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WATER CONSERVATION, CHERRY ORCHARDS, IRRIGATION MANAGEMENT, SUSTAINABLE AGRICULTURE, PRECISION FARMING

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Abstract. *Water scarcity poses a significant threat to the sustainability and profitability of fruit production, particularly in water-intensive crops like sweet cherries. This research evaluated the effectiveness of a precision irrigation management strategy, integrating soil moisture sensors and evapotranspiration (Etc) data, on water conservation, tree physiology, and fruit quality in a mature "Bing" cherry (Prunus avium L.) orchard in a semi-arid region. Over two consecutive growing seasons, a randomized block design was implemented, comparing a sensor-based precision irrigation (PI) treatment against the orchard's conventional irrigation (CI) practice, which followed a fixed calendar-based schedule. The PI treatment applied water only when soil moisture in the root zone (0-60 cm depth) fell below 65% of field capacity, with volumes adjusted weekly using local ETc and crop coefficient (Kc) values. Results demonstrated that the precision irrigation system achieved a 22.3% average reduction in seasonal irrigation water use compared to conventional practice, without inducing significant water stress. Midday stem water potential measurements confirmed similar plant water status between treatments. Importantly, fruit yield, average fruit size, and soluble solids content were not statistically compromised. Furthermore, the PI trees exhibited a marginal, though not significant, increase in fruit firmness. The discussion highlights that the water savings were primarily attributed to the elimination of unnecessary irrigation events during periods of low evaporative demand or following rainfall. These findings underscore the potential of sensor-based precision irrigation as a critical tool for sustainable agriculture in cherry orchards. By maintaining productivity and fruit quality while substantially reducing water inputs, this approach offers a viable pathway for enhancing water conservation and ensuring the long-term economic and environmental resilience of cherry production systems.*

Keywords*: cherry, orchards, irrigation management, sustainable agriculture, precision farming*.

INTRODUCTION

Global freshwater resources are under increasing and unprecedented strain, a crisis driven by the twin pressures of climate change and escalating agricultural demand. Anthropogenic climate change is altering hydrological cycles, leading to more frequent and severe droughts, reduced snowpack, and shifting precipitation patterns in key agricultural regions. Concurrently, the agricultural sector, which accounts for approximately 70% of global freshwater withdrawals, faces the immense challenge of producing more food for a growing population while contending with this diminishing and increasingly variable water supply (BALAN ET AL., 2022, SMULEAC ET AL., 2020). This tension is acutely felt in the production of high-value specialty crops, such as sweet cherries (Prunus avium L.), which are predominantly cultivated in irrigated arid and semi-arid regions where water is inherently scarce.

These environments provide ideal climatic conditions for cherry fruit development, specifically, well-drained soils and abundant sunshine, but they are wholly dependent on controlled irrigation to meet crop water requirements. For cherry growers, water is not merely an input but the critical determinant of both fruit yield and, more importantly, the premium quality parameters, size, firmness, sweetness, and colour, that dictate market value and profitability.

Consequently, precise irrigation management is not just an agronomic best practice but an existential imperative for the economic sustainability of the cherry industry (CRASSOUS ET AL., 2017).

Traditionally, irrigation scheduling in many orchards has relied upon fixed calendar-based regimes or subjective measures such as visual inspection of soil or crop condition. These heuristic approaches, while operationally simple, are fundamentally misaligned with the dynamic water needs of the crop, which fluctuate daily based on atmospheric demand (evapotranspiration), soil characteristics, and the tree's phenological stage. Calendar-based irrigation often applies water on a pre-set schedule, irrespective of actual soil water depletion or upcoming weather, inevitably leading to periods of over-irrigation. This practice results in significant water waste, inefficient use of energy for pumping, and the increased risk of nutrient leaching beyond the root zone, which contributes to groundwater contamination. Conversely, it can also lead to unintended under-irrigation if the schedule does not account for periods of high evaporative demand, inducing plant water stress that compromises fruit size and yield. In an era of tightening water regulations, rising pumping costs, and growing social responsibility for environmental stewardship, taught also in Life sciences universities, this traditional paradigm is no longer tenable (PASCALAU ET AL., 2025, SMULEAC ET AL., 2024).

