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FACULTY OF MATHEMATICS AND COMPUTER SCIENCE
SPECIALIZATION [Secție]

DIPLOMA THESIS

Precision Agriculture: Predicting a crop based on environmental data.

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ABSTRACT

This paper aims to illustrate how integrating AI into agriculture can potentially enhance production. It also seeks to encourage documenting the environmental conditions and outcomes associated with each crop field for future development with AI and agriculture data with aim on improving efficiency and yield. Workers in this field face challenges in considering all factors when making decisions, often relying on intuition. However, this paper will delve into these natural factors that significantly influence crop outcomes, outlining the potential long-term impact it could have in agriculture, regarding the knowledge farmers posses about the quality of the soil. Introducing a tool that would make it easier for them to make decisions while taking such data into account would greatly benefit them. By providing chemical data about the soil at the start of the year, this machine learning algorithm can predict the yield of different crops. This can later be developed to use these results to recommend what crop would be best for the current year, or what the chemical levels of the soil should be for their desired crop. This model was initially trained on a public dataset from India. However, it can easily be adapted to other countries with varying climates, provided there is access to relevant training data.

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Introduction

1.1 Motivation

In recent years, our climate has undergone significant changes, deeply impacting the agricultural sector. On top of the constant change of the climate making it harder for farmers to predict which would be the best crop to be planted, our society continues to expand while arable land is finite. At the same time, not all farmers consider all the knowledge there is about crops. Reaching better productivity out of the current resources we have would be a great improvement on top of making certain decisions easier for farmers. I was determined to look for options to implement artificial intelligence into our agricultural sector in a way that would make farming smarter and more efficient.

1.2 Objective

The objective of this project is to encourage the advancement of implementing ai into this field and bringing more efficiency and effectiveness to farming practices. I want to promote both the collecting and utilization of data by showing the effects it can have. With future developments in this field, we anticipate simpler decision-making processes for our farmers, coupled with reducing the waste of resources such as fertilizer. This approach ensures optimal utilization of resources where they are most needed, which provides greater efficiency and sustainability. Additionally, the data collected, and the progress achieved in this field could have the potential to stimulate further innovations in the agricultural sector.

1.3 Structure of the thesis

This Paper is divided into 3 main chapters: Theoretical background, Crop Yield Prediction Application and a Synthesis.

First, this paper will describe the background for the field, discussing the importance of improving the productivity of the crops due to the population situation as well as the climate change situation. The key chemical factors to take into consideration when talking about improving productivity of crops are the three chemical elements: potassium (K), nitrogen (N), and phosphorus (P). In this chapter I will delve into their significance for various crops and how achieving optimal balances of these elements can lead to better annual crop yields.

Second, I will present the project of this thesis along with the objectives. I will present the technologies used, the selected machine learning algorithms and the reasons behind choosing them, as well as their respective results. Then I will proceed to show the application and how these algorithms and their results can be used to help the decision making of the farmers. Lastly, I will talk about encouraging future data gathering in this field to facilitate further development into making agriculture more efficient and less wasteful.

Lastly, I will summarize the contents of my paper while bringing together the conclusions made along the way. These conclusions will be examined, and their impact will be discussed, along with future developments that can be made on this project.

Chapter 2

Theoretical Background

2.1 World population

The population of the earth experienced a rapid increase to 7 billion in 2011. It was estimated at that time that by the year 2025 we would reach 8 billion, and by 2050 it would reach 9 billion. As we have reached the year 2024, we can already see that the first prediction was accurate, as we currently reached 7.95 billion people. The following graph serves as visual aid to illustrate the demographic expansion2.1.

