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Sensor-Based Fertigation Management Enhances Resource Utilization and Crop Performance in Soilless Strawberry Cultivation

Lucia Bonelli [1], Francesco Fabiano Montesano [2,*], Massimiliano D'Imperio [1], Maria Gonnella [1], Angela Boari [1], Beniamino Leoni [2] and Francesco Serio [1]

1 Institute of Sciences of Food Production (ISPA), National Research Council (CNR), Via G. Amendola 122/O, 70126 Bari, Italy; lucia.bonelli@ispa.cnr.it (L.B.); massimiliano.dimperio@ispa.cnr.it (M.D.); maria.gonnella@ispa.cnr.it (M.G.); angela.boari@ispa.cnr.it (A.B.); francesco.serio@ispa.cnr.it (F.S.)

2 Department of Soil, Plant and Food Sciences, University of Bari Aldo Moro, Via G. Amendola 165/A, 70126 Bari, Italy; beniamino.leoni@uniba.it

* Correspondence: francesco.montesano@uniba.it

Abstract: The use of wireless sensors for real-time sensing of substrate water status and electrical conductivity could be an effective tool for precision irrigation management in soilless cultivation. In this research, the effects of timer-based (TB) compared to smart sensor-based irrigation (SB) were investigated. The highest consumption of fertilizers and water were recorded in TB, with nutrient solution and total applied water savings of 38% and 26%, respectively, in SB. The highest yield was obtained in SB treatment, with a total and marketable yield decrease of 7% in TB, with no differences in terms of the total soluble solids content, dry matter, firmness, juice pH and titratable acidity of the strawberry fruits. The higher yield, combined with water and nutrient saving in SB, allowed water use efficiency (fresh weight of marketable fruits per liter of total water applied) to be increased by 46% and nutrient productivity (fresh weight of marketable product per gram of nutrient supplied via nutrient solution) by 74%. The study confirms that sensor-based, compared to empiric fertigation management, ameliorates the sustainability of open, free-drain, soilless cultivation of strawberry, leading to better resource use without compromising crop performance and fruit quality.

Keywords: *Fragaria* × *ananassa* cv. Sabrosa; Teros 12 sensors; wireless; leaching; volumetric water content; pore electrical conductivity

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1. Introduction

Water is an increasingly scarce resource. It is becoming an issue not only in arid regions but also where water availability has not been considered until recently a limiting factor. Among all sectors, agriculture is the largest consumer of freshwater resources, with around 70% of all freshwater withdrawals [1,2]. The human population is estimated to exceed nine billion by 2050, with an increase in food demand by 70–100% from the current levels [3]. This, along with climate change, is expected to increase agricultural water requirements. One of the major problems in agriculture is the suboptimal use of water. It is thought that less than 60% of all the water supplied with irrigation is effectively used by crops [4].

In the last several decades, the processes of greenhouse production, accompanied with the development of Soilless Culture Systems (SCSs), have greatly advanced [5]. SCSs include any method of growing plants without the use of soil, in which nutrients are supplied through water, i.e., a nutrient solution (NS) [6]. Several advantages are connected to SCSs: the absence of soil-borne pathogens, efficient nutrient regulation and increased yield and product quality [7]. Compared to soil-bound cultivation, soilless systems allow higher yields per unit of water applied to be obtained [8].