This research therefore investigates the application of precision farming principles to revolutionize irrigation management in cherry orchards. Precision agriculture moves beyond field-level management to a sub-field, data-driven approach, leveraging information technology to tailor inputs to specific spatial and temporal needs. The core innovation examined here is the integration of real-time, in-situ soil moisture sensor data with modelled crop evapotranspiration (ETc) estimates to create a responsive, closed-loop irrigation system. Soil moisture sensors provide a direct, physical measurement of water availability in the root zone, while ETc models, calculated from local weather data and established crop coefficients, provide a physiological estimate of the tree's daily water use. By synthesizing these two data streams, irrigation can be triggered and dosed with unprecedented accuracy, applying water only when and in the exact amount the crop requires.

The primary objective of this research was to rigorously quantify the magnitude of water savings achievable through this sensor- and model-driven precision irrigation strategy in a commercial sweet cherry orchard. Furthermore, it aimed to holistically evaluate the agronomic and horticultural impacts of this reduced water input, ensuring that conservation does not come at the cost of productivity or quality. This was achieved by meticulously monitoring key response variables: tree water status through direct physiological measurements (midday stem water potential), total fruit yield, and critical fruit quality parameters (size, firmness, and soluble solids concentration) (HARRELL ET AL., 2007). By establishing a direct link between irrigation practice, resource use, and crop outcomes, this research seeks to provide a robust, evidence-based framework for cherry growers to transition towards more efficient and sustainable production systems.

The ultimate contribution is a validated management protocol that aligns environmental stewardship, through substantial water conservation, with the economic imperative of maintaining high yields of superior quality fruit, thereby supporting the long-term resilience and viability of cherry agriculture in water-limited regions.

MATERIAL AND METHODS

The research was conducted over two consecutive, complete growing seasons, spanning the 2022 and 2023 agricultural years, within a mature, commercially productive sweet cherry orchard (KVIKLYS ET AL., 2015). The orchard featured “Bing” scions, the industry-standard variety prized for its firmness, flavour, and marketability, grafted onto Gisela®6 dwarfing rootstock. The selection of this specific rootstock-scion combination is significant, as Gisela®6 is known for its high productivity and efficiency in high-density plantings, but it also possesses a relatively shallow and fibrous root system that can be particularly sensitive to water stress, thereby presenting a rigorous test for irrigation management strategies. The experimental site was situated in a representative semi-arid fruit-producing region, characterized by hot, dry summers, minimal summer precipitation, and a reliance entirely on irrigation for crop production. The soil at the site was classified as a sandy loam, a texture that provides good drainage but has a relatively low water-holding capacity, necessitating careful and frequent irrigation management to prevent moisture depletion in the root zone.

The experimental design employed was a randomized complete block design (RCBD), a robust structure chosen to account for any inherent spatial variability within the orchard, such as subtle gradients in soil composition or slight microclimatic differences. The orchard block was divided into four distinct blocks or replicates, each representing a major stratum of variability. Within each of these four blocks, two experimental treatment plots were randomly assigned, ensuring that each treatment had an equal chance of being in any position within a block, thereby minimizing bias. Each experimental plot was functionally defined as a group of five adjacent, uniform cherry trees, with the central three trees serving as the core data trees for all measurements and the outer two trees acting as guard rows to buffer against edge effects from adjacent plots with different irrigation treatments. Where it was necessary, different materials and studies were translated from different languages into English, using a perfect translation workflow for that (PASCALAU, 2023, PASCALAU ET AL., 2021, 2023).

Two distinct irrigation management treatments were applied and compared throughout the research. The first treatment, designated Conventional Irrigation (CI), served as the control and represented standard grower practice. This regime utilized the existing drip irrigation system but followed a fixed, calendar-based schedule determined by the orchard manager’s historical experience and generalized regional guidelines. The schedule typically involved irrigating for a set duration two to three times per week, with minor adjustments made subjectively based on visual inspection of the trees or recent high temperatures. This approach embodies the common industry practice that the precision strategy aimed to improve upon.
The second treatment, Precision Irrigation (PI), constituted the experimental intervention. This data-driven strategy integrated two complementary technological components.

First, in each PI plot, a suite of multi-depth capacitance-based soil moisture sensors was permanently installed within the drip zone of a representative data tree. These sensors were positioned at 20, 40, and 60 cm depths to monitor water content across the primary root zone profile. Irrigation events were automatically triggered only when the integrated soil water content across these depths fell below a predetermined threshold of 65% of field capacity, a level established from prior soil physical analysis and known to be above the point where cherry trees experience water stress (ANTOGNOZZI et. Al., 2019).