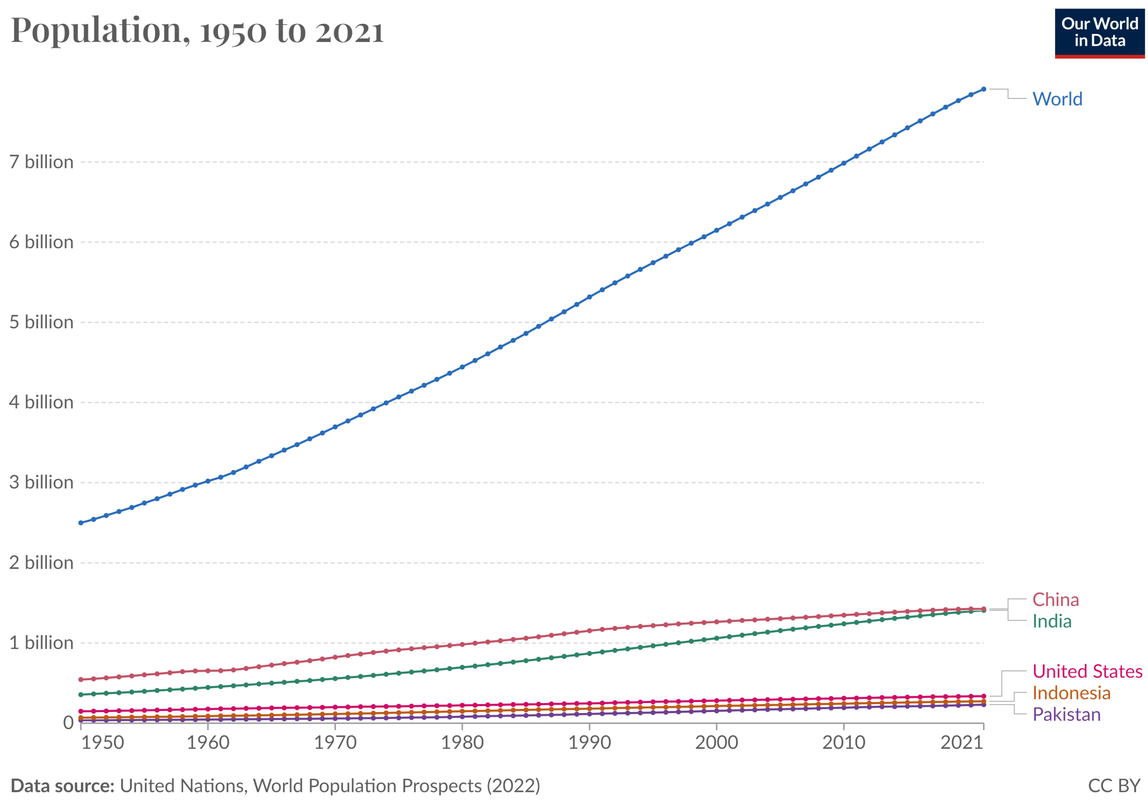

Figure 2.1: Population Demographic [RRGM+23]

The growth of population has multiple implications on the demand for food, one of them being the shift in age distribution2.2. As the average age of the population rises, so does the percentage of elderly people, affecting available agriculture labor force. This means that with this increase, there is a corresponding decline in the proportion of people eligible to work on crop fields. This shift enforces the need of finding simpler and more efficient methods in agriculture to meet the increasing demand for food.

