and pesticides. This can increase profitability and make farming more sustainable. Machine learning can help farmers optimize irrigation schedules and identify alternative water sources.
- *Risk Management:* Farmers can use ML to predict which environmental or weather-related factors might harm their business and take steps to mitigate their impact and reduce wastage.
- *Decision-making:* ML models are capable of analyzing vast amounts of historical and real-time data to make informed decisions about plant or animal treatment and crop management. Machine learning enables farmers to make better decisions about when to plant, how to irrigate, and when to apply fertilizers. It can help increase efficiency and accuracy in decision-making while simultaneously minimizing risks and costs associated with agricultural operations. By analyzing real-time sensor data and historical trends, machine learning and agriculture can empower farming decision-making. Machine learning and agriculture amplify decisions on what crop species to grow and what activities to perform during the growing season. They provide farmers with data-driven insights that complement their traditional expertise. Although technology can enhance our decision-making, it cannot replace years of field experience and local knowledge.
- *Price Forecasting:* ML models can predict crop prices and market demand based on historical trends. Fluctuations in market prices for crops and livestock pose significant challenges for farmers and agribusinesses. Machine learning algorithms analyze historical market data, weather patterns, and consumer demand trends to predict price movements accurately. These forecasts let farmers decide when to sell their produce or invest in additional resources.
- *Crop Quality:* This is very consequential for the market and is related to soil and climate conditions, cultivation practices and crop characteristics, to name a few. High quality agricultural products are typically sold at better prices, hence, offering larger earnings to farmers. Many factors go into crop quality. For example, a grower must assess the firmness of a fruit's flesh, its soluble solid content, and skin color at harvest time and be careful about this all through the cold chain to the consumer.
- *Water Quality:* This is one of the most critical issues in reservoir management. It has strong effects on the environment and human life and livestock management. Machine learning can be used to predict water quality in reservoirs.
- *Weather Forecasting:* An accurate and reliable forecast of weather can reduce the toil faced by farmers. Weather prediction based on ML technique known as support vector machines has been proposed. Applications of ML allow convergence of the most appropriate weather forecast for a specific location.
- *Production Output Prediction:* Farmers typically plan the cultivation process based on their previous experiences. The ML algorithms can be used to predict the preferred profitable output. The prediction is based on analyzing a static set of data using supervised ML techniques.

CHALLENGES

The agriculture sector faces multiple risks and uncertainties due to changing climatic conditions and market trends. Significant production losses and wasted resources often happen because of these uncertainties. A significant challenge lies in integrating and analyzing extensive agricultural data, requiring advanced technologies and a deep comprehension of farming practices and crop biology. Climate change presents a global challenge with diverse detrimental issues, impacting various facets of human life and the environment. Other challenges include the following [14,18]:

- *Ethical Concerns:* There are ethical concerns to consider, particularly for data privacy. Farmers need to feel confident that their data is used responsibly and transparently. Building trust through clear communication and robust data protection practices is crucial for fostering wider adoption of AI/ML.
- *Data Availability:* Data lies at the heart of farming decisions, and the potential is enormous. It is the cornerstone of any machine learning AI solution and unfortunately, the lack of quality data is the key hurdle for many farmers. Agricultural data can often turn out outdated due to its accumulation over time in various formats. This further limits the development of predictive models with machine learning algorithms as their output will prove far less accurate with aged data. Farmers can use publicly available datasets for ML model training without having to collect additional data at their own farms.
- *Cultural Barriers:* Implementing ML in agriculture can benefit both the world's largest agricultural conglomerates and small family farms. However, those who fall into the latter category are more reluctant to transform their farms because of an elaborate set of decades-old principles, traditions, and assumptions. For example, many farmers firmly believe that the strength of the emotional connection between them and their livestock is the biggest prerequisite for high-quality outputs. ML vendors should carefully consider these regional specifics when offering ML-based solutions to those who need them the most.
- *Regulations:* The agriculture industry is highly regulated, and this has hindered the integration of machine learning in many ways. Regulations imposed by governments, such as agrichemical regulations or labor laws, can heavily limit the use of ML applications on farms due to compliance and safety considerations. Thus, any new ML application for agriculture should not only meet the existing regulations but also made to avoid putting workers at a disadvantage.
- *Precision Spraying:* Crop health heavily depends on spraying to prevent the infestation of pests and diseases. Machine learning projects in agriculture address this area. Precision or targeted spraying is the technology that takes the best from intelligent software and computer vision in the agriculture sector. Thus, the technology obtains the target information such as the size and shape of the plant, and then applies herbicides as needed. This technique allows for a more precise application of pesticides and fertilizers based on crop type.
- *Insect Detection:* Insects are a major threat to crops in agricultural facilities. To protect the facility, farmers use pesticides that not only kill the pests, but can also harm other beneficial pollinators that live around the farm. Discerning the "bad actors" is difficult when done manually. The use of drones to detect insects in farming is not new, but the use of machine learning in this process has seen an increase recently. Thus, machine learning companies help farmers label pests to capture and identify them.
- *Price Forecasting:* The prices of agricultural commodities are volatile. They are subject to numerous variables, including climate, government policies, demand including other factors. Price prediction is helpful for deciding on the types of crops for planting. For decades, economists have tried to forecast prices for crops using statistical models. But with the advent of machine learning, there are now, cutting-edge ways to get a much more accurate prediction of crop prices. Machine learning in agricultural economics can help organizations understand price fluctuations and offer risk management measures.
- *Training:* Introducing machine learning technology involves more than simply deploying new tools. Training farmers and agricultural workers builds confidence in using these systems effectively. Workshops, tutorials, and ongoing technical support ensure that users understand the technology's capabilities and can make informed decisions based on the insights it generates.