Second, once a watering event was triggered, the volume of water to apply was not fixed. Instead, it was calculated weekly using a crop water budgeting approach. This calculation multiplied the local reference evapotranspiration (ETo), obtained from a certified on-site weather station, by a staged crop coefficient (Kc) specific to sweet cherries, which varies with phenological phases (dormancy, bloom, fruit development, harvest, and post-harvest). This calculated crop evapotranspiration (ETc) provided an estimate of the water lost from the system, which was then replaced via irrigation, considering irrigation efficiency. This combination of soil-based triggering and climate-based dosing created a responsive, closed-loop management system.

A comprehensive suite of plant- and fruit-based measurements was collected to evaluate treatment effects. Volumetric soil water content was logged continuously by the sensor network in PI plots and verified periodically in CI plots with a portable probe. Plant water status was assessed bi-weekly, from fruit set through post-harvest, via direct measurement of midday stem water potential, the gold-standard physiological indicator of tree water stress. Total seasonal irrigation volume applied to each plot was precisely recorded by in-line flow meters. At commercial harvest, all fruit from each core data tree were picked, counted, and weighed to determine total yield and average fruit weight. Fruit quality was rigorously assessed on a random sub-sample of 50 fruit per plot: firmness was measured using a digital penetrometer with a plunger tip, and soluble solids concentration (a proxy for sugar content) was determined using a digital refractometer. All collected data were subjected to appropriate statistical analysis to determine the significance of observed differences between the two irrigation treatments across the two growing seasons.

RESULTS AND DISCUSSIONS

The implementation of the precision irrigation (PI) management system resulted in a substantial and statistically significant reduction in water consumption. Analysis of flow meter data across both growing seasons demonstrated that the PI treatment reduced total seasonal irrigation water application by an average of 22.3% compared to the conventional irrigation (CI) practice, a difference that was highly significant ($p<0.01$). This significant conservation was consistent between years, although the absolute savings varied slightly with seasonal weather patterns, being more pronounced in a cooler, wetter spring. Crucially, this major reduction in water input did not come at the expense of tree health or function. Measurements of midday stem water potential, a sensitive and direct indicator of plant water status, revealed no physiological compromise. Both values remained well above established thresholds for water stress in sweet cherry, indicating that trees under the PI regime maintained optimal hydration throughout the critical fruit development and ripening periods (CIRILLI ET AL., 2017, ARTLIP ET AL., 2020).

The agronomic and economic outputs of the orchard were fully preserved under the water-saving regime. Final harvest data showed no significant difference in total yield per tree between the two treatments. Similarly, the average individual fruit weight, a primary determinant of market grade and price, was statistically identical. This confirms that the precision strategy did not induce the yield penalties or fruit size reductions often feared with deficit irrigation approaches. Fruit quality analysis further supported the viability of the PI system. The soluble solids concentration, measured, which directly correlates with perceived sweetness and flavour intensity, showed no significant variation between treatments. A noteworthy, though not statistically significant at the $p=0.05$ level, trend was observed in fruit firmness. Fruit from PI plots exhibited a mean firmness of 324 g/mm, compared to 315 g/mm for CI fruit. While this 9 g/mm difference did not reach formal significance in this two-year research, the consistent directional trend across both seasons is biologically suggestive and commercially relevant, as even marginal gains in firmness can enhance post-harvest shelf life and shipping tolerance.

The discussion of these results logically centres on identifying the precise source of the 22.3% water savings without negative agronomic impact. A detailed temporal analysis of irrigation events provided clear mechanistic insight. The PI system's logic, being driven by direct soil moisture measurement and calculated evapotranspiration (ETc), allowed it to dynamically respond

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to environmental conditions, analysis performed also in study programmes in specific universities (PASCALAU ET AL., 2025). It systematically avoided unnecessary irrigation during two key periods where the conventional schedule consistently applied water.

First, during periods of low atmospheric evaporative demand (e.g., cloudy, cool, or humid days), the PI system either skipped events or applied markedly reduced volumes, as the soil moisture threshold was not met and the calculated ETc was low.

Second, and perhaps more importantly, following measurable rain events, the PI system automatically accounted for the incoming precipitation, delaying the next irrigation cycle until the soil moisture was again depleted. The fixed CI schedule, in contrast, continued its pre-programmed cycles irrespective of these natural water inputs, leading to applications on already wet soil and contributing directly to drainage and waste.

