Faiz Firdaus

# How can machine learning improve agricultural productivity while promoting environmental sustainability?

## Objective

This paper aims to explore the application of machine learning in the field of agriculture. We will dive deep into the potential that machine learning and technology have in increasing crop yields and encouraging environmental sustainability. It will discuss the need for agricultural innovation as well as the problems with traditional agricultural practices. Curation of multiple peer-reviewed papers will be used to convey factual information on this topic to ensure the credibility of the statements within this paper. The intended audience for this paper is the director of the United Nations Food and Agriculture Organization (FAO), Dr. Qu Dongyu. Given the FAO's influence over global food and agricultural policies, informing the FAO director of current problems and potential innovations for agriculture can enable effective and strategic planning to serve the world's food security and mitigate looming environmental disasters.

## Introduction

According to the United Nations, the global population will rise to 9.4-10.1 billion in 2050, and continue increasing to 9.4-12.7 billion in 2100 [1]. With the ever-growing rise in population growth, food demand will inevitably need to increase to cope with the rising population [2]. By 2050, it is estimated that global food demand will increase by 70%, which poses a problem for countries that are still dependent on their agricultural sector [2]. The rising global population is not the only problem that looms around agriculture. With pressing environmental challenges such as climate change, droughts, and soil degradation becoming more prevalent, food security and environmental sustainability are under threat [4][5]. Agriculture, in particular, is affected by these growing issues. As part of the UN's Sustainable Development Goals (SDG) of *Zero Hunger* and *Life on Land*, the problem of both a growing population and environmental challenges underscore the need for an innovative agricultural solution that can advance society closer to these goals [2][4].

Sustainable development has always centered around food, water, and energy, which will likely grow in importance as our resources is put under increased stress [3]. The current landscape of agriculture hinders progress towards sustainable development [7]; many traditional agricultural practices inefficiently use natural resources and do not maximize food productivity [5].

Li et al. [6] reported that one way unsustainable agriculture practices can be addressed is through smart farming, also known as precision agriculture, where data-driven decisions dictate the workflow in agriculture. Smart farming's use of data-driven decision-making can ensure the long-term sustainability of food production through data processing software, web-based applications, and mobile tools [6,7]. Hence, the modernization of agriculture is a potential answer for the growing food demands and declining environmental conditions.

Machine Learning (ML) has emerged as a prime candidate to transform smart farming to new heights [8]. By leveraging existing smart farming tools like Unmanned Aerial Vehicles (UAV), the Internet of Things (IoT), and robots, machine learning can produce data-driven decision-making that optimizes resource use, reduces waste, and increases crop yields [2,8]. Machine learning models can predict crop yields and detect diseases early, preventing financial losses and enhancing agricultural productivity and sustainability [8,9].

Despite these seemingly ideal applications of machine learning in agriculture, the adoption of ML-driven solutions in agriculture is limited in many places, particularly where farmers come from rural areas with limited access to and experience with technology and the fact that they do not typically own the financial resources to afford smart farming tools [9]. Farmers who lack access to smart technologies tend to rely on traditional agricultural practices which typically involve intensive manual labor [8]. Due to the high physical demand and ineffectiveness of manual labor, traditional agriculture practices is unsuitable to face the rapidly changing climate and stress on food demand [9,10].

This white paper explores the need for global food production and how machine learning is capable of addressing the challenges posed by traditional agriculture, pushing us closer to finding solutions for growing food demand and the deteriorating environment. This paper selects peer-reviewed articles, research papers, and academic journals related to agriculture, technology, and machine learning. The curation of findings is done by searching keywords such as: "agriculture AND technology", "precision agriculture", "machine learning AND (agriculture OR environmental sustainability", "smart farming", and "sustainable farming". The literature explored ranges from precision irrigation techniques to ML-assisted hydroponic farming. This paper's goal is to inform the need to enhance agricultural productivity and environmental sustainability. It serves to give actionable insights related to the future of agriculture, encouraging effective strategies to solve the growing food demand and the declining environmental condition.

## The need to increase agricultural productivity for the global population

As the global population is expected to rise to 9.4-10.1 billion by 2050 [1], the demand for food will substantially increase by approximately 60%-70%, emphasizing the need to drastically escalate global food production [4]. Many developing countries, particularly those in Asia and Sub-Saharan Africa, face growing challenges to provide more food for their rapidly growing population [10]. In order to combat the risk of food insecurity with a growing population and limited resources, careful revision and planning to farming strategies are needed [10].

