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DIGITAL TRANSFORMATION OF THE AGRICULTURAL SECTOR: KEY ELEMENTS AND THEIR IMPACT ON WINTER WHEAT PRODUCTIVITY

Tretiakova Svitlana
k. s.-g. Sciences, associate professor
Uman National University, Ukraine
ID 0000-0002-1183-4479
Vasiliev Oleh
PhD Candidate of the Faculty of Agronomy
Uman National University, Ukraine
Tretiakova Alina
Student of MLKB 1-24 group
Faculty of Oriental Languages
Kyiv Capital University
named after Borys Grinchenko, Ukraine
ID 0009-0008-9957-8537
Kompaniiets Yehor
PhD Candidate of the Faculty of Agronomy
Uman National University, Ukraine
Chabaniuk Yaroslav
Faculty of Agronomy 31-A group
Uman National University, Ukraine

Introduction. The past decade has witnessed a true digital revolution in the agro-industrial complex, where the adoption of digital solutions has fundamentally transformed traditional approaches to land cultivation and farm management. These changes are converting farming into a high-tech industry, enhancing its profitability, precision, environmental safety, and level of automation [1].

Unlike existing approaches that examine technologies in isolation, this study proposes an integrative model combining Geographic Information Systems (GIS), remote sensing, Unmanned Aerial Vehicles (UAVs), and analytical platforms in the context of winter wheat productivity formation. This approach optimizes yield formation through differentiated management of key yield components: plant stand density, spike length, number of grains per spike, and 1000-grain weight, collectively leading to a 15-25% increase in wheat yield compared to conventional methods.

The aim of this research is to systematize and evaluate the impact of key digital technologies on the productivity and yield of winter wheat. The novelty of the study lies in the comprehensive analysis of modern digital technologies as interconnected elements of a unified system for transforming the agricultural sector [2].

Research Methodology. The study was based on an integrated approach combining field agronomic experiments with modern digital monitoring methods on a winter wheat experimental plot. The methodological framework included the following stages:

Development of a Geographic Information System (GIS) model in QGIS software, integrating soil survey data, historical yield data, and field boundary data. Field zoning was performed based on the analysis of remote sensing data (Sentinel-2 satellite imagery) and UAV imagery from previous years.

As a result, three test zones with different historical yield potential were delineated: Zone 1 (low potential), Zone 2 (medium potential), and Zone 3 (high potential). For each zone, application maps for differential seeding and nitrogen fertilization were generated based on vegetation indices (NDVI) at key growth stages.

Throughout the growing season, regular monitoring was conducted using the EOSDA Crop Monitoring satellite service (weekly NDVI, weather data) and a UAV equipped with a multispectral camera (3 cm/pixel resolution) during the tillering, stem elongation, and heading stages. UAV data were processed to generate orthophoto maps, elevation models, vegetation index maps (NDVI, NDRE), and biomass maps.

Within each of the three zones, micro-plots were established with different seeding rates (3.0, 4.5, 6.0 million seeds/ha) of the Letanivka and Ilias varieties. Nitrogen top-dressing was applied differentially based on prescription maps generated from UAV multispectral imagery.

At the end of the season, the harvest was collected from the micro-plots with parallel analysis of yield structure (spike length, number of grains per spike, 1000-grain weight). These data were correlated with the dynamics of vegetation indices obtained from UAVs and satellites to establish correlative dependencies.

The implementation of this digital toolkit enabled a shift from uniform to precision management decisions, directly influencing yield structure components.

Key Findings and Discussion. During winter wheat cultivation, the Variable Rate Application (VRA) method for fertilizers is crucial. It helps apply the optimal amount of nitrogen fertilizers, thereby preventing nitrogen surplus and, consequently, low crop yield. Based on a vegetation map, the field can be divided into zones to determine the required amount of nitrogen for each zone and calculate potential resource savings.

