THE INTEGRATION OF THE LATEST TECHNOLOGICAL ADVANCEMENTS IN AGRICULTURE. WHAT ARE THEIR EXACT APPLICATIONS AND HOW DO THEY WORK?

Alexandru TĂBUȘCĂ[1]

Ștefan BĂICOIANU[2]

Abstract

Agriculture is not only about planting crops and raising animals, it is way more than that. Agriculture is a business which supports human life, provides raw materials and builds strong economies, playing an extremely important role in our livelihoods, even if we may not always notice that. Experts from this sector, however, say that the new global situation asks for a so called "revolution" in agriculture. Only in the last two decades, climate changes have been responsible for a productivity decrease of 21% in this business. Moreover, taking into consideration the pandemic and the political situation from the recent years, which led to a raise of the production costs, farmers and entrepreneurs are more and more worried about the way they are going to make their businesses profitable.

We should also mention that the worldwide food need is going to be 50% higher in 2050 than in the present. Fortunately, technological advancements come as a solution to these problems. Not only do they have an impact on the production costs, but they also help in reducing pollution around the world. A 2022 Deloitte study in collaboration with the Environmental Defense Fund revealed that the use of technology in agriculture can decrease with 9.8 gigatons the production of carbon dioxide-equivalent emissions (CO2e) between 2020 and 2050, as well as save up to 100 billion US dollars in costs to farmers by 2030. The agricultural technology, also known as "AgriTech", promises a more efficient use of equipment and an increase in crop yields, all of these while following a sustainable production plan, generally referred to as "precision agriculture".

Keywords: precision agriculture, artificial intelligence, internet of things, drones, robots, sustainability, optimization

JEL Classification: O13

1. Introduction

[1] PhD, Associate Professor, Romanian-American University, Romania, alex.tabusca@rau.ro
[2] Student, "Mihai Viteazul" National College, Ploiești, Romania, stefanbaicoianu24@gmail.com

Technological advances have always played an important role in the history of agriculture. In fact, we are going now through a period in which the future of our planet is shaped by these modern tools. This article explains in detail the application of the latest technologies in agriculture, describing in parallel how they work. Artificial Intelligence (AI) and the Internet of Things (IoT) are the two main components of AgriTech.

The Artificial Intelligence in Agriculture Market is "projected to grow from USD 1.7 billion in 2023 to USD 4.7 billion by 2028", reveals a report of MarketsandMarkets [1]. The integration of AI and IoT technologies transforms traditional farming practices into efficient and sustainable operations. From autonomous tractors to robots and drones, Artificial Intelligence and Internet of Things underlie all new machinery and systems used in agriculture.

2. Key applications

The Internet of Things connects devices and systems with processing ability with other computers, ensuring at the same time continuous data transfer. The information received over the Internet (or other communication networks) can be farther incorporated in a software programme. This is how AI and IoT add functionality to the modern tools used in agriculture (such as drones and robots). In short, a dataset, which for example can be formed of images or temperature readings over a week, is collected by sensors and cameras. Then, this information is analyzed by Artificial Intelligence algorithms, allowing farmers to make data-driven decisions regarding their crops. Next, we will delve deeper into how these modern agricultural machineries work and what is their exact application.

2.1. Drones

Drone technology plays a significant role in the agricultural sector, providing a unique view on sustainable farming. Drones are equipped with advanced cameras, furnishing high-resolution aerial images in order to monitor crop health. In this regard, some farmers already use satellite images, but their accuracy and precision are less exact. Modern drones are so precise that based on camera input, they are able to indicate specific location to the millimeter. It can be about a place where a plant disease was spotted, so that farmers can treat it in a very rapid and efficient way, before being too late and losing from the harvest. Or it can be about the security and management of a farm. For example, in this way, the use of machinery and equipment can be remotely monitored, saving both time and money, because the demand of security people is less.