Among crops suitable to be grown under soilless conditions, strawberry represents an important one [9]. Its cultivation represents one of the most profitable horticultural enterprises in many countries [10]. In recent years, in respond to the increase in demand and consumers' awareness of their nutritional value and antioxidant benefits [11], strawberry cultivation has doubled worldwide [10]. In Italy, it covers about 268,000 hectares, with a total value of EUR 360 million, and southern Italy is the area of greatest production [12]. Strawberry cultivation is mainly conducted in soil-bound conditions, under tunnels [12]; however, problems linked with soil-borne strawberry diseases, salinity, unsuitable soil characteristics and water resource limitations have contributed to the expansion of a soilless culture [10]. However, the sustainability of soilless cultivation is closely related to the management of the NS. Traditionally, irrigation scheduling is based on the grower's decision and on the use of a timer, resulting in a water/nutrient solution automatic supply according to a prefixed schedule [13,14]. This generally leads to excessive irrigation and, consequently, water and fertilizer losses [15]. The adoption of free-drain open-cycle management with a high (20–40%) leaching fraction (LF), aimed to empirically prevent drought stress and avoid salt accumulation in the root zone, is predominant in areas with a low-tech greenhouse industry, such as the Mediterranean area [16,17]. In SCSs, irrigation and fertigation are critical inputs [15]. Operating on the timing and the dose of irrigation scheduling, it is possible to affect plant performance, optimize economic return, increase water use efficiency (WUE), maximize yield and stimulate vegetative or generative growth [15]. This is bringing agriculturalists, engineers and policymakers to revisit the way water is used. In strawberry cultivation, the irrigation schedule is mainly based on the model-based estimation of the crop's evapotranspiration, but recent experiences report that tension or soil matric potential-based measurements can provide better growth and yield, together with water and labor savings [18]. In the last few years, several methods to improve water use efficiency (WUE) have been developed. Among these, several reliable and affordable sensors, principally based on frequency domain reflectometry (FDR) to measure the volumetric water content (VWC) and electrical conductivity (EC) in growing substrates have become available [9,19]. The application of these sensors for irrigation management is based on a simple principle: with evapotranspiration, the substrate moisture level decreases, and when it reaches a predetermined threshold value detected by sensors, irrigation is automatically activated [19]. Combining these sensors with the adoption of proper irrigation setpoints corresponding to proper substrate water availability conditions could be a successful approach for optimal fertigation management [17]. Compared to timer-based irrigation, sensor-based irrigation may considerably reduce water consumption and increase WUE, providing water (and fertilizers) on-demand just when plants require it and reducing the drainage fraction to minimum values (<10%). In previous studies recently conducted, increases in WUE, ranging from 25 to 70%, were observed with sensor-based compared to timer-based irrigation management for several horticultural crops, including lettuce [20], basil [19], green bean and rocket [13,14]. In the case of strawberry, an experiment conducted in Korea to investigate the potential application of an irrigation schedule based on FDR sensors and VWC measurement showed that the total irrigation volume was 1.7-fold higher with the timer-based than with sensor-automated irrigation, with no differences in terms of plant growth, fruit yield and soluble solid content [21].

Given the above considerations, the objective of the present study was to evaluate input (namely, water and fertilizers) use, crop yield and the marketable quality of soilless strawberry with fertigation operated by an automatic system based on a combined VWC and EC real-time sensor-based measurement compared to an empirically timer-based irrigation. For this purpose, a prototype cloud-connected system for wireless, sensor-based irrigation management was implemented, hypothesizing that the use of smart technologies could improve the sustainability of soilless cultivation.

2. Materials and Methods

2.1. Plant Materials and Growing Conditions

The experiment was carried out in a plastic (polymethacrylate) greenhouse at the Experimental Farm "La Noria" of the Institute of Sciences of Food Production (ISPA-CNR) in Mola di Bari (BA, Italy) (41.062156° N, 17.066914° E) during the 2021–2022 growing season.

Strawberry bare root seedlings (*Fragaria* × *ananassa* cv. Sabrosa, June bearer type variety) obtained by a cooperative company (Apofruit Italia Soc. Coop., Scanzano Jonico, Italy) were transplanted on 16 November 2021 into 27 L bags containing a mix of coir fiber and perlite ('Agripan cocco-perlite', Perlite Italiana, Corsico (MI), Italy) (50:50 *v*/*v*), 10 per bag.

Bags were arranged in a randomized complete block design with two treatments (see Section 2.2 for a detailed description of treatments) and three replicates (blocks). Each experimental unit (a replicate) consisted of 30 plants (3 grow bags) placed on a trough covered with polyethylene film and with a 1.5% slope for a total of 90 plants per treatment.

During the initial part of the growing cycle, all plants were watered with a prefixed irrigation schedule to allow the seedlings to establish.

The nutrient solution (NS) was prepared with precollected rain water to achieve the following macronutrient concentrations (mg L^{-1}): N-100, K-120, P-20, Mg-15, Ca-113 and S-59, resulting in electrical conductivity (EC) of 1.40 mS cm^{-1} and pH of 6.2. Micronutrients were supplied according to Jhonson et al. (1957) [22]. The above-described stock NS was supplied to the crop adopting proper dilution rates ranging from 30% to full strength, according to the plant growing stage [30% strength, 1–24 days after transplant (DAT), seedling establishment stage; 50% strength, 25–84 DAT, vegetative–early flowering stage; 80% strength, 85–149 DAT, flowering–fruiting; 100% strength, 150–182 DAT, full-fruiting stage]. Plants were irrigated using 4 $L \cdot h^{-1}$ pressure-compensated drip emitters (one each two plants).

