Evaluation of Soil Moisture Retention and Water Use Reduction under Simulated Agrivoltaic Systems in Semi - Arid Consumption of Iraq

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Abstract :
A new approach in agriculture to reduce water consumption involves the use of agrivoltaic systems, which provide shade to crops and help conserve water during the growing season. This study aims to quantify the reduction in water use achieved by implementing an agrivoltaic system. The results revealed a significant difference in the total water applied between plots using the agrivoltaic system and those in open-field conditions. Agrivoltaic systems can also help mitigate the impacts of climate change in arid and semi-arid regions, where extreme weather conditions negatively affect plant growth and reduce overall crop productivity.

Keywords: Agrivoltaic systems, evapotranspiration, water consumption, soil texture.

Introduction :

Agricultural land can be converted to an agrivoltaic system to reduce water consumption and increase water-use efficiency (15). Agrivoltaic systems can decrease irrigation requirements for plant growth by lowering evapotranspiration. Marrou et al. observed that agrivoltaic systems reduced water usage for crops by 14-29% due to evapotranspiration during the spring and summer of 2011 (from March 22nd, 2011, to August 31st, 2011) on an experimental prototype in Montpellier, France, where lettuce and cucumber were grown beneath solar panels (12). They found that the water needed for plant growth during the season was significantly lower beneath agrivoltaic systems compared to the open area.

Elamri et al., used model simulations to predict the benefits of agrivoltaic installations and grow lettuce in the experimental platform of Lavalette (IRSTEA Montpellier, France) (7). They found that agrivoltaic systems can reduce irrigation amounts by 20% from irrigation amounts. Another study showed that crop water consumption in agrivoltaic systems was reduced by 20%–30% in the Lavalette station of IRSTEA, Montpellier, France (9 .(
Esmail et al. showed that irrigation in navel orange fields was reduced by 20% under shading by 25% compared to the open area in Egypt (1). A similar study for peach trees noticed irrigation was reduced by 25% using a black net to reduce the light by 18% in Spanish (8). Agrivoltaic systems were installed over a 10-year-old 'Golden Delicious' apple orchard and studied during three experimental seasons (2019–2021) in the south of France to evaluate the impact of fluctuating shading (between 4% and 88% during the day) (10). They found the lower

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radiation and stressful microclimate in agrivoltaic systems decreased irrigation between 6% and 31%, reduced fruit size by 17% in 2019, but was maintained in 2020 and 2021 because accumulated water under the agrivoltaic systems was more than in the open area.

Recently, Ramos-Fuentes et al. grew maize (Zea mays L., RAGT IXABEL) for three years (2019, 2020, and 2021) beneath solar panels with deficit irrigation in the South of France (Mediterranean climate) (14). They found that agrivoltaic systems reduce irrigation inputs by up to 19-47% compared to the open area by reducing soil water depletion and reference evapotranspiration.

Omer et. al. measured evaporated water underneath agrivoltaic systems with two types of shades: concentrated-lighting agrivoltaic systems and Even-lighting agrivoltaic systems at Fuyang City, Anhui Province in China (13). They found that water evaporation was reduced in concentrated-lighting agrivoltaic systems and Even-lighting agrivoltaic systems by about 21% and 33%, respectively.

Al-agele et al., grew Tomato plants (Solanum lycopersicum var. Legend) underneath agrivoltaic systems within three locations (control, interrow, and underneath panels) and with two different irrigation treatments (full and deficit) (3). They found that soil moisture content significantly increased underneath the solar panel compared to the open area .

Another study in agrivoltaic systems investigated the effect of the three different levels of shade (19%,30.4%, and 38%) on kiwifruit yield and water productivity in China (10). They found that kiwifruit growth and yield were less affected, and water productivity was increased with reduced water consumption by reducing evapotranspiration in the shade compared to the open area .

Barron-Gafford et al. planted varieties of crops underneath the agrivoltaic system in the center north of Tucson, AZ, USA (5). They found that the shade generated by solar panels has a positive effect on plants in terms of reducing the effect of air temperature and direct solar radiation and reducing the water requirements of plants during the day. Also, they noticed that water applied was reduced by about 65 % in agrivoltaic systems compared to open areas.

Another study (4) investigated the impact of the development of two agricultural Photovoltaic systems, Spectrum Splitting and Concentrated APV (SCAPV), and Even-lighting Agricultural Photovoltaic (EAPV) on the sweet potato quality and yield growth compared to the open area. They found SCAPV and EAPV reduced the average ET by 31% and 23%.

