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ORIGINAL ARTICLE

Shading solutions for sustainable water management: impact of colors and intensities on evaporation and water quality

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Abstract

This study investigated the effectiveness of suspended shade covers in reducing evaporation rates and improving evaporation suppression efficiency. The experiment tested different shading colors (black, white, and green) and intensities (50, 70, and 90%) while considering ecological and economical aspects. Evaporation was determined using class-A evaporation pans, and various microclimatic variables were measured below the shade covers. Additionally, water quality parameters such as EC, phosphate, nitrate, and chloride concentrations were monitored. The results showed that black covers had the highest evaporation suppression efficiency with values of 56.8, 53.6, and 51.7% observed under 90% shading intensity for the black, green, and white covers, respectively. Despite variations in water quality parameters which all met Jordanian and FAO standards for irrigation water, the economic feasibility of installing these covers was found to be viable due to the resulting benefits in water conservation and crop production. However, selecting the best shading cover should consider the multipurpose use of agricultural reservoirs, including aquaculture, and further studies are recommended to investigate other overlapping aspects on a reservoir scale.

Keywords Agricultural ponds · Evaporation · Evaporation barriers · Evaporation suppression efficiency · Water quality

Introduction

In recent years, many areas in the Middle East and Northern Africa (MENA) have been grappling with challenges related to water quality and quantity (Beithou et al. 2022). Jordan, located in the MENA region's arid and semi-arid climate zones, is currently ranked as the world's second-most water-stressed country (Daoud et al. 2022). The country faces serious water challenges in terms of spatial and temporal water availability, with a per capita water supply of less than 100 m^3, falling far below the international water poverty threshold of 1,000 m^3 (Ministry of Water and irrigation (MWI, 2017). Jordan's climate is characterized by a prolonged dry season during the summer months (Abu-Allaban et al. 2015), with most areas receiving less than 100 mm of rainfall per year, with variations in terms of distribution and intensity (Al-Kharabsheh 2021). Climate change has further compounded the problem, with human activities such as industrialization and urbanization exacerbating the impact on water quantity and quality (Al Qatarneh et al. 2018; Hussein et al., 2020).

Agricultural consumption has increased due to the improvement of public irrigation in the Jordan Valley and the implementation of private groundwater schemes in the highlands (Molle et al. 2008). The agricultural sector is the biggest user of water in Jordan, accounting for 52% of total water consumption (MWI, 2017). Water storage reservoirs play a significant role in meeting municipal, industrial, and agricultural needs. In recent years, there has been an increase in the number of agricultural ponds in Jordan, some of which are larger than 14,000 m^2 (Fig. 1). However, climate change is expected to reduce the amount of stored water, particularly in small reservoirs, according to Althoff et al. (2020), which will have implications for water supply.

According to Martínez Alvarez et al. (2008), evaporation is a significant cause of water loss from reservoirs. As a

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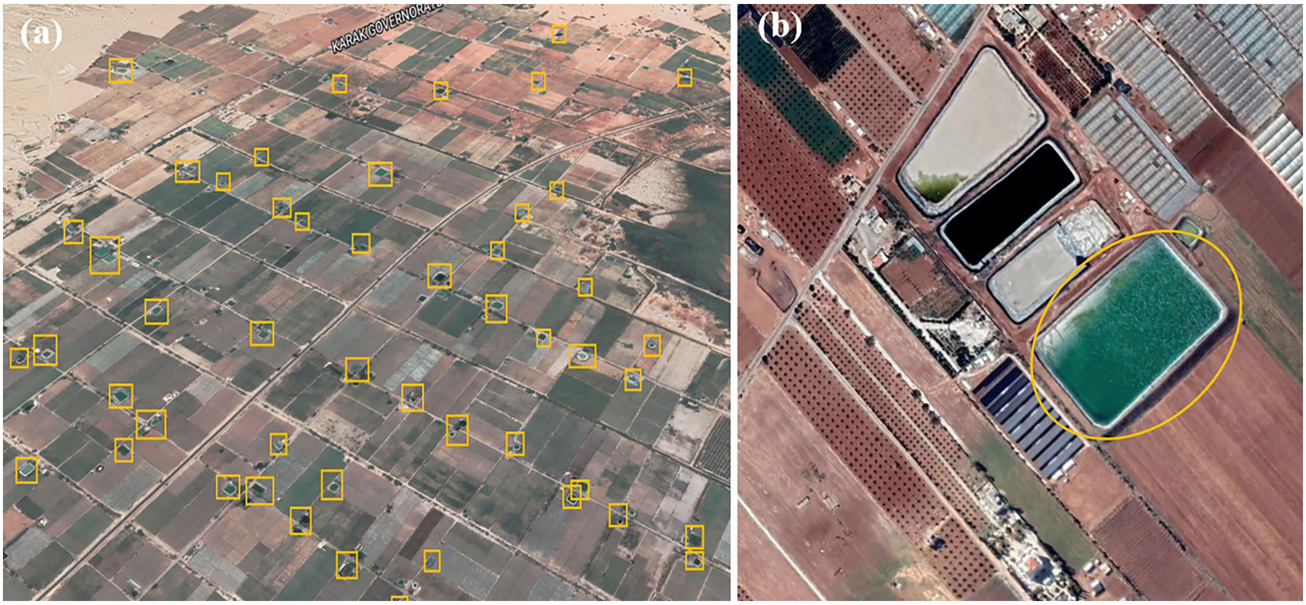

Fig. 1 **a** Satellite image showing the wide spread of the agricultural ponds in Ghor Al Mazra'a. **b** Satellite image showing an agricultural pond with an area of more than 14,000 m^2 in Ramtha city (32°32′02.7" N, 35°58′48.3" E). Agricultural ponds are highlighted in yellow. The source is Google Erath

result, several methods have been used to reduce evaporation from water reservoirs such as impermeable barrier for the water surface by using monolayer molecular films in the 1960s. Since then, many methods have been designed and developed to enhance control of evaporation losses. Among these techniques, physical methods, such as floating covers or suspended covers atmosphere Alvarez et al. 2006). Therefore, using suspended shade covers as a physical barrier to mitigate this problem has raised concerns due to their high evaporation suppression efficiency (ESE) of 74.6% (Abdallah et al. 2021). In Australia, the use of suspended shade covers resulted in a reduction of the evaporation rate (ER) by 90.0% (Finn & Barnes 2007), while in Spain, ER reduced by 85% after using suspended shade covers (Gallego-Elvira et al. 2011). Moreover, Maestre-Valero et al. (2011) demonstrated that these covers have long-lasting durability in field conditions. Shalaby et al. (2021) defined various factors that impact ESE, such as coverage percentage (CP), cover color, and cover geometry.

