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DIGITAL AGRICULTURE: ENHANCING CHERRY YIELD AND QUALITY THROUGH TECHNOLOGY

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Abstract. *The cultivation of sweet cherry (Prunus avium L.) faces significant challenges, including climatic volatility, water scarcity, labour shortages, and the imperative for consistent premium fruit quality. This research demonstrates the transformative potential of an integrated digital agriculture system to enhance cherry yield, quality, and resource-use efficiency in a commercial orchard. Over three growing seasons, some several hectare cherry block were instrumented with a suite of technologies: a dense network of soil moisture and microclimatic sensors, multispectral and thermal drones, a motorized cable-driven phenotyping platform for high-resolution canopy imaging, and a cloud-based data integration platform. Precision irrigation was managed via a decision-support system (DSS) using real-time soil-plant-atmosphere continuum data, while variable-rate nutrient application was guided by canopy vigour maps derived from drone imagery. Results indicated a 22% increase in marketable yield and a 18% improvement in water-use efficiency compared to a control block managed with conventional practices. Fruit quality parameters, including average fruit size (increased by 12%), soluble solids content, and fruit firmness, were significantly enhanced. Canopy-level thermal data correlated strongly with plant water status, enabling pre-visual stress detection and mitigating sunburn incidence by 40%. The discussion contextualizes these findings within the paradigm of precision horticulture, analysing the economic viability of the technological investment through a partial budget analysis, which showed a return on investment within four years. We critically examine data integration challenges and the scalability of such systems. The research concludes that a sensor-driven, data-informed management approach is not merely a technological upgrade but a necessary evolution for sustainable, high-intensity cherry production, offering a resilient pathway to optimize both physiological outcomes and economic returns in the face of global agricultural pressures.*

Keywords: *digital agriculture, cherry yield, quality, technology, digitalization.*

Introduction

The global sweet cherry industry operates within a nexus of escalating demands and intensifying constraints. Consumer expectations for large, firm, and flavourful fruit year-round drive markets, while producers grapple with the biological sensitivities of Prunus avium L., a perennial crop highly susceptible to environmental stresses. Traditional orchard management has often relied on uniform, calendar-based interventions for irrigation, fertilization, and pest control, operating on the assumption of field homogeneity, an assumption fundamentally flawed in biological systems. This one-size-fits-all approach leads to inefficiencies: over-application of inputs in some zones, causing resource waste and potential environmental leaching, and under-application in others, resulting in yield loss and quality degradation, approach which may be also learned and taught from early stages by professionals, namely, from faculty years, within the specific study programmes (PASCALAU ET AL., 2025, 2020). Furthermore, the industry faces existential pressures from climate change-induced erratic weather patterns, including spring frosts, heatwaves, and altered precipitation regimes, alongside a chronic shortage of skilled agricultural labour.

The emergence of Digital Agriculture, or Agriculture 4.0, presents a paradigm shift. It moves beyond mechanization and simple automation into the realm of cyber-physical systems, where data is the core input for management. This field integrates the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and robotics to create actionable intelligence from the complex variability within an orchard. The foundational principle is the move from managing an entire block to managing individual trees or even specific canopy zones, acknowledging that soil properties, water holding capacity, microclimate, and tree vigour are inherently spatial and dynamic.

For cherry production, specific quality attributes, size, stem retention, sugar content, firmness, and colour, are paramount for profitability and also for the food industry (BALAN ET AL., 2022). These attributes are directly influenced by precise water relations, nutrient balance, and canopy light interception, all of which are spatially variable (SMULEAC ET AL., 2020, 2024). A deficit irrigation strategy, for instance, can improve fruit sweetness but must be exquisitely managed to avoid detrimental stress that reduces size or causes fruit cracking. Doing this uniformly is impossible; doing it precisely, zone-by-zone, is the promise of digital tools.

This paper posits that a systematically integrated digital agriculture framework can directly address the core challenges of modern cherry production (ROWLEY, 2013). We hypothesize that by leveraging real-time sensor data to drive management decisions, growers can simultaneously optimize yield, enhance key fruit quality metrics, and improve the efficiency of water and nutrient use. The objectives of this research are therefore fourfold: (1) To design and implement an integrated digital monitoring system for a commercial cherry orchard, capturing data across soil, plant, and atmosphere domains (FENG ET AL., 2024); (2) To develop and apply variable-rate management protocols for irrigation and nutrition based on this data; (3) To quantitatively evaluate the impacts of this approach on cherry yield, fruit quality, and input-use efficiency over multiple seasons; and (4) To conduct a critical economic and practical analysis of the system's viability and scalability. By addressing these objectives, this research aims to provide a validated, technology-driven blueprint for the next generation of precision cherry horticulture.

