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SMART-agronomy in the context of strengthening agriculture

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Abstract: Agronomic systems can be considered with good reason as complex nonlinear multiparametric natural engineering systems. Numerous and diverse physical, chemical and biological processes take place in these systems, which nature cannot always cope with in a short time. While the planet is constantly increasing population growth and limiting territories, the problem of shortage of final products of the agricultural sector, as well as ensuring its high quality for all end consumers, is becoming more acute. Innovative technologies help in solving this problem. At the moment, innovative technologies are being introduced into all sectors of the national economy, and, accordingly, there are no special barriers to its use in the field of agro-industry. The paper provides a method for virtual simulation of digital farming processes, which allows conducting research outside the time frame of work in the field. Where you can observe in real time the indicators that we influence the provided method of virtual simulation of digital farming processes, which allows you to conduct research outside the time frame of work in the field. Where you can observe in real time the indicators that we influence.

Keywords: Task map, fertilizers, digital control;

SMART-agronomia w kontekście wzmacniania rolnictwa

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Streszczenie: Systemy agronomiczne można uważać za złożone nieliniowe wieloparametrowe systemy inżynierii naturalnej. W tych systemach zachodzą liczne i różnorodne procesy fizyczne, chemiczne i biologiczne, z którymi natura nie zawsze potrafi sobie poradzić w krótkim czasie. Podczas gdy planeta stale zwiększa przyrost populacji i ogranicza terytoria, problem niedoboru produktów końcowych sektora rolniczego, a także zapewnienia ich wysokiej jakości dla wszystkich konsumentów końcowych, staje się coraz bardziej dotkliwy. Innowacyjne technologie pomagają w rozwiązaniu tego problemu. Obecnie innowacyjne technologie są wprowadzane do wszystkich sektorów gospodarki narodowej, a zatem nie ma szczególnych barier w ich stosowaniu w dziedzinie przemysłu rolno-spożywczego. W artykule przedstawiono metodę wirtualnej symulacji procesów rolnictwa cyfrowego, która umożliwia prowadzenie badań poza ramami czasowymi pracy w terenie. Gdzie można obserwować w czasie rzeczywistym wskaźniki, na które wpływamy przedstawiona metoda wirtualnej symulacji procesów rolnictwa cyfrowego, która umożliwia prowadzenie badań poza ramami czasowymi pracy w terenie. Gdzie można obserwować w czasie rzeczywistym wskaźniki, na które wpływamy.

Słowa kluczowe: Mapa zadań, nawozy, sterowanie cyfrowe;

1. Introduction

In the modern era, agriculture is emerging as one of the most dynamic sectors of the economy, actively leveraging scientific and technological advancements to increase productivity and optimize production processes. One of the most progressive approaches driving the development of the agricultural sector is precision farming. This concept is based

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on the application of innovative technologies, particularly digital management systems, to ensure more efficient resource utilization and high yields. Precision farming involves not only the integration of new technologies into agricultural production but also a deep understanding of biological and technical processes to achieve maximum results.

Given that land resources are limited and the growing population demands a continuous increase in agricultural production, finding new methods for rational resource use becomes critically important [1]. Precision farming technologies offer the ability to optimize soil management, fertilizer application, irrigation, as well as pest and disease control. Through the use of precise field maps, GPS systems, and automated equipment management, agriculture is becoming more predictable and productive. However, the effectiveness of implementing and combining different approaches in precision farming remains an important issue, which is the subject of this research.

A key aspect of precision farming is the use of digital systems to manage agricultural machinery. With modern technologies, farmers can optimize processes such as soil tillage, seeding, fertilization, and harvesting. These systems significantly reduce the loss of material resources and enhance yield, as they account for the specific characteristics of each field plot. In the context of this study, two approaches to digital agricultural equipment management were considered: task mapping and real-time operation adjustments.

Task mapping (prescriptive control) allows for the pre-determination of optimal strategies for each field plot, based on historical data, satellite imagery, and soil analysis. This method ensures precision and predictability in agricultural operations, although it has certain drawbacks, including limitations in adapting to unforeseen real-time conditions, such as weather changes or sudden pest infestations. Real-time adjustments, on the other hand, utilize data from sensors and monitoring systems directly during operations, providing flexibility and immediate response to changes. However, this approach may be less effective without proper prior planning.