Figure 1. An example of a camera-equipped agricultural drone[3]

Moreover, drones are used to spray pesticides and fertilizers. According to Tom Wolf's article on "Sprayers 101" website, this practice is widespread in south-east Asia, a great percentage of the agricultural areas being treated in such manner [2]. Using this technique, farmers improve crop yield by targeting specific areas and save chemical costs by applying no more solution than needed (which is almost impossible when referring to traditional spraying methods). Besides, by using a smaller quantity of pesticides, soil pollution is reduced and the nutritional quality of the crop is improved. This measure has a positive effect on human health, too. A study of the "World Health Organization" (WHO) from 2018 reveals that "about one-tenth of the world's population becomes ill every year from eating contaminated food" [3]. "Contaminated food intake is the main pathway for soil contaminants to the human body" informs research of "Science Communication Unit" in collaboration with "University of the West of England" [4].

Figure 2. Drone applying spray treatment[4]

[3] Source: https://www.croptracker.com/blog/drone-technology-in-agriculture.html
[4] Source: https://www.croptracker.com/blog/drone-technology-in-agriculture.html

In addition to pest detection, drones' camera vision technology provides information about plant health according to leaf color. Normalized Difference Vegetation Index (NDVI) is the metric used in this process. The principle behind this indicator is based on the spongy layers found on leaf backside. When healthy, leaves reflect a great amount of Near Infrared (NIR) light. At the opposite side, stressed and dead leaves reflect less NIR light. This is how NDVI imagery distinguishes healthy plants from sick ones.

Such information is essential for crop management because in this way farmers are able to identify irregularities and combat them. One of the reasons for plant stress is the lack of water. By getting NDVI feedback from drones, farmers are able to optimize water usage by irrigating only the problematic areas of the crop and not the entire land. We all know that these days our planet confronts water scarcity and it is crucial to use this resource carefully.

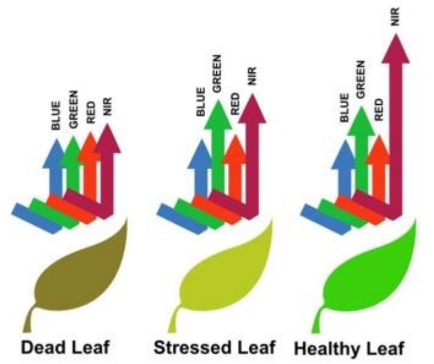

Figure 3. A representation of the light reflected by three types of leaves[5]

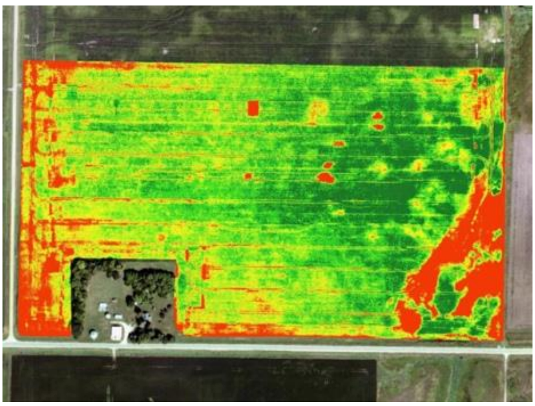

Figure 4. An example of NDVI imagery[6]

[5] Source: http://www.agasyst.com/portals/NDVI.html
[6] Source: http://www.agasyst.com/portals/NDVI.html

2.2. Robots

Robots represent a valuable tool within the agricultural industry, especially when talking about large farms, but not only. These robots are mainly designed to be able to harvest fruits and vegetables without damaging them. Being equipped with sensors and cameras (as in the case of drones), agricultural robots detect when crops are ready to be picked and with the help of an articulated arm and a transport unit for mobility, they successfully achieve their tasks. In fact, harvesting robots integrate in their design parts from both traditional six-axis robots and mobile robots.

Figure 5. An example of a harvesting robot[7]

Apart from harvesting, agricultural robots are used for planting and seeding tasks. In order to drive autonomously, robots use both computer vision technology and predefined GPS coordinates, so that they require no human intervention. Some of the widespread types of robots from this category include autonomous tractors and robotic arm planters. From drilling holes and depositing seeds at precise depths, to covering them with soil, planting robots are capable of achieving repetitive human tasks. Actually, when talking about this kind of actions, robots have higher accuracy and precision than people do, their operations leading to better crop yields. According to Markets and Markets, agricultural robots' market in the entire world was estimated at USD 13.5 billion in 2023 and is expected to reach USD 40.1 billion by 2028 [5].