Environmental conditions inside the greenhouse were measured using a CS215-L temperature and relative humidity probe (Campbell Scientific, Logan, UT, USA) and a LI-190R quantum sensor (LI-COR, Lincoln, NE, USA), both connected to a CR1000 datalogger (Campbell Scientific). The average daily air temperature and relative humidity throughout the crop cycle ranged between 6 and 24 °C and 47 and 93%, respectively.

The daily light integral (DLI) during the crop cycle ranged from 0.58 to 19 mol m^{-2} d^{-1}, with a mean value of 6 mol m^{-2} d^{-1}.

2.2. Irrigation Treatments

Treatments were started on 9 February 2022 (with plants at the early flowering stage, ≈4 leaves) and consisted of (i) timer-based irrigation (TB) used as control and (ii) sensor-based irrigation (SB).

In TB treatment, plants were automatically irrigated with an electronic timer providing a prefixed irrigation schedule, periodically adjusted to achieve a target value of a ≈20% leaching rate, according to the common practice. The number of daily irrigation events in TB ranged between 3 and 14, with a duration of 1 min each event. Occasional irrigation with rain water was empirically provided with the aim of preventing salinity excess by leaching out salts from the substrate. In particular, two leaching irrigations were provided on 8 April and 27 April, respectively, after the occurrence of reduced or no leaching events resulting from the normal irrigation schedule.

In SB treatment, automatic sensor-based irrigation was adopted through a Greenhouse Irrigation Control Kit (GICK2), a prototype system implemented for research and demonstration purposes, made up of hardware, firmware and software components able to acquire, store, plot and process data provided by a LoRA WAN wireless sensor network and then turn on and off the solenoid valves [23]. Teros 12 sensors (Meter Group, Pullman, WA, USA) were used to measure the real-time substrate volumetric water content (VWC), electrical conductivity (EC) and temperature through FDR (frequency domain reflectometry) technology. The sensors were installed in the middle part of the central grow bag (out of three) in each experimental unit at an equal distance between emitters. With a scan rate of 15 min, the system acquired the outputs of the sensors, processed and stored the data and evaluated the conditions for irrigation based on an algorithm that takes into account VWC and EC data. Raw sensor outputs were converted into substrate VWC and pore water EC (ECp) using the calibration equation provided by the sensor manufacturer for soilless growing media and the Hilhorst equation [24], respectively. If the VWC dropped below a specific setpoint (0.45 $m^3 \cdot m^{-3}$ in the current experiment), the system established that irrigation was needed; then, if the substrate ECp was below a specific setpoint (ranging from 1 to 1.2 $dS \cdot m^{-1}$, according to the growing cycle stage), irrigation with NS was automatically provided (1 min, ≈0.33 L per grow bag), while if the ECp was above the setpoint, irrigation with precollected rain water was provided (1.5 min, ≈0.5 L per grow bag) with the aim of leaching out excess salts and lowering the substrate EC below the setpoint.

The three replications in each treatment received the same amount of irrigation NS/water. The total amounts of macronutrients supplied during the treatment period, respectively, in TB and SB were (g/plant) N 1.91 and 1.17, P 0.38 and 0.23, K 2.29 and 1.40, Ca 2.16 and 1.32, Mg 0.28 and 0.17, and S 1.12 and 0.69.

The experiment was terminated on 16 May (182 DAT).

2.3. Measurements

2.3.1. Water and NS Consumption

Water/NS consumption was calculated based on the number of irrigation events automatically operated and recorded by the GICK2 in SB or deduced from the irrigation schedule in TB multiplied by the volume of NS/water applied per single irrigation event.

Leachate from each experimental unit was collected in buckets placed at the lower end of the troughs, and the volume, pH and EC were measured on collected leachate approximately every two days.

2.3.2. Yield and Quality

The harvest stage started 131 DAT and finished 182 DAT. At each harvest, ripe strawberries (with approximately 80% of red skin) were weighed and classified as marketable (conical strawberries with the characteristics required for Extra, I and II classes by the Commission Regulation EC No. 843/2002 [25]) and unmarketable fruits (affected by rot or other alterations, warty and/or with color defects). All plants of the experimental unit were sampled for this measurement, with the exclusion of the first two plants at the highest and lowest end of the trough.