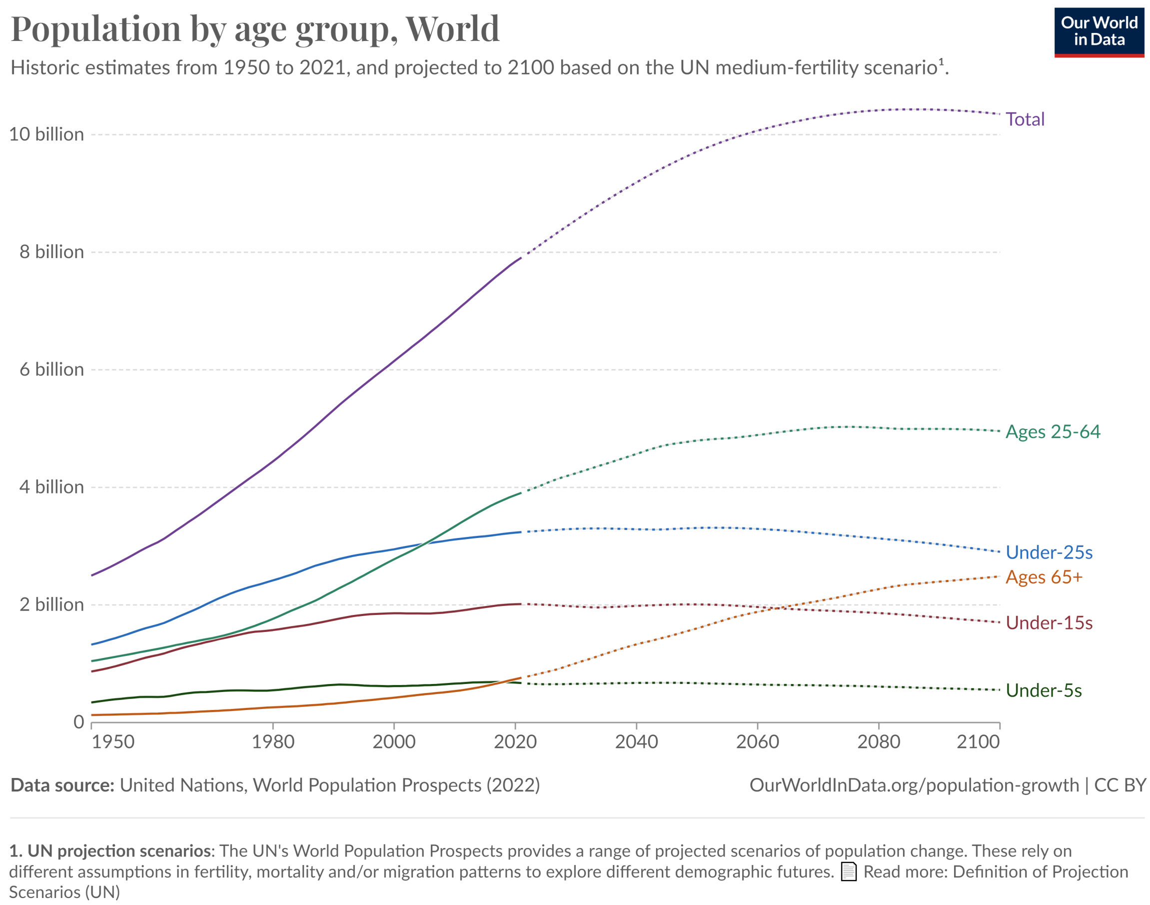

Figure 2.2: Population by age group demographic[RRGM$^+$23]

This trend is not unique to other countries or just the general demographic of the world. Romania has been mirroring the global trend towards aging population2.3. Not to mention the fact that more and more of the teen workforce are migrating to urban areas in search for job opportunities. This trend is further exacerbating the decline in the agricultural workforce.

2.2 Arable land

Although the population of the earth continues to rise, it is crucial to acknowledge that the land suitable for cultivation remains constant. As we reflect on the predictions made regarding the earth's population growth, it becomes clear that the

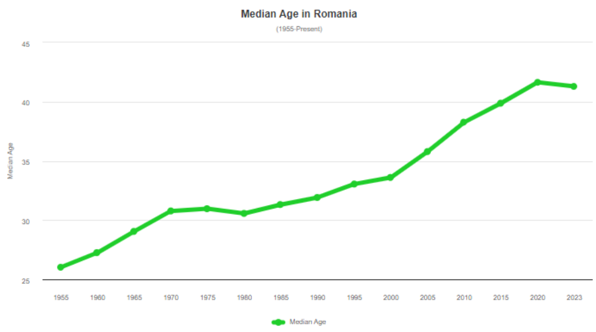

Figure 2.3: Median age in Romania [worb]

agricultural district should have at least a similar growth rate. The static availability of cultivable land creates a necessity for innovation in terms of productivity and efficiency.

The expansion of agricultural land continues to take place, predominantly in the developing countries. Data shows that the expansion of arable land continues to be an important factor in the agricultural growth in sub-Saharan Africa, Latin America and East Asia. However, in the developed countries there is a decline in arable land. This decline has been accelerating over time. This is further illustrated in the following graph2.4.