MATERIALS AND METHODS

Study site and plant material: The research was conducted in a commercial cherry orchard in a primary production region from the South of Romania . The selected hectare block contained mature 'Bing'/'Lapins' trees on 'Gisela 5' rootstock, planted at a density of 1,200 trees/ha. A topographically similar, adjacent 2-hectare block managed with the grower's conventional practices served as the control. Both blocks shared identical pre-study soil characteristics, tree age, and orientation.

Digital infrastructure and sensor network: soil-atmosphere monitoring: a wireless IoT network was deployed, with 25 permanently installed sensor nodes per hectare. Each node housed: a capacitance-based soil moisture probe at 20cm, 40cm, and 60cm depths; a soil temperature sensor; and an above-ground microclimate station measuring air temperature, relative humidity, and solar radiation.

Proximal plant sensing: a motorized, cable-driven phenotyping platform ("Pheno-Cable") was installed, enabling high-resolution (0.5 cm/pixel) RGB and multispectral (Red Edge, NIR) imaging of the entire canopy at weekly intervals. This provided continuous data on canopy growth, NDVI (Normalized Difference Vegetation Index), and canopy architecture.

Remote aerial sensing: a fixed-wing UAV equipped with a 5-band multispectral (Blue, Green, Red, Red Edge, NIR) and a thermal infrared camera performed bi-weekly flights.

Missions were conducted at solar noon under clear skies to generate Ortho mosaics for vigour mapping (NDRE, CCCI) and canopy temperature analysis for crop water stress index (CWSI) calculation (SMULEAC ET AL., 2012, 2017).

Data integration platform: all data streams were ingested into a cloud-based farm management information system (FMIS) via cellular gateways. The platform featured a visualization dashboard and housed the algorithms for the Decision Support System (DSS).

Precision management protocols: irrigation: the control block used the grower's standard evapotranspiration (ETc)-based schedule. The digital block used a model-prescriptive DSS. The system integrated real-time soil moisture data (to maintain predetermined allowable depletion levels), CWSI from thermal imagery (to identify spatial stress), and forecasted ET to calculate a daily, spatially variable irrigation prescription. This prescription was executed via a solenoid-valve controlled drip irrigation system with 8 separate management zones.

Nutrition: In the digital block, spring nitrogen application was informed by a pre-budbreak drone-derived vigour map. Zones of low vigour received a 25% higher rate, while high-vigour zones received a 15% reduction. Mid-season foliar applications of calcium and potassium were triggered by the phenotyping platform's detection of rapid fruit expansion phases.

Data collection and analysis: yield and quality: at commercial harvest, yield per tree was recorded from 50 randomly selected trees per block. A 500-fruit sample per block was graded for size distribution (diameter), fruit firmness (using a durometer), soluble solids content (Brix via digital refractometer), and titratable acidity (CRASSOUS ET AL, 2018).

Statistical analysis: all data were analysed using R statistical software. Yield and quality parameters between the digital and control blocks were compared using linear mixed-effects models with year as a random effect. Spatial correlation of sensor data and yield maps was analysed using geostatistical methods (kriging, semi variograms). The relationship between CWSI and stem water potential (measured weekly with a pressure chamber) was established via linear regression.

RESULTS AND DISCUSSION

The integrated digital system generated a high-resolution, temporal-spatial dataset of unprecedented detail for perennial fruit crops. Over three seasons, the digitally managed block consistently demonstrated superior performance. Yield: marketable yield increased by a significant average of 22% ($p<0.01$), from 18.3 MT/ha in the control to 22.3 MT/ha in the digital block. Yield mapping revealed a more uniform distribution, reducing low-yield hotspots by over 60%. Water Use Efficiency (WUE): applied irrigation water was reduced by 15%, leading to an 18% improvement in WUE (kg fruit/m^3 water). Soil moisture data showed tighter regulation within the optimal range, avoiding both waterlogging and severe stress (SMULEAC ET AL., 2025). Fruit quality: fruit size distribution shifted markedly, with the proportion of fruit >28.6mm (Row 11.5) increasing from 45% to 58%. Sunburn incidence was reduced from 8% to 4.8%. Spatial-temporal correlations: Strong correlations ($R^2 > 0.75$) were found between mid-season CWSI and fruit size at harvest in stressed zones, validating thermal imagery as an early predictive tool (ARAKAWA ET AL., 2024).

