GeoTerrace-2026-078

Digital Technologies to Support Sustainable Orchard Land Use in Ukraine's Territorial Communities

M. Malashevskyi, O. Kishchak *(National Academy of Agrarian Sciences of Ukraine)*, ***O. Malashevska** (*National University of Life and Environmental Sciences of Ukraine*), **Y. Kishchak, A. Slobodianiuk** (*National Academy of Agrarian Sciences of Ukraine)*

SUMMARY

The study aims to substantiate the application of digital technologies to support sustainable orchard land use in the territorial communities of Ukraine. The methodological framework relies on the concept of sustainable land use, evaluated through the case of establishing a sweet cherry orchard on the semi-vigorous clonal rootstock Krymsk 5 with planting densities of 667 and 889 trees/ha. A research field of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine with an area of 14,800 m² was used as a reference plot. An optimization model is proposed to select land parcels and tree planting schemes for achieving maximum economic efficiency. Simultaneously, the capabilities of the QGIS environment and Sentinel-2 remote sensing data are integrated. The use of GIS tools and remote sensing for terrain analysis and monitoring orchard condition via the EVI index is substantiated. The mathematical algorithm incorporates constraints regarding environmental conditions as well as spatial and technological characteristics of land parcels. A combination of GIS, remote sensing, and mathematical optimization is proposed to foster sustainable land use. The study integrates key modern approaches to land management with experimental research findings in horticulture, specifically regarding tree spacing patterns, canopy training systems, planting densities, and orchard spatial layout. The proposals of this study are aimed at expanding potential for green infrastructure development, increasing its area, and enhancing community land-use resilience under current conditions in Ukraine.

Keywords: Sustainable land use, Digital technologies, Orchard land use, Green infrastructure

Corresponding Author: o_malashevska@nubip.edu.ua

Introduction

Under modern conditions, ensuring the sustainable development of Ukraine's territorial communities is a critical issue. Orchard land use combines production, ecological, and social functions. Therefore, the development of orchard land use is of great importance in the context of ensuring food security, preserving the natural potential of territories, mitigating the consequences of climate change (Pensa Corrêa et al., 2021), ensuring the economic efficiency of land use (Ghelfi & Palmieri, 2022; Iglesias et al., 2024), and developing modern settlements (Guo et al., 2026).

Digital technologies make it possible to perform analysis, model scenarios, accumulate information, assess conditions, and monitor orchard land use in Ukraine's territorial communities. Under current conditions, geoinformation tools, remote sensing techniques, satellite imagery, and digital mapping enable a multi-factor assessment of the current state of land use (Sadeghi et al., 2026; Wagner & Egerer, 2022), the determination of productivity and yields, the identification of environmental risks, and the planning of measures for rational land use and protection (Agidew & Singh, 2017).

Digital management methods for historically established orchards (Du et al., 2026) and the analysis of processes transforming barren land into orchards (Ahmadi et al., 2025) are of significant interest. At the same time, orchard establishment exhibits notable zonal peculiarities, making it necessary to adapt key approaches to using digital technologies when establishing orchard land uses under modern Ukrainian conditions.

The objective of this study is to substantiate the application of digital technologies to support sustainable orchard land use in the territorial communities of Ukraine.

Method and Theory

The study is conducted within the framework of the concept of creating green infrastructure in Ukraine (Malashevskyi & Malashevska, 2025). The research was carried out using the case of establishing and managing sweet cherry orchard land uses on the semi-vigorous clonal rootstock Krymsk 5 (Kishchak et al., 2026) with planting densities of 667 and 889 trees/ha. The establishment of orchards with the following training systems is considered: KGB, rounded single-tier, and rounded with a lowered fruiting zone. A research field with an area of 14,800 m² belonging to the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (sweet cherry plantings established in 2018) serves as the reference land use.

In long-term field experiments, as well as through mathematical modeling, optimal planting schemes for sweet cherry trees on Krymsk 5 rootstock were established: 5×3 m on fertile soils, and 4.5×2.5 m on less fertile soils (Kishchak et al., 2026) (Figure 1). Land parcel selection is performed to minimize the area not occupied by perennial fruit plantings. The optimization model allows for the determination of the usable area and the selection of a land parcel whose area will be utilized optimally. Such an approach is important as an element in substantiating the creation of orchard land uses on existing land parcels within a territorial community and during land redistribution in the process of territorial spatial optimization (Malashevskyi et al., 2025).