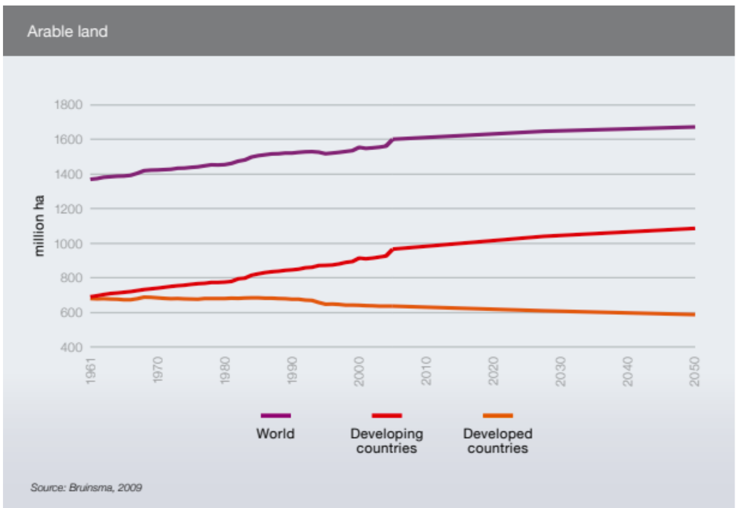

Figure 2.4: Arable land[NBVJB11]

From this graph we can conclude that although the arable land available is increasing, the rate of this increase is decelerating over time. Also, if we look further into the future, as more countries become developed and more land is sacrificed for the expansion of the cities due to the growth of the population, we can anticipate that it can start declining.

On top of the slow deceleration in the creation of new arable land, another very important factor to take into consideration is the degradation of existing arable land. This poses a global environmental challenge, as 25 percent of the total arable land has been degraded. Scientists recently approximated that around 24 billion tons of fertile soil was lost per year, with the biggest contributing factor being unsustainable agriculture practices. This alarming reality underscores the necessity of innovation in the field[GEF].
Examples of soil degradation can also be found in Romania, where it is estimated that the country loses roughly one thousand hectares annually due to desertification in the southern hemisphere, in regions like Dolj or Mehedinti, which rely heavily on the agriculture industry[Ian24].

Figure 2.5: Desert soil[Tru24]

We need to explore new sustainable methods for our agriculture sector, driven not only by considerations of production and efficiency but also by the urgency of addressing these alarming factors. Considering this, it becomes essential that future development and innovation in the agriculture district occurs, raising the efficiency of the farms.

2.3 Food security

Agriculture-driven growth and food security are at risk. Due to multiple shocks, such as Covid-19, extreme weather conditions, pests and conflicts, the food system has been greatly impacted. Climate change is also having a great impact as it is changing the conditions the crops grow in and altering productivity. The goal of ending global hunger by 2030 is currently off track[Wora].

The findings of the Global Report on Food Crises 2023 suggests that more than 250 million people were in Crisis or worse, as the food insecurity levels have increased for the fourth consecutive year. Weather extremes, economic shocks and conflicts are the most common and recurring factors that are affecting the agriculture security[GRF].

For a better visualisation of the prevalence of acute food insecurity among the countries in GRFC, we can refer to the following graph, showing data over the years 2016-2022.

