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Yield and Water Use Efficiency of Drip Irrigation of Pepper

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Abstract: Drip irrigation is gaining importance in mitigating the consequences of water scarcity even in regions with abundant rainfall. The transition from surface to subsurface drip irrigation is accompanied by numerous problems. To overcome these issues, shallow subsurface drip irrigation can be potentially used as an effective drought control tool that brings additional benefits compared to conventional surface drip irrigation techniques. This research investigated the effects of different calculations of daily crop water requirements, reference evapotranspiration (ETo), and pan evaporation (Eo) on the yield and water use efficiency of pepper irrigated with a surface and shallow subsurface drip irrigation system. The experiment was conducted in field conditions in the Vojvodina region, the northern part of Serbia. The irrigation scheduling was based on the water balance approach. The calculated evapotranspiration rate was about 400 mm for the pepper growing period, regardless of the calculation method. The highest yield of pepper and evapotranspiration water use efficiency was obtained on the Eo variant with surface drip irrigation. However, irrigation water use efficiency showed no statistical significance concerning the calculation of evapotranspiration and irrigation type. The results indicated that both calculation methods and irrigation types can be used in pepper production, but priority should be given to pan-evaporation-based calculation.

Keywords: kapia pepper; drip irrigation; shallow subsurface drip irrigation; pan evaporation; reference evapotranspiration

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1. Introduction

Pepper (*Capsicum annum* L.) is widely used for human nutrition as fresh or processed. The global production is estimated to be 35.9 million tonnes with an average yield per hectare of 17.5 t [1]. It is the second largest crop in Serbia after potatoes, with 9974 ha in 2020 with an average yield of 10 t ha^{-1} [2]. The kapia type of pepper, distinguished by its red color, conical shape, thinner wall, and thicker skin in the middle, is traditionally used in Balkan cuisine. The soil water status is the most important factor in kapia pepper production because the pepper is highly sensitive to water shortage. In vegetable production, pepper is regarded as one of the most vulnerable crops to water stress [1].

Sufficient water supply is essential throughout the crop cycle for high yields and quality [3,4], and in such conditions, the yield of kapia pepper can reach over 40 t ha^{-1} [5]. Pepper is especially sensitive to water shortage during the flowering and fruiting stages, but also to excessive soil moisture and poor soil aeration. Although bell pepper is frequently produced with extensive irrigation, this practice does not result in improved plant growth or fruit yield; however, a mild deficit in irrigation strategies could be considered since no impact on fruit yield and quality despite the reductions in plant water status, growth, and leaf gas exchange was determined [4]. Irrigation planning is therefore a key factor in pepper water management.

In recent years, increased demand for limited water resources has raised the need to move the production trend toward more efficient irrigation methods, such as drip irrigation (DI). However, the further shift to subsurface drip irrigation is limited due to the higher installation and maintenance costs [6]. To overcome the shortcomings of subsurface irrigation, drip tubing can be installed in a shallow soil layer, less than 10 cm, making the initial investment lower and easier for maintenance and renewal [7]. Since the drip line is removed after the growing season, this shallow subsurface drip irrigation (SSD) is recommended for single-season vegetables. This irrigation method can be potentially used as an effective drought control tool that brings additional benefits compared to conventional surface and subsurface drip irrigation techniques. Previous research primarily focused on the subsurface drip irrigation of pepper [6,7], and research on SSD in pepper production is scarce.

Important benefits of drip irrigation, such as increased water use efficiency, improved crop yield and quality, and reduced deep percolation, have played a major role in the greater expansion in vegetable production [8]. Drip irrigation has contributed significantly in arid and semiarid areas in minimizing the salinity hazard to plants by keeping the salts more diluted in the soil's water by frequently irrigating and moving salts beyond the active plant root zone [8]. However, the productivity of drip irrigation depends on salinity levels and irrigation regimes, that is, the salt accumulation within the pepper root zone increases with increasing salinity and the amount of irrigation water [9]. When irrigating with saline water, full irrigation is recommended for drip-irrigated pepper grown under field conditions, but deficit irrigation, e.g., 80% of crop water needs, as well as deficit irrigation during the ripening stage, could be considered since high yields and water productivity are achieved under mild water deficit conditions [10]. Ünlükara et al. [11] stated that soil salinity increased with the increase in salinity of irrigation water, and they reported a threshold value of 1.2 dS m^{-1} for soil salinity after which the yield of green pepper, grown in a greenhouse, decreased. In regions where irrigation has a supplementary characteristic, no major detrimental effect on chernozem soil due to irrigation with saline water has been determined in field production, but constant monitoring of the water and soil is necessary [12].