The maintained plant water status and full productivity under PI provide strong evidence that the conventional practice inherently incorporates a substantial “safety factor” of excess irrigation. This safety margin is applied by growers to buffer against the uncertainty of weather and the risk of stress, but it represents a significant reservoir of inefficiency. The PI system effectively eliminates this guesswork and uncertainty by providing real-time, plant-relevant data, allowing growers to replace the safety factor of extra water with the security of precise information. The observed trend toward increased fruit firmness under PI, while requiring further long-term validation, aligns with physiological principles. Excessively abundant or poorly timed water availability during the final stages of fruit swell and ripening, as can occur under less discriminating schedules, can promote rapid cell expansion and potentially lead to slightly weaker cell structure. The more controlled and precise hydration provided by the PI system may promote a firmer fruit texture by avoiding the peaks of surplus water, leading to more consistent growth. This highlights a potential quality enhancement benefit, moving beyond mere conservation.

In a broader context, these findings powerfully align with and strengthen a growing body of research from other perennial tree crops, including almonds, peaches, and citrus. They collectively demonstrate that precision irrigation, when properly calibrated, is not merely a water-saving tool but a sophisticated yield- and quality-preserving management strategy. It represents a paradigm shift from applying water based on time to applying water based on direct plant and soil need. This research provides concrete, quantified evidence for cherry growers that adopting such sensor- and model-based systems can directly address pressing environmental and regulatory pressures for water conservation while safeguarding, and potentially even enhancing, the economic foundations of their orchards (ALBRECHT ET AL., 2020). The results argue convincingly that precision irrigation is a cornerstone practice for achieving true agricultural sustainability, where resource efficiency and crop productivity are not competing goals but mutually achievable outcomes.

CONCLUSIONS

This research conclusively demonstrates that a precision irrigation management strategy, integrating real-time in-situ soil moisture sensing with modelled evapotranspiration data, can dramatically enhance water conservation in commercial sweet cherry orchards without compromising the critical agronomic metrics of yield and fruit quality. The data-driven approach, which triggers irrigation based on direct root-zone measurements and doses water according to calculated crop demand, achieved a substantial and statistically significant average reduction of 22.3% in seasonal irrigation water use compared to conventional calendar-based scheduling. This significant conservation was accomplished while maintaining nearly identical plant water status, as confirmed by stem water potential measurements, and with no detrimental impact on total fruit yield, average fruit size, or soluble solids content. The consistent trend toward improved fruit firmness, though not statistically significant in this two-year trial, further suggests that precision management may not only conserve but also refine key quality parameters by avoiding the fluctuations in soil moisture associated with less discriminate irrigation practices.

The magnitude of this water saving represents more than an incremental gain; it is a transformative improvement with profound dual implications for economic efficiency and environmental sustainability. From an economic perspective, reducing water consumption by over one-fifth directly lowers pumping costs and associated energy expenditures, an increasingly critical factor as energy prices rise. More importantly, it mitigates operational risk by building resilience against water scarcity, regulatory curtailments, and the escalating competition for water resources. By proving that such savings do not come at the cost of production volume or marketable fruit quality, this research directly addresses the primary economic concern of growers, facilitating the adoption of conservation technologies. Environmentally, this level of reduction significantly decreases the water footprint of cherry production, alleviates pressure on local aquifers and surface water sources, and minimizes the potential for nutrient leaching and runoff, thereby protecting water. In regions chronically facing drought and water scarcity, these contributions are vital for the long-term social license to operate and the ecological health of the agricultural landscape.

Therefore, the widespread adoption of such precision farming technologies provides a clear, evidence-based pathway for the global cherry industry to improve its resource use efficiency, economic viability, and climate resilience. This transition aligns directly with the core pillars of sustainable agriculture, which seeks to balance productivity, environmental stewardship, and economic profitability. By replacing the uncertainty and inherent waste of traditional scheduling with the accuracy of a data-driven feedback loop, growers can move from a defensive posture of applying “safe” excess water to a proactive, optimized management model. This represents a crucial step toward climate-smart agriculture, where production systems are adapted to be more efficient and resilient in the face of changing environmental conditions.

To build upon these promising findings and accelerate industry adoption, targeted future work is essential. Research should investigate the long-term (e.g., 5-10 year) effects of sustained precision irrigation on deeper aspects of orchard health, including root system architecture, soil microbial communities, long-term tree vigour, and cumulative yield potential. Furthermore, a comprehensive analysis of the economic feasibility of sensor system implementation at scale is urgently needed. This includes detailed cost-benefit analyses that account for capital investment, maintenance, data management, and labour, weighed against water, energy, and potential premium-quality savings across diverse orchard sizes and operational contexts. Finally, research should explore the integration of this irrigation data with other precision agriculture tools, such as remote sensing and variable-rate technology, to create a fully integrated, holistic orchard management system. By addressing these next steps, the industry can solidify precision irrigation not as an experimental concept but as a foundational, profitable, and sustainable standard practice for modern cherry production.

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