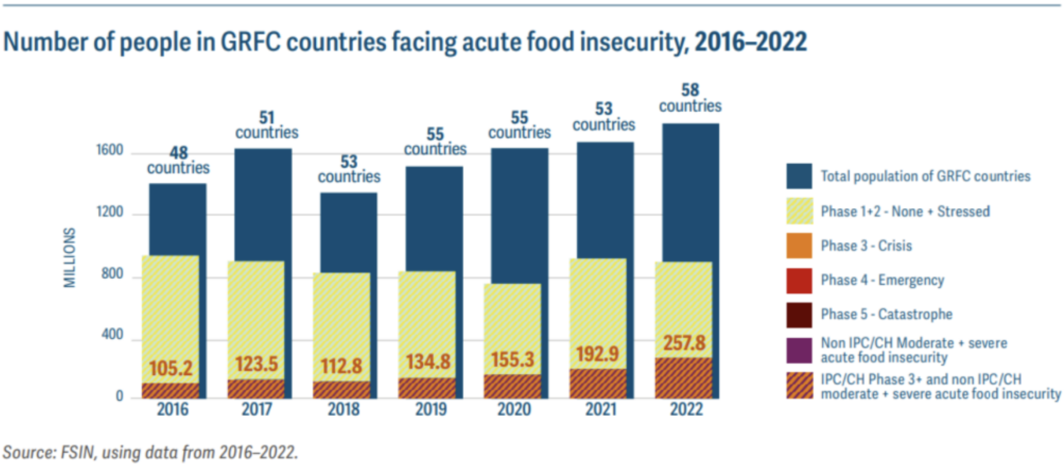

Figure 2.6: Number of people with food insecurity, 2016-2022[GRF]

While food waste and distribution are driving factors, agriculture productivity significantly influences the global availability of crop resources.

2.4 The major three plant nutrients: N, P, K

Essential nutrients needed by the plants to grow can be found naturally in the soil. Certain soils may lack the necessary nutrients for optimal plant growth and nutrition. In such cases, the levels of the nutrients in the soil are raised using fertilizers. The most important nutrients with the highest impact on the growth of the plant are Nitrogen(N), Phosporus(P) and Potassium(K). I will now delve deeper into the importance of all of these macronutrients and their impact on the plant.

2.4.1 Potassium(K)

As one of the three primary plant macronutrients, potassium enhances the overall growth of the plant, especially fruit development and aroma. It is classified as macronutrient because plants take a large quantity of K during their life cycle. Potassium has a high impact on the plants resistance to diseases, it's movement of water, nutrients and carbohydrates in the plant tissue. He is also envolved with enzyme activation within the plant, for an approximate number of over sixty plant enzymes for plant growth. As we can tell, Potassium has a high impact on the development of the plant, especially on cereals that have high K demand, which is further enforced by experiments with using different levels of the nutrient2.7.

Figure 2.7: Impact of different K levels on cereals[oIiawTTBS20]

Potassium deficiency, often called "hidden hunger", can be quite difficult to identify during growth season. While K plays such a key role at cellular level, visual symptoms of K deficiency are hard to identify. For a better identification, we can turn to the soil, where we can check if the K concentrations are sub-optimal for grass or crop production. This deficiency can manifest in various ways, including stunted growth, yellowing or browning of leaves, and decreased overall vigor. For instance, in grasslands, potassium deficiency may result in sparse vegetation and reduced forage quality. For reference, in the following image we can see parts of the field that are either rich or deficient in Potassium2.8.

Similarly, in cultivated grasses, such as turfgrass or pasture grasses, potassium deficiency can lead to diminished yields, poor root development, and increased vulnerability to pests and diseases. Diminished yields can easily be observed as in the example bellow2.9.

Figure 2.8: Grasslands K defficiency[oIiawTTBS20]

Figure 2.9: Two fields with different K levels[oIiawTTBS20]

2.4.2 Nitrogen(N)

The importance of nitrogen in the development of the plant cannot be overstated. Nitrogen is a crucial component of amino acids, proteins, and chlorophyll, essential for various metabolic processes. It plays an essential role in the development of the vegetative parts of the plant, as well as in the ability of the plant to perform photosynthesis. Nitrogen is a common element that is present in approximately 78% of the earths atmosphere. As the compound cycles through the air, soil and water, it undergoes transformations and takes different forms, resulting in nitrogen-based compounds and molecules, which are much needed for the growth of plants. We can see this cycle represented in the figure down below2.10. But before it can be used by plants, it needs to be converted to a form that are available for plants. This process is called mineralization. Following this process, the nutrients can be absorbed through the roots of the plant.
Preferably, it would be best both economically and environmentally if the nitrogen would never leave this cycle. However, as we can see in the figure2.10, leakages can occur. When nitrogen leaves the cycle in high quantities it can lead to environmental harm, such as water contamination, air pollution, climate change and eutrophication. On top of that, a soil that is too rich in nitrogen can also affect the