The aim of this work is to explore various systems of digital agricultural machinery management, specifically pre-created task maps and real-time adjustments. The research examined the advantages and disadvantages of each approach separately, as well as analyzed the possibility of their combined use to achieve synergy. Additionally, recommendations were developed to improve both methods and their integration for maximum efficient resource use.

In the current state of research in precision farming, much attention is given to innovative technologies for managing agricultural machinery. Leading scientists and engineers are developing new approaches to data integration, process automation, and precise monitoring of plant and soil conditions. Key publications in this field confirm that the proper combination of different machinery management systems can significantly enhance the efficiency of agricultural processes [2]. However, the issues of simultaneously using various digital management methods and their combined impact on agrotechnological processes remain underexplored.

The main goal of this work is to study and optimize different approaches to digital management of agricultural machinery. Within the research, new methods were also proposed to improve each approach separately and their joint application to achieve better results.

2. Materials and Methods

In modern precision farming research, virtual simulations are increasingly used to model agrotechnical processes and their impact on yield, resource costs, and environmental sustainability. In this work, we applied a method of virtual simulation of digital farming processes, which allowed us to avoid the physical constraints of fieldwork and reduce the time required for experiments. This approach enables the study of the impact of various variables on the effectiveness of agrotechnical operations in a controlled environment, which is a significant advantage for understanding complex systems of agricultural machinery management.

The main software was the video game Farming Simulator 22, as it fully recreates the farming process and at the time of writing this article it was the best. The addition of Precision Farming helped to significantly improve the reliability of the obtained result and emphasize the parameters we studied. The Precision Farming Free DLC is a project initiated by John Deere in Germany and funded by EIT Food, Europe's leading Food Innovation Initiative. Co-funded by the EU, it is meant to highlight sustainable technology in agriculture in collaboration with the Institute of Animal Reproduction and Food Research of the Polish Academy of Sciences, Grupo AN in Spain and the universities of Hohenheim (Germany) and the University of Reading (UK). [6]

2.1 Description of the Virtual Simulation Platform

The main tool for research was a simulation platform that models real conditions of precision farming, including machinery operation, changes in climatic factors, and variability of soil and plant characteristics. This platform enabled us to simulate the operation of various digital agricultural machinery management systems and investigate their interactions under different conditions. Due to the ability to adapt models to real data, we were able to conduct tests and evaluate the effectiveness of various management methods, such as pre-created task maps and real-time adjustments.

The simulator was configured based on actual agricultural data, which allowed the creation of realistic conditions. The parameters influencing the course of simulations included:

1. Geographical and climatic conditions;
2. Soil condition data (fertility, moisture, structure);
3. Specific characteristics of crops (rapeseed, sunflower, soy, etc.);
4. Parameters of agricultural machinery operation (tractors, sprayers, seeders);
5. Use of fertilizers, herbicides, and other agrochemicals.

The use of virtual simulation allowed us to conduct experiments under conditions that would be difficult or expensive to organize in real fields. As a result, we could test different options for working with digital management systems and immediately observe the impact of each on key indicators such as machinery productivity, resource costs and yield.

2.2 Research Methodology

The research was built on an iterative process that included several stages. The first step was to identify key parameters for analysis. We focused on comparing two main approaches in precision farming: pre-created task maps and real-time adjustments. These approaches are used to manage field operations with precise resource application and loss minimization. To ensure sufficient data for analysis, we conducted dozens of simulations for each approach, varying the key management system parameters and environmental conditions.

1. Pre-created Task Maps — a method that involves forming tasks for machinery based on pre-collected data on soil, climate, and crop condition. For this, satellite images, soil analysis, and weather forecasts were used. Pre-created maps included recommendations on fertilizer application, water usage, and plant protection, aimed at optimizing each operation for a specific field plot.
2. Real-Time Adjustments — this approach involves the dynamic change of machinery operation parameters based on information collected in real-time using sensors. During the experiments, sensors were used to monitor soil moisture, fertilizer concentration, plant condition, and other important factors. This method allowed immediate response to changing conditions and provided flexibility in field operations.