At 142 DAT, 151 DAT and 161 DAT, fruit firmness (N) with a penetrometer (53207, Turoni, Forli, Italy) and total soluble solids content (TSS) using a portable refractometer (DBR55, Giorgio Bormac) and expressed in °Brix were measured on a representative sample of marketable fruits (10 per replicate). Dry weight was determined by placing approximately 100 g of fruits in a forced-draft oven at 65 °C until a constant weight, and titratable acidity (TA) was measured using a potentiometric titrator (HI 901, Hanna Instruments) according to the method described by Teka (2013) [26] on the same amount of fruits.

2.3.3. Water Use Efficiency and Nutrient Productivity

Water use efficiency (WUE) was calculated as the fresh weight of marketable product per liter of water supplied as irrigation during treatment application. The partial factor productivity (PFP) of the main nutrients (N, P, K, Mg, Ca and S) was expressed as the fresh weight of marketable product per gram of nutrient supplied during treatment application [27].

2.3.4. Plant Physiology and Growth Analysis

At 141 DAT, the leaf net CO_2 assimilation rate (An), stomatal conductance to water vapor (g_{sw}) and transpiration (E) were measured using a portable photosynthesis system (LI-6400; LI-COR Biosciences, Lincoln, NE, USA), which provided a photosynthetic photon flux (PPF) of 800 μmol m^{-2} s^{-1} and a CO_2 concentration of 400 μmol mol^{-1}. The measurements were performed on three plants per replication on three fully-developed young green leaves per plant well-exposed to sunlight for a total of nine replicated measurements per treatment. Moreover, on five plants per experimental unit, leaf chlorophyll content was measured nondestructively using a handheld leaf chlorophyll meter (MC-100, Apogee Instruments, Logan, UT, USA).

At 180 DAT, two plants per experimental unit (six plants per treatment) were sampled, and the following parameters were measured: leaf area using a leaf area meter (LI-3100; LI-COR Biosciences, Lincoln, NE, USA) and the fresh weight of fruits, leaves, stems and roots. Then, the plant materials were dried to a constant weight in a forced-draft oven at 65 °C to determine the dry weight.

2.4. Statistical Analysis

Data were subjected to analysis of variance (ANOVA). Treatment means were separated by the least significant difference (LSD) test when there was a significant effect at the $p < 0.05$ level. The statistical software STATISTICA 10.0 (StatSoft, Tulsa, OK, USA) was used for the analysis.

3. Results and Discussion

3.1. Irrigation Consumption, VWC and EC

Different irrigation strategies involved different irrigation consumption. In TB treatment, the irrigation schedule was based on prefixed schedules subjected to periodical adjustments during the growing cycle based on leaching volume measurements. In particular, the daily irrigation number was modified during the growing cycle to obtain a target value of a ≈20% leaching rate.

The highest total irrigation consumption (irrigation with NS + irrigation with water for leaching purposes) was recorded in the TB treatment (22.4 L plant^{-1}), while a ≈26% lower value was observed in SB (16.6 L plant^{-1}; Table 1). Significant water savings are generally observed with soil moisture-based methods compared to other scheduling methods [28]. With specific reference to greenhouse vegetables, several recent studies confirm lower irrigation consumption with sensor-based compared to timer-based irrigation management [13,14,23].

Table 1. Total water consumption, total applied nutrient solution (NS), water-to-leached-out-salts consumption and runoff in TB and SB treatments (limited to the treatment periods).

Treatments	Total Irrigation (NS + Water, L Plant^{-1})	NS Irrigation (L Plant^{-1})	Water Irrigation (L Plant^{-1})	Runoff (L Plant^{-1})
TB	22.4	21	1.3	4.5
SB	16.6	13	3.6	3.2
Significance	-§	-§	-§	-§

-§ ANOVA not conducted because there was only one solenoid valve per treatment. TB = timer-based fertigation management. SB = sensor-based fertigation management.

A 4.5 and 3.2 L plant^{-1} runoff was recorded in TB and SB, respectively (Table 1). Preventing excessive runoff is considered a key point to improve the sustainability of the open-cycle free-drain soilless culture, aimed at reducing environmental impact related to surface and groundwater resource contamination as an effect of discharge into the environment of NS leaching [13,17].

For both treatments, the cumulative irrigation trends showed a sharp increase with the transition from the winter to spring season as a result of the irrigation schedule adjustments related to the increased crop evapotranspiration (Figure 1).