Suminarti et al. (2023) studied the effect of shading level on strawberry microenvironment. They found that solar radiation intensity was inversely proportional to the shading percentage; the unshaded treatment (control) received the highest solar radiation intensity of 1366 μmol m^{-2} s^{-1}, while the shaded treatment received 542, 432, and 334 μmol m^{-2} s^{-1} for the 25, 50, and 75 shading percentage, respectively. In a similar trend, they observed a reduction in air temperature as the shading percentage increased. However, this reduction in air temperature was not significant. Moreover, Friman-Peretz et al. (2020) reported a similar result of no significant differences in air temperature and humidity between shaded and unshaded treatments.

Dayrit et al. (2023) observed a reduction in water temperature and therefore an increase in dissolved oxygen under shading treatment compared to unshaded treatment. Also, Maestre-Valero et al. (2011b) demonstrated that as a results of reducing evaporation after using the shading cloths, the electrical conductivity was reduced due to the positive water balance. Moreover, they found a reduction in water turbidity and suspended particles under shaded treatment which reduces the need of filtering and emitter clogging risk, eventually, it improves water use efficiency especially when storing low-quality water under the shade (Maestre-Valero et al., 2011b). However, the ecological consequences of shade color and intensity on water quality and evaporation suppression are still an area in need of research. In our previous work (Albalasmeh et al., 2023), we introduced a novel approach to robust optimization in the context of shading types aimed to control the performance of water reservoirs. Our current study represents a significant advancement in the field of sustainable water resource management. By examining how the choice of shading cover color and intensity can impact both water conservation and quality, our work addresses a critical gap in current knowledge. Therefore, this study aims to evaluate the efficacy of shading in reducing evaporation rates (ER) from water reservoirs, primarily those used for agriculture. The study will also investigate the effectiveness of different cover colors (black, white, and green) and shading intensities (50, 70, and 90%), as well as examine some ecological and economic aspects.

Materials and methods

Study site

This experiment was conducted at the Agricultural Research and Training Directorate, Jordan University of Science and Technology (JUST), Ramtha, Jordan (32° 28′ 0.41" N, 35° 58′ 30.22" E) (Fig. 2), which took place from June 21st to September 30th 2022. The region experiences hot, dry summers, with a mean daily temperature range of 19–30 °C, and an average annual rainfall of 213.8 mm (Awawdeh et al. 2015).

Experimental setup

Three different shading intensities (50,70, and 90%) and colors (black, white, and green) have been used in addition to control (no shade cover). Each treatment was replicated three times. For this purpose, thirty class-A evaporation pans were manufactured at the JUST engineering workshop according to the guidelines of the U.S. National Weather Service. The pans were made of galvanized iron with a thickness of 0.119 mm, an internal diameter of 120.7 cm, and an internal depth of 25 cm. They were elevated on a platform that was 15 cm high to minimize energy exchange and equipped with scales for water height measurement.

At the beginning of the experiment, each evaporation pan was filled with water up to a depth of 20 cm from the bottom, as outlined by Abtew et al. (2011). Water replenishment was carried out weekly, with the water being sourced from an underground well with a pH of 8.3 and an electrical conductivity of 445 µS/cm. Twenty-seven of the evaporation pans were covered with a single layer of polyethylene shade cover, each with a different color and intensity and measuring 2 × 2 × 1 m in size. The shade cover was supported by a frame consisting of four metal rods, one meter in height above the ground, was fastened using cable ties, and had a front side that could be opened for measurement purposes (Fig. 3). To prevent the interaction effect between treatments, the pans were placed two meters apart from each other, and the appropriate distance was determined using Amethyst ShadowFx Software.