2.3 Efficiency Assessment Parameters

To evaluate the effectiveness of each method, we used a set of indicators that characterize the economic and environmental feasibility of each approach:

1. Yield — the main indicator reflecting the overall result of applying technologies on a specific field area. We analyzed yield depending on the management methods used.
2. Resource utilization efficiency — includes the use of fertilizers, water, fuel for machinery, and other material resources. During the study, we evaluated how each method affects resource costs and potential losses.
3. Time of field operations — since the timely execution of agricultural operations significantly impacts yield, we analyzed in detail how quickly and efficiently each approach allows completing operations.
4. Economic efficiency — analysis of costs for implementing each method, including expenses on equipment, software, and labor. We assessed the profitability of each method for agricultural enterprises of different scales.

2.4 Utilization of Previous Experience

The study largely utilized knowledge and experience gained from previous research in areas such as agronomy, geographic information systems (GIS), artificial intelligence (AI), and the digitalization of agriculture. This enabled us not only to correctly configure simulation models but also to evaluate their results according to modern requirements for precision farming. In particular, the use of GIS technologies allowed effective work with large volumes of spatial data, which formed the basis for creating accurate field maps.

Artificial intelligence and machine learning also played a crucial role in developing models for real-time adjustments. Thanks to these technologies, the simulator could automatically analyze sensor data and make decisions on optimizing machinery operations. This approach allowed reducing resource losses and increasing the precision of fertilizer and other agrotechnical operations.

2.5 Advantages of Virtual Simulations

One of the main advantages of using virtual simulation was cost reduction for research. Virtual models allowed avoiding expenses for fieldwork, reducing the risk of crop loss, and obtaining results in a short time. Additionally, the simulation platform allowed conducting numerous experiments, which would be impossible in real conditions due to time and resource limitations.
This approach enabled us to conduct multiple iterations of the study with minimal costs, allowing for a more in-depth examination of the efficiency of each management method and finding new opportunities for their improvement and integration.
In this way, the methods used in this work allowed for a detailed analysis of the efficiency of different agricultural machinery management systems in precision farming conditions, which is an important step towards optimizing agricultural processes and increasing agricultural productivity.

3. Results

During the research, two main approaches to digital management of agricultural machinery were compared: real-time adjustments and pre-created task maps. Each of these approaches has its own characteristics and benefits, and their application allows for significant results in improving resource efficiency and yield. This section provides a detailed description of the results obtained during the studies and relevant conclusions.

3.1 Real-Time Adjustments

Real-time adjustments involve direct interaction with current data during field operations. This approach allows for quick responses to changes in soil condition, plant health, and climatic conditions, which is especially important for achieving optimal results [3].

Results:
- Fertilizer Savings in Top Dressing: Thanks to dynamic control over nutrient levels in the soil and plant conditions, a fertilizer savings of 6.8% was achieved. This was possible through precise dosing of fertilizers in areas where their use was necessary and reducing expenses in areas with sufficient nutrition levels.

- Yield Increase: The average yield increase across the entire field was 5%. This resulted from taking into account all key indicators that directly affect plant growth and development, such as soil moisture, nutrient availability, and weed levels.

- Fertilizer Utilization Efficiency: Using the real-time adjustment system increased fertilizer utilization efficiency by 18%. This means that more rational resource use and reduced over-application, which could lead to losses or negative environmental impacts, were achieved through more precise fertilization.

- Herbicide Savings: Depending on the level of field weed infestation, significant herbicide savings were recorded. In areas with low weed levels, savings amounted to 90%, while in areas with higher weed infestation — 30%. This was possible through the use of sensors that instantly identified weeds and applied herbicides only in places where they were really needed.

-Impact on yield with reduced herbicide load: Yield increases in cases of reduced herbicide load ranged from 5% to 15%. This highlights the importance of optimal use of chemical plant protection products, which not only preserves the environment but also positively impacts final yield indicators.

3.2 Pre-Created Task Maps

The pre-created task maps method is based on the analysis of historical data, which allows creating detailed plans for agricultural operations. This approach relies on prior planning and data preparation, which ensures clear and coordinated work of machinery.