In water-scarce areas, the important issue in plant production is to obtain maximum gain out of a unit of water, which is the improvement in water use efficiency (WUE). Drip irrigation opens up further opportunities to apply deficit irrigation strategies to increase WUE [13]. Irrigation with non-saline water results in a generally higher WUE than with saline water [14]. The same authors stated that deficit irrigation with non-saline water at 80% of pepper evapotranspiration in the vegetative or fruiting stage significantly increases WUE. But, when applying lower amounts in a drip irrigation system during the entire vegetation period of pepper, it causes significantly reduced yields, while WUE decreased with increasing irrigation levels [15]. The difference in irrigation level causes changes in root characteristics, that is, lower levels of drip irrigation produce roots with more length and less mass [16].

The plant water requirement is the main component in irrigation scheduling and in improving the water use efficiency of crops. Pan evaporation integrates the climatic factors affecting evapotranspiration into a single measurement and it is generally used to schedule the irrigation of bell pepper [17]. Numerous types of evaporimeter pans are used worldwide. In Serbia, the Class A pan is commonly installed at main meteorological stations and the lack of evaporation data for local conditions is a limiting factor for the wider application of this method. The FAO-56 Penman–Monteith equation is recommended as a standard method for reference evapotranspiration [18]. This method requires numerous meteorological data samples that are not available at local weather stations. Under data-limited conditions, preference should be given to the Hargreaves equation since it requires a minimum amount of data and is easier to compute than the Penman–Monteith equation with acceptable accuracy in irrigation management [19].

The aim of the research was to evaluate the most favorable method for the determination of evapotranspiration in irrigation scheduling and the applicability of surface and shallow subsurface irrigation in pepper production for the modern continental climatic conditions of northern Serbia.

2. Materials and Methods

The study examined the effects of different calculations (reference evapotranspiration, ETo, and pan evaporation, Eo) of crop water needs on the yield and water use of pepper irrigated with a surface (SD) and shallow subsurface (SSD) drip irrigation system.

2.1. Site Description

The experiment was conducted in field conditions in 2020 in the Vojvodina region, the northern part of Serbia, at Rimski Šančevi experimental field at the Institute of Field and Vegetable Crops in Novi Sad (45°19.927′ N, 19°50.252 E, 87 m a.s.l.). The soil at the experimental site belongs to Calcic, Vermic Chernozem (Clayic, Pachic) according to the FAO-WRB classification [20], and is a loamy clay using the Tommerup classification. The main physical and water-physical properties are presented in Table 1.

Table 1. Soil properties of the 0–30 cm layer at the experimental field in Rimski Šančevi, Serbia.

Mechanical Composition			BD, g cm^{-3}	FC, %	LCM, %	WP, %	RAW, mm	pH	ECe, (dS m^{-1})	$CaCO_3$, %	Organic Matter, %
Sand, %	Silt, %	Clay, %									
48.76	27.61	23.63	1.44	26	15	12	47.52	7.34	0.763	3.53	2.29

Notes: BD—soil bulk density, FC—field water capacity (at matric potential of −33 kPa), LCM—lentocapillary moisture (at matric potential of −625 kPa), WP—wilting point (at matric potential of −1500 kPa), RAW—readily available water, ECe—soil salinity. Source: [21].

The source of irrigation water was dug wells located in the experimental area. The water used for irrigation had a pH value of 7.96 and electrical conductivity of 1.2 dS m^{-1}. Of the water-soluble salts, bicarbonates of calcium and magnesium dominated. Of the anions, the contents of bicarbonates, chloride, and sulfate content were 13.54, 1.14, and 1.05 meq L^{-1}, respectively. Of the cations, the contents of calcium, magnesium, potassium, and sodium were 4.35, 5.60, 0.09, and 5.37 meq L^{-1}, respectively. According to the classification of the US Salinity Laboratory, the sampled water belongs to the C3S1 class, which means that it is mineralized water that can cause the process of salinization in poorly drained soils, but not alkalinization, due to the low sodium content. With all soils, it is necessary to take special measures to prevent salinization (constant or occasional salt leaching, good natural or artificial drainage). Also, the water has a low sodium content (S1), so it can be used to irrigate most soils without any particular risk of alkalization. Climatic and soil conditions of the area, primarily the amount and distribution of precipitation during the year, the fact that irrigation is supplementary, as well as the favorable water–air regime of chernozem, prevented an accumulation of salt in the root zone and the possibility of negative consequences being pronounced [21].