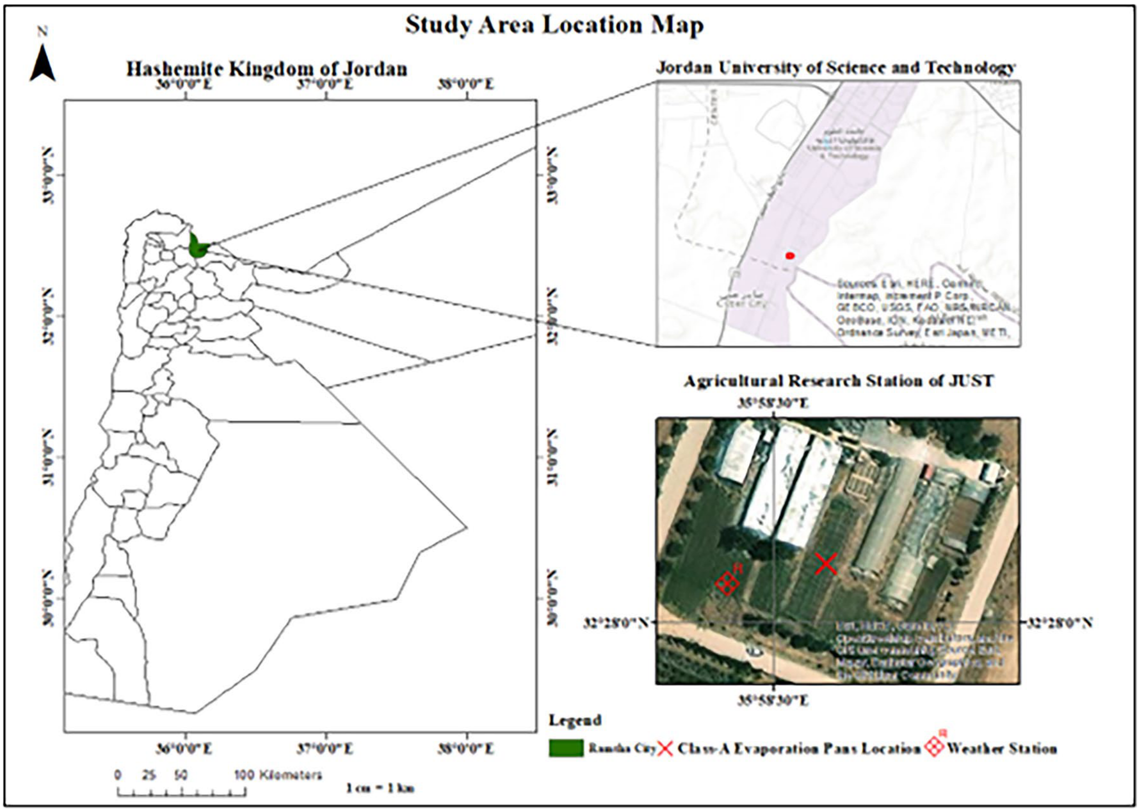

Fig. 2 Location of the study area; showing the experiment site where Class-A evaporation pans and the weather station were installed

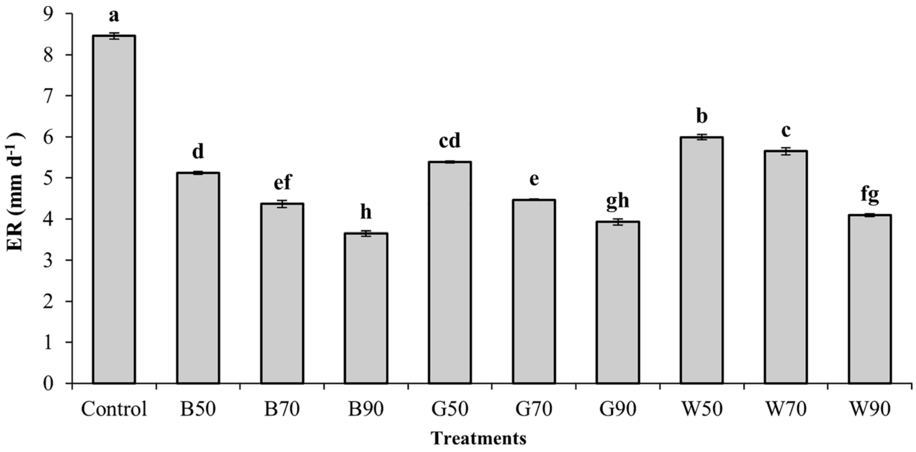

Fig. 3 Average evaporation rate (ER mm d^{-1}) from June to September for ten treatments. The treatments include Control (unshaded treatment), B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%). The error bar represents the standard error, and the letters **a**-**h** in the figure indicate statistically significant ranking order between the treatment means at a probability level of $\alpha < 0.05$

Evaporation measurement

Daily measurement of ER was carried out for both the shaded and the control pans. The ER was calculated daily by determining the difference in water levels of class-A pans between successive days using Eq. (1).

$$\mathrm{ER} = \mathrm{P} - \left(V_1 - V_2\right) \tag{1}$$

where V_2 represents the water depth (mm) on a particular day, V_1 represents the water depth (mm) on the previous day, and P represents the precipitation which was zero during the experimental period (Mekoya 2019).

Evaporation suppression efficiency (ESE) was calculated for the shaded pans using Eq. (2).

$$\mathrm{ESE}(\%) = \frac{\mathrm{ER}u - \mathrm{ER}c}{\mathrm{ERu}} \times 100\% \tag{2}$$

where ER_u is the daily evaporation of the control pan (mm d^{-1}), and ER_c is the daily evaporation of the covered pan (mm d^{-1}) (Abdallah et al. 2021).

Microclimate measurements

ATMOS 41 weather station (Meter group, Inc., USA) was installed two meters above the ground to monitor key climatic factors impacting evaporation (Meziani et al., 2020). The weather station measures air temperature, relative humidity, wind speed, solar radiation, and precipitation. The measurement of light intensity was conducted using the HOBO Temperature and Light Pendant data logger (Onset Computer Corporation, Bourne, MA, USA). The relative humidity and air temperature were measured using the HOBO MX2301A Temp/RH Data Logger (Onset Computer Corporation, Bourne, MA, USA). These measurements were taken beneath the shade cloth and for the control. The data loggers were positioned at the height of 0.5 m for ten treatments and set to a 10 min logging interval.

Vapor pressure deficit (VPD) was calculated using the following Eqs. (3, 4, 5) below:

$$e_\mathrm{s} = 611\exp\frac{17.27T_\mathrm{a}}{237.3 + T_\mathrm{a}} \tag{3}$$

$$\mathrm{RH} = \frac{e}{e_\mathrm{s}} \tag{4}$$

$$\mathrm{VPD} = e_\mathrm{s} - e \tag{5}$$

where e_s is the saturated vapor pressure (Pa), T_a is the average air temperature (°C), e is the actual vapor pressure (Pa), and RH is the average relative humidity (%) (Abtew & Melesse 2013).

Water quality analysis

Throughout the experimental period, various water quality parameters were measured directly in the field before and after refilling the pans. These parameters included pH, electrical conductivity (EC), dissolved oxygen (DO), and semi-quantitative measurement of chlorophyll-a in algal cells. In addition, the water temperature was measured at 9:00 AM daily (Table 1).