Results:

- Fertilizer Savings in Top Dressing:

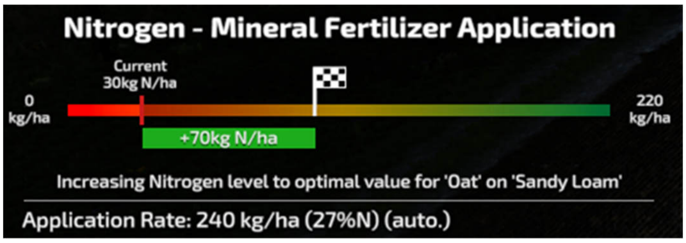

Figure 1. The pre-created task maps method (Obtained in the simulation platform)

Fertilizer savings amounted to 5%, primarily through pre-planned routes of machinery that avoided unnecessary field crossings and prevented excessive fertilization.

Figure 2. Planned routes for equipment movement (Obtained in the simulation platform)

- Yield Increase from Optimal Nitrogen Fertilization:Thanks to the optimal application of nitrogen fertilizers according to task maps, the yield increase was 9%. This confirms that proper dosing of fertilizers based on soil condition data is an effective way to boost yield and reduce costs.

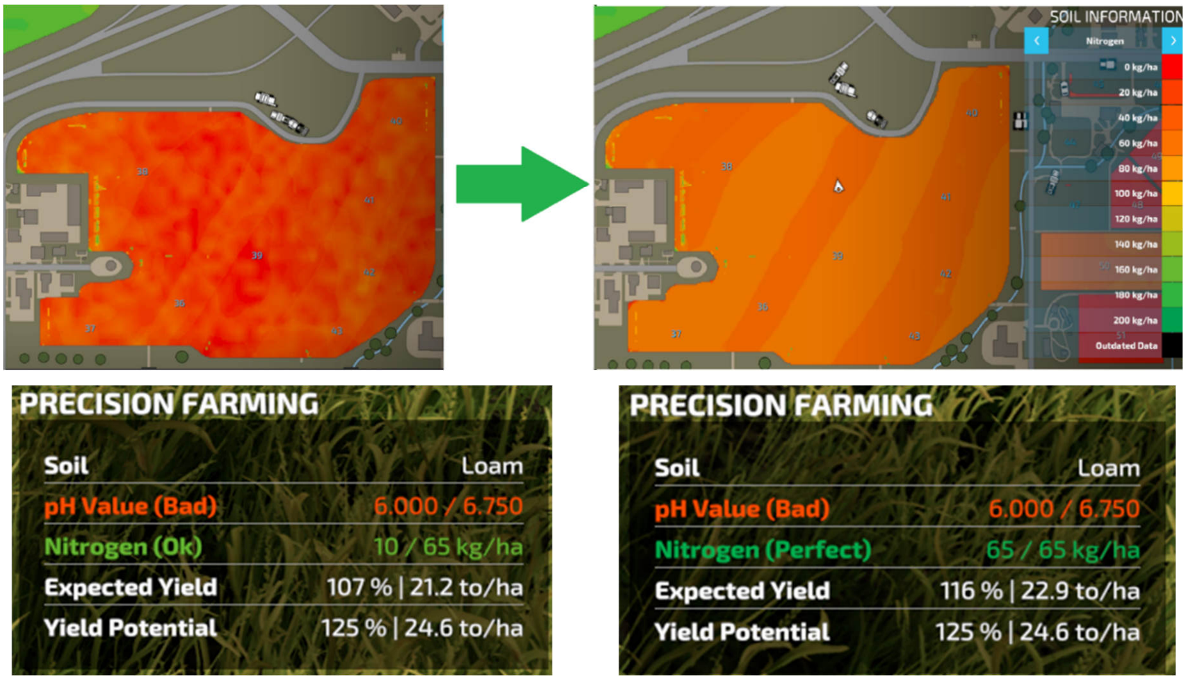

Figure 3. Optimal application of nitrogen fertilizers (Obtained in the simulation platform)