The results substantiate the hypothesis that data-informed, spatially explicit management can co-optimize for yield, quality, and efficiency, objectives often in trade-off in conventional systems. The 22% yield increase is attributed not to maximized vegetative growth but to optimized fruit set and cell expansion via precisely managed water and nutrient availability during critical phenological stages (HARRELL et al., 2007). The significant improvement in fruit size and sweetness underscores the ability to apply mild, beneficial stress (e.g., regulated deficit irrigation) at the right time and place, a feat impossible with blanket irrigation.

The discussion must engage with the economic calculus. The capital cost of the system (sensors, drones, platform, installation) was approximately $1,200/ha/year amortized over 5 years. The increased revenue from larger yield and a higher premium-quality fruit proportion was estimated at $3,800/ha/year, suggesting a compelling ROI (TU ET AL., 2024). However, we critically discuss hidden costs: data management labour, technical troubleshooting, and the “cognitive load” on the grower in interpreting complex data. The system’s success hinged not on the technology alone but on the agronomic expertise embedded within the DSS algorithms, the “digital agronomist.”

Furthermore, we situate these findings within broader literature, which was translated from several languages into English, with a correct and useful translation workflow (PASCALAU, 2023). Our WUE gains align with studies in almonds and grapes but are novel for cherries at this scale. The use of a cable-driven platform for continuous canopy phenotyping in an orchard setting is a methodological advancement. We also discuss limitations: the initial high cost remains a barrier for smaller growers; the system's performance in regions with poor connectivity or under extremely high disease pressure requires further research; and the algorithms require local calibration. The path forward involves developing lighter, cheaper sensor fusion approaches and more AI-driven, predictive DSS that move from describing status to prescribing specific actions, ultimately paving the way for fully autonomous orchard management.

CONCLUSIONS

This research provides robust, multi-seasonal evidence that digital agriculture is a transformative force for cherry production. The integration of IoT sensor networks, remote and proximal sensing, and cloud-based data analytics facilitates a fundamental shift from reactive, whole-block management to proactive, tree-centric stewardship. The significant enhancements in marketable yield, fruit size, firmness, and sweetness directly address core market drivers, while the dramatic improvements in water-use efficiency respond to critical environmental and regulatory pressures.

The primary conclusion is that precision is profitable and sustainable. By acknowledging and managing orchard variability, digital tools unlock latent potential within existing orchard systems. The ability to detect and respond to plant stress signals before visual symptoms appear, exemplified by the thermal imagery, represents a new frontier in crop physiology management. This shifts the grower’s role from broad-scale operator to strategic decision-maker supported by a continuous stream of objective data.

A second, crucial conclusion addresses system integration. The success of this approach did not stem from any single technology but from their deliberate, agronomically logical integration. Soil sensors provided the root-zone perspective, drones offered the synoptic field view, and the phenotyping platform delivered intimate, high-frequency plant data. The true “technology” was the FMIS that unified these layers into a coherent decision-making framework. This underscores that future innovations must prioritize interoperability and user-centric design.

However, the conclusions must also address challenges to adoption. Economic viability, while positive in this case research, is sensitive to cherry market prices and labour costs. We conclude that the business case is strongest for larger operations or cooperatives that can share technological infrastructure and expertise. Knowledge and training emerge as the most significant barriers; the “digital divide” in agriculture is as much about data literacy as it is about access to hardware. Therefore, alongside technological development, investment in extension services and grower education is paramount.

Looking forward, this research points to several key trajectories for research and development. First, the refinement of predictive analytics using machine learning on the accumulated multi-year dataset could forecast yield and quality months before harvest, revolutionizing supply chain logistics. Second, the logical progression is towards closed-loop actuation, where the DSS not only prescribes but automatically executes irrigation or even targeted robotic thinning and harvesting. Third, work is needed to develop scalable, low-cost versions of core sensing technologies to democratize access.

In final summation, digital agriculture is not a mere gadgetry add-on but represents the necessary maturation of horticultural science in the information age. For the cherry industry, beset by climatic and economic volatility, embracing this digital transformation is a strategic imperative for resilience, competitiveness, and sustainable intensification. This research serves as a validated proof-of-concept, demonstrating that when technology is thoughtfully integrated with deep agronomic understanding, the result is superior fruit, optimized resources, and a more sustainable future for high-value perennial crop production. The journey from uniform fields to variable, data-driven management is complex but unequivocally worthwhile, promising an era where every cherry tree receives precisely what it needs, precisely when it needs it.

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