To assess changes in water quality, water samples with known volumes of 125 mL were collected periodically from

Table 1 Analysis and reference methods used to monitor different water quality parameters

Parameter	Unit	Method/Instrument	Reference
pH	–	pH meter	(Walk lab Ti 9000, Trans Instruments, Singapore)
EC	µS/cm	EC meter	(DDB-11A, Baoshishan, China)
DO	Mg L^{-1}	Dissolved oxygen meter	HOBO U26 Dissolved Oxygen data logger (Onset Computer Corporation, Bourne, MA, USA)
Water temperature	C°	Digital water thermometer	
Chlorophyll-a in algal cells (Field measurement)	–		AquaFluor Handheld Fluorometer/Turbidimeter, (Turner Designs, USA)
Chlorophyll-a in algal cells (Laboratory measurements)*	µg L^{-1}	UV/vis spectrophotometer	(Jones & Lee 1982)* (PhotoLab 7600 UV–vis, WTW GmbH, Germany)
Phosphate (PO_4^{3-}), nitrate (NO_3^-), and chloride (Cl^-)	mg L^{-1}	Test-kits	(WTW Spectroquant test kits, WTW GmbH, Germany)

*AquaFluor Handheld Fluorometer field readings are semi-quantitative, quantitative measurement of chlorophyll-a was performed following a simplified method derived from the (APHA) standard methods for the examination of water and wastewater (Jones & Lee 1982)

each pan at a depth 10–15 cm from the center of the pan, taking into consideration the initial values of the various water quality parameters. These samples were stored in a dark glass bottle. Subsequently, phosphate (PO_4^{3-}), nitrate (NO_3^-), chloride (Cl^-), and quantitative measurement of chlorophyll-a were analyzed (Table 1).

Economic viability

The amount of water lost (L^3) due to evaporation was estimated for each treatment by using the pan surface area and the corresponding evaporation rate values using the following equation:

$$V = \mathrm{ER} \times A \times T \tag{6}$$

where ER (L/T) is the evaporation rate, A is the pan's surface area in (L^2) and T (T) is time. The cost was calculated based on a useful life of ten years, which is the minimum guaranteed lifespan by the manufacturer for the shading covers. The cost of water was determined to be 0.7 USD/m^3 according to the MWI water prices in this area.

Statistical analysis

The means of three replicate samples for ER, ESE, and water quality measurements were determined, and error bars were included to show the standard error. Differences among the treatments were analyzed using the *R* software program. Firstly, analysis of variance (ANOVA) was performed to confirm the significant differences between the two groups with and without shading and among the nine groups with the shading of different colors and intensities. The values of *F* statistics were convincing enough to consider the impact. Then, at a 95% confidence level, Fisher's protected least significant differences (LSDs) identified the ranking order of treatment means, and the letters a-h in the figures indicate the statistically significant ranking order.

Results and discussion

Effect of suspended shade covers color and intensity on ER and ESE

The results indicate that during the hottest four months of the summer season (June to September), the shaded pans exhibited lower ER (Fig. 3) and higher ESE (Fig. 4) compared to the unshaded pans (Control). Notably, different ER and ESE values were detected within treatments under different shade cover colors and intensities. Particularly, the highest ESE of 56.8, 53.6, and 51.7 % were identified under 90% shading intensity for the black, green, and white covers, respectively.

At the same shading intensity, the lowest ER was observed in the black-shaded pans. Statistical analysis showed that the mean ER varied significantly between black-shaded and white-shaded pans under 50, 70, and 90% shading intensities, but not between black-shaded and green-shaded pans. This suggests that using black shading covers may be more effective in enhancing ESE than white covers, while green covers may have a comparable effect to black ones. In an outdoor evaporation pan, Alvarez et al. (2006) examined the efficacy of different single layers of polyethylene (PE) nets with a coverage percentage (CP) of 100%. They found that the green, black, and white covers resulted in ESE of 76.2, 75.1, and 54.7%, respectively. The decreased ESE observed for the white PE was attributed to a high percentage of transmitted radiation (61.1%) compared to the black (6.4%), and green (12.2%) PE nets. Moreover, the high emissivity of the black PE covers led to an increased condensation rate of water drops below the net.

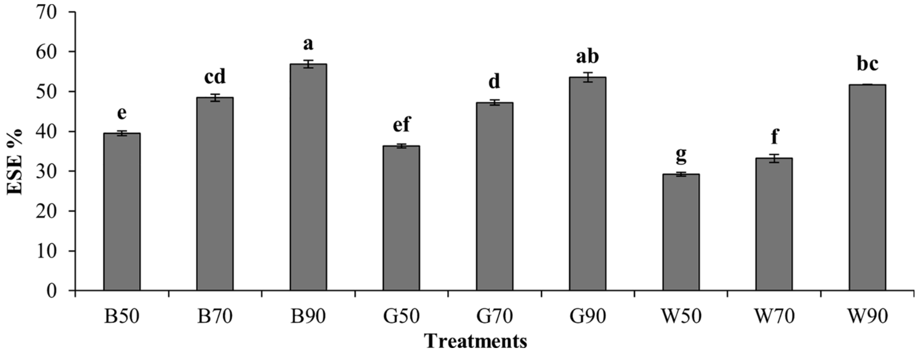

Fig. 4 Average evaporation suppression efficiency (ESE %) for nine shaded treatments, ranging from June to September, is presented. The treatments include B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%). The error bars represent the standard error, and the letters **a-g** in the figure indicate statistically significant ranking order between the treatment means at a probability level of $\alpha < 0.05$

Our results showed that as shading intensity increases, the ER decreases across all treatments of the same color. However, the ESE% was found to be lower than the corresponding shading intensity percentage across all treatments. This implies that a 90% shading intensity will not lead to 90% ESE. Several studies have highlighted the nonlinear correlation between shading intensity and ESE (Han et al., 2020; Lehmann et al., 2019; Rezazadeh et al. 2020). This relationship is influenced by factors such as climate conditions (wind and relative humidity), energy balance, and cover geometry (Ruskowitz et al. 2014). The lower ESE observed in our experiment compared to Alvarez et al. (2006) may be attributed to the aforementioned factors. For instance, in our study, shading covers were used to enclose the evaporation pans to measure the ER beneath the shade instead of suspending them directly above the pan surface. However, this installation method could be impacted by wind speed, which might result in decreased ESE.

Effect of suspended shade cover on microclimatic variables

The daily changes in the key climatic variables that impact the evaporation process, such as air temperature, RH, wind speed, and solar radiation, are depicted in Fig. 5. Notably, no rainfall was recorded throughout the research period from June to September.

