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Impact of colored water pillows on yield and water productivity of pepper under greenhouse conditions

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ABSTRACT

This study was conducted to investigate the effects of colored water pillows on yield and water productivity of two pepper cultivars under greenhouse conditions in 2018 and 2019. Irrigation treatments were arranged as: drip without mulching, black water pillow, blue water pillow, drip + black mulching and drip + blue mulching. The first year, total plant water consumption amount was about 421 mm for drip and 301 mm for the other treatments and respectively as 439 and 305 mm in the second year. In both years, approximately 38% less water was applied in water pillow irrigation treatments. Significant differences were not observed in yields of water pillow and drip + mulching treatments, but drip irrigation treatments were found to be significantly different from the other treatments in both years. For Captain capia and Yellow Stone chili pepper cultivars, as the average of two years, the highest yields were obtained from water pillow treatments as 39.65 and 32.3 t ha^{-1}, respectively, and the lowest yields were obtained from the drip irrigation treatments as 28.9 and 22.7 t ha^{-1}. There were significant differences in irrigation water productivity (IWP) and water productivity (WP) values of drip irrigation and the other treatments. For Captain capia and Yellow Stone chili pepper, as the average of two years, the highest IWP values were obtained from the water pillow treatments as 121.3 and 96.8 kg ha^{-1} mm^{-1}, and the lowest IWP value was obtained from the drip irrigation treatments as 65 kg ha^{-1} mm^{-1}. Similarly, the highest WP values were obtained from the water pillow treatments as 129.5 and 103.25 kg ha^{-1} mm^{-1}, and the lowest WP value was obtained from the drip treatments as 52.5 kg ha^{-1} mm^{-1}. A great energy saving was achieved with water pillow method. The amount of energy used in water pillow was about 2% and 5% of the energy used in drip and drip + mulching treatments, respectively. In both years, water pillow and drip + mulching treatments had higher soil temperatures than drip treatment as 1.3 °C. Weeds were not encountered in water pillows and drip + mulching treatments. In conclusion, present findings revealed that water pillows were clearly superior to drip irrigation. Although yield values of water pillows and drip + mulching treatments were not significantly different, no extra energy demand, inherent mulching characteristics and quite low labor costs have made water pillows more advantages over drip + mulching treatments.

1. Introduction

Pepper is largely grown worldwide and consumed in various ways. In 2018, world annual pepper production was 36.4 million tons and annual pepper production of Turkey was 2.7 million tons (Anonymous, 2020a, 2020b). Irrigation is the primary input in agricultural production activities to increase yield levels. Quite higher irrigation efficiencies and yields are achieved when drip irrigation was used together with mulching (Paul et al., 2013). Mulch is defined as organic or inorganic materials covering the soil surface and it has several benefits in agricultural production activities (Ramakrishna et al., 2006). Mulching prevents evaporations from the plant root zone, thus allows more efficient use of irrigation water, decelerates upward movement of salts at different depths of soil profile, thus prevents salinity formation in soils (Qi et al., 2018), prevents weed growth and development (Nwosisi et al., 2019). Mulching also protects soils against water and wind erosion (Cong et al., 2016), reduces direct exposure to sunlight and keeps soil moisture, thus stimulates soil biological activity (Jabran, 2019). Organic mulching materials decompose in time and thus improve soil physical, chemical and biological characteristics and enrich soils in hu-

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mus and organic matter (Ranjan et al., 2017). Dark-color mulching materials increase soil temperature, then improve root development, yield and quality (Tegen et al., 2015). Since the soil is continuously moist, plants spend less energy for water intake and such a case then reflects in yield and quality (Fan et al., 2016). Since soil moisture is kept for a long time within the root zone, total irrigation water quantity is reduced and irrigation interval is increased (Schonbeck and Evanylo, 2008). Colored plastic mulching materials have positive effects on plant yield and quality (Franquera and Mabesa, 2016).