FUTURE OF MACHINE LEARNING IN AGRICULTURE

Agriculture is undergoing a profound modification with the adoption of machine learning. Machine learning equips farmers and agribusinesses to meet the growing global need for food while minimizing environmental impact. The adoption of machine learning in agriculture has redefined how businesses in the industry approach efficiency, profitability, and sustainability. AI and ML have the potential to significantly improve the agricultural industry by reducing environmental harm, improving yields, food quality, and making processes more efficient.

Artificial intelligence and machine learning will soon transform the agriculture industry, offering new ways to improve productivity and decision-making. As the industry continues to evolve, one thing is clear: The future of farming will be shaped by those who successfully integrate technology while staying true to agriculture's time-honored principles. While the potential is vast, researchers caution that successful AI/ML adoption requires overcoming challenges related to data quality and accuracy. The technology is only as good as the data feeding into it. The future of AI/ML in agriculture is not about replacing people; it is about equipping them with better tools to work smarter. The goal is to use technology as an ally to the farmer, not a replacement [19]. This is clearly illustrated in Figure 8 [20].

CONCLUSION

Machine learning is a research field in artificial intelligence that develops computational methods that can be used to learn from data and predict with new data.

It has massive potential to disrupt every part of the agriculture industry in the next 100 years. Machine learning is changing every industry, and agricultural leaders need to understand the basic principles, the potential, and the limitations.

Today, machine learning in agriculture is one of the fastest-growing areas. Its applications in farming range from simple analytical systems to complex robotics hardware. It is revolutionizing agriculture by enabling precision, efficiency, and sustainability in farming practices. It is applied across the entire agricultural lifecycle, from pre-planting to post-harvest management.

Several ML techniques have been developed for learning rules and relationships automatically from diverse data sets. These simplify the often tedious and error-prone process of acquiring knowledge from empirical data [21]. Farms and agribusinesses that implement these strategies unlock the potential of machine learning and sustain their operations against growing industry demands. More information on machine learning in agriculture is available in the books in [5,22-26] and the following journals:

- Agriculture
- Sensors
- Agronomy Journal
- Artificial Intelligence in the Life Sciences
- Computers and Electronics in Agriculture

