doi:10.14720/aas.2025.121.2.22121 Original research article / izvirni znanstveni članek

Combining mulching and drip irrigation for water conservation in tomato crops: case of Mitidja plain (Algeria)

Imerina TANKEUOO KOPA [1, 2], Abdelhadi AMMARI [1], Mohamed MEDDI [1]

Received March 19, 2025; Accepted May 26, 2025
Delo je prispelo 19. marec 2025, sprejeto 26. maj 2025

Combining mulching and drip irrigation for water conservation in tomato crops: case of Mitidja plain (Algeria)

Abstract: Water scarcity in agriculture necessitates innovative practices for sustainable water management. This study evaluated the effects of organic mulching, specifically a mixture (composed of wood chips, sawdust, and wheat straw in equal proportions) and recycled crop waste (RCW), combined with drip irrigation, on water conservation in tomato crops cultivated in the Mitidja Plain, Algeria. Field experiments were conducted from July to October 2023, comparing mulched and non-mulched plots under surface and subsurface drip irrigation (SSDI). Results showed that the mixture mulch with SSDI saved 29.6 % of water, while RCW saved 22.2 %, compared to surface irrigation. Mulching regulated soil moisture, temperature, and electrical conductivity, though water application efficiency slightly decreased (96.1 % for mixture, 96.4 % for RCW vs. 97.1 % for control). However, the slight soil acidification observed in mulched plots (pH 6.20–6.52) warrants attention, as it may influence nutrient availability over time. Despite this, soil organic matter (OM) remained stable (1.09 %–1.70 %), confirming that mulching enhances soil fertility without compromising its structure. These findings highlight the potential of combining organic mulching with drip irrigation for sustainable water management in tomato cultivation, offering practical insights for farmers in arid regions.

Key words: water scarcity, soil protection, sustainability, water application efficiency (EA), irrigation; mulch, Mitidja plain

Vpliv prekrivk in kapljičnega namakanja na ohranjanje vode v nasadu paradižnika: vzorčen primer iz planote Mitidja (Alžirija)

Izvleček: Pomanjkanje vode v kmetijstvu zahteva inovativne prakse za trajnostno upravljanje z vodo. Ta študija je ovrednotila učinke organskih prekrivk (mešanica iz enakih deležev lesnih sekancev, žagovine in pšenične slame) ter recikliranih kmetijskih ostankov (RCW), kombiniranih s kapljičnim namakanjem, na varčevanje z vodo pri pridelavi paradižnika na planoti Mitidja v Alžiriji. Terenski poskusi so potekali od julija do oktobra 2023, pri čemer so primerjali prekrite in neprekrite parcele pri površinskem in podpovršinskem kapljičnem namakanju (SSDI). Rezultati so pokazali, da je mešanica z SSDI prihranila 29,6 % vode, RCW pa 22,2 % v primerjavi s površinskim namakanjem. Prekrivka je uravnavala vlažnost, temperaturo in električno prevodnost tal, čeprav se je učinkovitost namakanja rahlo zmanjšala (96,1 % za mešanico, 96,4 % za RCW v primerjavi s 97,1 % pri kontrolni skupini). Kljub temu je rahlo zakisanje tal v prekritih parcelah (pH 6,20–6,52) potrebno spremljati, saj lahko sčasoma vpliva na dostopnost hranil. Organska snov v tleh (OM) je ostala stabilna (1,09 %–1,70 %), kar potrjuje, da prekrivka izboljšuje rodovitnost tal brez ogrožanja njihove strukture. Te ugotovitve poudarjajo potencial kombinacije organske prekrivke s kapljičnim namakanjem za trajnostno upravljanje z vodo pri pridelavi paradižnika, kar ponuja praktične vpoglede za kmete v sušnih območjih.

Ključne besede: pomanjkanje vode, zaščita tal, trajnostnost, učinkovitost namakanja (EA), namakanje, prekrivka, planota Mitidja

1 Higher National School of Hydraulics (ENSH), LGEE, Blida, Algeria
2 Corresponding author: i.tankeuookopa@ensh.dz

1 INTRODUCTION

Water scarcity is one of the most pressing challenges of the 21st century, with agriculture accounting for nearly 70 % of global freshwater withdrawals (FAO 2017). In arid and semi-arid regions, such as Al geria's Mitidja Plain, the situation is exacerbated by climate change, prolonged droughts, and increasing water demand (Meddi et al., 2015). This region, known as the "breadbasket of Algeria," plays a critical role in the nation's food security, particularly for tomato production: a crop that not only sustains local livelihoods but also fuels the country's agri-food industries (Bessaoud et al., 2019). However, the sustainability of this vital sector is under threat due to inefficient water management practices and the overexploitation of limited water resources (Karambiri et al., 2021; Rastogi et al., 2024).

In response, conservation agriculture has emerged as a transformative approach, integrating innovative practices such as drip irrigation, mulching, and soil cover to optimize water use, enhance soil health, and reduce environmental impacts (Yang et al., 2023; Du Preez et al., 2024). Among these practices, the combination of organic mulching and subsurface drip irrigation (SSDI) has shown exceptional promise. While drip irrigation minimizes water loss by delivering water directly to the root zone (Ayars et al., 2015), organic mulching acts as a protective barrier, reducing evaporation, regulating soil temperature, and improving moisture retention (Simsek et al., 2017; Telkar et al., 2017). Together, these techniques offer a (synergistic solution to the dual challenges of water scarcity and sustainable crop production (Sharma et al., 2023; Wang et al., 2024).

Despite their individual benefits, the combined effects of organic mulching and SSDI remain underexplored, particularly in the context of tomato cultivation in water-stressed regions like the Mitidja Plain. Previous studies have highlighted the advantages of mulching in conserving soil moisture (Simsek et al., 2017; Telkar et al., 2017) and the efficiency of SSDI in reducing water use (Ayars et al., 2015; Yang et al., 2023). Recent research by-Wang et al. (2024) has demonstrated that mulched drip irrigation significantly enhances water use efficiency and crop yields in arid regions, particularly for high-value crops like tomatoes. Similarly, (Tankeuoo et al., 2023) have shown that organic mulches improve soil moisture retention and water infiltration in tomato crops, underscoring their potential for sustainable agriculture in water-scarce environments. However, there is a critical gap in understanding how these practices interact to enhance water conservation, improve crop yields, and support long-term agricultural sustainability (Admasu & Tamiru, 2019).

This study addresses this gap by evaluating the performance of different organic mulches in combination with surface and subsurface drip irrigation systems. Conducted in the Mitidja Plain, the research aims to identify the most effective strategies for water conservation in tomato cultivation. By providing evidence-based insights, this study seeks to empower farmers, researchers, and policymakers with practical solutions to enhance water efficiency, ensure food security, and promote sustainable agricultural practices in Algeria and beyond (Iqbal et al., 2020; Gouda et al., 2023).

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE EXPERIMENTAL SITE

The experiments were conducted on the Mitidja Plain, a fertile agricultural region in northern Algeria, specifically at the experimental site of the Higher National School of Hydraulics (ENSH) in Blida. Geographically located at 36°30'31" N and 2°53'15" E , with an altitude of 116 m above sea level, the site lies within the sub-humid Mediterranean bioclimatic zone, characterized by mild winters and hot, dry summers (Laribi et al., 2023). The Mitidja Plain spans four wilayas (Blida, Tipaza, Boumerdès, and Algiers) and is a vital agricultural hub, contributing significantly to Algeria's food production, particularly for high-value crops like tomatoes. The study was carried out over four months, from July to October 2023, during the peak growing season for tomatoes. Climatic data collected by an on-site agro-meteorological station revealed an average air temperature (Tmean) of 26.39 °C, with extremes ranging from 26.31 °C (Tmin) to 41.30 °C (Tmax). The average relative humidity (Hmean) was 62.40 %, fluctuating between 19.54 % and 86.48 %, while solar radiation (Rs) averaged 227.04 W m^{-2}. Wind speed (Ws) was moderate, averaging 1.97 km h^{-1}, and precipitation (Pi) was scarce, with a sum of 22.4 mm over the study period. The daily reference evapotranspiration (ETR) averaged 3.17 mm day^{-1}, reflecting the high evaporative demand typical of the region. Soil analysis conducted by (Tankeuoo et al., 2023) confirmed that the experimental site features a fine loam soil.