- Herbicide Savings: On average, herbicide savings amounted to 35%, which indicates that this approach can effectively reduce the use of chemicals by pre-identifying zones with high weed concentrations and focusing on targeted processing.
- Lime Savings:

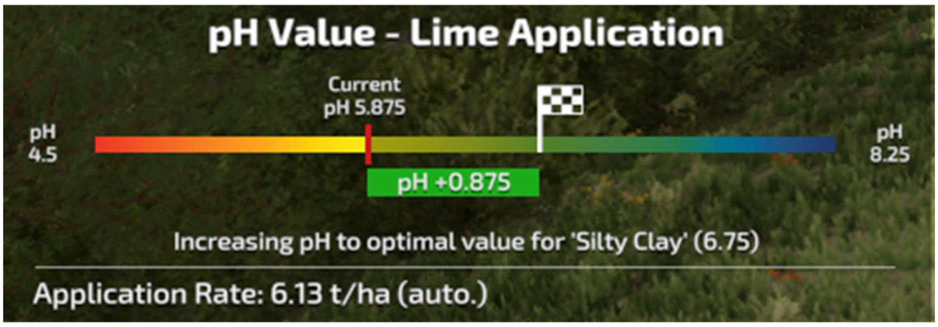

Figure 4. Lime saving (Obtained in the simulation platform)

Depending on the soil characteristics in different parts of the field, lime savings for pH adjustment ranged from 20% to 30%. This demonstrates that the use of task maps can significantly reduce costs for liming and other agrochemicals needed to maintain optimal soil parameters.

Figure 5. Using task cards (Obtained in the simulation platform)

These results confirm the effectiveness of both approaches in managing agricultural operations. Each of these approaches has advantages that can improve resource efficiency and yield. Further discussion and recommendations on the use of these approaches will be presented in the following sections.

3.3 Comparison of the Efficiency of the Two Approaches

Both approaches used in the study demonstrated high efficiency, but in different areas. This indicates their complementarity rather than competition. They are suited for different types of tasks and have their specific advantages.
-Task mapping is well-suited for working with parameters that can be predicted in advance and do not change instantly. Among such parameters are:

- soil acidity level (pH);

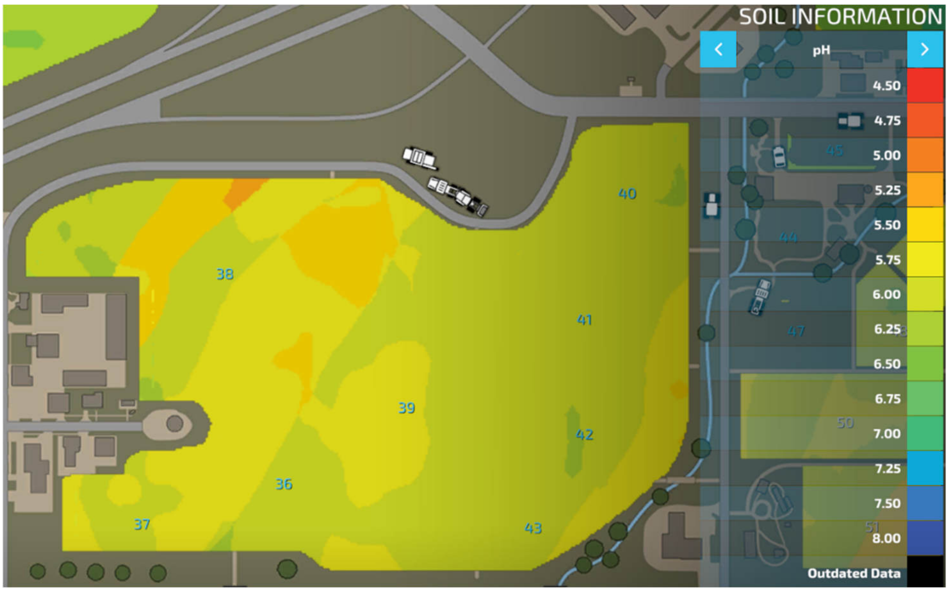

Figure 6. Soil acidity level (pH) (Obtained in the simulation platform)

- nitrogen content;