The climate in the study area is semiarid in the summer period, but weather conditions are very variable where drought is a regular phenomenon and with occasional periods of extremely high precipitation [22]. Yearly climate variability is presented in Figure 1.

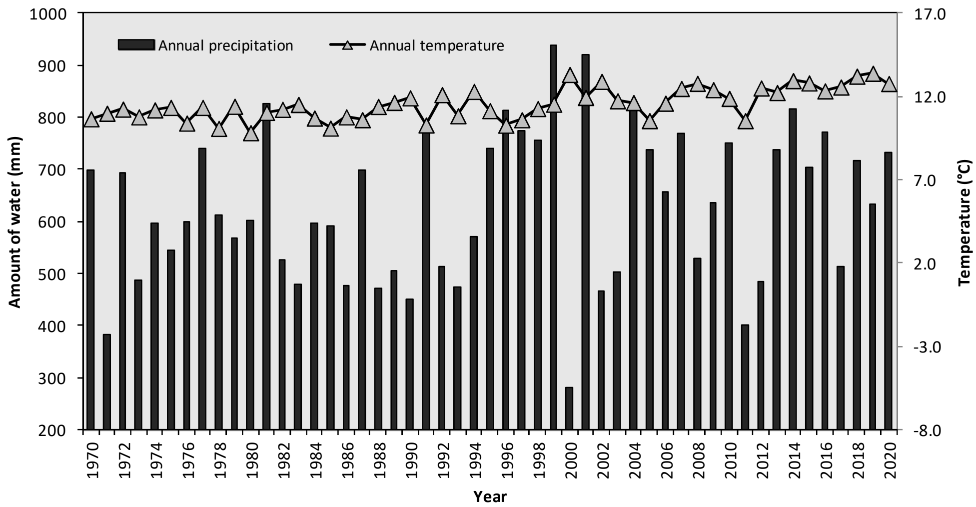

Figure 1. Yearly climate variability (annual sum of precipitation and mean annual air temperature) at the experimental field in Rimski Šančevi, Serbia.

2.2. Experimental Design

The experiment was organized as a block design adapted to the technical specifications of the drip irrigation system (Figure 2). The experiment included the kapia pepper "Amfora", transplanted to the field at the end of May, with a between-row spacing of 0.7 m and an inter-row spacing of 0.25 m. Each plot was 8.4 m^2 and replicated three times. Harvest was conducted on 14 September at maturity.

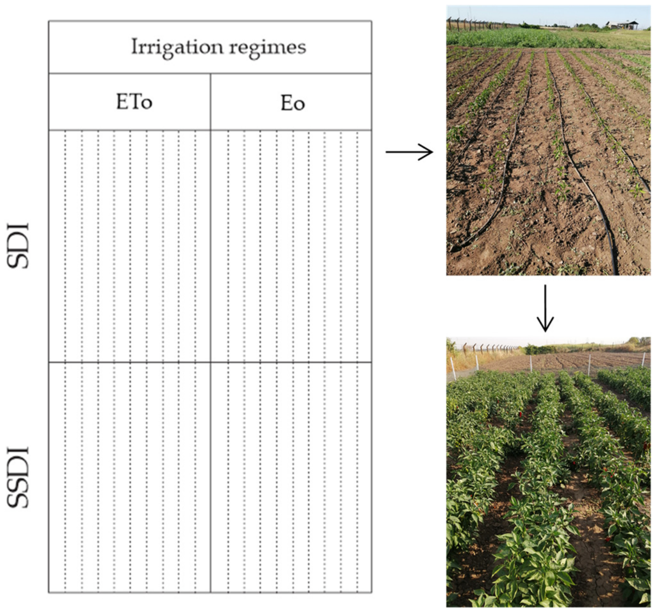

Figure 2. Experimental setup—design scheme, lateral placement, and study site.

Standard field management practices were applied to each experimental plot. The preceding crop was wheat. Before pepper transplantation, the field was plowed at a depth of 0.3 m, followed by the seedbed preparation with a seedbed cultivator. Pepper hand hoeing was conducted on 26 June and 11 July. The first fertilizer application was carried out on 14 July with ammonium nitrate in an amount of 200 kg ha^{-1}. The second fertilizer application of pepper was carried out on 1 August with NPK fertilizer rating 6-12-24 in an amount of 200 kg ha^{-1}.