2.2 SITE DESIGN AND TREATMENTS

The experimental site was prepared through light plowing and harrowing to ensure optimal soil conditions for seeding. A total of six plots were established, each measuring 2 m × 2 m (4 m^2), resulting in a total experimental area of 24 m² (Fig. 1). The design included two replications, with each replication comprising two plots: one equipped with a surface drip irrigation system (SURDI) and the other with a subsurface drip irrigation system (SSDI) installed at a depth of 10 cm. This setup allowed for a direct comparison of the two irrigation methods under identical environmental conditions. Each plot contained 18 tomato plants of the hybrid variety Badja F1, known for its high yield and adaptability to Mediterranean climates. The plants were spaced at 50 cm intervals, while the drippers were positioned 33 cm apart, ensuring uniform water distribution to the root zone. The irrigation system operated at a constant flow rate of 2.3 l h^{-1}, with irrigation cycles scheduled every 2 hours between 4 a.m. and 7 a.m. to minimize evaporation losses during the cooler morning hours. Three distinct treatments were applied: P1 (mixture mulch of wood chips, sawdust and wheat straw in equal proportions); P2 (bare soil without mulch) and P3 (RCW mulch composed of wood chips and dead leaves) and control The choice of mulching materials was guided by their local availability, cost-effectiveness, and proven efficacy in previous studies (Chachoua, 2015; Telkar et al., 2017). The experimental design followed a Latin square pattern, ensuring balanced spatial distribution of treatments and minimizing the impact of soil variability. Irrigation scheduling was optimized based on the field capacity (FC) and wilting point (WP) of the soil, which ranged from 32-38 % and 14-17 %, respectively. These parameters were determined using a calibration sheet provided by the TDR 150 manufacturer, ensuring precise irrigation control and efficient water use.

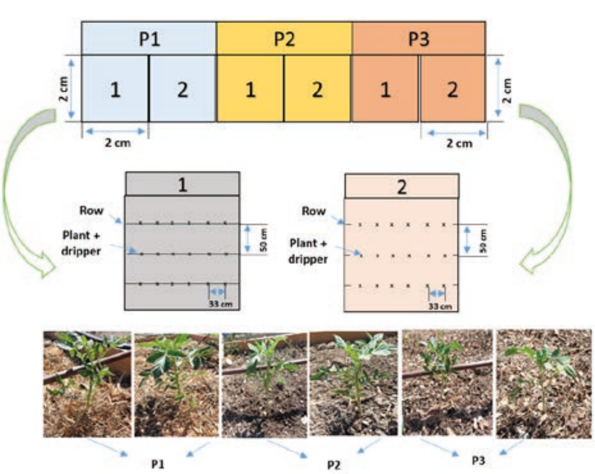


Figure 1: Design of the experimental area. P1 = Mixture plots (same ratio of wood chips + sawdust + wheat straw); P2 = Control plots (bare soil); P3 = RCW plots (woody debris and dead leaves). 1 = Surface drip irrigation system; 2= Subsurface drip irrigation system (10 cm depth)

2.3 SOIL PHYSICAL AND CHEMICAL ANALYSIS

To assess the suitability of the soil for tomato cultivation and to understand its impact on crop performance, physical and chemical properties were analyzed for each experimental plot. Specifically, soil pH and soil organic matter (OM) were measured, as these parameters are critical for nutrient availability, microbial activity, and overall soil health.

Soil pH was determined using a calibrated pH meter, which provided accurate and reliable measurements of soil acidity or alkalinity. This parameter is essential for understanding nutrient solubility and uptake by plants, as well as for identifying potential soil amendments to optimize growing conditions.

Soil organic matter (OM) was quantified using the loss on ignition (LOI) method, a widely recognized technique for measuring organic content. This method involves heating soil samples to high temperatures to combust organic materials, with the mass loss corresponding to the organic matter content. OM is a key indicator of soil fertility, as it influences water retention, nutrient cycling, and soil structure.

2.4 SOIL MOISTURE, TEMPERATURE, AND ELECTRICAL CONDUCTIVITY DATA COLLECTION

Soil water levels were monitored continuously from the sowing of the tomato plants until the end of the growing period, spanning July to October 2023. The TDR 150 probe was selected for this study due to its affordability, reliability, accuracy, and ease of use. This advanced instrument is capable of measuring soil moisture, electrical conductivity, and temperature simultaneously at the same depth and time scale, providing comprehensive data essential for effective irrigation and nutrient management. In the field, the TDR 150's rods were inserted at four depths: 5 cm, 10 cm, 15 cm, and 20 cm, adjacent to selected tomato plants in each plot. These depths were chosen to capture variations in soil water dynamics across the root zone, ensuring a detailed understanding of water distribution and uptake by the plants. Measurements were conducted daily, with three replicates per plot, between 7 a.m. and 9 a.m. to minimize variability caused by diurnal fluctuations in temperature and evaporation. All data were meticulously recorded on standardized data sheets for subsequent analysis.

The recorded data were analyzed using XLSTAT software, employing advanced statistical tools to ensure robust and reliable results. A correlation matrix was first generated to assess the relationships between key variables, including soil moisture, temperature, and electrical conductivity parameters. This step provided preliminary insights into the interactions between the studied factors. Subsequently, an Analysis of Variance (ANOVA) was performed to evaluate the significance of differences among treatments. The F-test was applied at a significance level of $p \leq 0.05$ to determine whether the observed variations were statistically significant. For parameters significantly affected by the studied factors, treatment means were compared using the Critical Difference (CD) method.

2.5 COLLECTION OF PLANT HEIGHT DATA ON CROPS, IRRIGATION, AND ACTUAL EVAPOTRANSPIRATION (ETA).

Plant height was measured at each stage (stage 1 = plant growth; stage 2 = plant flowering; stage 3 = plant fruiting; stage 4 = plant maturation + harvest) of development to monitor growth patterns and assess the impact of different treatments.

Irrigation data were meticulously recorded, with water volumes measured during each irrigation event. These volumes were then summed for each growth stage and treatment, allowing for a detailed analysis of water use efficiency. At the end of the growing season, the total water volumes applied to each plot were converted to m³ per hectare to facilitate comparisons and evaluate water savings across the different irrigation systems. Additionally, irrigation frequencies were tracked and summed for each growth stage.