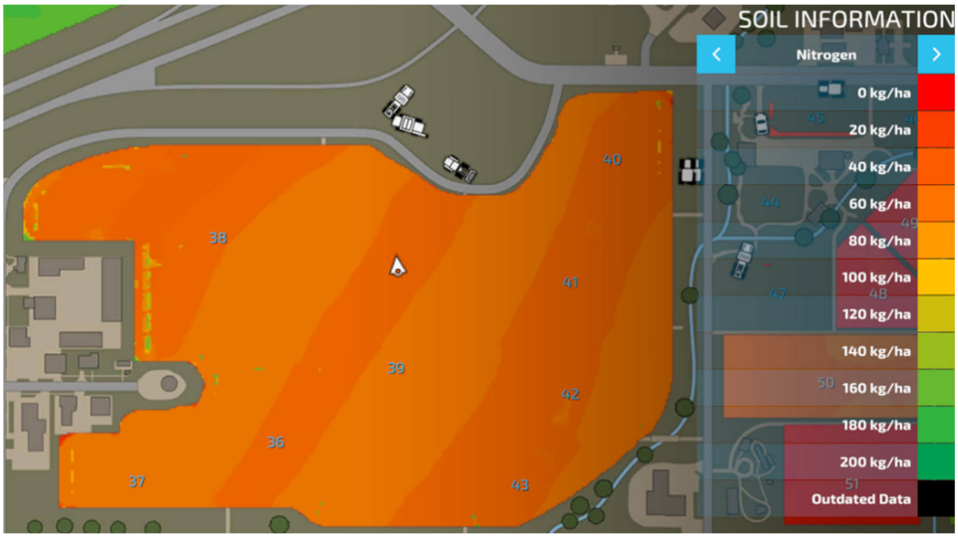

Figure 7. Nitrogen content (Obtained in the simulation platform)

- depth of the plow pan;
- yield levels from the previous season;

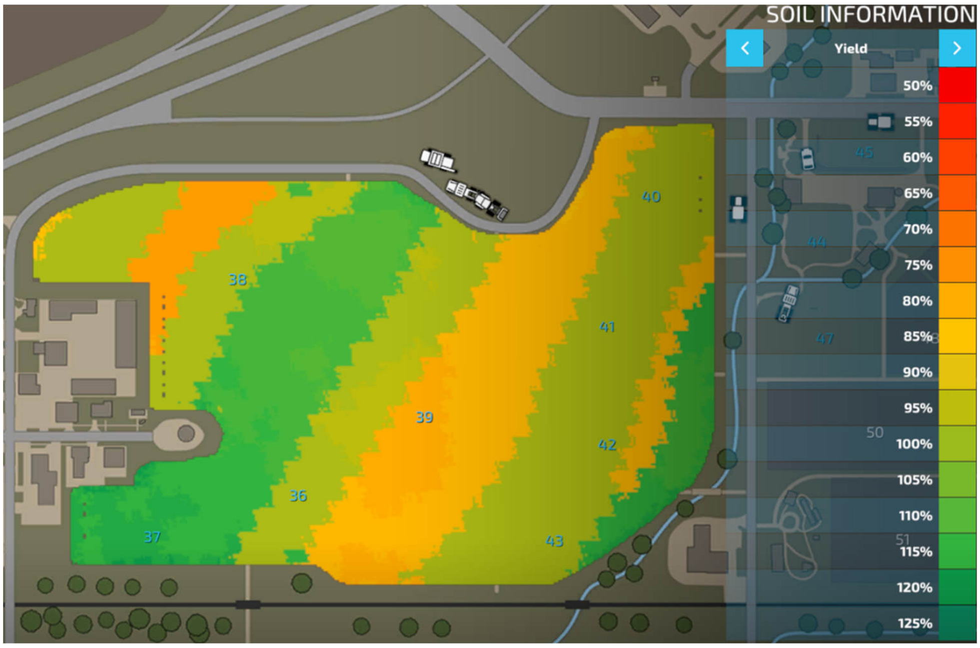

Figure 8. Yield, which correlates with the type of soil (Obtained in the simulation platform)

- soil moisture reserves.