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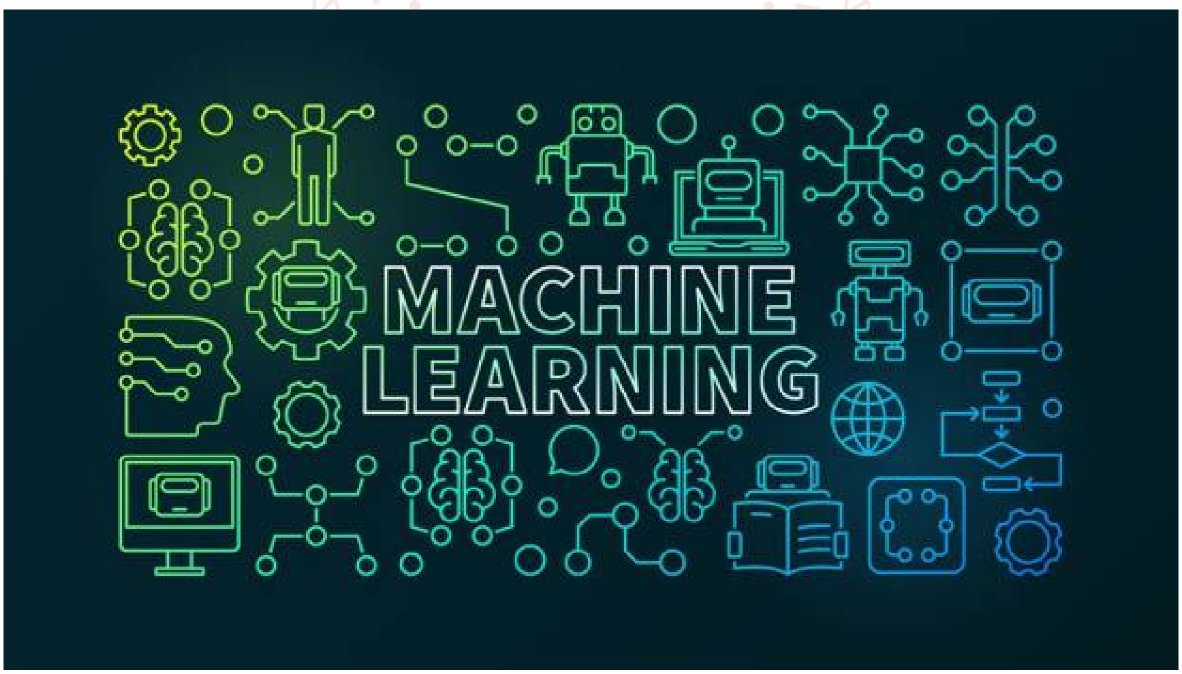

Figure 1 A symbol of machine learning [3].

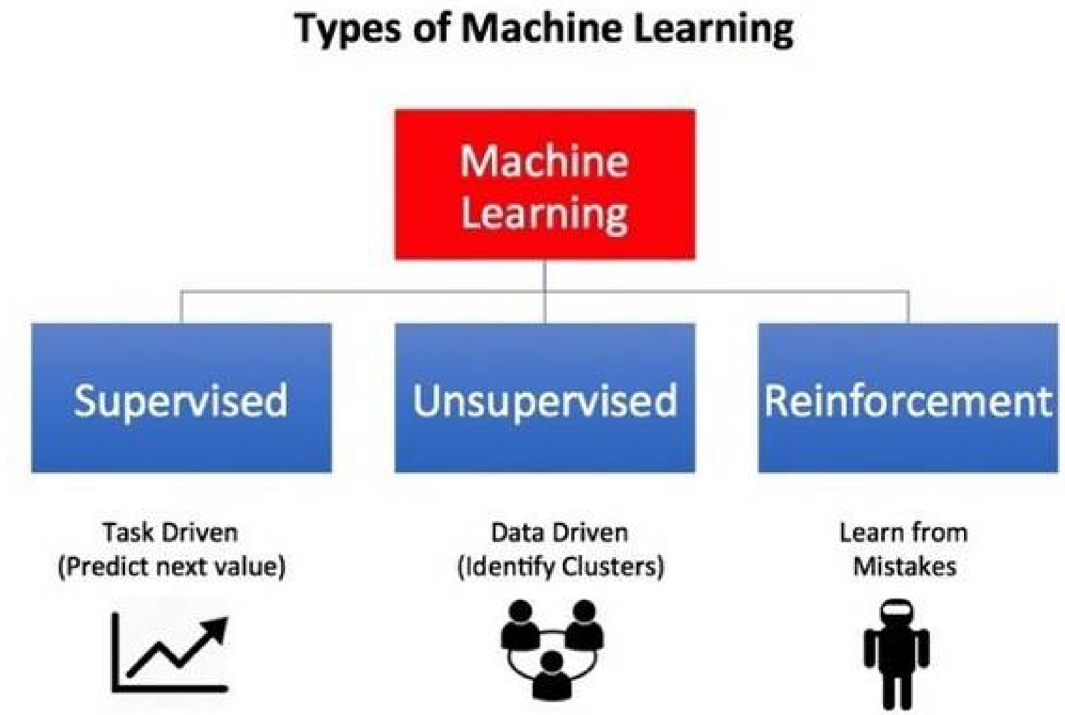

Figure 2 Different types of machine learning [3].