This study aims to measure how much an agrivoltaic system can hold soil moisture during the season and how much water it can save under two irrigation deficit irrigation levels (35% and 50% .(

Materials and methods:

Site Description and Preparation

The field study was conducted in a simulated agrivoltaic system located in Babylon Province, Iraq. The dimensions of the experimental field were 40 m by 45 m (1,800 m^2) (length by width). The field was plowed and divided into experimental plots measuring 3 m by 6 m, situated beneath the simulated solar panels, between the panels, and in a control area (see Figure 1). The simulated agrivoltaic system was constructed from wood and covered with blue plastic on top, which shaded the soil. The choice of blue plastic as

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the shading material was inspired by the spectrographic measurements below the solar panels of (2) who found the largest impact in blue light. The dimensions and slopes of the design were selected to mimic a typical fixed-tilt solar architecture. The design of the simulated agrivoltaic system measured 3 m in width and 45 m in length, with a height of 3 m and an angle of 30 degrees (Figure 1.(

Figure 1. Potato growth in three different locations (shade, partial shade, and open area(

Each plot contained three lines of drip tube with a 0.75m distance between the lines. Each drip line had 0.2 m spacing between emitters, and each emitter had a flow rate of 4 L/h .

The potato tubers class (Arizona) was bought from the Netherlands. Potatoes were planted in Silty Loam soil texture on January 12, 2024, with three lines in each plot (coincident with the drip line) with three replications for each treatment permutation of: beneath simulated solar panels, between panels, control area, fertilizer application level, and deficit irrigation level, respectively.

The shade and light treatments created by the simulated agrivoltaic canopy were classified as 1) the plots immediately below the shade structures. These plots experienced the most shade and are designated as S for shade. Plots located between the shade canopy structures experienced a partial shade, partial sun condition; these treatments are designated as B for between. Control plots, located outside the influence of the shade canopy experience the full sun, full light condition. These treatments are designated as L for light.

Two irrigation deficit irrigation levels (35% and 50%) were used to define the irrigation treatments. Note that both deficit levels are defined relative to the available water content in the soil, and a 35% water deficit plot receives more water than the 50% deficit plot. The deficit is relative to full watering to available soil capacity .

Soil measurement

Soil moisture content was measured for soil samples taken from three depths (0.2 m, 0.4 m, and 0.6 m). These soil samples were collected from each plot in the control area, with nine replicates for each depth taken from both the shaded and partial shade areas. Soil moisture content was measured depending on the weighting method described in (Black et al. 1965.(

Statistical analysis

GenStat software version 12.1.0.3278 was used to analyze the experiment data using a Split-Split Design within a Randomized

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Complete Block Design (RCBD). The comparison was made using the treatment means with the Least Significant Differences Test (L.S.D) at significance levels of 0.05 and 0.01 to determine statistical significance .

Results and Discussion :

The soil moisture content was represented in Table (1) with all the study factors. Soil moisture content increased in the shade area more than between the shade and open area. The statistical analysis showed significant differences in soil moisture content in the shade compared to partial shade and open area. Also, soil moisture significantly increased with soil depth. The bi-directional interactions between soil depth and irrigation levels and shade, and irrigation with shade showed significant differences between them. There were significant found in tri-directional interactions between shade, partial shade, and open area.

These results are consistent with findings by with the literature review by [6, 4, 11] in different regions. These results encourage to installation of solar panels in agricultural land to conserve soil moisture in the arid and semi-arid regions .

Table 2. Soil moisture content at different depths from different locations (Shade, partial shade, and open area)

Soil Sample depth	**Irrigation Levels**	**S**	**B**	**L**	**D*I**
D1	$I_{0.35}$	21.5	18.36	17.22	18.69
	$I_{0.50}$	19.53	17.69	15.55	17.22
D2	$I_{0.35}$	21.97	19.83	16.98	18.95
	$I_{0.50}$	19.95	16.99	16.69	17.15
D3	$I_{0.35}$	19.26	18.96	17.11	18.03
	$I_{0.50}$	18.65	17.43	16.62	17.98
LSD (0.05)		2.03			1.28
S		20.23	18.48	17.07	
LSD (0.05)		0.98			
					D
D*S	D1	19.04	17.57	15.95	16.33
	D2	19.92	17.82	16.07	17.51
	D3	20.01	18.46	16.89	19.01
LSD (0.05)		1.65			0.88
					I
I*S	$I_{0.35}$	19.95	18.37	15.85	18.08
	$I_{0.50}$	18.41	16.25	14.53	16.78
LSD (0.05)		1.4			0.81

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*

Note: S = Shade, B = Between the shade, L = Light area, D: soil sample depth, D1 = 0.2 m, D2 = 0.4 m, D3 = 0.6 m, I0.35 and I0.50 are two irrigation levels.

The results showed the total water applied to the field during the season Figure (2) and Figure (3) represented the percentage of water applied in shade and partial shade compared to open area at both deficit irrigation levels (Figure 2). The two-tailed T-test showed significant differences at p-value (0.05) between total water consumption applied in shade, partial shade, and open area. Also, there was no significant difference between shade and partial shade .

These results were totally in agreement with the literature review by [6, 4, 11,3,10] in different regions. These results encourage installing solar panels in the agricultural land to save water and increase land use efficiency in the arid and semi-arid regions .