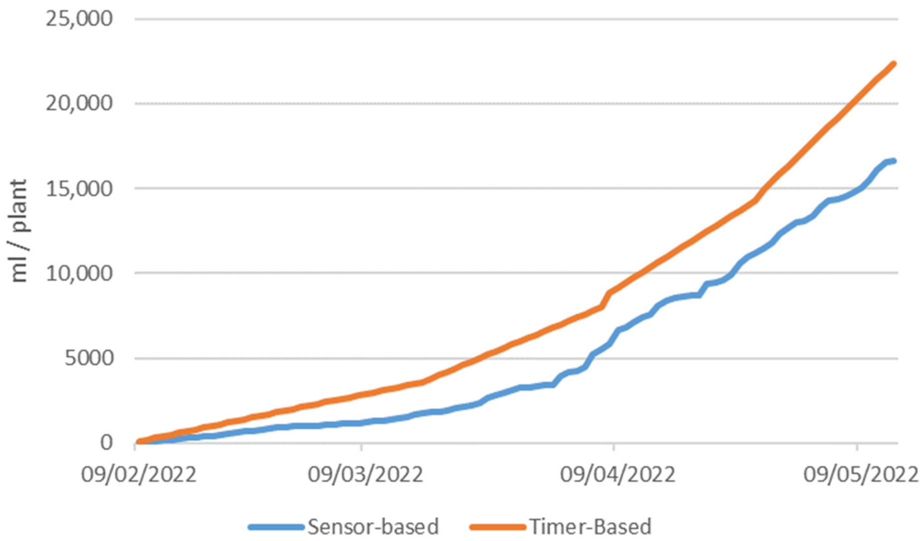

Figure 1. Cumulative irrigation consumption (limited to the treatment periods) in timer- and sensor-based irrigation of soilless-grown strawberry.

The irrigation schedule was prefixed in TB, with periodical manual adjustments based on the observation of the leaching rate, leading to fixed daily irrigation volumes provided to plants for a certain time span occurring between adjustments (Figure 2). Irrigation with timers, based on prefixed schedules subjected to periodical adjustments (generally weekly or on a higher time-span basis), is generally inefficient because it does not take into account the changes in real plant water consumption occurring on a certainly shorter timescale [20,29].

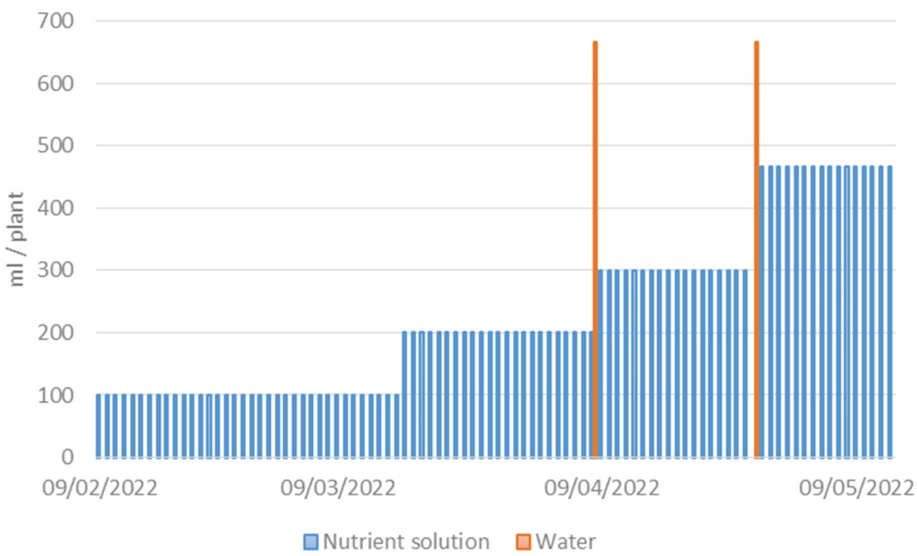

Figure 2. Daily irrigation consumption (limited to the treatment periods) of soilless-grown strawberry with timer-based fertigation management.

In contrast, in SB, the daily irrigation volume was affected by sensor-based real-time automatic adjustments, resulting in on-demand irrigation (Figure 3). It is interesting to observe that, in SB, daily irrigation volumes fluctuated according to variability in plant water consumption and the corresponding changes in the rate of substrate water depletion, as typically observed when a sensor-based approach is adopted [20]. A visual correspondence of daily irrigation with air temperature variations inside the greenhouse was observed (Figure 3).