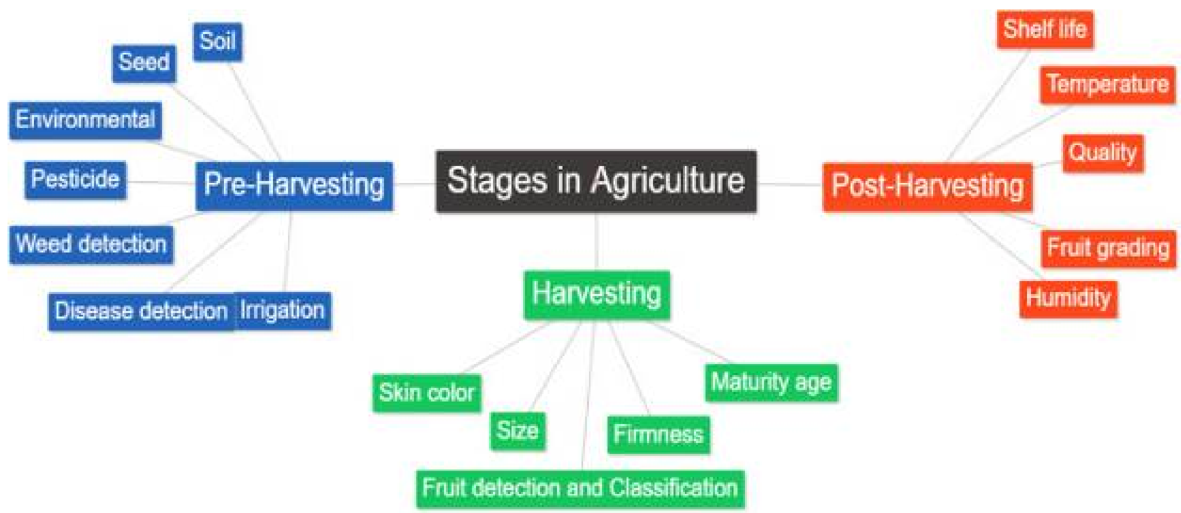

Figure 3 General categorization of agriculture tasks [8].

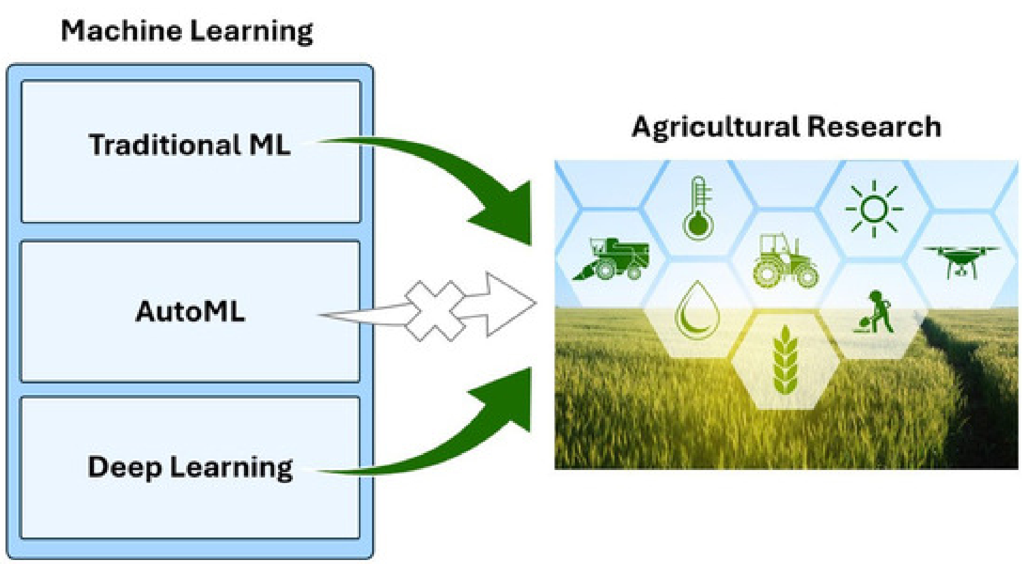

Figure 4 The integration of ML techniques in agricultural research [9].