The suspended shade covers can modify the physical properties of water or the water's surface environment, reducing the evaporation rate (ER) in the area below the shading cover (Han et al., 2020). Meanwhile, Nguyen et al. (2020) found that ER tends to increase as air temperature rises and RH drops. The study observed a higher RH percentage under the shade cover compared to the control. Moreover, all treatments led to a decrease in air temperature except for the white 90% treatment (Table 2). Although there were variations in air temperature and RH among the treatments, they were not statistically significant. It is worth noting that air temperature and RH do not have the same impact on the ER, as vapor pressure deficit (VPD) plays a more crucial role in water evaporation (Meziani et al., 2020).

In the treatments with black shading, the 90% shading intensity treatment exhibited the highest VPD but the lowest ER. Interestingly, in the white 90% treatment, the VPD was higher (2753 Pa) compared to the control (2749 Pa), but its ER was only half of the control (Table 2). However, managing the process of evaporation involves a comprehensive approach that encompasses climatology, hydraulics, and material science (Li et al. 2021).

Effect of shading on water quality

While several studies have examined the high ESE of suspended shading covers, few have investigated its ecological impact on water quality. Therefore, we monitored various water quality parameters during the implementation of the shading covers experiment, such as water temperature, dissolved oxygen (DO), light intensity, chlorophyll-a concentration (Ch-a), pH, electrical conductivity (EC), nitrate, phosphorus (as orthophosphate), and chloride concentration. The average water temperature for all treatments is depicted in Fig. 6. Notably, the white 70% treatment recorded the highest water temperature. However, there were only minor variations in water temperature among the other treatments. We attribute these slight differences to the type of shading material used. Because of the unavailability of the same shading cover material, insect cloth with 70% intensity was used.

According to Rezazadeh et al. (2020), under windy conditions, the water temperature under the black cover was 2.5 °C colder than under the white cover. However, without the wind effect, the water temperature was warmer

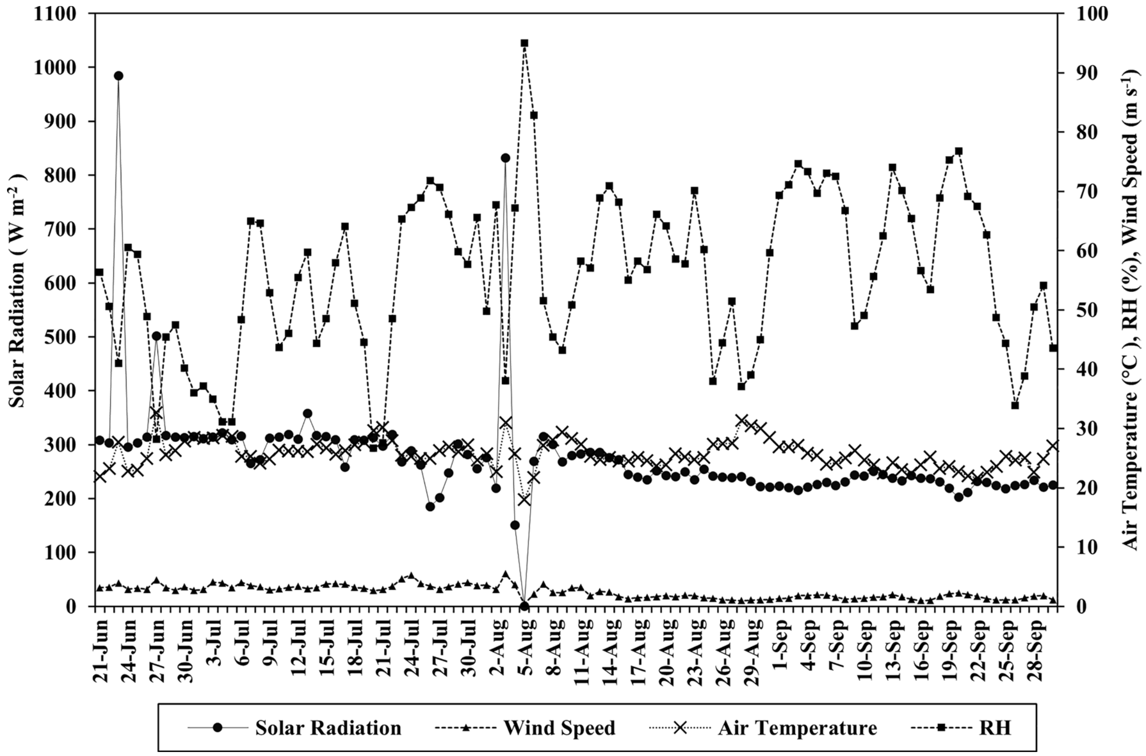

Fig. 5 Atmospheric weather data including air temperature (°C), relative humidity RH (%), wind speed (m s^{-1}), and solar radiation (W m^{-2})

Table 2 Average evaporation rate, air temperature, relative humidity, and vapor pressure deficit for all treatments

Treatments	T_a (°C)	RH (%)	VPD (Pa)	ER (mm d^{-1})
Control	31.5	40.5	2749	8.5
B50	29.6	43.7	2334	5.1
B70	30.7	43.1	2513	4.4
B90	30.5	42.5	2516	3.6
G50	30.2	43.3	2431	5.4
G70	30.8	42.0	2583	4.5
G90	30.1	43.7	2396	3.9
W50	31.4	41.8	2677	6.0
W70	30.9	42.4	2569	5.6
W90	31.6	40.9	2753	4.1

ER: Average evaporation rate (mm d^{-1}), T_a: air temperature (°C), RH: relative humidity (%), and VPD: vapor pressure deficit (Pa)

The treatments include control (unshaded treatment), B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%)

under the black cover. These findings highlight the dynamic effect of the shade cover which is strongly influenced by the surrounding environment (Abdallah et al. 2021). In multipurpose reservoirs, the impact of shade covers on water temperature is a significant concern due to potential adverse effects on the water ecosystem and its biological heath (Rezazadeh et al. 2020). Changes in water temperature can particularly affect dissolved oxygen (DO), which is a crucial factor for the aquatic system (El Baradei and Al Sadeq, 2020).