Water pillows are combined application of drip and mulching and offer the benefits of both drip and mulching with a single system (Gerçek, 2006). Resistant and soft plastic pipes are so called as water pillows. Diameters of the pipes change based on plant row spacing. Water plows are placed between the plant rows. Seepage holes (1 mm in diameter) are provided along the center line of the bottom surface of the pipes in contact with soil surface. Hole spacing varies between 50 and 100 cm based on plant species. Water is filled into plastic pipes, then head and end sections are knotted tightly. Water infiltrates from the holes into the soil profile with gravity. There is no need for an extra pressure supply as it was in drip irrigation. A descending flow regime is demonstrated based on the amount of water in pillow. Since irrigation water is filled into plastic water pillows, there is no direct contact of water with the soil, thus soil erosion is not experienced in this method as it was in surface irrigation methods. Although this novel irrigation method is quite similar to drip irrigation, there is no need for extra pressure for the operation of the system. Therefore, the method is quite a hybrid of pressurized irrigation and surface irrigation methods (Gerçek et al., 2017).

In previous studies, water pillows were compared to furrow irrigation and superior yield, water use efficiency, weed control and economics of water pillows were put forth in soybean (Gerçek et al., 2009a), pepper (Gerçek et al., 2009b) and maize (Gerçek and Okant, 2010). Later on, drip and drip + mulching treatments were compared in tomato (Gerçek et al., 2017; Altunlu et al., 2017) and eggplant (Gerçek and Demirkaya, 2020). Those studies revealed the advantages of drip + mulching treatments in terms of yield, efficient water use, weed control, irrigation labor, energy consumption and irrigation economics. The Yellow Stone chili pepper (*Capsicum annuum* L. cv. Chili var. Yellow Stone) is a medium-early cultivar and has strong plant structure. Captain capia pepper (*Capsicum annuum L.* cv. Capia var. Captain) has a thick fruit flesh and used either for fresh consumption or paste and canned food production.

The effects of colored water pillows on Captain capia and Yellow Stone chili pepper cultivars have not been investigated, before. Therefore, this study was conducted to investigate the effects of blue and black water pillows on yield and water use efficiency of Yellow Stone chili pepper and Captain capia pepper cultivars. Drip + blue and black mulching treatments were compared with single drip irrigation treatments under greenhouse conditions.

2. Material and method

2.1. Experimental site

Experiments were conducted in 10 × 20 m, Venlo-type, East-West oriented polycarbonate greenhouse of the Experiment and Research Center at Safiye Çıkrıkçıoğlu Vocational Collage of Erciyes University between May–November of 2018 and 2019. The greenhouse is geographically located between 38° 42′ N Latitude and 35° 31′ E Longitudes and has an altitude of 1101 m. Terrestrial climate with cold and snowy winters and hot and dry summers is dominant in the region. Greenhouse indoor temperatures and relative humidity values in 2018 and 2019 were measured hourly with Testo-175 data logger placed 1 m above the ground in the middle of the greenhouse (Table 1). Disturbed and undisturbed soil samples were taken from 0 to 30 and 30–60 cm soil depths and physico-chemical analysis results are provided in Table 2.

2.2. Experimental design

Each experimental plot had 3.3 × 4.2 m dimensions and 4 rows with 32 plants. There were 5 different irrigation treatments: regular drip irrigation, black water pillow, blue water pillow drip + black mulching and drip + blue mulching. Seedlings were planted in double rows with 60 cm row spacing, 50 cm on-row plant spacing and 90 cm double-row spacing (90 × 60 × 50 cm). To prevent interactions, 120 cm spacing was provided between the treatments (Fig. 1). The rooted seedlings with equal sizes and 7–8 true leaves were used. Seedlings were planted on 17th of May in the first year and 11th of May in the second year. In both years, a total of 25-mm irrigation water was applied to all seedlings in 3 day intervals to have a better seedling development throughout the initial growth stages. The cultural practices performed throughout the experiments are provided in Table 3. Experiments were conducted in randomized blocks design with four replications.