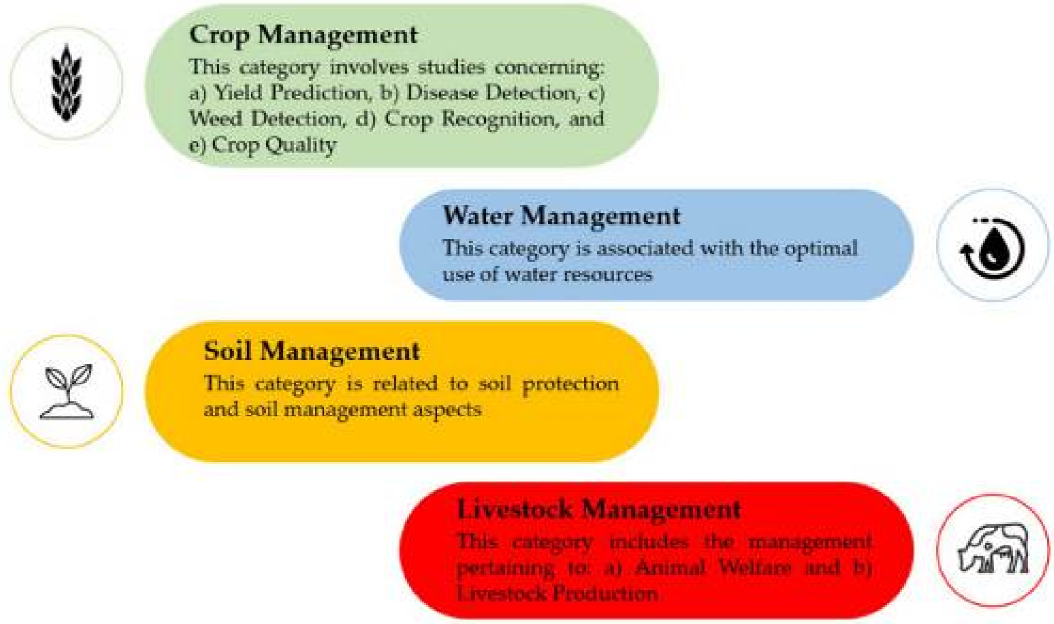

Figure 5 Some applications of ML in agriculture [10].

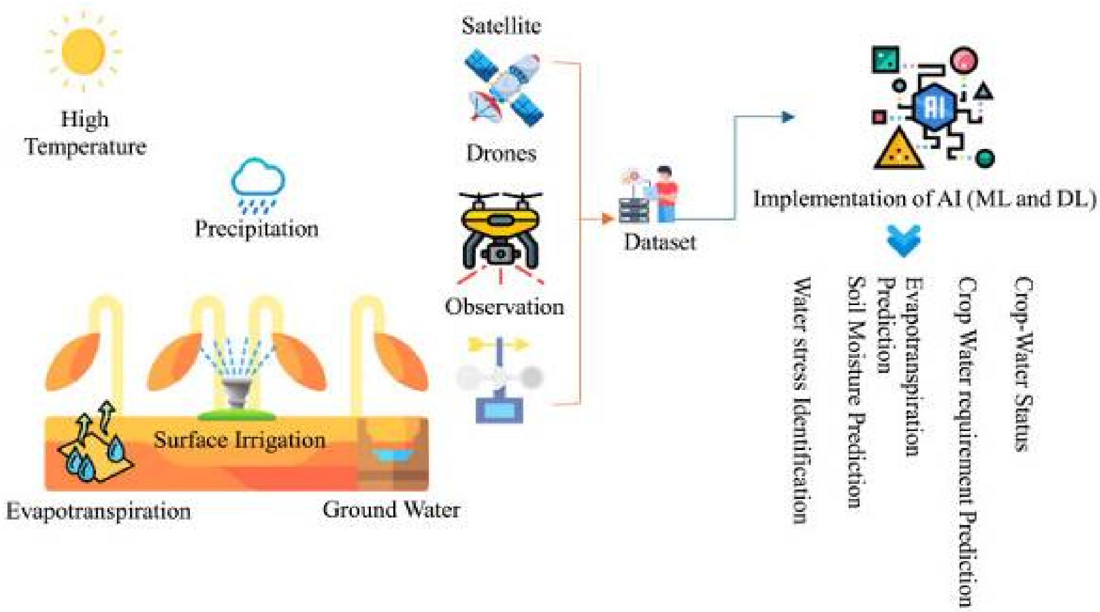

Figure 6 A schematic representation of water management by ML and DL [15].

Figure 7 A mechanized irrigation system [16].

Figure 8 Technology is an ally to the farmer [20].