Actual evapotranspiration (ETA) was calculated using the FAO Penman-Monteith formula, a widely recognized method for estimating crop water requirements. This formula incorporates weather station data (such as temperature, humidity, wind speed, and solar radiation) and crop coefficients (K) specific to each growth stage. The equation used is as follows:

$$ETA = ETR \times K \qquad (2.1)$$

Where: *ETA* = Actual evapotranspiration (mm/day); *ETR* = Daily reference evapotranspiration (mm day^{-1}), calculated using the Penman-Monteith method and *K* = Crop coefficient, which varies according to the growth stage of the tomato plants

2.6 IRRIGATION APPLICATION EFFICIENCY (EA)

Water application efficiency (EA) is a critical metric in irrigation management, expressed as a percentage that indicates how effectively irrigation water is delivered to the crop root zone. Specifically, EA measures the proportion of applied water that is stored in the root zone and made available for plant use, minimizing losses due to evaporation, runoff, or deep percolation. According to (Gouda et al. 2023), the equation for calculating EA is as follows:

$$EA = \frac{e \times q_{min} \times T}{V} \times 100 \qquad (2.2)$$

Where: *EA* = Application efficiency (%); *e* = Total number of drippers; *qmin* = Minimum flow rate of drippers (l h^{-1}); *T* = Total irrigation time (h); *V* = Total volume of water applied (l)

3 RESULTS

3.1 SOIL PHYSICAL AND CHEMICAL ANALYSIS

The Table 1 compares two irrigation systems (SURDI and SSDI), by analyzing OM and soil pH across six plots (P1-P6). For OM, values range from 1.09 % to 1.70 %, with no significant differences between SURDI and SSDI (Pr > F = 0.87), indicating that the irrigation system does not significantly affect OM. However, for

Table 1: Statistical analysis of soil organic matter (OM) and soil pH across plots under two irrigation types (SURDI and SSDI)

IR. Type	Plot unit	OM %	Soil pH -
	P1	1.54a	7.04a
SURDI	P2	1.50a	6.90a
	P3	1.70a	7.06a
	P1	1.24a	6.20b
SSDI	P2	1.54a	6.30b
	P3	1.09a	6.52b
	SEm±	0.09	0.16
	Pr > F	0.87	0.91
	CD (P=0.05)	6.08	6.08

The treatment details are provided in the Materials and Methods section soil pH, SURDI plots show higher pH values (6.90–7.06) compared to SSDI plots, which have lower pH values (6.20–6.52), marked with "b" to indicate significant differences (Pr > F = 0.91). This suggests that SSDI may lead to slight soil acidification, possibly due to reduced surface evaporation and altered nutrient dynamics. Despite this, both systems perform similarly in terms of OM content, highlighting that SSDI remains a viable option for water conservation without significantly compromising soil organic matter.

3.2 LENGTH AND SIZE OF EACH GROWING SEASON

Figure 2 shows plant duration and height at each stage in mulched and bare plots. During growth (P3), plants are the largest and take the longest time. Flowering phase (P2) lasts longer under both irrigation systems, and P1 is larger with SURDI. Fruiting sees P1 as the tallest and longest. Mulched plots, especially P1, outperform others. RCW mulch excels with SSDI, mixture mulch with SSDI.

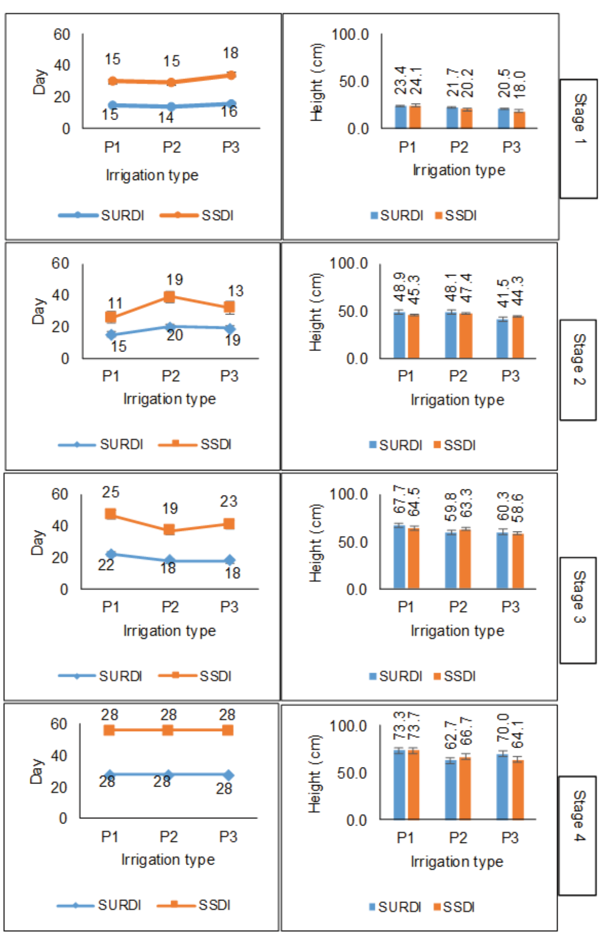


Figure 2: Average duration and height of plants per growing stage according to irrigation system and treatment applied to tomato crop. The bars indicate the standard errors. Details of the treatment are provided in the Materials and Methods section.

3.3 CHARACTERIZATION OF SOIL MOISTURE, TEMPERATURE AND ELECTRICAL CONDUCTIVITY OF EACH GROWING SEASON

3.3.1 Growth stage (stage 1)

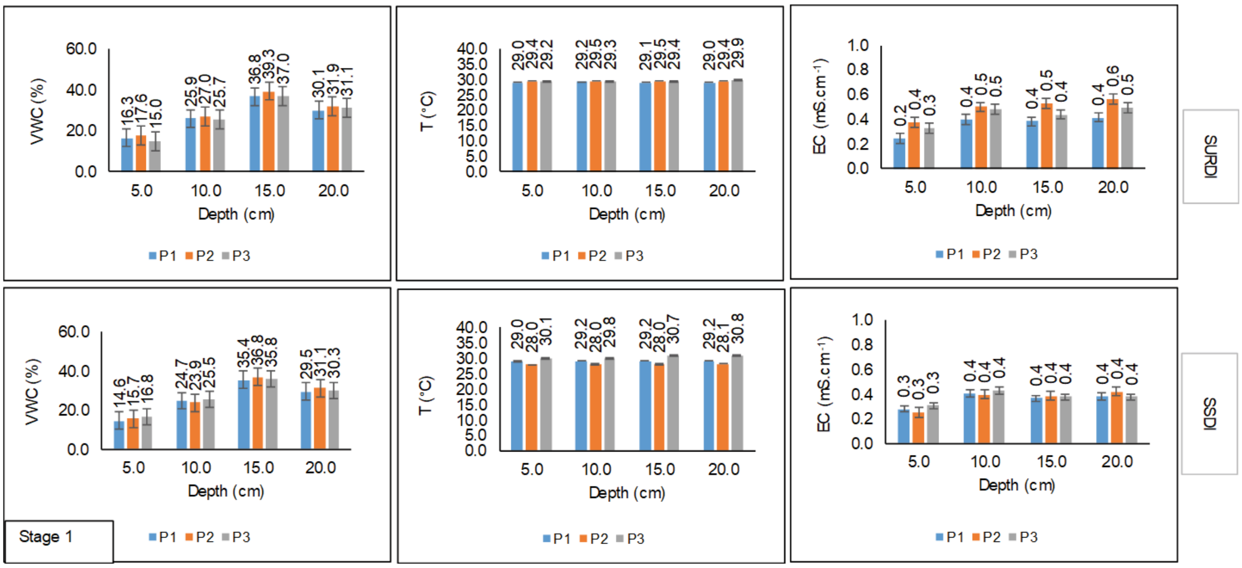
Figure 3a shows the impact on soil under SURDI and SSDI irrigation systems. With SURDI, mulch reduces soil moisture at 15-20 cm depth, especially in P1, but increases it at 5-10 cm in P3. Mulch lowers soil temperature, with P1 being the coolest, and decreases electrical conductivity, with P1 the lowest. Under SSDI, mulch acts as a regulator, increasing moisture at 5 cm in P3 and decreasing it in P1, while fully increasing at 10 cm and decreasing at 15-20 cm in both P1 and P3. Mulch raises temperature, notably in P3, and affects electrical conductivity, increasing it at 5-10 cm and decreasing at 15-20 cm.