Pepper protection treatment was carried out with two fungicides, copper hydroxide in a concentration of 0.5% and mancozeb in a concentration of 0.25%, on 31 July. Treatment with insecticide cyantraniliprole-ciazapyr at a dose of 0.75 L ha^{-1} was conducted with a wetting agent Silwet® in an amount of 0.1 L ha^{-1} on 10 August. Due to the occurrence of a green stink bug (*Nezara viridula* L.) on 14 August, pepper was treated with insecticide chlorantraniliprole in a dose of 0.2 L ha^{-1}, imidacloprid in a dose of 0.3 L ha^{-1}, and the wetting agent Trend® in an amount of 0.5 L ha^{-1}.

Laterals were placed in every row on the surface (SD) and buried under the soil surface at a depth of <10 cm (SSD). Drippers were placed every 0.33 m with an average flow of 2.0 L $hour^{-1}$ under a pressure of 70 kPa. Irrigation water applied was controlled using a manometer and a flow meter.

2.3. Irrigation Scheduling and Evapotranspiration Calculation

The irrigation time was determined by the water balance method, which includes all water inflows and outflows. The content of readily available water in the soil layer up to 40 cm was calculated daily, according to the following formula:

$$SWc = SWp + P + I + CW - ET - DP - Rf \quad (1)$$

where SWc is the soil water content (mm) on the current day, SWp is the soil water content (mm) on the previous day, P is the daily precipitation (mm), I is the net irrigation amount on the previous day (mm), CW is the inflow from the capillary rise (mm), ET is the daily evapotranspiration (mm), DP is the vertical percolation (mm), and Rf is the surface runoff (mm). The water table was significantly deeper than the root zone and the soil surface was flat; therefore, CW and Rf were negligible. The initial SWp was determined at the time of planting by the thermogravimetric analysis of soil moisture converted into the soil water content in mm.

When SWc was reduced to a minimum, irrigation with a predetermined norm started. Watering was conducted at rates of 20, 30, and 15 mm at the early, mid, and late seasons, respectively. The irrigation rate for the growing season was 150 mm on ETo and 175 mm on Eo.

The evapotranspiration (ET) of pepper was estimated using reference evapotranspiration (ETo) and pan evaporation (Eo). The ETo data were downloaded from the Republic Hydrometeorological Service of Serbia website [23], where reference evapotranspiration was calculated by the Hargreaves equation. Crop evapotranspiration was determined by the crop coefficient approach using a single crop coefficient from 0.3 to 1.1 depending on the development stage [18]. Eo was estimated by the pan evaporation method using a Class A pan, and crop evapotranspiration was calculated using pan coefficients [24]. Daily pan evaporation values were obtained from the meteorological station close to the experimental plot.

The soil–water dynamic is presented in Figure 3. After the rainy period at the beginning of the growing season, the water content in the soil was slightly depleted during the first days of July on both treatments, with a slightly lower water content on ETo. By the middle of July, two waterings were carried out, which led to an increase in the water content in the soil. A higher calculated daily water consumption on ETo caused slightly earlier watering compared to Eo. The heavy rain, followed by small frequent irregular amounts of rain, increased the water content in the soil at the beginning of August, but at the end of August, the water content was at a minimum, which caused the irrigation on the Eo variant. During the vegetation period, plants were optimally provided for both variants. The different soil content temporal patterns are associated with the different calculations of evapotranspiration between the variants.

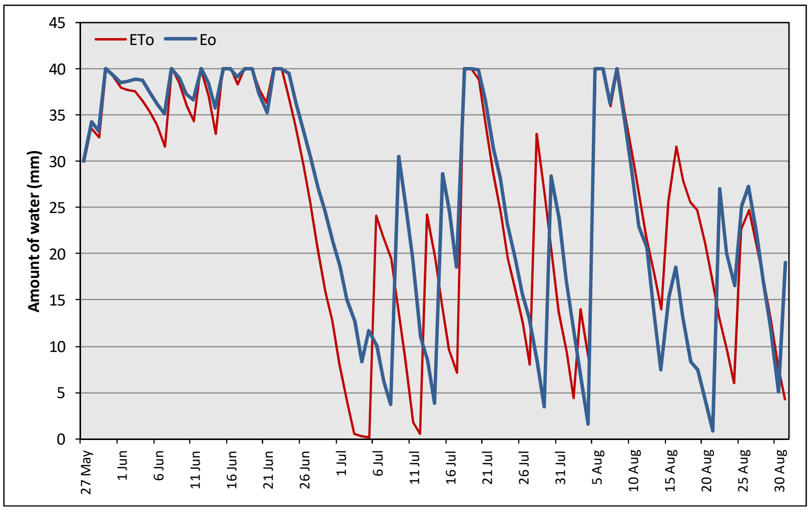

Figure 3. Soil water dynamics at experimental plots on ETo and Eo variant.