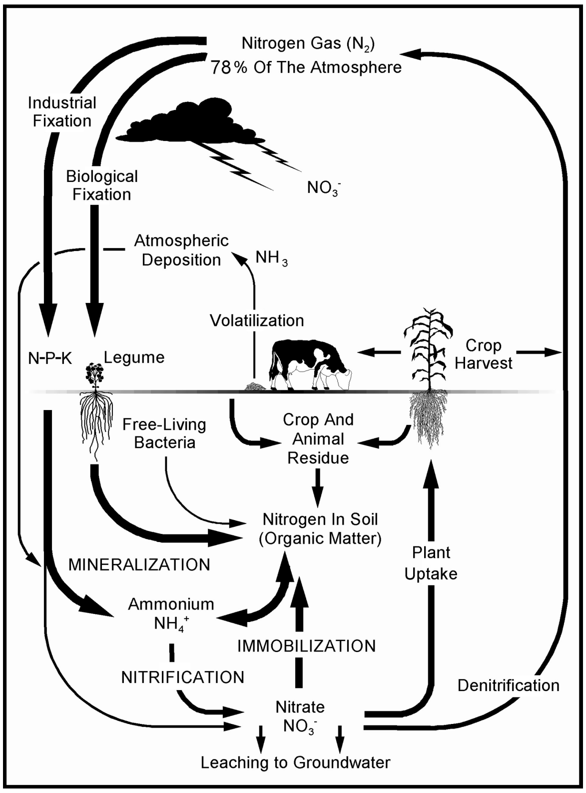

Figure 2.10: Nitrogen cycle[oAF05]

plant negatively, as it constrains the crops absorption of other nutrients. This further proves the importance of optimized usage of fertilizers to supplement the levels of nitrogen.

2.4.3 Phosphorus(P)

Phosphorus takes his rightful place together with Nitrogen and Potassium among the three macronutrients essential for plant growth. It has a high impact on flowering and fruit formation, it enables photosynthesis and helps the plant cope with stress.
One of the easiest signs of phosphorus deficiency is the color of older and lower leaves. The leaves become become a darker yellow or green with large bronze, brown or slightly blue splotches or spots, as we can see in the following examples2.11.
Phosphorus moves in a cycle through rocks, water, soil, sediments, and organisms. Over time, rain and weathering cause rocks to release phosphate ions and other minerals, distributing them in soils and water. Plants absorb inorganic phosphate from the soil, which is then incorporated into organic molecules such as DNA. When plants or animals die and decay, the organic phosphate is returned to the soil, where it can be made available to plants again through mineralization by soil bacteria.

(a) Caption for Image 1 (b) Caption for Image 2

Figure 2.11: Leaves with Phosphorus defficiency

Phosphorus in soil can also end up in waterways and eventually oceans, where it becomes incorporated into sediments over time. We can watch this cycle through the following visual representation2.12