3.3.2 Flowering stage (stage 2)

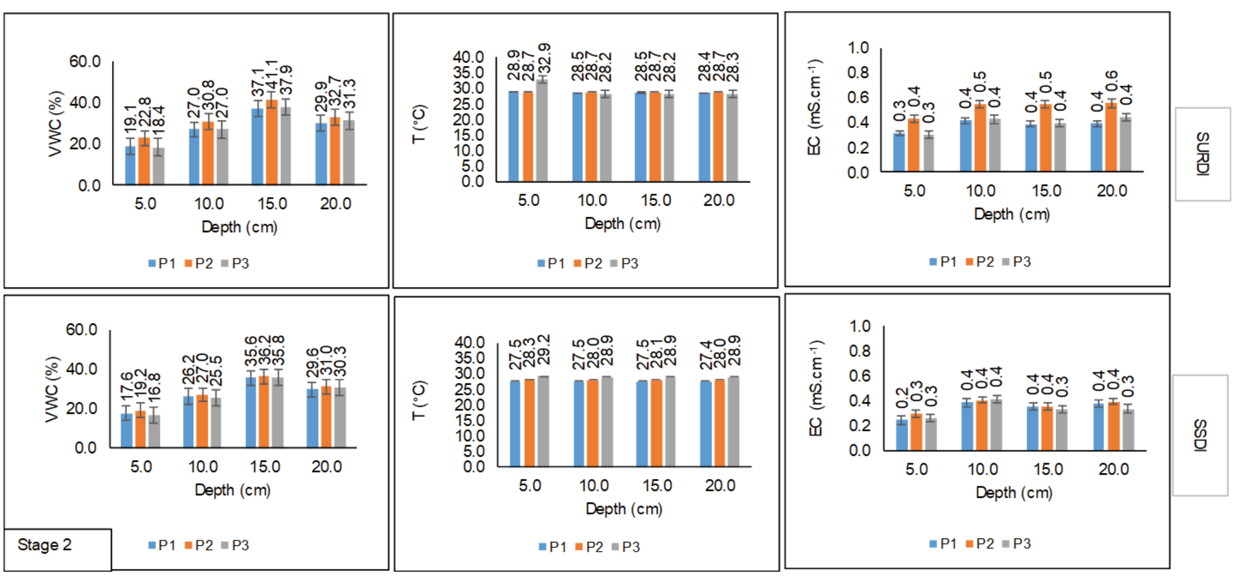
Figure 3b illustrates that in the SURDI scenario, mulched plots exhibit lower soil moisture levels compared to un-mulched plots across different depths, with P3 showing the lowest values. Soil temperature in mulched plots is also lower than the control, with P1 recording the lowest temperature. Additionally, soil electrical conductivity is lower in mulched plots compared to the control, with P3 being lower than P1 at 5 cm depth. In the SSDI scenario, mulched plots display lower soil moisture levels compared to the control, with P3 having lower values than P1. Soil temperature varies, with P1 being the lowest, and electrical conductivity is generally lower in mulched plots compared to the control, although variations exist at different depths.

3.3.3 Fruiting stage (stage 3)

In Figure 3 c's analysis, within the SURDI context, mulched-covered plots consistently show lower soil moisture levels compared to the control across various depths, with P3 surpassing P1. Similarly, soil temperature is lower in mulched plots than the control, with P1 recording the lowest temperatures. In a)



b)

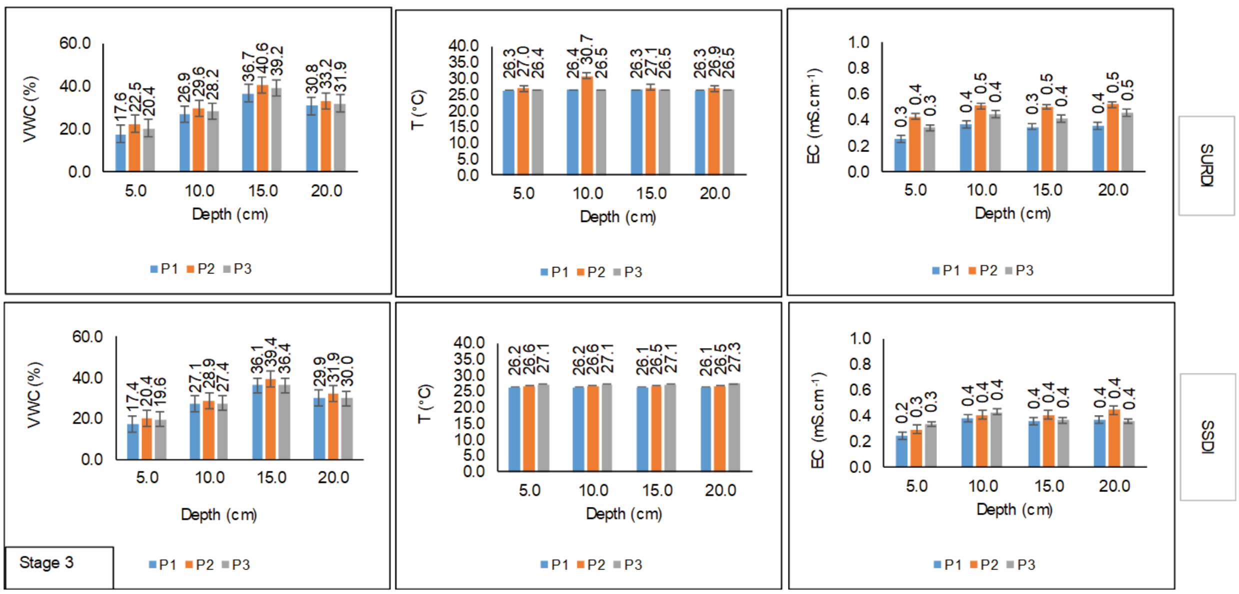


terms of soil electrical conductivity, mulched plots consistently demonstrate lower values than the control. In the SSDI scenario, mulched plots exhibit lower soil moisture levels than the control at different depths, with P3 surpassing P1 from 10 cm upwards but the reverse at 5 cm. Soil temperature in mulched plots varies, both increasing (P3) and decreasing (P1) compared to the control at different depths. Electrical conductivity varies, with some depths showing lower (P1) and higher (P3) values compared to the control.

3.3.4 Maturation stage + harvest (stage 4)

In Figure 3d, SURDI shows that mulched plots have lower soil moisture compared to un-mulched ones, with P3 higher than P1. Soil temperature varies, with both lower (P1) and higher (P3) values compared to control. Soil electrical conductivity is lower in mulched plots, with P3 higher than P1. In SSDI, mulched plots have lower soil moisture, with P1 lower than P3 at certain depths. Soil temperature increases at some depths in mulched plots compared to control, with P3 showing the highest increase. Soil electrical conductivity varies, with P3 higher than P1 at certain depths.

c)



d)