2.3. Irrigations and measurements

In drip irrigation treatments, in-line drippers with a discharge of 4 L h-1 were spaced 30 cm apart within the lateral lines. In drip + mulching treatments, two lateral lines were placed beneath the mulching materials covering the entire plot surface. For the water pillow treatments, soil surface was leveled to get an equal water distribution. In the water pillow treatments, two elastic plastic pipes were used and the space between the rows was covered with the same color mulching material. In other words, both in drip + mulching treatments and water pillow treatments, soil surface was fully covered with mulching materials. The UV-reinforced plastic pipes of mulching and water pillow treatments had a wall thickness of 0.3 mm. In plastic

Table 1
- Average monthly greenhouse indoor temperature and relative humidity values.

Months	Years	May	June	July	August	September	October	November
Temperature, °C	2018	21.2	24.2	27.5	25.9	22.7	16.5	12.1
	2019	21.8	24.9	24.3	24.6	21.5	17.2	13.1
Relative humidity, %	2018	62.2	56.7	52.2	49.3	44.8	50.8	64.3
	2019	59.8	56.7	48.9	47.1	46.4	51.3	54.7

Table 2
Some physical and chemical characteristics of the greenhouse soil.

Soil depth, cm	Texture	FC, %	PWP, %	pH	Bulk density, g cm^{-3}	EC., dS m^{-1}	Lime, %	OM., %	K_2O kg ha^{-1}	P_2O_5 kg ha^{-1}
0–30	Loamy	26	12	7. 9	1.39	0.41	7.02	3.95	5.87	1.88
30–60	Loamy	25	12	7. 8	1.41	0.56	7.41	4.35	5.36	1.09

FC: field capacity; PWP: permanent wilting point; EC: electrical conductivity; OM: organic matter.