Apart from the growing global population, the threat of climate change has increased the appeal for creating more productive agriculture systems [5]. With temperatures expected to shift by 0.5 to 8 Fahrenheit by the end of the century [14], the shifting climate patterns challenge the agricultural industry, addressing the need for innovations to mitigate its effects to make better-informed decisions [9,10,11]. Taryn Wilson et al. [9] highlighted how rising temperatures, greater weather fluctuation, and changing rainfall patterns from climate change have resulted in significant challenges for agricultural productivity as traditional farmers have troubles adapting to the rapid changes.

Increased occurrence of droughts and soil degradation due to climate change and excessive fertilizer use have also contributed to the mounting challenges for agriculture [12]. For many traditional farmers, droughts and soil degradation mean that they need to produce more food with fewer resources available [12,13]. Additionally, the rapid urbanization of many developing countries has resulted in increased soil degradation and reduced land space available for farmers to grow their crops [5,12]. Such problems with natural resources limit agricultural productivity where food demand is growing. In places where agriculture is an integral part of the economy, maintaining a stable and productive agricultural system is also essential in remaining economically competitive on the global stage [13].

## How are traditional agricultural practices becoming inapt for the changing world?

With the rapid population increase and pervasive change to our climate, agricultural practices are racing to adapt [5,12,8]. Unfortunately, traditional methods in agriculture are not well-equipped to meet the rising demands [8]. Currently, around 1.9-2.2 billion farmers in the world rely on traditional forms of farming, often involving manual labor [14]. On the other hand, almost all farmers in the United States have shifted to smart farming, also known as precision agriculture, in some way [13]. This disparity highlights the importance of providing farmers greater access to technology to advance agriculture worldwide.

As most parts of the world still rely on antiquated agricultural practices, many farms struggle to keep up with rising food demands and shifting climate patterns [8]. Although these methods have worked historically, the changing landscape of our climate and the rapid population growth mean their inherited knowledge is becoming less reliable [14,15]. This results in many traditional farmers missing out on maximizing their yields and ensuring environmental sustainability [10].

One particular problem with traditional methods of agriculture is inefficient resource consumption [4,8]. For example, traditional irrigation methods, like field flooding, often lead to overuse of water resources and depletion of the local water supply [16]. As climate change is already a serious problem, this can exacerbate stress in areas where water supply is already scarce due to climate-inflicted challenges, such as droughts [11]. Similarly, traditional farmers typically distribute fertilizers and pesticides based on intuition [11]; the excess presence of fertilizers and pesticides can deteriorate soil quality, which results in decreased healthy lands for sustainining the long-term viability of agriculture [9,17]. With a growing need to sustain our natural resources, traditional agricultural practices pose a stumbling block to progressing toward environmental sustainability [10].

Apart from not being environmentally sustainable, traditional practices do not produce as much yield as their farm's potential [8]. Many popular agricultural methods rely on manual labor and self-informed decisions [5,11]. The strenuous physical demands of manual labor mean that farmers are more likely to become fatigued and, thus, do not yield maximum results [18]. Additionally, as traditional practices require farmers to carry out important tasks like seeding and disease detection by hand, it is slow and laborious, hindering productivity [5]. Many traditional farmers also rely on their intuition and experience to make decisions on their farms, which is often misleading [11]. As previous experience typically overlooks shifting factors such as the changing climate and degradation of soil quality, decisions made from past experiences may not produce effective results, leading to decreased productivity of the land and unsustainable food production [11,15].

## Smart farming as a step forward from traditional farming

Unlike traditional farming, smart farming embraces digital technologies in agriculture, focusing on data-driven decision-making to enhance efficiency, sustainability, and productivity [6,15]. Balasundram et al. [7] suggest one way smart farming encourages sustainability is through efficient resource utilization; task automation and IoT devices have contributed to efficient irrigation, water loss management, and continuous identification of soil nutrients in certain areas. Effective water and land management is crucial in reducing waste and excess use of fertilizers and pesticides [5,7]. The continuous stream of data from interconnected technologies further contributies to mitigation strategies for climate change by providing scientific solutions to effectively minimize energy demands and reduce chemical use, ensuring long-term environmental sustainability [19].

The digitization of agriculture do not only promote environmental sustainability, it also increases agricultural productivity [9,11]. By collecting data on climate conditions, soil health, and market demands, smart farming can take advantage by recommending the most optimal crops to plant, automating crop health management, and providing predictions for crop yields [8,9,11]. Reducing manual input from farmers through smart farming enables more efficient production as bodily fatigue and antiquated farming knowledge are excluded from the equation [9,18,11]. Furthermore, as the shifting climate affects resource supply in some areas due to droughts and pest infestations, smart farming provides farmers the ability to manage larger areas with fewer resources [8]. This reduces the overall labor needed to produce the same number of crops as it would have taken with traditional farming, thus enhancing agricultural productivity [4,5,8].