The use of Variable Rate Technology (VRT) for fertilizing crops according to the specific needs of each plot section allows for the reduction of financial costs and the volume of fertilizers wasted due to leaching from fields. The vegetation index aids in dividing the field into zones for VRA calculation. In red zones, where crop development is insufficient, more fertilizer should be applied.

Modern remote monitoring technologies, particularly aerial photography using Unmanned Aerial Vehicles (UAVs), provide farmers with unique analytical tools for management decision-making. An orthophoto map, as a geometrically correct image of the terrain, plays a key role in this process, from accurate area determination to detailed crop analysis.

The obtained data allow not only for the identification of agronomic problems, such as sparse areas or plant loss but also for their quantitative assessment by measuring areas and creating vector layers for further use in precision farming systems. The analysis showed a high correlation between vegetation index values (NDVI, NDRE) obtained by UAV during the heading stage and final yield parameters (grain weight per spike, 1000-grain weight). This confirms that digital indices are reliable predictors of potential yield and allow for highly accurate yield forecasting before harvest.

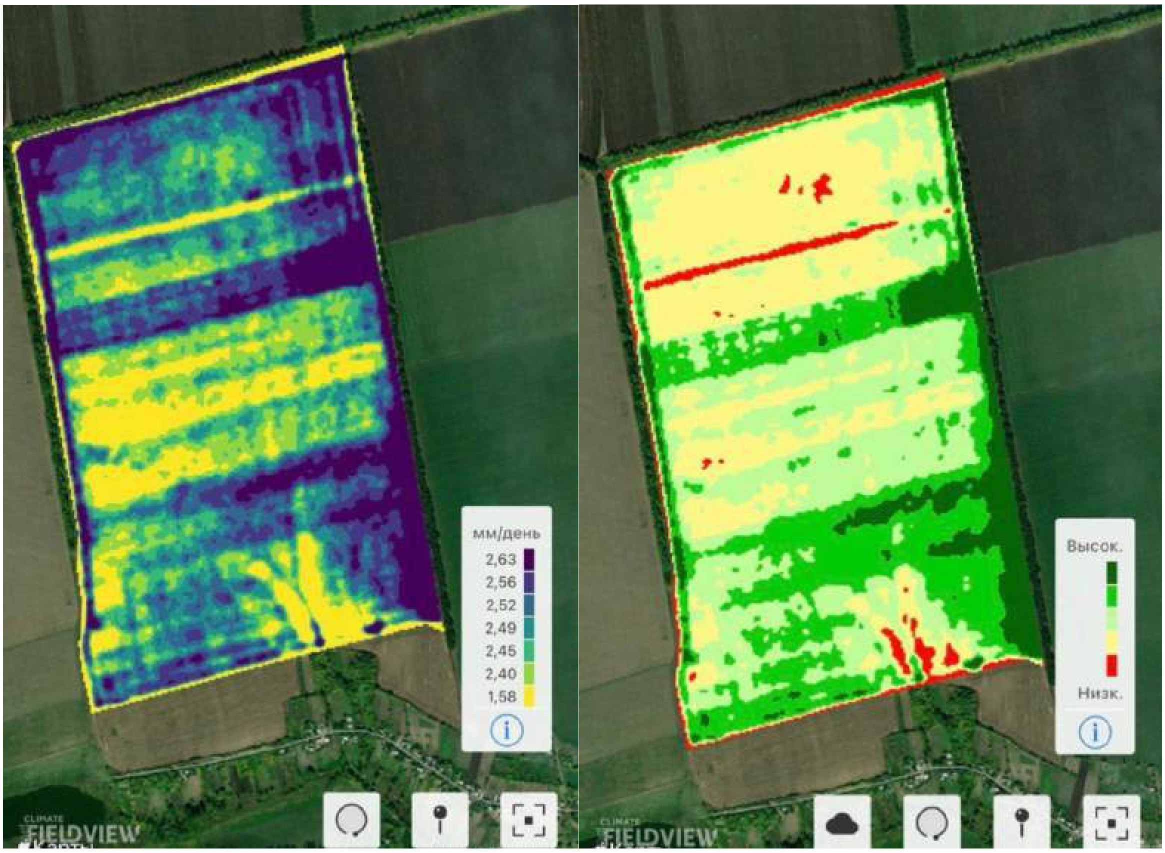
An important product of UAV data processing is the Digital Elevation Model (DEM), which visualizes the topographic features of a field using a color palette and contour lines. This map is a tool for identifying problem areas related to microclimate and hydrological regimes, as well as for planning operations such as creating tasks for parallel driving systems.