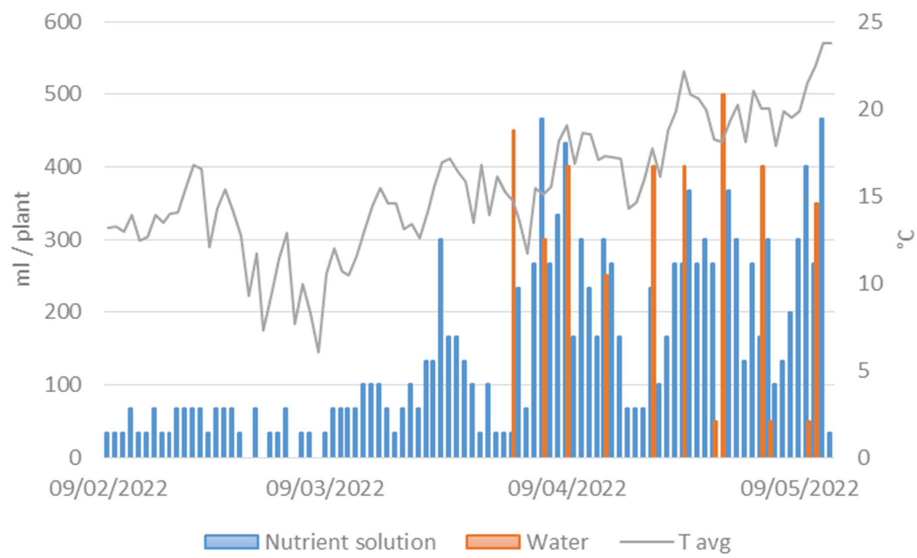

Figure 3. Daily irrigation consumption (limited to the treatment periods) of soilless-grown strawberry with sensor-based fertigation management and average daily temperature trend inside the greenhouse.

In TB, ≈94% of total irrigation consumption was represented by NS, since irrigation with water (no fertilizers) was only occasionally adopted for the empirical prevention of salt accumulation in the substrate (Table 1). In contrast, the rate of total irrigation consumption represented by NS dropped to ≈38% in SB, where the alternate use of NS and water was automatically adopted for the sensor-based control of substrate EC (Table 1; Figure 3). The automatic irrigation system used in SB treatment proved to be effective in maintaining adequate conditions in terms of water availability and substrate ECp (Figure 4).

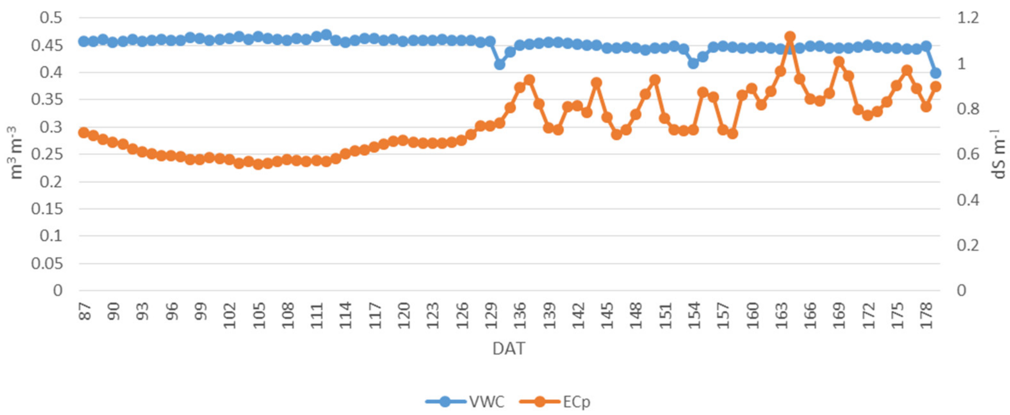

Figure 4. Substrate volumetric water content (VWC) and pore water electrical conductivity (ECp) trends (limited to treatment periods) measured by dielectric sensors in soilless strawberry subjected to sensor-based irrigation management.