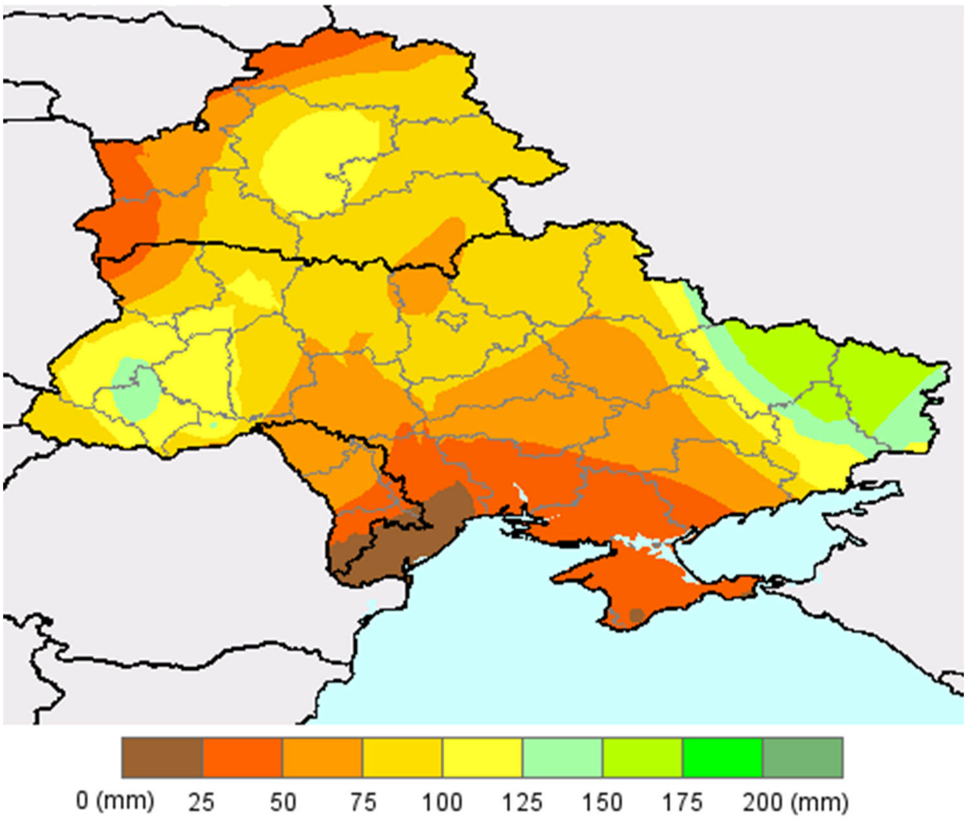

Figure 9. Subsurfasce soil moisture [5]

By analyzing these parameters, it is possible to accurately calculate the required amount of fertilizers, lime, and other resources, which allows for cost optimization and reduces the negative impact on the environment [2].

- Real-time adjustments are more effective when dealing with parameters that can change instantly and require immediate response. These include:

- vegetation index (NDVI);
- availability of specific nutrients;
- presence and types of weeds [4].

The ability to quickly collect and process data in real time allows for rapid decision-making, which directly affects the efficiency of ongoing operations and minimizes resource losses.

3.4 Interaction of Approaches

The research showed that task mapping and real-time adjustments complement each other and can be used together to achieve maximum effect. For example, creating task maps based on the analysis of long-term indicators helps set general strategies for resource application, while real-time adjustments allow refining these strategies during field operations based on actual data.

This combination leverages the advantages of both approaches: the flexibility and precision of immediate response with the efficiency of planning based on long-term forecasts. Such an integrated approach can achieve better results with fewer resources, which is particularly important in modern conditions, where there is increasing attention to sustainable development and the environmental sustainability of agricultural production.

3.5 Conclusions on the Results

The obtained results confirmed the effectiveness of both approaches to digital management of agricultural machinery. Real-time adjustments allow for significant resource savings and increased yields by promptly responding to changing conditions. Task mapping enables the optimization of long-term planning and the rational use of resources based on soil analysis and past seasons' data.

Therefore, the combined use of these approaches could be a key factor in enhancing agricultural production efficiency and reducing costs, making them essential tools for the development of precision.

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