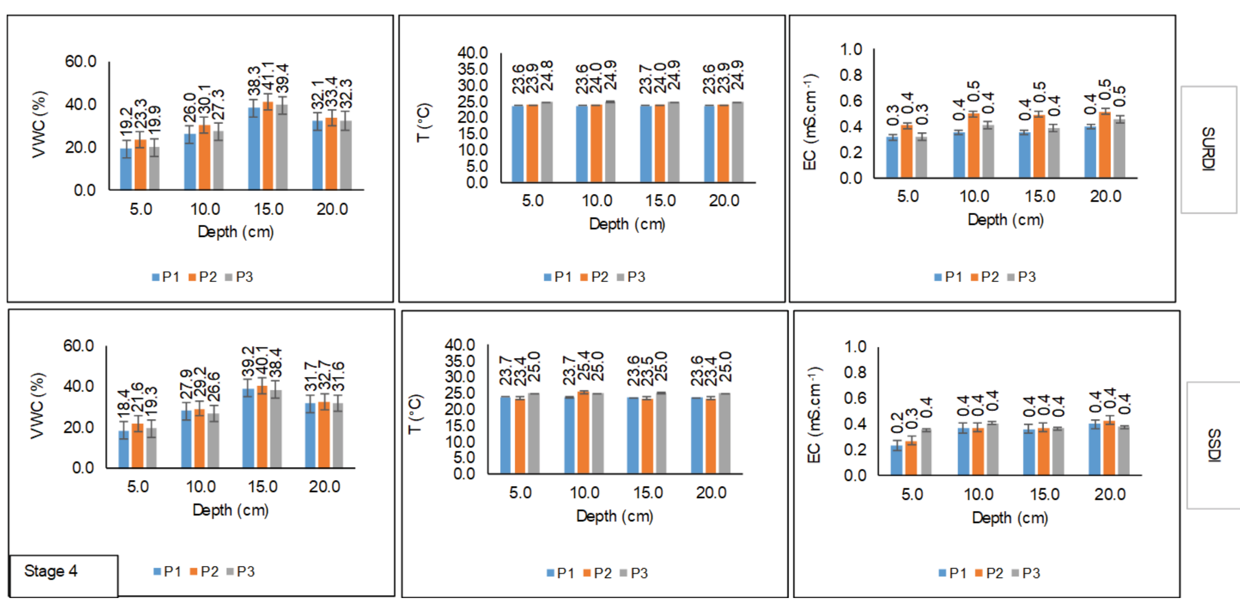


Figure 3: Evaluation of soil moisture (VWC), temperature (T), and electrical conductivity (EC) at depths of 5 cm, 10 cm, 15 cm, and 20 cm across different growth stages: (a) Stage 1, (b) Stage 2, (c) Stage 3, and (d) Stage 4. Error bars represent standard errors. Treatment details are provided in the Materials and Methods section.

3.4 STATISTICAL ANALYSIS FOR SOIL MOISTURE, TEMPERATURE AND ELECTRICAL CONDUCTIVITY PARAMETERS

3.4.1 Correlation matrix between soil moisture, soil temperature and soil conductivity during plant development

The correlation matrices (Table 2) analyze the relationships between Volumetric Water Content (VWC), Temperature (T), and Electrical Conductivity (EC) across different depths (5 cm, 10 cm, 15 cm, and 20 cm) for three plots (P1, P2, and P3) under two irrigation systems (SURDI and SSDI). Generally, VWC and EC show strong positive correlations (ranging from 0.53 to 0.95), reflecting the role of water content in enhancing electrical conductivity through improved ion mobility. Temperature, however, exhibits minimal correlation with VWC and EC, indicating its limited influence on these variables. Specifically, in P1, the VWC-EC relationship is robust (0.68–0.95) across depths, with SSDI slightly strengthening this correlation compared to SURDI, likely due to the mulch's ability to retain moisture and improve water distribution under SSDI. In P2, the VWC-EC correlation is weaker under SURDI (0.19–0.36) but improves under SSDI (0.42–0.86), suggesting that SSDI enhances water-conductivity dynamics even in the absence of mulch. P3 shows strong VWC-EC correlations (0.53–0.89), similar to P1, with SSDI further enhancing this relationship, indicating that RCW mulch, like the mixture mulch, effectively retains moisture and optimizes water distribution under SSDI. Across all plots, VWC-EC correlations tend to decrease with depth, particularly in P2, likely due to reduced water movement or soil heterogeneity at deeper layers. Temperature remains stable and independent across depths, reflecting uniform thermal behavior. Overall, the data highlight the critical role of mulch types and irrigation systems in shaping soil water-conductivity dynamics: mixture and RCW mulches enhance water retention and conductivity, particularly under SSDI, while the control plot shows weaker relationships unless SSDI is applied. These findings underscore the importance of mulch and irrigation strategies in optimizing soil water management and conductivity.

3.4.2 Statistical analysis of VWC, T, and EC under SURDI and SSDI during plant development

The Table 3 presents data on soil parameters (VWC), T, and EC) measured at four depths (5 cm, 10 cm, 15 cm, 20 cm) under two irrigation systems (SURDI, SSDI). The results show that SSDI significantly improves water distribution in deeper soil layers (15 cm, 20 cm), with lower VWC values at 5 cm but higher efficiency in retaining moisture at greater depths compared to SURDI. Additionally, SSDI effec-

Table 2: Correlation matrices of VWC, T, and EC across different depths (5 cm, 10 cm, 15 cm, 20 cm) and mulch types (P1, P2, P3) under SURDI and SSDI irrigation systems.

SURDI												
P1	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	0.18	1.00										
EC	0.92	0.09	1.00									
VWC	0.74	0.07	0.65	1.00								
T	0.10	0.85	0.02	0.24	1.00							
EC	0.71	0.10	0.67	0.92	0.27	1.00						
VWC	0.73	0.01	0.68	0.92	0.16	0.86	1.00					
T	0.11	0.85	0.03	0.25	1.00	0.27	0.17	1.00				
EC	0.68	0.07	0.65	0.89	0.25	0.95	0.89	0.26	1.00			
VWC	0.59	-0.14	0.54	0.72	0.01	0.59	0.80	0.02	0.61	1.00		
T	0.10	0.84	0.02	0.25	1.00	0.27	0.17	1.00	0.26	0.02	1.00	
EC	0.61	0.04	0.59	0.83	0.24	0.86	0.85	0.24	0.93	0.60	0.24	1.00
P2	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	-0.06	1.00										
EC	0.29	0.02	1.00									
VWC	0.90	-0.08	0.21	1.00								
T	0.04	0.50	-0.03	0.00	1.00							
EC	0.28	-0.01	0.95	0.18	-0.02	1.00						
VWC	0.83	-0.06	0.19	0.95	-0.01	0.16	1.00					
T	-0.06	0.99	0.00	-0.08	0.50	-0.01	-0.07	1.00				
EC	0.27	0.02	0.92	0.18	0.00	0.96	0.17	0.03	1.00			
VWC	0.75	-0.14	0.36	0.83	-0.05	0.32	0.85	-0.14	0.35	1.00		
T	-0.06	0.99	0.00	-0.08	0.50	-0.01	-0.07	1.00	0.03	-0.15	1.00	
EC	0.24	0.03	0.86	0.14	-0.04	0.91	0.13	0.03	0.94	0.32	0.03	1.00
P3	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	0.03	1.00										
EC	0.72	0.05	1.00									
VWC	0.90	0.03	0.78	1.00								
T	-0.06	0.37	-0.09	-0.04	1.00							
EC	0.79	0.06	0.77	0.89	0.10	1.00						
VWC	0.83	-0.06	0.69	0.92	-0.14	0.81	1.00					
T	-0.06	0.37	-0.09	-0.04	1.00	0.09	-0.14	1.00				
EC	0.76	0.07	0.75	0.86	0.12	0.95	0.83	0.12	1.00			
VWC	0.58	-0.01	0.53	0.69	-0.11	0.59	0.80	-0.11	0.65	1.00		
T	-0.09	0.36	-0.10	-0.06	0.92	0.11	-0.17	0.93	0.14	-0.11	1.00	
EC	0.72	0.06	0.69	0.79	0.05	0.86	0.78	0.05	0.91	0.67	0.07	1.00