Figure 7 shows the DO concentration and water temperature for one week, which were recorded by a DO data logger at one-minute logging interval. DO measurement was available for black 70% shading intensity only. On September 19th, the minimum DO concentration was 6.94 mg L^{-1}, while the maximum DO concentration of 11.5 mg L^{-1} was recorded on September 21st. This significant increase could be attributed to the water refill in the pan that occurred on September 20th. However, DO concentrations above the critical level of 4.5 mg L^{-1} suggest good water quality in an aquatic ecosystem (Banerjee et al. 2019).

The quality of water in aquatic bodies is greatly influenced by the extent to which light penetrates and is attenuated within them (Stefan et al. 1983). Additionally, this light penetration has an impact on the growth and nutrient uptake of algae in the water (Meseck et al. 2005). The impact of light on aquatic life is well established, as covering the surface of the water will alter the intensity of light and subsequently affect its aquatic life (El Baradei and El Sadeq, 2020). During daylight time (6:00:00 AM–6:00:00 PM), the average light intensity (Lux) was recorded for the treatments. Overall, the

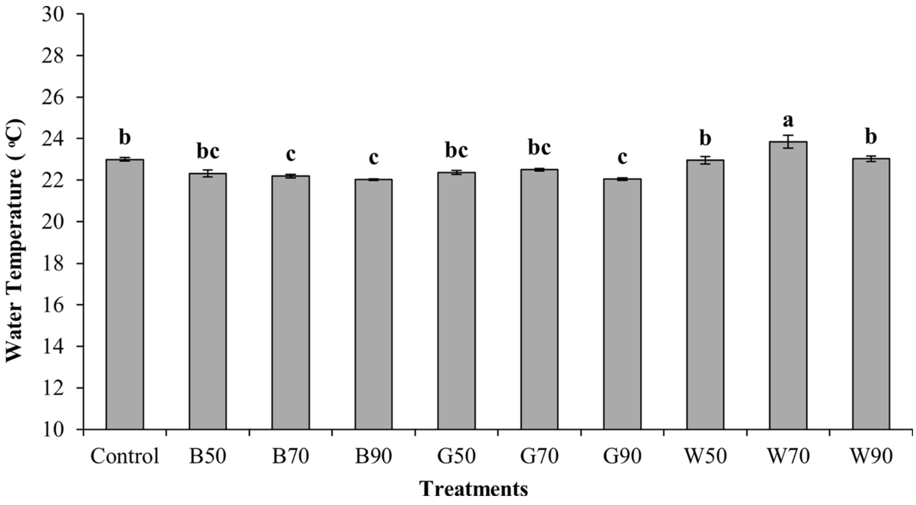

Fig. 6 Average water temperature (°C) for all treatments at 9:00 AM from June to September. The treatments include Control (unshaded treatment), B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%). The error bar represents the standard error, and the letters **a**-**c** in the figure indicate statistically significant ranking order between the treatment means at probability level of $\alpha < 0.05$

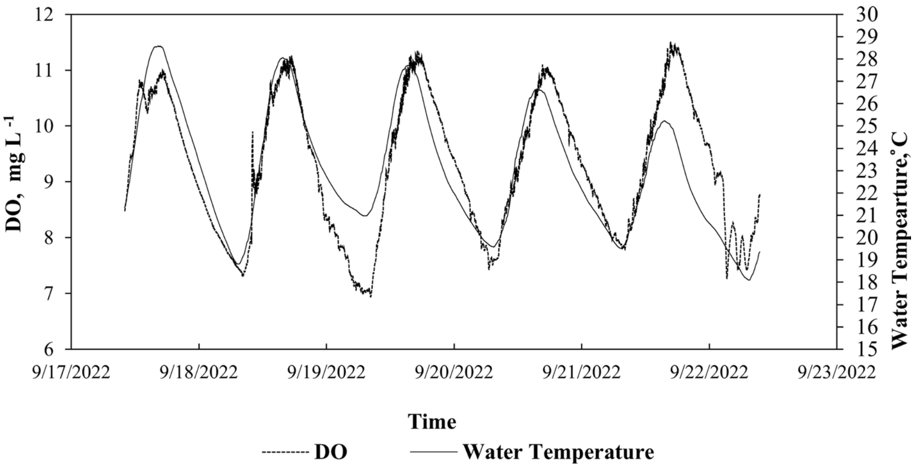

Fig. 7 One-week measurements of dissolved oxygen DO (mg L^{-1}), and water temperature (°C) for treatment black 70%. Recorded with one-minute logging interval

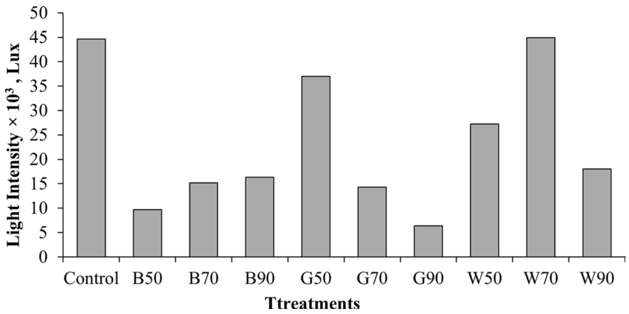

Fig. 8 The average light intensity (Lux) for ten treatments during daylight time (6:00:00 AM–6:00:00 PM). The treatments include Control (unshaded treatment), B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%)

shaded treatment resulted in a decrease in light intensity compared to the control. However, it is worth noting that an exception to this trend was observed in the white 70% treatment.

Figure 8 shows that among the black-shaded pans, black 90% showed the maximum light intensity of 16.3×10^3 (Lux). In contrast, in green-shaded pans, green 50% showed the highest light intensity of 37.0×10^3 (Lux). In terms of ESE, no significant differences were observed between black 90% and green 90% treatments. However, the light intensity was 2.5 times higher in black 90% than in green 90%.