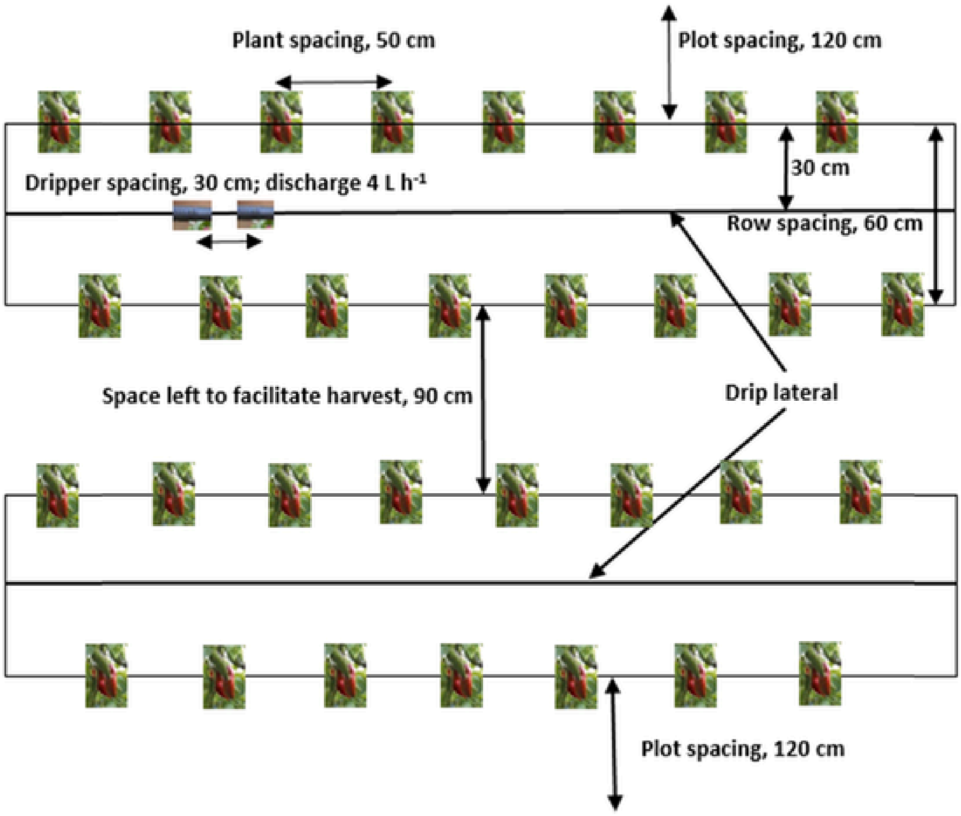

Fig. 1. Drip irrigation design.

Table 3
Cultural practices performed in both years.

Process		2018	2019
Initiation of irrigation treatments		11 June	04 June
Number of irrigations	Drip	29 times	32 times
	Water pillow and drip + mulching	15 times	16 times
First harvest	Yellow Stone chili	16 July	12 July
	Captain capia	24 July	19 July
Last harvest	Yellow Stone chili	12 Nov.	15 Nov.
	Captain capia	06 Nov.	13 Nov.
Number of harvests	Yellow Stone chili	14 times	16 times
	Captain capia	13times	15 times

pipes installed in water pillow treatments, 1 mm diameter holes were opened along the middle bottom section at 50 cm spacing. Irrigation water infiltrated into the soil through leakage from these holes. Initial maximum flow rate of these holes was 2.12 L h^{-1} and such a value decreased in time based on hydraulic load in plastic pipe. Such a case resulted in having shallow root distribution in water pillow treatments. Since drip treatments had a constant dripper discharge, irrigation water infiltrated deeper in soil profile than the water pillow treatments. Irrigation interval was selected as 5 days in drip treatments and 10 days in water pillows and drip + mulching treatments (Gerçek et al., 2017). Mulching materials for the drip treatments and plastic pipes of water pillows were placed on 10th of June in the first year and 4th of June in the second year.

Soil moisture before the irrigation was determined gravimetrically with the use of Eq. (1) and deficit water within the root zone was brought to field capacity. In drip treatments, wetted area percentage (P) was taken as 33% (Yıldırım, 2008). The amount of applied irrigation water was measured with a precise water flow meter and recorded. Irrigation water electrical conductivity was 0.4 dS m-1 and pH value was 7.78. Irrigation water class was C_2S_1 (FAO, 1985). Waters in this class can be used without special measures to irrigate moderately salt-tolerant crops on soils with good permeability.

Water productivity (WP) and irrigation water productivity (IWP) were calculated with the use of Eqs. (2) and (3) (Howell et al., 1990), seasonal plant water consumption was calculated with the use of Eq. (4) (Doorenbos and Kassam, 1986). Since experiments were conducted under greenhouse conditions and irrigation water requirement for 0–60 cm soil profile was provided in a measured fashion and irrigations were performed through drip lines and water pillows, precipitation, deep percolation and surface runoff were not taken into consideration in the following equations. Then, Eq. (4) was rearranged as Eq. (5).

$$Daw = [(FC - \boldsymbol{\theta}_i) \times Db \times d \times P]/100 \quad (1)$$

$$WP = Y/ET \quad (2)$$

$$IWP = Y/I \quad (3)$$

$$ET = I + P + D_p + R_{off} \pm \Delta S \quad (4)$$

$$ET = I \pm \Delta S \quad (5)$$

Where; Daw is the net irrigation water quantity to be applied in each irrigation (mm); FC is the field capacity (%); $\boldsymbol{\theta}_i$ is the currently available moisture (%); P is the wetted area percentage (%); Db is the soil bulk density (g cm^{-3}); d is the soil depth to be wetted (mm); WP is the water productivity (kg ha^{-1} mm^{-1}); Y is the marketable yield per hectare (kg ha^{-1}); ET is the evapotranspiration (mm); IWP is the irrigation water productivity (kg ha^{-1} mm^{-1}), I is the irrigation water quantity (mm), P is the precipitation (mm), D_p is the deep percolation (mm), R_{off} is the surface runoff (mm), ΔS is the change in soil moisture (mm).