In SB, the VWC was almost stable, with little fluctuations around the irrigation setpoint value (Figure 4). A similar VWC trend was observed in other studies based on sensor-based irrigation for soilless crops [13,19]. Similarly, the system managed irrigation in order to prevent salt accumulation exceeding the ECp setpoint. In particular, the system automatically provided rainwater for flushing every time the substrate ECp was detected above the setpoint, leading to a decrease in ECp, followed by a new rise as an effect of NS supply (Figure 4). A similar approach was proposed by Valdés et al. (2015) [30] for the management of substrate salt accumulation in a cultivation of potted geranium subjected to saline water irrigation. The importance of sensor-based flushing as an effective strategy for controlling substrate salt accumulation has been outlined by recent studies, so much so that new specific salinity indices have been proposed as an alternative to the simple measurement of electrical conductivity [31]. However, to avoid overirrigation in flushing, reliable data on soil salinity are required. Although the measurement of EC by sensors is still considered problematic because it is affected by several variables (including temperature, VWC, salinity, and physical properties of the different growing media [13]), the most commonly adopted approach, consisting of converting bulk EC measured by the sensors into substrate pore water EC using the Hilhorst equation [24], is considered a sufficiently reliable salinity index only when the substrate VWC is high and is constantly maintained [31], as in the case of the present study. However, further studies are ongoing with the aim to elaborate more performing models for sensor-based EC estimation and use in practical applications.

The EC of the leaching fraction was slightly higher in TB that in SB treatment, with higher peak values and for longer periods in TB (Figure 5).

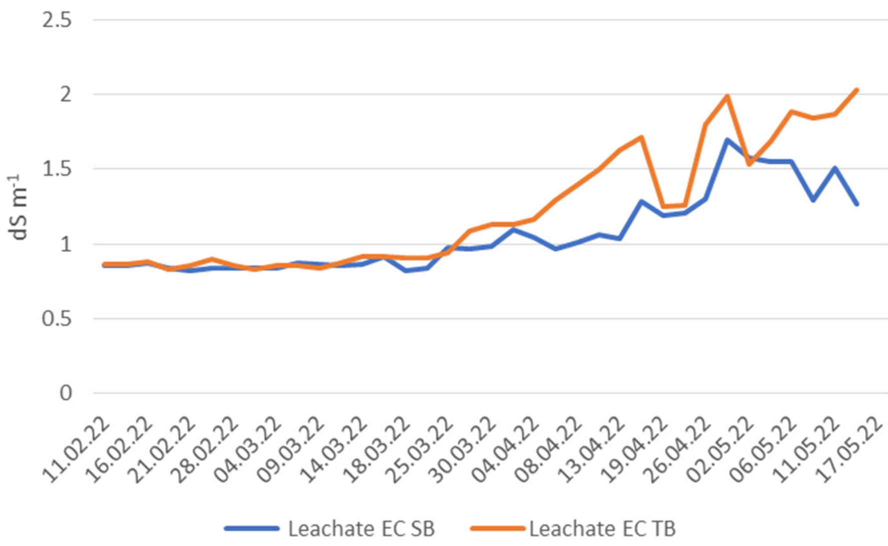

Figure 5. Leaching fraction electrical conductivity (EC) trend during the growing cycle (limited to treatment periods).

3.2. Plant Growth, Yield, Fruit Quality, WUE and PFP of Nutrients

No differences were observed between treatments in terms of plant physiology and growth, with average values of 410 µmol m^{-2} and 2978 cm^2 for leaf chlorophyll content and leaf area, respectively, and with an average plant dry matter of 24% (Table 2). Similar results were recorded in terms of photosynthetic parameters, with no differences between treatments and average values of 0.253 mol m^{-2} s^{-1}, 16.8 mol m^{-2} s^{-1} and 6.11 mmol m^{-2} s^{-1} for g_{sw}, An and E, respectively (Table 2).

The highest yield was obtained in the SB treatment, with a total and marketable yield decrease of 7% in TB (Table 3). This improvement can be related, in general, to the better control of the growing conditions at the root-zone level achieved with the sensor-based automatic management of fertigation, both in terms of VWC (with stable and optimal levels of water availability) and EC. In particular, strawberry is one of the most salt-sensitive crops [32–34]. Salinity affects several physiological and biochemical processes. Plant development and metabolism, water and nutrient uptake, photosynthetic performance, antioxidant mechanism and yield are examples [34]. In some studies, it was reported that exceeding soil salinity over a saturation medium extract threshold value of 1 dS m^{-1}, the yield decreased by 33%, with each EC unit increasing [32]. Probably, in the current study, the suboptimal substrate salinity management in TB during fruit development and ripening (Figure 5) may have caused a slight and discontinuous osmotic stress that slightly reduced the yield, although critical effects on physiological parameters investigated in the study were not observed. Similar results were observed by Denaxa et al. (2022) [34] in a study conducted on two strawberry cultivars subjected to three levels of electrical conductivity (0, 4, 2 and 4 dS/m), with an average yield decrease of 19% at an electrical conductivity level of 2 dS/m in comparison with the control. Irrigation treatments did not affect fruit quality, which was preserved despite the water saving obtained in SB. Indeed, no differences were observed on TSS, dry matter, fruit firmness, juice pH and TA (Table 3).