As mentioned before, the reduction of light intensity caused by covering the water's surface can negatively impact aquatic organisms. To monitor the growth of algal cells, chlorophyll-a concentration (Ch-a) was measured throughout the entire period. The highest Ch-a concentration of 66.39 μg L^{-1} was observed in treatment with 50% white coverage. However, it is important to note that the differences in Ch-a concentration among the treatments were not statistically significant (Fig. 9).

It is noteworthy that the white 50% treatment exhibited rapid algal growth, which was accompanied by the presence of numerous air bubbles in the water. These observations may indicate the presence of different algal species in the

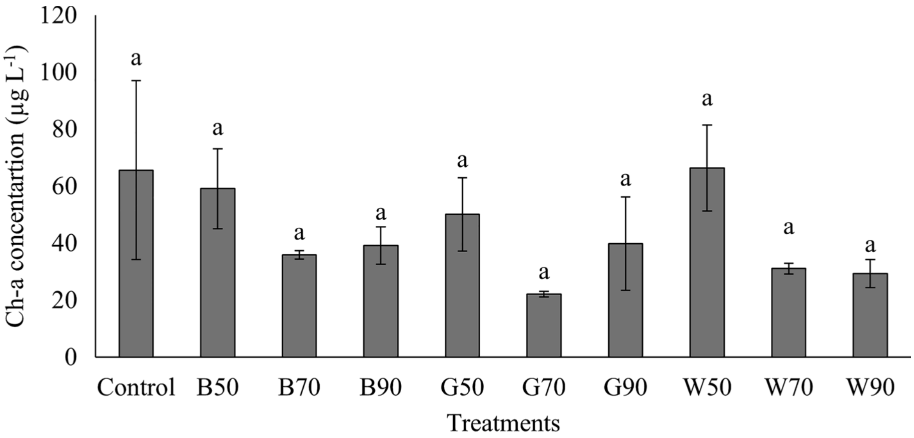

Fig. 9 Average Chlorophyll-a concentration in algal cells. The treatments include Control (unshaded treatment), B50 (black 50%), B70 (black 70%), B90 (black 90%), G50 (green 50%), G70 (green 70%), G90 (green 90%), W50 (white 50%), W70% (white 70%), and W90 (white 90%). The error bar represents the standard error and the letter a in the figure indicates no significant statistical ranking order between the means of treatments at probability level $\alpha < 0.05$

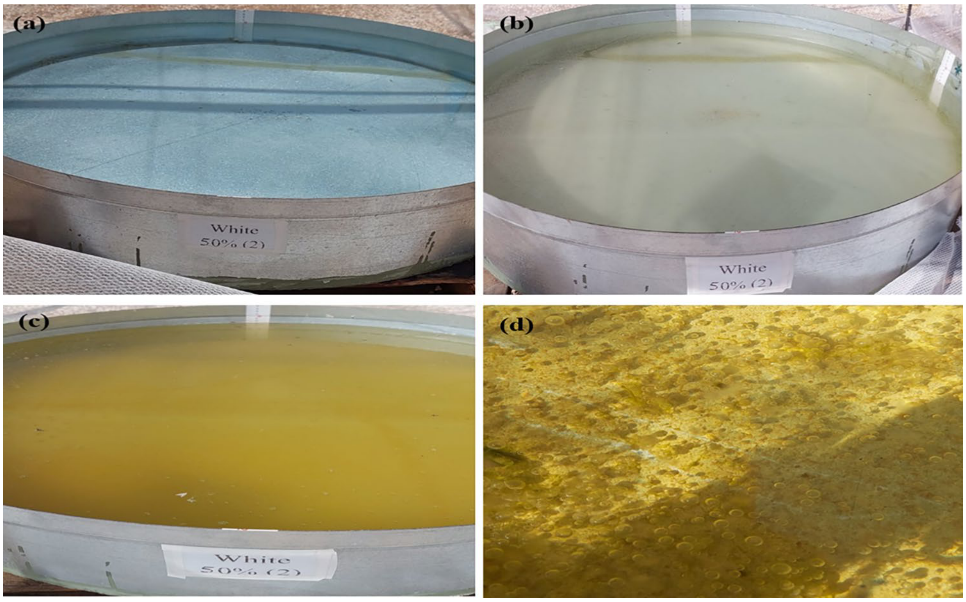

Fig. 10 The progression of algal cells growth in the same replicate of the white 50% treatment. **a** the pan's water at the beginning of the experiment **b** after one week **c** after three weeks and d the air bubbles observed after one month

water. Figure 10 depicts the changes in water that occurred due to the increase in the algal cells in the same replicate of the white 50% treatment; (a) shows the pan's water at the beginning of the experiment (b) shows the water after one week (c) shows the water after three weeks and (d) shows the air bubbles that were observed after one month. This finding may be of interest to farms that utilize water reservoirs for multi-purposes, including irrigation and aquaculture.

Table 3 presents the average pH, EC, nitrate, phosphate, and chloride concentrations in all treatments. The principal component analysis (PCA) for the average values of ER, EC, pH, nitrate, and chloride, shown in Tables 2 and 3, resulted in the first principal component $0.417 \times \text{ER} + 0.479 \times \text{EC} - 0.472 \times \text{pH} + 0.485 \times \text{nitrate} + 0.373 \times \text{chloride}$ (Fig. 11), indicating almost equal significance of ER and those water quality parameters in explaining the different effects of the shading treatments. The measured values were compared to the Jordanian Standards for Irrigation Water (JSMO 2006) and the guidelines for irrigation set forth by the Food and Agriculture Organization (FAO) (Ayers & Westcot 1985).