Further field analysis is significantly enhanced by multispectral imagery, which allows for zoning the territory based on plant stress indicators, biomass, chlorophyll content, and weed infestation levels. Based on these data, a differentiated strategy for plant protection product application is formed, opening the possibility of choosing between traditional methods and high-precision application using agricultural drones, which minimize mechanical impact on the soil.

Modern Unmanned Aerial Systems (UAS) enable the creation of a highly accurate cartographic base with a spatial resolution of up to a few centimeters per pixel. This opens new opportunities for analyzing crop conditions, particularly allowing for a more detailed study of the formation of yield structure components.

The study demonstrates that the synergistic integration of GIS, remote sensing, UAVs, and data analytics into a single management cycle forms the core of digital transformation in wheat cultivation. This integrated model facilitates a transition from reactive to predictive and prescriptive agriculture, optimizing both economic and environmental outcomes.

An important advantage of UAV aerial photography is its capability for differentiated accounting of various land use categories, including arable land, hayfields, pastures, perennial plantations, fallow land, tilled land, and growing crops. Compared to satellite imagery, UAVs provide higher detail due to adjustable flight altitudes (from 100 to 600 meters), enabling spatial resolution at the level of single centimeters.



The operational flexibility of unmanned systems is noteworthy – they allow for image capture even under conditions of partial cloud cover, which is a significant advantage over satellite technologies and traditional aerial photography. This technological benefit ensures the stability of monitoring studies regardless of meteorological conditions, a key factor for making timely management decisions in agricultural production.

An important aspect is the impact of agronomic practices on plant productivity. The formation of the winter wheat spike structure was significantly influenced by the biological characteristics of the studied varieties and the applied seeding rates. The research results indicate that the spike length of the Letanivka variety ranged from 7.6 to 8.7 cm, while in the Ilias variety this parameter was 7.3 to 8.5 cm. The minimum spike length values were recorded at the densest sowing rate of 6.0 million seeds/ha, amounting to 7.6 cm for Letanivka and 7.3 cm for Ilias. In contrast, the maximum spike length values were observed at the lowest seeding rate of 3.0 million seeds/ha, which is attributed to the creation of optimal conditions for plant development by increasing the feeding area for each plant in the stand.

The number of grains per spike depended on the biological characteristics of the variety. Thus, in the Letanivka variety, the number of grains per spike was 31–35, and in the Ilias variety – 29–32. These indicators were highest at the seeding rate of 3.0 million seeds/ha, amounting to 35 for Letanivka and 32 for Ilias. Increasing the seeding rate from 3.0 to 6.0 million seeds/ha led to a reduction in the number of grains per spike.

The grain weight per spike depended on the seeding rate of winter wheat. On average, the grain weight per spike was 1.35–1.39 g for the Letanivka variety and 1.31–1.36 g for the Ilias variety.

Conclusions. The obtained data on yield structure are directly related to the capabilities of modern crop condition diagnostic technologies. Analyzing the spatial variability of the crop using multispectral imagery allows for the detection of plant stress zones at early stages. This enables timely measures to optimize growing conditions, particularly through differential fertilizer application.

Remote sensing technologies, such as the EOSDA Crop Monitoring platform, significantly enhance the efficiency of plant nutrition management. The Variable Rate Application (VRA) method not only optimizes the use of mineral fertilizers but also prevents environmental pollution associated with their excessive application.

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