2.4. Biomass parameters

In both years, harvests were practiced in every 10 days. Plant and fruit samples were taken from twelve plants in the middle two rows, then fruit weight and number of fruits were determined. Yield per plant (g plant^{-1}) and number of fruits per plant were determined from twelve plants per treatment. Total yield (kg ha^{-1}) and number of fruits per m^2 were calculated.

2.5. Soil thermometer

Soil thermometer, TES-1307 data logging K/J thermometer, was installed at 10 cm depth. Soil temperature measurements were performed two days after the irrigations.

2.6. Weeds measurements

Weeds were counted only in drip treatments. To do this, 1 m^2 plot area was designated, weeds growing in this area was cut and weighed, then they were dried at 70 °C for 48 h and reweighed (Gerçek et al., 2017).

Experimental data were subjected to analysis of variance with the use of "SSPS13.0 for Windows" software and significant means were compared with the use of LSD (Least Significant Difference) test at 5% significance level.

3. Result and discussion

3.1. Yields

Yield values of pepper cultivars are provided in Table 4. In the first year, the highest yield in Captan capia peppers was obtained from drip + blue mulching treatments (38.7 t ha^{-1}) and the highest yield in Yellow Stone chili peppers was obtained from blue water pillow treatments (33.8 t ha^{-1}). The lowest yields in both pepper cultivars were obtained from drip irrigation treatments (27.3 and 22.0 t). Black and blue water pillow treatments had about 35% greater Captain capia pepper yields than drip treatments. Such a difference was 36% in drip + black and blue mulching treatments. A similar case is also valid for Yellow Stone chili pepper cultivar. Black and blue water pillows, drip + black and blue mulching treatments had around 44% greater yield per hectare values than drip treatment. In the second year, the highest yields were obtained from black water pillow treatments (42.7 t ha^{-1}) in Captain capia peppers and from drip + black mulching treatments (31.7 t ha^{-1}) in yellow stone chili peppers. As it was in the first year, the lowest yields in both cultivars were obtained from drip irrigation treatments (30.5 and 23.4 t). As compared to drip irrigation, in Captain capia pepper cultivar, a yield increase of 37% was achieved with black and blue water pillows and a yield increase of 31% was achieved with drip + black and blue mulching treatments. Such increases in Yellow Stone pepper cultivar were respectively measured as 32% and 31%.

Black and blue water pillow and drip + black and blue mulching treatments clearly had quite greater yield per plant, number of fruits per plant and m^2 values than drip treatments. It was clear that drip treatments had quite lower yields than other treatments and significantly different values.

As the average of two years, the highest yields in Captain capia and Yellow Stone chili pepper cultivars were obtained from water pillow treatments, respectively with 39.2 and 31.3 t ha^{-1}. Such yield values were about 2% greater than the yields in drip + mulching treatments. The difference was quite small and insignificant ($p < 0.05$). Effects of black and blue colors on yield were not significantly different. However, mean yields in black color treatments were about 2% higher than the yields in blue color treatments. Such a case indicated that black and blue water pillows had similar effects on soil and plants with drip + black and blue mulching treatments. The difference in yields of Captain capia and Yellow Stone chili peppers was attributed to cultivar characteristics.

Yield increase in colored water pillows and drip + colored mulching treatments was mostly resulted from mulching effects. Such increases in yields were mostly attributed to mulching materials since plastic mulching covered the entire soil surface, prevented moisture loss (Zhanga et al., 2017), increased soil temperature (Zhao et al., 2012), suppresses weed growth (Li et al., 2020), improved microbial activity

Table 4
Effects of irrigation treatments on pepper yield components in 2018 and 2019.