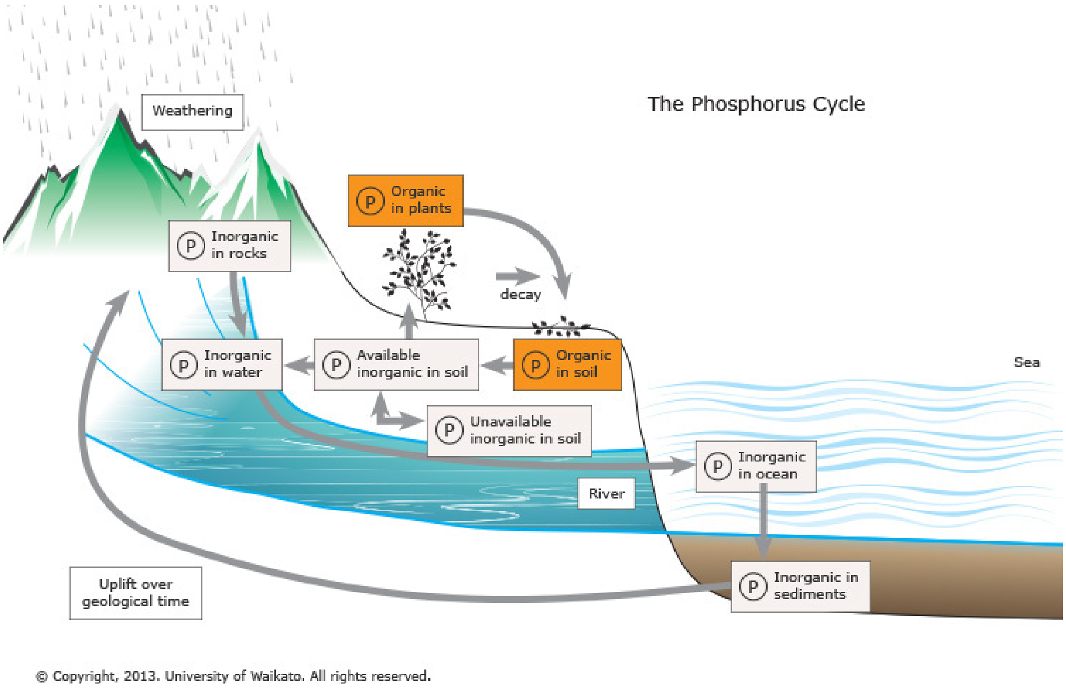

Figure 2.12: Nitrogen cycle[cyc13]

It can also be harmful to the environment as it leaks outside the cycle, by contributing to eutrophication, which occurs when excessive nutrients stimulate the growth of algae and other aquatic plants. When these die and decompose, they consume oxygen, leading to suffocation of the fish and other organisms.

2.4.4 Supplementation trough fertilization

Each of these three macronutrients has specifics when it comes to fertilizers, but one key factor about them is their mobility. This directly affects how easily they can be replenished in the soil through fertilization. Down below we can see a representation of the mobility each macronutrient has in the soil.2.13. These different mobilities make for different fertilizing practices. For example, Nitrogen(N), being highly mobile, makes it susceptible to leaching, necessitating frequent application to meet the plant demands. Phosporus, on the other hand, exhibits lower mobility due to its strong adsorption to soil particles, leading to fixation and reduced availability to plants. As a consequence, fertilizers for Phosporus supplementation are generally applied in advance, during soil preparation season. Potassium, beeing somewhat in the middle when it comes to mobility, allowing for flexibility in fertilizer application timing.

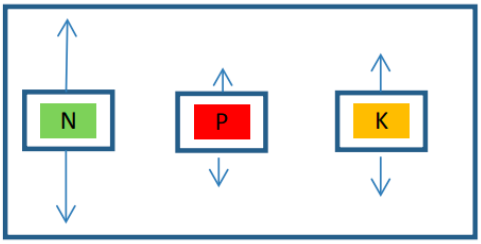

Figure 2.13: Mobility of Macronutrients[oIiawTTBS20]

As we concluded from the previous chapters about the three macronutrients, excess can be very harmful to the environment. This makes it really important for the farms to use the right amount of fertilizer, as it is not only wasteful and costly, but it also has negative impacts on the surroundings.
Inserarea și Referirea la Tabelul 2.1.

Nume algoritm	Toate soluțiile	Soluția optimã
Nume 1	20	5
Nume 2	20	2

Table 2.1: Soluții obținute

Adaugarea și Referirea la o Ecuație 2.1.

$$ws_N4 = w_{14} * N1 + W_{24} + N2 + w_{34} * N3 \tag{2.1}$$

Chapter 3

Machine Learning

3.1 Integrating AI into Agriculture

3.1.1 State of the art

As stated in the previous chapters, the three macronutrients, Nitrogen, Phosphorus and Potassium are the most influential factors when it comes to soil. Aside from the soil factors, the climate and weather also play a huge role. When it comes to the integration of machine learning in agriculture, due to the accessibility of the weather and climate data, there have been numerous initiatives that have sought to forecast crop production based on meteorologic data. In contrast to this approach, this study aims to integrate soil factors into the predictive model, as well as explore what other valuable insights can be derived from this comprehensive dataset.

3.1.2 My Vision

3.2 Machine learning

3.2.1 Data processing

3.2.2 Extreme Gradient Boosting

3.2.3 Convolutional Neural Network

3.2.4 CNN Reverse process

Chapter 4

Titlul capitolului

Chapter 5

Concluzii

Concluzii ...

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