The main water source used to fill the pans had an initial pH value of 8.3. The pH value increased in all treatments, including the control, and ranged between 8.8 and 9.0. This increase suggests that factors other than the shading contributed to the pH increment. Nonetheless, the recorded values remain within the Jordanian standards for irrigation range (6.0–9.0) but are slightly above the FAO range (6.0–8.5). Throughout the entire experimental period, phosphorus was below the detection limit of 0.05 g L^{-1}. The shaded treatments showed a decrease in EC and nitrate concentration compared to the control, except for the white 70% treatment. Under the black-shaded treatments, the concentration of chloride increased as the shading intensity increased, whereas the opposite trend was observed in the green and white covers. Nonetheless, all measurements met both the Jordanian and FAO standards for irrigation

Table 3 The concentrations of various water quality parameters (pH, EC, nitrate, phosphate, and chloride) in all treatments

Treatment	EC (µS/cm)	pH	Nitrate (mg L^{-1})	Phosphate[a] (mg L^{-1})	Chloride (mg L^{-1})
Control	725.6	8.8	11.40	<0.05	64.67
B50	625.4	8.9	9.35	<0.05	44.83
B70	631.3	9.0	9.15	<0.05	50.00
B90	558.5	9.0	7.60	<0.05	50.50
G50	686.0	8.9	9.97	<0.05	60.58
G70	650.4	8.9	9.50	<0.05	60.50
G90	624.9	9.0	8.45	<0.05	59.58
W50	658.0	8.9	10.80	<0.05	70.92
W70	775.7	8.8	12.73	<0.05	75.33
W90	607.2	9.0	7.99	<0.05	62.42
Jordanian standards for irrigation (JSMO 2006)	2340	6.0–9.0	70		0–400
FAO guidelines for irrigation (Ayers & Westcot 1985)	0–3000	6.0–8.5	0–620[b]		0–1050[b]

a The detection limit of phosphate is 0.05 for phosphate Test-Kits (WTW Spectroquant test kits, WTW GmbH, Germany)

b According to FAO guidelines for irrigation (Ayers & Westcot 1985), the allowable concentration of nitrate is (0–10) meq L^{-1}, and for chloride is (0–30) meq L^{-1}

water. In general, the same trend was observed for both the EC and the nitrate concentration, with a strong correlation of 0.9125 Pearson correlation coefficient. The black 90% treatment showed a minimum EC of 558.5 µs/cm and a nitrate concentration of 7.6 mg L^{-1}. These results could be attributed to the lowest ER rate of 3.6 mm d^{-1} recorded in the same treatment.

Economic viability

The economic viability of implementing shade covers can be assessed by considering various factors (Abdallah et al. 2021). One such factor is the increase in ESE, which in turn increases the value of the saved water, ultimately contributing to the economic efficiency of the investment (Martínez Alvarez et al. 2009). The economic feasibility of shade covers is not only based on the value of water saved but also on the potential increase in crop production and farmland extension, which can be affected by the availability of water (Han et al., 2020). However, in areas with scarce water resources, the rising water cost may also affect farmers' decision-making. Molle et al. (2008) suggested that farmers must reconsider the benefits and risks associated with using shade covers in areas with higher water prices. Other factors that can affect economic feasibility include maintenance costs and the expected lifespan of the shading cover. A shading cover that requires frequent maintenance or needs to be replaced after only a few years may not be economically viable in the long run, even if it saves water in the short term. Therefore, it is important to consider all of these factors when evaluating the economic feasibility of using shading covers in agriculture (Martínez Alvarez et al. 2009; Martínez Álvarez et al. 2006).

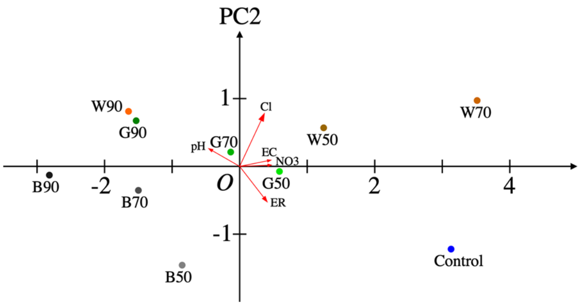

Fig. 11 Biplot for the principal component analysis (PCA) for the average values of ER, EC, pH, nitrate, and chloride

It appears that the cost of installing the shade covers may be high, but it is justified by the benefits that result from the increase in the amount of water saved. The manufacturer guarantees a lifespan of at least ten years for the shading covers, so the cost was estimated over that period. Although the cost includes the shading cover, supporting structure, and labor costs, the benefits resulting from the increased water savings over ten years make the installation of these covers economically feasible.

Conclusion

In this study, we conducted a comprehensive assessment of the impact of varying shading cover colors and intensities on water evaporation rates and water quality parameters.

Our findings provide valuable insights into the complex dynamics between shading cover configurations and their consequences for both water conservation and water quality. Our investigation revealed that shading cover color and intensity significantly affect water evaporation rates. Specifically, 90% shading intensity for the black, green, and white shade covers had the highest ESE of 56.8, 53.6, and 51.7%, respectively. These findings have direct implications for water resource management, where the reduction of evaporation losses is of paramount importance. We also examined the influence of shading covers on water quality parameters. Our analysis of water quality parameters (EC, nitrate, phosphate, and chloride) demonstrated notable variations under different shading cover conditions. Importantly, these changes generally remained within acceptable ranges for standards for irrigation water, suggesting that the adoption of shading covers can effectively reduce evaporation without compromising water quality. Throughout the entire experimental period, phosphorus was below the detection limit of 0.05 g L^{-1}. The shaded treatments showed a decrease in EC and nitrate concentration compared to the control. The concentration of chloride increased as the shading intensity increased under black covers, whereas the opposite trend was observed in the green and white covers. EC and the nitrate concentration showed a strong correlation of 0.9125 Pearson correlation coefficient. The black covers 90% treatment showed a minimum EC of 558.5 µs/cm and a nitrate concentration of 7.6 mg L^{-1}. While the economic feasibility of deploying shading covers appears justifiable, given their potential benefits in bolstering crop production and expanding farmland utility, careful consideration should be given to selecting the most suitable shading cover type. This selection process should also account for the versatile use of agricultural reservoirs, including applications such as aquaculture. We recommend further studies to explore the full potential of shading covers at the reservoir scale, ensuring a more comprehensive understanding of their multifaceted impacts on agriculture and water resource management.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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