SSDI												
P1	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	0.18	1.00										
EC	0.87	0.20	1.00									
VWC	0.88	0.11	0.82	1.00								
T	0.17	1.00	0.19	0.10	1.00							
EC	0.80	0.27	0.86	0.89	0.26	1.00						
VWC	0.80	-0.01	0.73	0.91	-0.01	0.81	1.00					
T	0.20	0.98	0.22	0.11	0.98	0.28	0.01	1.00				
EC	0.78	0.17	0.79	0.88	0.16	0.93	0.89	0.18	1.00			
VWC	0.62	-0.05	0.53	0.76	-0.07	0.66	0.85	-0.06	0.73	1.00		
T	0.18	1.00	0.20	0.10	1.00	0.27	-0.01	0.98	0.17	-0.06	1.00	
EC	0.83	0.11	0.84	0.86	0.10	0.91	0.85	0.13	0.91	0.75	0.11	1.00
P2	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	0.01	1.00										
EC	0.86	0.02	1.00									
VWC	0.77	-0.09	0.62	1.00								
T	0.05	0.25	0.06	-0.03	1.00							
EC	0.70	0.04	0.68	0.86	0.07	1.00						
VWC	0.64	-0.18	0.49	0.83	-0.07	0.70	1.00					
T	0.01	0.70	0.02	-0.10	0.35	0.07	-0.07	1.00				
EC	0.62	-0.06	0.53	0.78	0.02	0.88	0.81	0.05	1.00			
VWC	0.30	-0.08	0.17	0.61	-0.07	0.42	0.65	-0.08	0.48	1.00		
T	0.07	0.66	0.02	-0.05	0.32	0.11	-0.04	0.95	0.10	-0.08	1.00	
EC	0.53	-0.06	0.50	0.72	0.01	0.74	0.75	-0.01	0.86	0.62	0.02	1.00
P3	5cm			10cm			15cm			20cm		
	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
VWC	1.00											
T	0.09	1.00										
EC	0.81	0.12	1.00									
VWC	0.87	0.11	0.74	1.00								
T	0.13	0.56	0.12	0.18	1.00							
EC	0.85	0.14	0.75	0.94	0.20	1.00						
VWC	0.84	0.03	0.75	0.92	0.06	0.85	1.00					
T	0.12	0.66	0.14	0.19	0.91	0.21	0.07	1.00				
EC	0.84	0.12	0.80	0.89	0.17	0.95	0.88	0.19	1.00			
VWC	0.69	-0.05	0.64	0.68	-0.01	0.61	0.81	-0.07	0.67	1.00		
T	0.12	0.63	0.13	0.19	0.94	0.22	0.06	0.97	0.19	-0.03	1.00	
EC	0.79	-0.02	0.76	0.77	0.09	0.83	0.81	0.04	0.89	0.74	0.09	1.00

Treatment details are provided in the Materials and Methods section.

Table 3: Statistical analysis of soil moisture, temperature and electrical conductivity parameters in plots at 5, 10, 15 and 20 cm depth until two types of irrigation (SURDI, SSDI)

	Depth	5 cm			10 cm			15 cm			20 cm		
IR. Type	Plot	VWC	T	EC	VWC	T	EC	VWC	T	EC	VWC	T	EC
SURDI	P1	18.23a	26.28a	0.28a	26.40a	26.29a	0.38a	37.37a	26.26a	0.36a	30.99a	26.21a	0.39a
	P2	22.05a	26.80a	0.41a	29.68a	27.63a	0.51a	40.67a	26.75a	0.51a	32.93a	26.72a	0.53a
	P3	18.71a	27.86a	0.32a	27.11a	26.84a	0.43a	38.56a	26.87a	0.40a	31.75a	26.96a	0.46a
SSDI	P1	17.12a	25.94a	0.25b	26.78a	25.96a	0.38b	37.03b	25.93a	0.36b	30.44b	25.89b	0.38b
	P2	19.67a	26.06a	0.28b	27.64a	26.75a	0.39b	38.47b	26.03a	0.38b	31.84b	26.01b	0.42b
	P3	18.13a	27.27a	0.33b	26.47a	27.19a	0.42b	36.75b	27.39a	0.36b	30.47b	27.44b	0.37b
	SEm±	0.70	0.31	0.02	0.50	0.25	0.02	0.59	0.23	0.02	0.39	0.25	0.03
	Pr > F	0.03	0.32	0.00	0.03	0.69	0.00	0.00	0.74	< 0.0001	< 0.0001	0.67	< 0.0001
	CD (P=0.05)	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82

Treatment details are provided in the Materials and Methods section.

tively reduces soil salinity, as indicated by significantly lower ECs values across all depths ($p < 0.0001$). Temperature remains stable and unaffected by the irrigation system, suggesting that neither SURDI nor SSDI significantly impacts soil thermal properties. Statistical indicators (SEm±, Pr > F, CD) confirm the reliability of the data, with significant differences ($p < 0.05$) in VWC and EC between the two systems. These findings highlight the advantages of SSDI in optimizing water use and controlling soil salinity, making it a promising solution for sustainable agriculture in arid and semi-arid regions. Farmers and researchers are encouraged to adopt SSDI to enhance irrigation efficiency and mitigate salinity-related challenges.

3.5 CHARACTERIZING ACTUAL EVAPOTRANSPIRATION (ETA)

3.5.1 Evaluation of eta during plant development stages

Observations at stage 1 (Fig. 4) reveal similar behavior in both irrigation systems initially, with slight differences emerging towards the cycle's end. Mulched plots (P1 and P3) exhibit higher ETA compared to non-mulched ones (P2) in both systems. Stage 2 (Fig.4) shows slight variations within P3 in both SURDI and SSDI. ETA is generally lower in SSDI compared to SURDI, with P3 displaying the lowest rates. Stage 3 (Fig.4) demonstrates differing behavior, with constant ETA in SURDI, higher in mulched plots, while overall, SSDI exhibits higher ETA. Stage 4 (Fig.4) displays consistent behavior across irrigation systems and plots. Key findings include higher ETA in mulched plots during phases 1 and 3, higher ETA under drip irrigation in general, but lower values in phase 2, and consistent ETA across plots in both systems during phase 4.

3.5.2 Relationship between actual evapotranspiration (ETA) and plant height

Figure 5 illustrates that mulched plot P1 displays the highest ETA and the largest plant size, consistent across

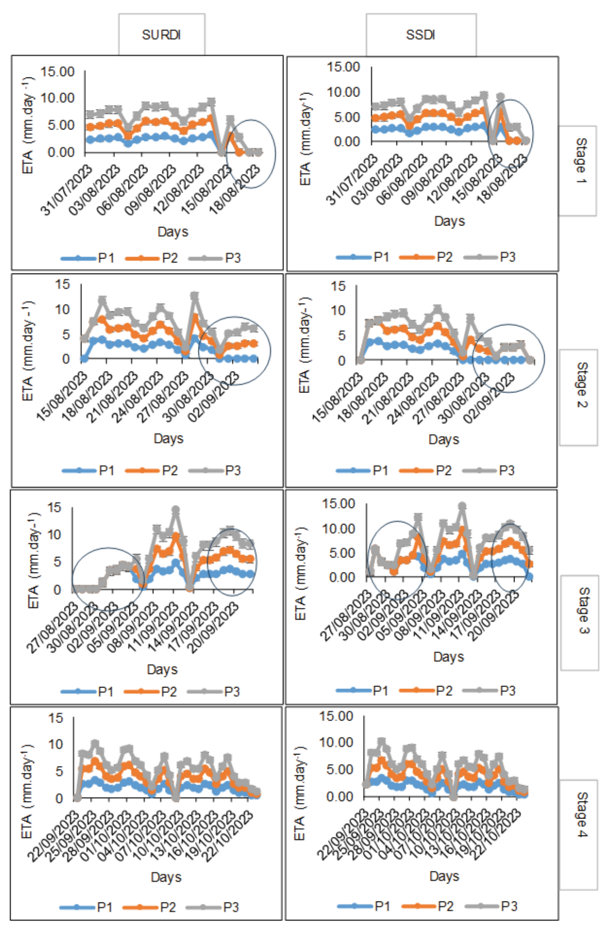


Figure 4: Evaluation of actual evapotranspiration (ETA) in different plots and growth stages under various irrigation systems. The bars indicate the standard errors. The treatment details are provided in the Materials and Methods section

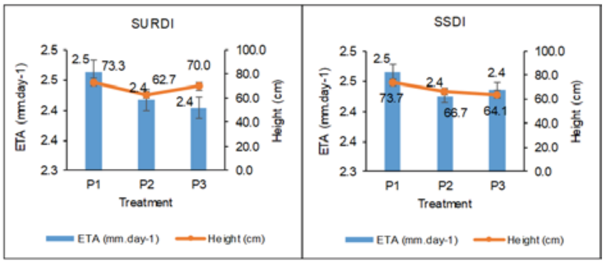


Figure 5: Relationship between actual evapotranspiration (ETA) and plant size in different treatments (mulch and control). The bars indicate the standard errors. The treatment details are provided in the Materials and Methods section

both surface and subsurface drip irrigation systems. The irrigation method doesn't alter this relationship. Mulching enhances plant transpiration over soil evaporation, maintaining stable soil moisture. Consequently, P1 benefits from consistent water access, fostering increased evapotranspiration and plant growth by reducing water stress. Comparing P2 and P3 under subsurface drip, despite equal ETA, plant sizes vary, with the control plot having the largest plants. This suggests deeper root systems seeking water, resulting in comparable or slightly higher transpiration rates despite smaller visible plant size.