3. Machine Learning in AgriTech

Machine Learning (ML) is a branch of Artificial Intelligence which enables computers to learn from a dataset and make predictions. ML models imitate the way humans learn, improving their accuracy once they have gathered a greater amount of data. The computer vision software used to develop drones and robots described in section 2 relies on Machine Learning algorithms, which are mostly created using *Python* programming language.

[7] Source: https://howtorobot.com/expert-insight/agricultural-robots

Along plant disease detection, ML is used in the agricultural sector to predict crop yield, which is an extremely important indicator. Depending on it, farmers adopt different strategies regarding land management. In this section we will focus on the ML algorithms behind crop yield prediction models.

First of all, according to the way that models are trained, Machine Learning is divided into two subcategories: supervised and unsupervised learning. Supervised learning is when machines receive labeled datasets, so that they do not have to independently identify any patterns within the information. Moreover, these algorithms analyze the relationship between input and output, so that they can make new predictions. For example, a supervised model might be used to predict crop yield based on specific parameters, such as soil type, temperature, precipitation or humidity. This category includes regression and decision tree algorithms. In contrast, unsupervised learning models are trained without any labels. Instead, machines group the information based on rules they create. Unsupervised learning algorithms are particularly suited for handling large amounts of data and establishing relationships between them, which is also the case of crop yield prediction. Artificial neural networks are used in this scope.

3.1. Artificial Neural Networks (ANNs)

Artificial Neural Networks are a more complex type of unsupervised learning algorithms, designed after the structure of a biological brain. ANNs are usually presented as systems of interconnected “neurons” (also known as “units”) divided into three types of layers. Data is received through input neurons, which is farther sent to the hidden layer, where patterns within the information are recognized. More complex networks may have more hidden layers. Finally, the “impulse” is transferred to the output neurons which return predictions as a response to the ANN input.

Links between units from different layers are called “synapses”. Each of them stores a “weight” attribute that determines the influence of the connection on the learning process (more specifically on the other artificial neurons). As in the case of the human brain, not all synapses have equal efficiencies (strengths).

Moreover, while biological neurons are stimulated by strong electrical impulses, ANNs are activated using mathematical functions which map the input to the output, as illustrated in figure 7. The learning technique behind ANNs is called “backpropagation” and consists of the modification of the “weight” feature according to the difference between predicted and actual outputs. It changes until the neural network reaches the minimal possible error rate.

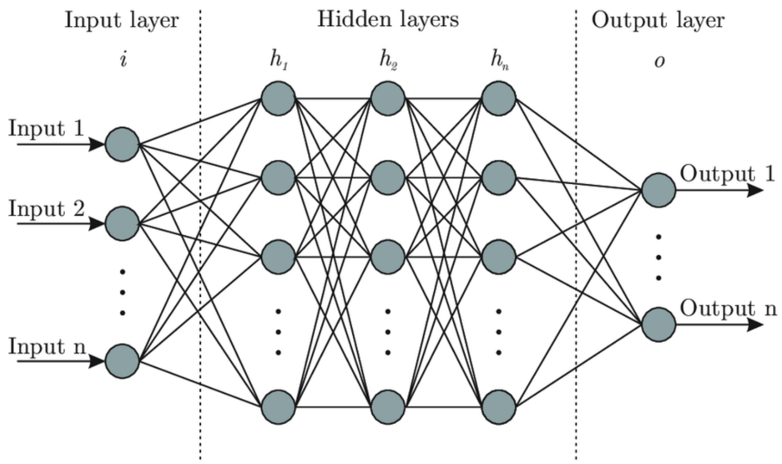

Figure 6. A representation of an Artificial Neural Network [8]

Artificial Network	Biological Network
Input layer	Dendrite
Neuron / Unit	Cell body
Weights	Synapses
Output layer	Axon

Table 1. An analogy between Artificial Neural Networks (ANNs) and Biological Neural Networks (BNNs)