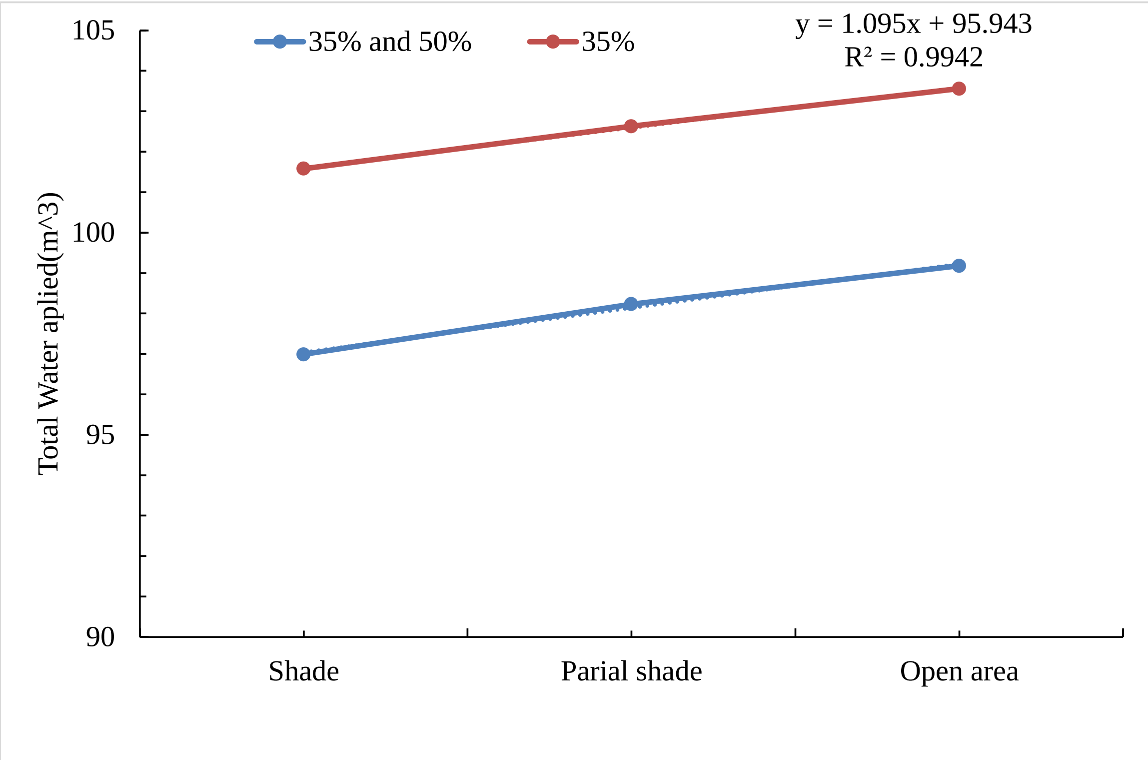

Figure 2. Total water applied at each zone at two deficit irrigation levels

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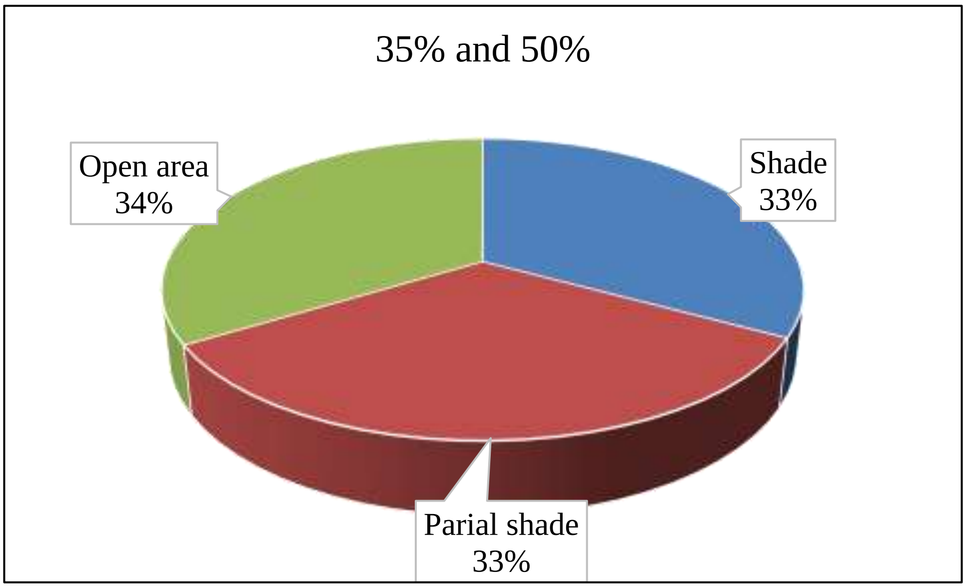

Figure 3. Percentage of water applied at each zone at two deficit irrigation levels

Conclusion :

A new approach in agriculture, known as agrivoltaic systems, helps reduce water consumption by providing shade through solar panel installations. This study investigates the extent to which agrivoltaic systems lower water usage during the growing season. The findings revealed a significant reduction in total water applied under agrivoltaic systems compared to open-field conditions, by saving soil moisture content longer for the plant. Agrivoltaic systems also offer potential to mitigate the effects of climate change in arid and semi-arid regions, where extreme weather conditions severely impact plant growth and overall crop productivity.

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