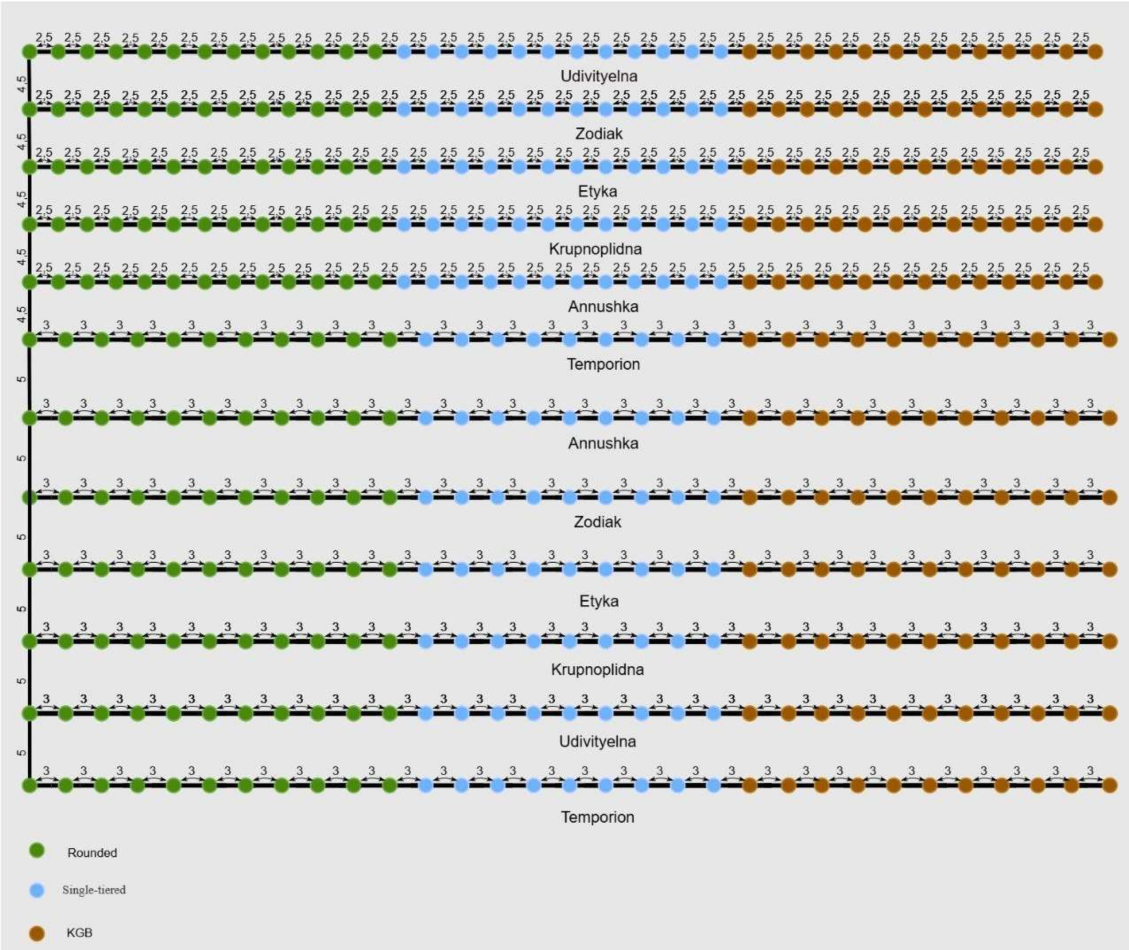

Figure 1. *Tree planting scheme on the experimental land parcel*

GIS-based land parcel selection for orchard establishment involves analyzing topography, soil quality, groundwater table depth, erosion hazard levels, and proximity to infrastructure.

Results

The following model is used for selecting land parcels. The orchard is established using planting schemes of 5 m ×3 m (Scheme 1, *i*=1) or 4.5 m ×2.5 m (Scheme 2, *i*=2). The variables are the number of trees in a row x_{li} (*i*=1,2) and the number of tree rows x_{di} (i=1,2). The objective is to maximize profitability while considering the parameters of the land parcel. The model accounts for statutory setback distances to land parcel boundaries, compliance with spacing between trees according to the aforementioned planting schemes, and the constraint that the planted area configuration must form a rectangle with an aspect ratio ranging from 1:1 to 1:4. The objective function and constraints are as follows:

$$Q_{max}(x) = \frac{V_1}{D_1} x_{l1}x_{d1} + \frac{V_2}{D_2} x_{l2}x_{d2}$$

$$5x_{d1} + 4.5x_{d2} - 1.5 \le d;$$

$$x_{l1} = \left[\frac{l-8}{3}\right] + 1;$$

$$x_{l2} = \left[\frac{l-8}{2.5}\right] + 1;$$

$$x_{d1} + 0.9x_{d2} - 0.6\, x_{l1} \le 1.3;$$

$$x_{d1} + 0.9x_{d2} - 0,15x_{l1} \ge 1,75;$$

$$x_{d1} + 0.9x_{d2} - 0.5x_{l2} \le 1.4;$$

$$-x_{l2}+8x_{d1}+7.2x_{d2} \geq 14.2;$$
$$x_{li} \geq 0 \text{ for i} = 1,2;$$
$$x_{di} \geq 0 \text{ for i} = 1,2,$$

where V is the profit per 1 ha at planting density D, thousand UAH; D is the planting density, trees/ha; d is the width of the land parcel; and l is the length of the land parcel. The length and width are determined in QGIS, taking into account the optimal orientation of tree rows (north to south) and, if necessary, excluding parts of the land parcel that are unsuitable for tree growth.

It is remote sensing methods that make it possible to identify unsuitable and marginally suitable lands, perform regular monitoring of vegetation status, and detect areas showing signs of degradation. Assessment of the vegetation cover condition of the study area was carried out using the Enhanced Vegetation Index (EVI), calculated from Sentinel-2 data (Figure 2).

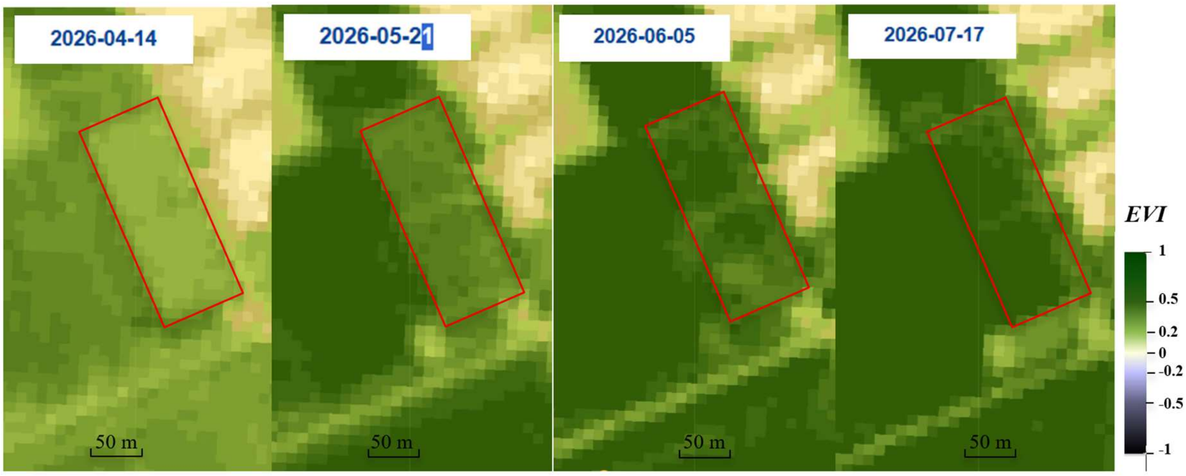

Figure 2. *Evaluation of the study area condition using the Sentinel-2 EVI index*

The spatial distribution of EVI enables a preliminary evaluation of areas characterized by stunted growth and development of fruit trees. Accordingly, it allows for timely measures to be taken to maintain the expected productivity of the land use.

Conclusions

The effectiveness of using digital technologies as a tool to support sustainable orchard land use in the territorial communities of Ukraine has been confirmed. Their application ensures the integration of diverse spatial and thematic information, enhances the efficiency of monitoring vegetation status and overall land use conditions, and serves as an information framework for managerial decision-making.

An optimization model has been proposed for selecting land parcels of optimal size in accordance with efficient tree planting schemes. Modeling makes it possible to achieve maximum profitability while taking into account the physical characteristics of the land parcel.

The combination of GIS, remote sensing, and spatial modeling allows for a comprehensive assessment of orchard management efficiency on land parcels within territorial communities, the monitoring of changes in their state, and the timely identification of environmental risks.

In this study, digital technologies are used not only as a tool for the development of horticultural land use, but also as a means for the spatial implementation of experimental research findings in horticulture—specifically regarding tree layout patterns, planting parameters, planting density, and orchard spatial layout. This provides a scientific justification for the spatial structure of orchard plantings, incorporating the actual technological and biological features of their cultivation. The proposals of this study aim to expand the potential for green infrastructure development and increase its area within Ukraine's territorial communities.

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