Table 2. Effects of irrigation treatment on plant growth, physiology and gas exchange parameters.

	TB	SB	Significance [1]
Leaf chlorophyll content (µmol/mq)	410	409	ns
Leaf area (cm^2)	3090	2867	ns
Plant dry matter (%)	25	24	ns
g_{sw} (mol m^{-2} s^{-1})	0.254	0.251	ns
An (mol m^{-2} s^{-1})	16.8	16.8	ns
E (mmol m^{-2} s^{-1})	6.13	6.10	ns

[1] Mean separation within rows by LSD test. ns: not significant. TB = timer-based fertigation management. SB = sensor-based fertigation management. g_{sw} = stomatal conductance to water vapor. An = Leaf net CO_2 assimilation rate. E = transpiration.

Table 3. Effect of irrigation treatment on yield and fruit quality.

	TB	SB	Significance [1]
Total fruits (g $plant^{-1}$)	308	332	*
Marketable fruits (g $plant^{-1}$)	294	314	*
TSS (°Brix)	8.4	7.9	ns
Dry matter (g 100 g^{-1} FW)	9.1	9.2	ns
Fruit firmness (N)	4.1	4.2	ns
Juice pH	4.0	3.9	ns
TA (g citric acid 100 mL^{-1} fruit juice)	0.46	0.47	ns

[1] Mean separation within rows by LSD test. ns and * not significant or significant at $p \leq 0.05$. TB = timer-based fertigation management. SB = sensor-based fertigation management. TSS = total soluble solids content. TA = titratable acidity.

Compared to TB, sensor-based irrigation increased WUE by 46% (Table 4) as an effect of increased yield and water saving. Furthermore, nutrient PFP increased by 74% for N, K, P, Mg, Ca and S in SB (Table 4) as an effect of the lower and more efficient supply of fertilizers via NS. Similar results were observed in a previous study on rocket [35], in which sensor-based irrigation management, in comparison with timer-based, increased WUE by about 61%, with a corresponding increase in the factor productivity of nutrients. Increased water and fertilizer use efficiency was also observed by Palumbo et al. (2021) [35] when soil-moisture sensors were used to drive on-demand irrigation in soilless rocket.

Table 4. Effect of irrigation treatment on water use efficiency (WUE) and partial factor productivity of nutrients (PFP) supplied via nutrient solution.

	TB	SB	Significance [1]
WUE ($g\ L^{-1}$)	13	19	**
PFP N ($g\ FW\ g^{-1}$ N)	154	268	**
PFP K ($g\ FW\ g^{-1}$ K)	128	223	***
PFP P ($g\ FW\ g^{-1}$ P)	768	1338	**
PFP Mg ($g\ FW\ g^{-1}$ Mg)	1023	1784	***
PFP Ca ($g\ FW\ g^{-1}$ Ca)	136	237	**
PFP S ($g\ FW\ g^{-1}$ S)	260	453	***

[1] Mean separation within rows by LSD test. ** significant for $p \leq 0.01$; *** significant for $p \leq 0.0001$. TB = timer-based fertigation management. SB = sensor-based fertigation management.

4. Conclusions

The use of dielectric sensors for real-time measurements of substrate water status and EC was an effective approach for the precision irrigation management of soilless-grown strawberry. While the most common approaches for strawberry irrigation management are mainly based on single variables, the results of this study demonstrate that a sensor-based approach, based on a combined monitoring of substrate VWC and EC, leads to better water and nutrient supplies.

Indeed, in the present study, sensor-based irrigation management led to better growing conditions for plants at the root-zone level due to the effective control of both water availability and electrical conductivity. Better results were also obtained in terms of crop performance. It is considered that the results of this study can open good prospects for a practical application of this approach.

Further studies are envisaged to adapt existing guidelines on recommended growing parameters (e.g., salinity threshold, optimal leaching rate, levels of nutrients) to new approaches based on smart sensor-based technology application, with the aim of maximizing the advantages in terms of overall sustainability and the results of the production process.

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Data Availability Statement: Data are contained within the article.

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