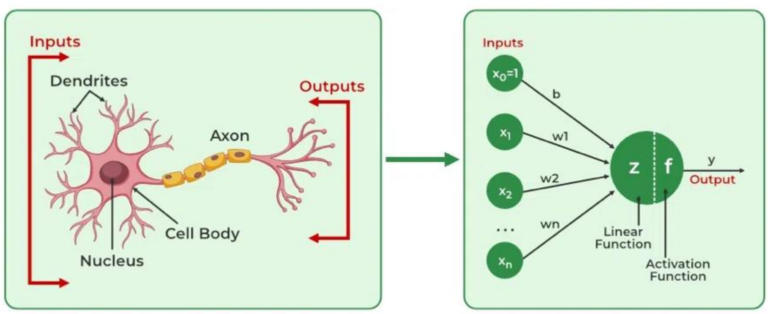

Figure 7. BNNs vs ANNs[9]

[8] Source: https://www.researchgate.net/figure/Artificial-neural-network-architecture-ANN-i-h-1-h-2-h-n-o_fig1_321259051
[9] Source: https://www.geeksforgeeks.org/artificial-neural-networks-and-its-applications/

3.2. Regression models

Regression analysis relies on the relationship between input and output data by fitting a mathematical equation (which can be linear or polynomial). Regression can be represented in a cartesian plane, where the x-axis is the input feature, and the y-axis is the target value. For example, when referring to linear regression, the prediction line is fitted so that the sum of the squared vertical distances between line and data points is minimal (which is the definition of error). This technique is called "Least Squares Regression". Figure 9 shows an example of a crop yield prediction dataset. In reality it is made up of 28248 rows and 7 columns of information.

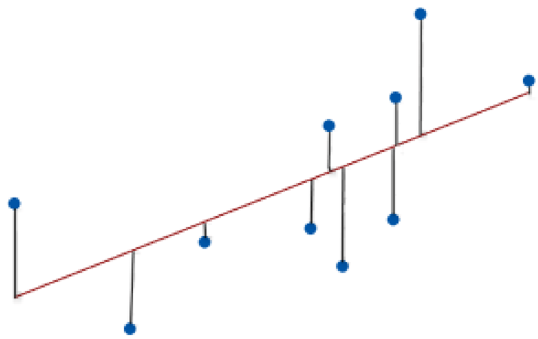

Figure 8. An illustration of a "Least Squares Regression" line[10]

	Area	Item	Year	hg/ha_yield	average_rain_fall_mm_per_year	pesticides_tonnes	avg_temp
1986	Bahamas	Cassava	1990	106667	NaN	484.59	25.74
1987	Bahamas	Maize	1990	15000	NaN	484.59	25.74
1988	Bahamas	Sweet potatoes	1990	38118	NaN	484.59	25.74
1989	Bahamas	Cassava	1991	100000	NaN	484.59	25.66
1990	Bahamas	Maize	1991	16667	NaN	484.59	25.66
1991	Bahamas	Sweet potatoes	1991	31385	NaN	484.59	25.66

Figure 9. A part of a dataset used for crop yield prediction[11]

3.3. Decision tree models

Decision tree algorithms use tree-like structures to make decisions and predictions. One of their greatest advantages is that they can handle high-dimensional data with good accuracy, which can be crucial when taking into consideration the scope of these models: crop yield prediction. They are similar to recursion functions, dividing input features into smaller and smaller subsets (based on their significance) until a dead end is reached. Each split of the

[10] Source: https://statisticsbyjim.com/regression/least-squares-regression-line/
[11] Source: https://www.javatpoint.com/crop-yield-prediction-using-machine-learning

tree is done by passing through a decision point (node), resulting in a new one or in a leaf which represents the outcome variable (the prediction). Connections between nodes are called "branches" and they are represented with arrows as in figure 10. When visualizing decision trees, branches are illustrated with responses to the decision rules such as *yes* and *no*. Final predictions are made by going through the entire tree, from the root node to a leaf.