3.6 IRRIGATION PARAMETERS

3.6.1 Irrigation frequency and total volume irrigation

Figure 6 presents the analysis of both irrigation frequency and total volume of irrigation across different plots and systems. In terms of irrigation frequency, P5 received the least surface irrigation (13 cycles), with stage 3 receiving the least water. On the other hand, P1 received the least subsurface irrigation (11 cycles), with stage 2 receiving the least water. Overall, P1 received the least irrigation across both systems. Subsurface plots generally required less water compared to surface plots, and subsurface drip irrigation demonstrated more favorable outcomes in terms of irrigation cycles. The mulch mixture was found to be more effective when used with subsurface drip, while RCW mulch performed better with surface irrigation.

Regarding the total volume of irrigation, P1 received the lowest total underground water (786.6 l), with the initial phase receiving the least amount (124.2 l). In contrast, P2 had the highest total water volume above ground (1117.8 l), with the flowering and ripening + harvesting phases recording the highest rates (414 l). This

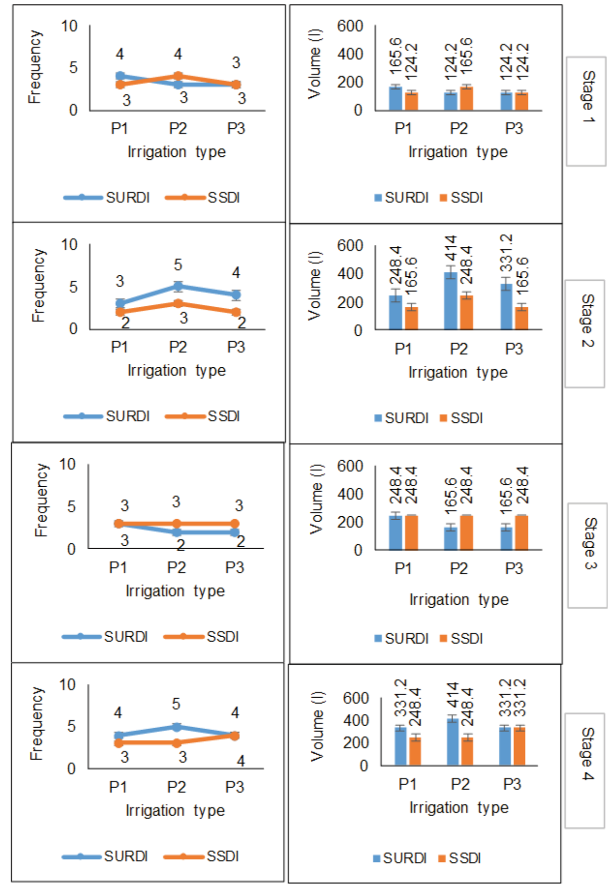


Figure 6: Irrigation frequency and total volume across treatments, crop development stages, and irrigation systems. The bars represent standard errors. Treatment details are provided in the materials and methods section

comprehensive analysis highlights the differences in water usage and efficiency between surface and subsurface drip irrigation systems.

3.6.2 Water savings and efficient irrigation application (EA) in different plots following various treatments

Figure 7a demonstrates the water savings achieved in each plot under surface and subsurface drip irrigation compared to control conditions. For example, P1 achieved significant water savings of 414 m^3 (14.8 %) under SURDI, while P2 saved 310.5 m^3 (11.1 %) under SSDI. Furthermore, when compared to surface drip irrigation alone, P1 saved nearly 828 m^3 (29.6 %), and P3 saved 621 m^3 (22.2 %).

Figure 7b illustrates the efficiency of irrigation application (EA) under different systems. Under SURDI, P2 recorded the highest EA at 97.1 %, slightly outperforming

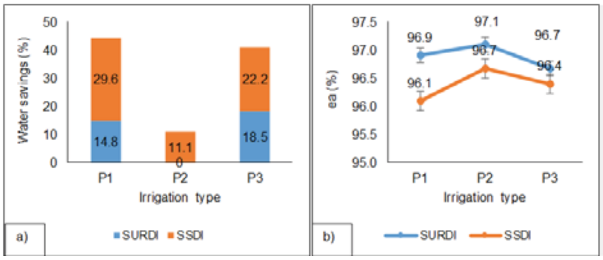


Figure 7: Overview of (a) water savings (m^3) compared to the surface control plot under surface and subsurface drip irrigation systems, and (b) water application efficiency (EA) in each plot

P1 (96.9 %) and P3 (96.7 %), with P1 showing a marginal advantage over P3. Similarly, under SSDI, P2 maintained the highest EA at 96.7 %, followed by P3 (96.4 %) and P1 (96.1 %). These findings underscore the effectiveness of specific treatments and systems in enhancing irrigation efficiency, with P2 consistently demonstrating superior performance across both systems.

4 DISCUSSION

The findings of this study highlight the significant potential of combining organic mulching with subsurface drip irrigation (SSDI) to enhance water conservation and improve soil conditions in tomato cultivation. These results align with previous research, which has shown that mulching and SSDI individually contribute to water savings and improved crop performance (Simsek et al., 2017; Yang et al., 2023). However, this study provides novel insights into their combined effects, particularly in the context of the Mitidja Plain, a region facing severe water scarcity.

The analysis of soil physico-chemical properties revealed significant differences between mulched and non-mulched plots. Mulched plots exhibited a slight soil acidification, with lower pH values (6.20–6.52) under SSDI compared to non-mulched plots (6.90–7.06). This acidification could be attributed to the decomposition of organic mulches, which release organic acids into the soil. While this acidification is moderate, it may influence nutrient availability and requires long-term monitoring. On the other hand, soil organic matter (OM) content remained stable, with values ranging from 1.09 % to 1.70 %, showing no significant differences between irrigation systems. This confirms that organic mulching improves soil fertility without altering its organic structure, which is crucial for the sustainability of agricultural systems (Kumar & Lal, 2012).

Mulching effectively regulated soil moisture, temperature, and electrical conductivity across all growth stages. The mixture mulch, in particular, showed superior performance in maintaining soil moisture levels, especially under SSDI. These findings are consistent with those of (Telkar et al., 2017), who reported that organic mulches reduce evaporation and improve water retention. The slight reduction in soil temperature in mulched plots further supports the role of mulch as a thermal regulator, as noted by (Gan et al., 2013). Additionally, the lower electrical conductivity in mulched plots suggests that mulching mitigates soil salinization, a critical issue in arid regions (Kumar & Lal, 2012).

Mulched plots exhibited higher plant growth and evapotranspiration (ETA) rates, particularly during the growth and fruiting stages. This is consistent with the findings of (Liasu & Achakzai, 2007), who reported that mulching enhances plant transpiration by reducing soil evaporation. The higher ETA in mulched plots under SSDI further highlights the synergistic effects of these practices in promoting crop growth and water use efficiency.