2.4. Parameter Calcultaion

The yield of pepper was measured using 8 handpicked consecutive plants per row from each plot at harvest maturity. The measured yield per plant was converted to yield per hectare. The irrigation water use efficiency (IWUE) was calculated from the ratio of marketable yield and irrigation rate, and evapotranspiration water use efficiency (ETWUE) as a ratio of marketable yield and seasonal pepper evapotranspiration [25].

2.5. Statistical Analyses

The statistical analyses were conducted by the analysis of variance (ANOVA) method using the TIBCO Statistica 14.0.0.15 software program (TIBCO, 2020). "Factorial ANOVA" was used to compare the results of yield and water use efficiency between treatments. The significance of differences between treatment means was determined by Fischer's test for a significance threshold of 5%.

3. Results and Discussion

3.1. Weather Conditions

Data on weather conditions were obtained from the nearby meteorological station and are presented in Figure 4. Precipitation was measured on the plot of the experimental field using a rain gauge. The total amount of rainfall in the summer months, June to August, was 377 mm, which was higher than the long-term average of 208 mm, and temperatures were at the same level as the long-term (21.1 °C). The growing period was characterized by frequent events of heavy rain; eight events occurred with precipitation above 20 mm. A significantly higher number of days with effective rainfall and rainfall amounts were in June (Figure 4a). Compared to the long-term average, there was 76 mm more precipitation in June, 81 mm more in August, and 11 mm more in July. The amount and, more importantly, the distribution of rainfall caused the need for irrigation mainly in July and August. In general, the weather conditions in the growing season can be described as humid.

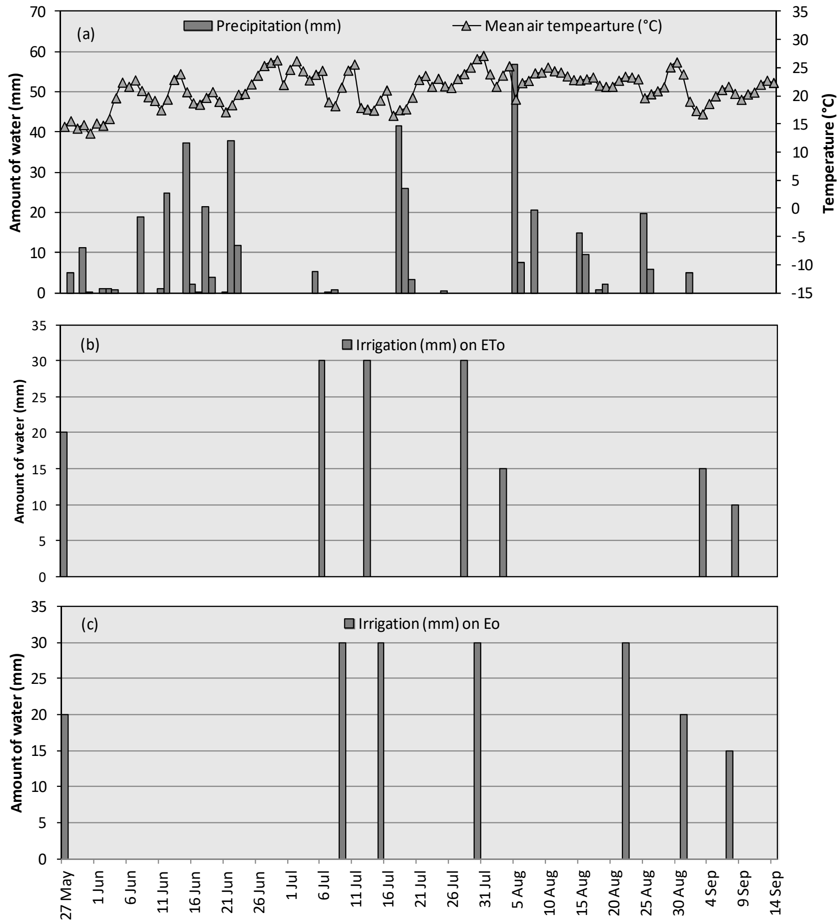

Figure 4. Daily weather data for the growing season (**a**) and irrigation water applied on ETo (**b**) and on Eo variant (**c**).

3.2. Pepper Yield

The effect of drip irrigation and different calculations of ET on pepper yield is presented in Figure 5.