## How can machine learning bolster the capabilities of smart farming?

Machine learning (ML) is the development and application of computer systems that improve self-sufficiently through experience [20]. A possible application of machine learning in smart farming is through improved resource allocation [4]. By leveraging clustering algorithms, which primarily excel in identifying characteristics of particular data clusters, machine learning can identify from the collected data how to best allocate resources according to their crop's needs, reducing environmental waste [4]. Additionally, by identifying specific characteristics of crops from farm data, machine learning models can use statistical insights to enhance decision-making, resource allocation, and sustainable agricultural practices [4]. These added capabilities fortify smart farming's sustainable practice.

With the help of models like Support Vector Machines (SVM), machine learning can provide predictions of crop yields and soil health from data collected from sensors, IoT, and radar data, enabling farmers to better manage their crops [8,15]. By processing extensive insights from the data collected through prediction models, machine learning can provide crop recommendations for farmers to best maximize their farmland [11]. This allows farmers to maximize their yields and sustain agricultural productivity [9].

Other machine learning models, such as Convolutional Neural Networks (CNN), can further strengthen smart farming by analyzing images taken from drones or smartphones [5,13]. CNNs work through object detection and image recognition, particularly useful for smart agriculture [5,8]. Some applications of image detection in smart farming include early pest and disease detection in addition to fruit and flower identification [5]. Through CNN's early disease detection capability, it can prevent massive disease spreads which, in turn, ensures minimal loss of crops [8,11]. Machine learning's ability to identify plants and flowers grants farmers optimal harvest time and effective resource allocation, promoting productivity and environmental sustainability [5].

## Discussion

The findings from this white paper emphasize the imminent global problem with food security and environmental sustainability. With the population continuing to grow, the climate shifting more drastically, and natural resources depleting, agriculture is being put under immense pressure to meet its expansive demands under a rapidly changing environmental landscape.

Currently, traditional agricultural practices make up a majority of the agriculture industry. However, it is unsuitable for meeting the rising global demands for food security and environmental sustainability; the intensive labor and the reliance on traditional knowledge produce ineffective crop yields and waste natural resources, posing a significant threat to food security and sustainability. As a result, it is reasonable to leave traditional farming behind in search of more sustainable alternatives capable of mitigating the shifting social and environmental landscape.

Smart farming has become increasingly popular in recent times as it offers a pathway to reduce manual labor and provide data-driven insights into agriculture, offering more productive yields and effective resource management. Hence, the integration of smart farming can mitigate the risk of food security and environmental degradation in many places.

Integrating machine learning with emerging technologies in smart farming can enhance its potential to resolve food insecurity and environmental sustainability. ML-driven smart farming systems can analyze vast amounts of data collected from sensors, satellites, and drones to provide actionable insights in real-time. By taking advantage of machine learning's prediction and classification capabilities, farmers can leverage machine learning to maximize their crop yields, better manage their resources, and reduce environmental impacts. Such precision and adaptability are pivotal for building effective agricultural systems capable of withstanding the uncertainties posed by the increasing population and climate change.

However, challenges such as financial cost and energy needs have become relevant obstacles in the mass integration of technology into agriculture [9]. Many farmers who come from lower-income rural families cannot afford to make this radical shift, emphasizing the need for policy changes and government support to push for a complete agricultural transition [4].

## Conclusion

As the global population is expected to surpass 9 billion by 2050 and climate change is increasingly threatening agricultural productivity, the need for innovative, data-driven solutions becomes more urgent. Machine learning, with its powerful prediction, classification, and optimization capabilities, offers a revolutionary approach to agriculture that ensures a more sustainable future for food production and the environment.

It is crucial to carefully reflect on the information presented in this paper and consider them for future agricultural strategies. As part of the FAO's mission to facilitate efforts to design sustainable agricultural policies and programs, ML-driven smart farming strongly aligns with FAO's goal. As such, providing support to farmers to enable this radical agricultural change is paramount. By prioritizing the adoption of machine learning into agriculture and designing policies around smart agricultural practices, the FAO can play a pivotal role in shaping a more sustainable, resilient, and equitable future for agriculture that brings us closer to achieving *Zero Hunger* and *Life on Land.*

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