The combination of mulching and SSDI resulted in significant water savings, with the mixture mulch saving 29.6 % and RCW saving 22.2 % compared to surface irrigation. These findings are consistent with studies by (Yang et al., 2023) and (Sharma et al., 2023), who highlighted the water-saving potential of mulched drip irrigation systems. However, the slight decrease in water application efficiency (EA) in mulched plots (96.1 % for mixture, 96.4 % for RCW vs. 97.1 % for control) suggests that while mulching improves water retention, it may also create channels that lead to uneven water distribution. This underscores the need for further optimization of mulching materials and irrigation strategies.

The results of this study have important implications for sustainable agriculture in water-scarce regions. By reducing irrigation frequency and water consumption, the combination of mulching and SSDI offers a practical solution for farmers in the Mitidja Plain and similar regions.

5 CONCLUSION

This study demonstrates that combining organic mulching with subsurface drip irrigation (SSDI) is an effective strategy for water conservation and sustainable tomato cultivation in the Mitidja Plain. The mixture mulch, in particular, saved up to 29.6 % of water compared to surface irrigation, while also regulating soil moisture, temperature, and electrical conductivity. However, the slight soil acidification observed in mulched plots (pH 6.20–6.52) warrants attention, as it may influence nutrient availability over time. Despite this, soil organic matter (OM) remained stable (1.09 %–1.70 .%), confirming that mulching enhances soil fertility without compromising its structure. Farmers in arid regions are encouraged to adopt these practices to improve water efficiency and crop yields, but should monitor soil pH and consider amendments if necessary. Policymakers should support the adoption of these practices through subsidies, training programs, and infrastructure development, while also promoting research and innovation in conservation agriculture. Scientific researchers should focus on long-term studies to evaluate the effects of mulching and SSDI on soil health, crop productivity, and environmental sustainability, as well as explore the economic feasibility and scalability of these practices for smallholder farmers. A key limitation of this study is its short-term scope, which restricts the ability to assess long-term impacts on soil health and crop productivity. Future research should also investigate the broader applicability of these practices to other crops and regions, as well as their potential to mitigate climate change impacts through improved water and soil management. By addressing these gaps, mulching and SSDI can be further optimized to support sustainable agriculture in water-scarce environments.

ACKNOWLEDGMENTS

The study was carried out at the Water and Environmental Engineering Laboratory (GEE) of the Higher National School of Hydraulics (ENSH) of Blida. The study was carried out within the framework of the "AFRICAN WATER RESOURCES MOBILITY NETWORK" (AWaRMN) project funded by the Intra-Africa Academic Mobility Scheme of the European Union. Also, the study is carried out within the framework of the SWATCH project (Prima project) funded by the DGRSDT, Algeria.

DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request

6 REFERENCES

Admasu, R., & Tamiru, Z. (2019). Integrated effect of mulching and furrow methods ontTomato (*Lycopersicum esculentum* L) yield and water productivity at West Wellega, Ethiopia. *Natural Sciences Research*.

Ayars, J., Fulton, A., & Taylor, B. (2015). Subsurface drip irrigation in California—Here to stay? *Agricultural Water Management*, *157*, 39-47.

Bessaoud, O., Pellissier, J.-P., Rolland, J.-P., & Khechimi, W. (2019). *Rapport de synthèse sur l'agriculture en Algérie* CIHEAM-IAMM].

Chachoua, I. (2015). *L'urée dans l'alimentation des ovins : conséquences sur la gestation, la parturition et le croît,* Universite el-hadj lakhdar-batna]. Algérie.

Du Preez, G., Marcelo-Silva, J., Azizah, N., Claassens, S., & Fourie, D. (2024). Time Matters: A Short-Term Longitudinal Analysis of Conservation Agriculture and Its Impact on Soil Health. *Journal of Soil Science and Plant Nutrition*, 1-16.

FAO. (2017). The future of food and agriculture: Trends and challenges. *Report of the Food and Agriculture Organization of the United Nations*.

Gan, Y., Siddique, K. H., Turner, N. C., Li, X.-G., Niu, J.-Y., Yang, C., Liu, L., & Chai, Q. (2013). Ridge-furrow mulching systems—an innovative technique for boosting crop productivity in semiarid rain-fed environments. *Advances in Agronomy*, *118*, 429-476.

Gouda, A., Nemichandrappa, M., Babu, M., Halidoddi, R., Reddy, M., & Ramesh, G. (2023). Influenece of different irrigation scenario's under mulched and non-mulched condition on soil moisture, yield and WUE of ridge gourd (*Luffa acutangula* L.). *International Journal of Environment and Climate Change*, *13*(11), 1385-1391.

Iqbal, R., Raza, M. A. S., Valipour, M., Saleem, M. F., Zaheer, M. S., Ahmad, S., Toleikiene, M., Haider, I., Aslam, M. U., & Nazar, M. A. (2020). Potential agricultural and environmental benefits of mulches—a review. *Bulletin of the National Research Centre*, *44*, 1-16.

Karambiri, S. D., Der Djamen, PN, Diallo, M., & Andrieu, N. (2021). Agriculture de conservation à Yilou (centre-nord, Burkina Faso): une construction locale à l'épreuve de la dispersion des systèmes culturaux existants. *DaloGéo, Revue Scientifique Spécialisée en Géographie, Université Jean Lorougnon Guédé*, *5*, 134-151.

Kumar, S. D., & Lal, B. R. (2012). Effect of mulching on crop production under rainfed condition: a review. *International Journal of Research in Chemistry and Environment*, *2*(2), 8-20.

Laribi, S., Boutonnet, J.-p., Brabez, F., Adem, R., & Kheffache, H. (2023). Les formes d'intégration agriculture-élevage. Le cas des systèmes de polyculture-élevage bovin laitier de la plaine de la Mitidja–Algérie. *Les Cahiers du Cread*, *39*(1), 307-348.

Liasu, M., & Achakzai, A. (2007). Influence of *Tithonia diversifolia* leaf mulch and fertilizer application on the growth and yield of potted tomato plants. *Agriculture And Environment* (Sci *2*(4)), 335-340.

Meddi, M., Boufekane, A., & Meddi, H. (2015). *Recharge artificielle de la nappe de la Mitidja*. Éditions universitaires européennes. https://www.editions-ue.com/

Rastogi, M., Kolur, S. M., Burud, A., Sadineni, T., Sekhar, M., Kumar, R., & Rajput, A. (2024). Advancing water conservation techniques in agriculture for sustainable resource management: A review. *Journal of Geography, Environment and Earth Science International*, *28*(3), 41-53.

Sharma, S., Basnet, B., Bhattarai, K., Sedhai, A., & Khanal, K. (2023). The influence of different mulching materials on Tomato's vegetative, reproductive, and yield in Dhankuta, Nepal. *Journal of Agriculture and Food Research*, *11*, 100463.

Simsek, U., Erdel, E., & Barik, K. (2017). Effect of mulching on

soil moisture and some soil characteristics. *Fresenius Environmental Bulletin*, *26*(12), 7437-7443.
Tankeuoo, K., I, Meddi, M., & Ammari, A. (2023). Influence of mulches on soil moisture and water infiltration in the tomato crop. *Acta agriculturae Slovenica*, *119*(4), 1–16-11–16.
Telkar, S., Kant, K., Pratap, S., & Solanki, S. (2017). Effect of mulching on soil moisture conservation. *Biomolecule reports*, *9*, 1-4.
Wang, Z., Chen, R., Li, W., Zhang, J., Zhang, J., Song, L., Wang, J., Li, H., Mou, H., & Li, Z. (2024). Mulched drip irrigation: a promising practice for sustainable agriculture in China's arid region. *npj Sustainable Agriculture*, *2*(1), 17.
Yang, P., Wu, L., Cheng, M., Fan, J., Li, S., Wang, H., & Qian, L. (2023). Review on drip irrigation: Impact on crop yield, quality, and water productivity in China. *Water*, *15*(9). https://doi.org/10.3390/w15091733