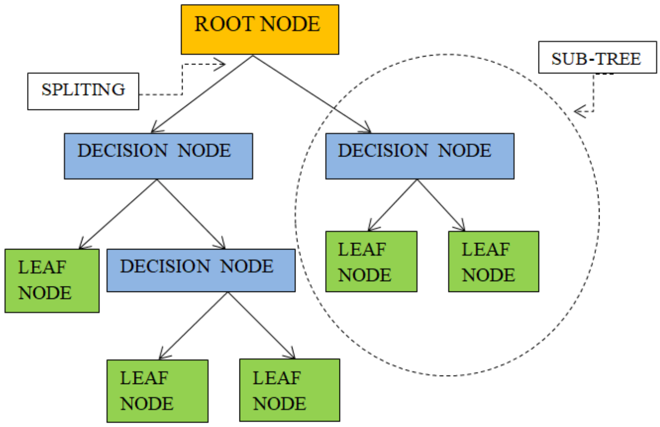

Figure 10. An example of a decision tree structure[12]

4. Conclusion

The integration of the latest technological advancements in agriculture is a "must", not a "should". Generally speaking, if we do not adapt to the current global situation and refuse to use the modern tools that we have at our disposal, the future of our planet is going to be worse and worse. The more is the case of agriculture, which is the second most polluting industry in the world, being directly responsible for almost 8.5% of total greenhouse gas emissions. Apart from the economic impact that tech innovations have on this sector, farmers and entrepreneurs should primarily focus on the environmental aspect that is in their hands. Even if buying such equipment may sound a bit expensive at the beginning (especially for small and midsize producers), there is nothing more important than a friendly environment which supports human life. Regarding this problem, governments should financially help farmers or directly provide them access to the latest technology. It is an extremely valuable tool for humanity and it would be a sin not to use it, especially when in the game is the future of our home, the Earth.

[12] Source: https://www.researchgate.net/figure/Decision-tree-structure_fig1_360443851

References

[1] https://www.marketsandmarkets.com/Market-Reports/ai-in-agriculture-market-159957009.html (the introduction section) – Global forecast to 2028 of Artificial Intelligence in Agriculture Market; last access: 26.05.2024

[2] https://sprayers101.com/challenges-drone/ (the introduction section) - A review about drone spraying; last access: 26.05.2024

[3], [4] https://openknowledge.fao.org/server/api/core/bitstreams/fe5df8d6-6b19-4def-bdc6-62886d824574/content/src/html/chapter-04-3.html (4.3.1 "Pathways for exposure" section) – Impact of soil pollution on human health; last access: 26.05.2024

[5] https://www.globenewswire.com/en/news-release/2023/08/16/2726443/0/en/Agriculture-Robots-Market-Size-Industry-Share-Trends-2028-MarketsandMarkets.html#:~:text=Agriculture%20robots%20market%20in%20terms,report%20published%20by%20MarketsandMarkets%E2%84%A2 - Global agriculture robots market size and trends to 2028; last access: 26.05.2024

Bibliography:

HENKE, C. – *Cultivating Science, Harvesting Power: Science and Industrial Agriculture in California.* ISBN 978-0-262-08373-7. August 2008

MUKHOPADHYAY, S. – *Smart Sensing Technology for Agriculture and Environmental Monitoring.* ISSN 1876-1100. February 2012

LI, D., ZHAO, C. – *Computer and Computing Technologies in Agriculture II, Volume 2*. ISSN 1571-5736/1861-2288. June 2009

https://www.cropin.com/iot-in-agriculture - Integration of IoT technology in agriculture; last access: 29.05.2024

https://www.forbes.com/sites/ganeskesari/2024/03/31/the-future-of-farming-ai-innovations-that-are-transforming-agriculture/ - AI innovations in the agricultural sector; last access: 29.05.2024

https://www.linkedin.com/pulse/ai-iot-powerful-duo-smart-farming-agriculture-clearspot-ai/ - AI and IoT in agriculture; last access: 29.05.2024

https://tolluncrewedsystems.com/blog/how-drones-are-used-in-agriculture/ - Use of drones in agriculture; last access: 29.05.2024 https://www.idtechex.com/en/research-report/agricultural-robots-and-drones-2017-2027-technologies-markets-players/525 - Agricultural robots and drones: market review and technology assessment; last access: 29.05.2024

https://howtorobot.com/expert-insight/harvesting-robots - An article about types of agricultural robots; last access: 29.05.2024

https://www.javatpoint.com/crop-yield-prediction-using-machine-learning - Machine Learning models used in crop yield prediction; last access: 29.05.2024

https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=7c68a32212c1f86f535f4c1658ff68399d0a9ddd – Artificial Neural Networks (ANNs) for crop yield prediction; last access: 29.05.2024