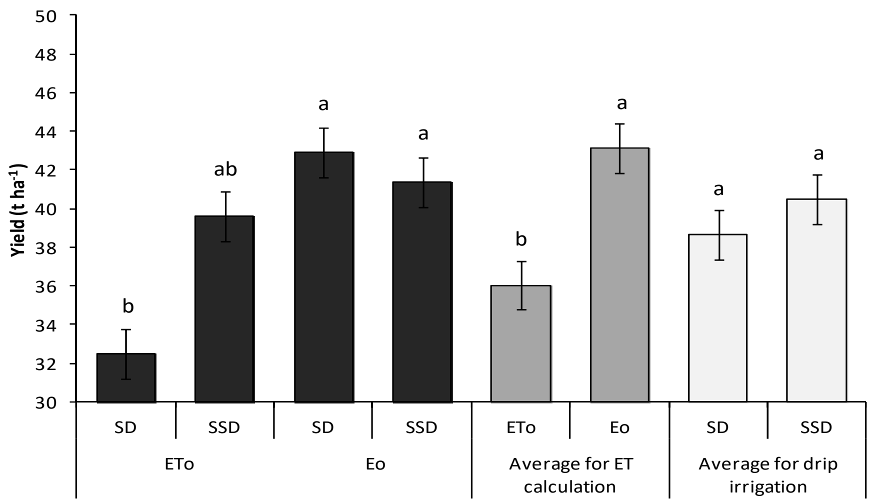

Figure 5. Effect of drip irrigation and different calculations of ET on pepper yield at Rimski Šančevi, Serbia. Different letters denote a significant difference between treatments.

The average yield varied from 32.48 to 42.94 t ha^{-1}. Plants were optimally supplied with water throughout the growing season on all treatments. The yields that were obtained are in agreement with the results of Bošnjak and Gvozdenović [26], who stated that pepper yields with optimal water supply varied from 25.89 to 39.35 t ha^{-1}, depending on the variety. The maximum marketable yields can be obtained if a full irrigation rate is applied [17,27]. Sezen et al. [15] reported a pepper yield of 47.8 t ha^{-1} when optimally supplied with water and a lower yield when deficit irrigation strategies are applied during the entire vegetation period. A somewhat lower yield (25.6 t ha^{-1}) was obtained in the research of Kabir et al. [4] for full irrigation rate treatment. In a drip irrigation system with a full water rate, high-yielding plants developed, having more height and a higher number of branches, while lower levels of drip irrigation produced roots with more length and less mass [16]. Full irrigation is recommended for achieving the highest yield, but a deficit during the late stage provides more economic benefits and water productivity [28].

The statistical analysis showed a significant effect of evapotranspiration calculation on pepper yield (Table 2). The average yield on Eo (43.12 t ha^{-1}) was significantly higher compared to the average yield on ETo (36.05 t ha^{-1}). This difference in yield could be attributed to the substantially lower yield on ETo-SD treatment. Different calculations of crop water needs resulted in somewhat different irrigation rates and intervals (Figure 4), producing higher yields and indicating the need to further investigate the appropriate calculation method for pepper water needs. According to Celebi [17], the calibrated pan evaporation method can be easily used by farmers. However, methods that require only values of daily temperature (e.g., Hargreaves) are the most practical for the determination of ETo [29]. This is even more pronounced since not all meteorological stations in the investigated region measure evaporation.

Table 2. Analysis of variance for pepper yield, irrigation (IWUE), and evapotranspiration (ETWUE) water use efficiency.

	Source	Sum of Squares	Df	Mean Square	F-Ratio	*p*-Value
Yield	A: ET calculation	1199.41	1	1199.41	6.58	0.0119
	B: drip irrigation	80.66	1	80.66	0.44	0.5076
	Interaction AB	674.21	1	674.21	3.70	0.0575
	Error	16,769.00	92	182.27		
	Total	18,723.3	95			
IWUE	A: ET calculation	8.83	1	8.83	0.13	0.7147
	B: drip irrigation	46.19	1	46.19	0.70	0.4039
	Interaction AB	272.30	1	272.30	4.15	0.0446
	Error	6042.98	92	65.68		
	Total	6370.3	95			
ETWUE	A: ET calculation	11.50	1	11.50	5.42	0.0484
	B: drip irrigation	0.58	1	0.58	0.27	0.6164
	Interaction AB	5.10	1	5.10	2.40	0.1598
	Error	16.99	8	2.12		
	Total	34.2	11			

No significant difference in average yield was found between SD (38.67 t ha^{-1}) and SSD (40.50 t ha^{-1}). According to Kong et al. [30], pepper yield under subsurface drip irrigation in a semiarid climate was significantly higher than under surface drip irrigation by 13%. Demir et al. [31] reported a pepper yield of 28 t ha^{-1} on SD and 41 t ha^{-1} on SSD for the continental climate in Turkey and concluded that water stress negatively affects pepper yield on both SD and SSD, with an adverse effect on nutrient availability. The best performance of SSD could be expected in arid regions, although maximum yields are also achieved in humid regions, indicating that the effect of SSD is more related to the amount of rainfall in the growing season than at the annual level [32].

3.3. Irrigation Water Use Efficiency

Average values of irrigation water use efficiency (IWUE) varied from 21.65 to 26.41 kg per m^3 and showed no statistical significance concerning the calculation of evapotranspiration and irrigation type (Figure 6).

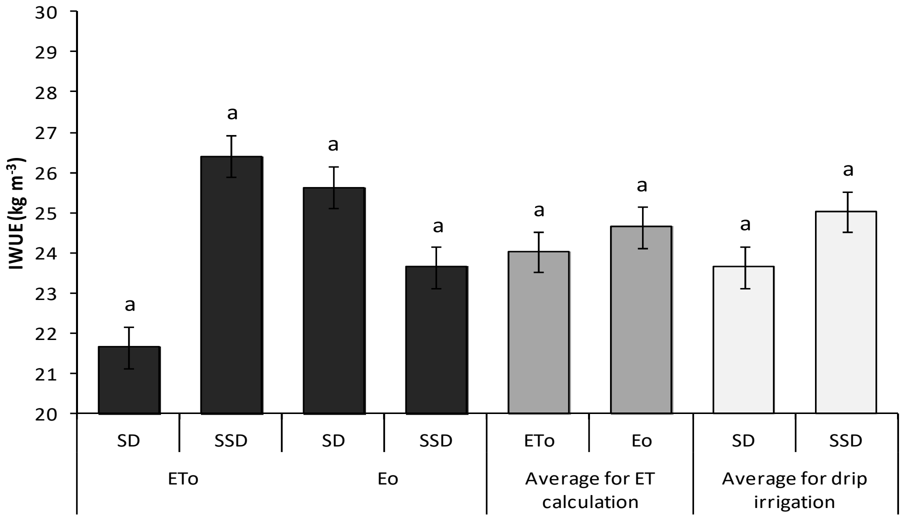

Figure 6. Effect of drip irrigation and different calculations of ET on irrigation water use efficiency (IWUE) at Rimski Šančevi, Serbia. Same letters denote there is no significant difference between treatments.

Different calculations of pepper water requirements caused somewhat different irrigation rates and frequencies that did not affect IWUE. Dukes et al. [33] reported IWUE values for drip-irrigated bell pepper from 16.0 to 52.6 kg m^{-3} in Florida, USA. A significantly higher WUE (10.72 kg m^{-3}) was observed when irrigating with non-saline water than with saline water (6.99 kg m^{-3}), while deficit irrigation at 60% ETc resulted in the largest saved amounts of non-saline irrigation water and a higher WUE (12.91 kg m^{-3}) [14]. However, high WUE should be associated with high yield [15]. Sezen et al. [3] found lower IWUEs, 5.1 to 8.1 kg m^{-3}, and concluded that irrigation water use efficiency values were significantly influenced by the irrigation intervals and rates. At the same fertilization application rate, the yield and IWUE of pepper first increased and then decreased with a greater amount of irrigation with a maximum of 75% of water needs [34]. Irrigating at 75% of water requirements could be recommended in conditions of water scarcity, but if water is not a limiting factor, 100% of water requirements can be used since no difference was found in yield and IWUE between the two irrigation regimes [35,36].

According to Rodríguez-Sinobas et al. [37], the water availability for plants is expected to be more variable on the surface than in subsurface irrigation plots at 10 cm underneath the soil. Our research showed that this variability in soil water content does not affect the yield of pepper. On the contrary, the subsurface drip irrigation of pepper on silt loam had a higher WUE than surface drip irrigation by 21% [30]. Values of water use efficiency in drip irrigation strongly depend on soil and soil clay content [38].

3.4. Crop Evapotranspiration and Evapotranspiration Water Use Efficiency

The values of crop water needs present the basis for optimum utilization of irrigation systems, in the process of planning and designing the irrigation projects. Pepper evapotranspiration was 409.4 mm on ETo and 400.6 mm on Eo. Calculated crop water requirements were similar, although the pan-evaporation-based methods tend to underestimate PMF-56 ETo according to Tabari et al. [39], while the temperature-based equations overestimated PMF-56 ETo from which one of the best performances was estimated by the Hargreaves equations.

Evapotranspiration values based on reference evapotranspiration were 75 mm in June, 138 mm in July, 122 mm in August, and 45 mm in September. The values of evapotranspiration based on evaporation from the free water surface were by month: June 50 mm, July 122 mm, August 166 mm, and September 51 mm. The average daily consumption of water for evapotranspiration was 2.5 mm in the ETo variant in June, 4.5 mm in July, 3.9 mm in August, and 3.2 mm in September; and in the Eo variant, it was 1.7 mm in June, 3.9 mm in July, 5.4 mm in August, and 3.7 mm in September. These values correspond to crop water needs calculated by Bošnjak and Gvozdenović [26] for the summer months (128 mm for June, 161 for July and August), but are lower for the vegetation period (571 mm) due to the shorter growing season. According to Sezen et al. [3], the seasonal crop evapotranspiration of pepper varied from 327 mm to 517 mm for the growing season depending on the irrigation regime.

The ETWUE showed a similar pattern as yield (Figure 7), and it was influenced by the calculation of ET with higher values on Eo (10.76 kg m^{-3}). Average values of ETWUE showed no statistical significance concerning the irrigation type (9.57 kg m^{-3} for SD and 10.00 kg m^{-3} for SSD). These values are in agreement with the results of Colak [36] for the Mediterranean region of Turkey, who reported ETWUE values from 8.6 to 12.7 kg m^{-3}. According to Sezen et al. [40], full irrigation resulted in the lowest ETWUE, 5.5 kg m^{-3} compared to deficit irrigation.

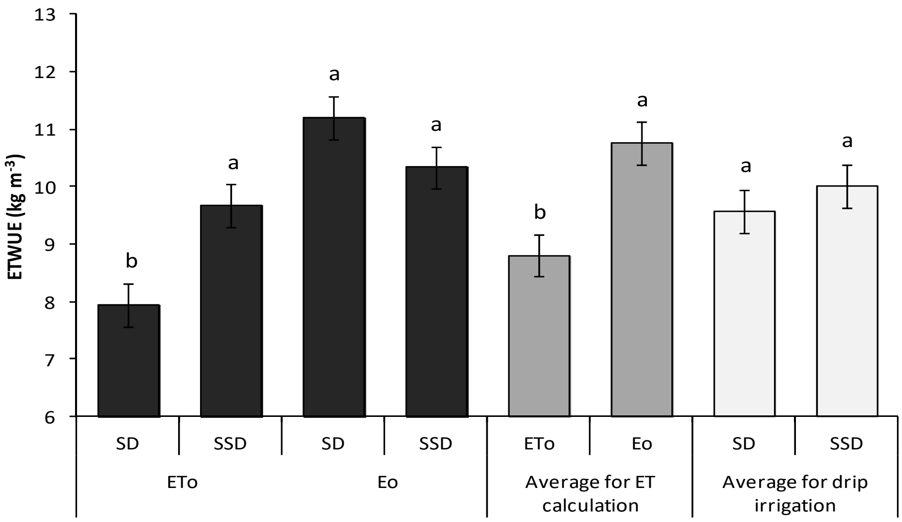

Figure 7. Effect of drip irrigation and different calculations of ET on evapotranspiration water use efficiency (ETWUE) at Rimski Šančevi, Serbia. Different letters denote a significant difference between treatments.

The dependence of yield on the amount of water added by irrigation is of great importance due to the increasing water scarcity. Therefore, the results of this research make a contribution to pepper growers in the improvement in cropping technology in terms of adopting more efficient irrigation methods such as drip irrigation. Furthermore, the research results indicate that the shift to shallow subsurface drip irrigation maintains high yield and irrigation efficiency as with drip irrigation systems. Also, pepper growers should be encouraged to use the calculation of crop water needs based on pan evaporation. However, it is first necessary to install pan evaporimeters at local meteorological stations and enable the use of data by producers.

4. Conclusions

Based on the data on yield and water use efficiency, it can be concluded that both surface and shallow subsurface drip irrigation can be used in pepper production. A higher yield was obtained when crop water needs for the irrigation scheduling were calculated using daily evaporation measurements rather than reference evapotranspiration with the Hargreaves equation. Although the Hargreaves calculation of pepper water requirements is more practical because of the lack of data from Class A-pan for local conditions, the results indicate that precedence should be given to pan-evaporation-based calculation.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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