Peppers	Treatments and years		Yield per hectare, t ha^{-1}	Yield per plant, g plant^{-1}	Number of fruits per plant, fruit plant^{-1}	Number of fruits per unit area, fruit m^{-2}	IWP, kg ha^{-1} mm^{-1}	WPkg ha^{-1} mm^{-1}
Captain capia	Drip	2018	27.3^b	1023^b	11^b	28^b	62^b	65^b
		2019	30.5^b	1145^b	11^b	30^b	68^b	70^b
	Black water pillow	2018	36.6^a	1374^a	15^a	38^a	115^a	122^a
		2019	42.7^a	1602^a	16^a	41^a	130^a	140^a
	Blue water pillow	2018	36.8^a	1381^a	15^a	39^a	116^a	122^a
		2019	40.8^a	1530^a	15^a	40^a	124^a	134^a
	Drip black mulching	2018	35.2^a	1320^a	14^a	37^a	111^a	117^a
		2019	39.5^a	1481^a	15^a	40^a	120^a	129^a
	Drip blue mulching	2018	38.7^a	1453^a	15^a	40^a	122^a	129^a
		2019	40.4^a	1530^a	15^a	39^a	123^a	133^a
Yellow stone chili	Drip	2018	22.0^b	828^b	442^b	1177^b	50^b	52^b
		2019	23.4^b	877^b	466^b	1241^b	52^a	53^a
	Black water pillow	2018	29.7^a	1114^a	559^a	1490^a	93^a	99^a
		2019	31.0^a	1160^a	610^a	1627^a	94^a	101^a
	Blue water pillow	2018	33.8^a	1266^a	637^a	1698^a	106^a	112^a
		2019	30.8^a	1156^a	630^a	1681^a	94^a	101^a
	Drip black mulching	2018	31.5^a	1181^a	585^a	1560^a	99^a	105^a
		2019	31.7^a	1191^a	650^a	1734^a	97^a	104^a
	Drip blue mulching	2018	31.7^a	1190^a	574^a	1530^a	100^a	105^a
		2019	29.9^a	1125^a	594^a	1583^a	91^a	98^a

within the root zone and thus stimulated root growth and development (Kader et al., 2017), A good root growth allowed plants to take sufficient water and nutrients, then improved yield and quality (Fageria and Moreira, 2011; Liang et al., 2011). Rahman et al. (2005) reported total root weight as 1686 g for mulching treatments and 697 g for non-mulched treatments. Such a difference in root structure influenced yields and about 45% increase was achieved in yield per hectare. López et al. (2007) reported yield per hectare of Jalapeno pepper cultivar as 20.52 tons for drip and 27.44 tons for drip + mulching treatment (about 34% increase was achieved with mulching). Positive effects of colored mulching materials on yield were reported in previous studies. Rajablariani et al. (2012) reported significant effects of transparent, blue, black, red and silver color mulching materials on tomato yield and had the highest yield from blue and black mulching materials. Black colored mulching materials absorb sunlight the most, prevent weed development, increase soil temperature, then provide the best growth ambient (Zhanga et al., 2017). Bora and Babu (2014) reported about 21% greater tomato yield for drip + black mulching treatments than for plain drip without mulching. Gerçek et al. (2017) compared black mulching + water pillow treatments with drip without mulching. Despite 52% less water application, water pillows had 18% greater yield than drip irrigation. Colored mulching materials may have different effects on different plants (Gordon et al., 2010).

In a previous study, effects of black and blue water pillows, drip + mulching and drip treatments on eggplant yields were investigated and 29% more yield was reported for black and blue water pillows as compared to drip irrigation, but differences between the yields of different colors were not found to be significant (Gerçek and Demirkaya, 2020). Ashrafuzzaman et al. (2011) reported pepper yield as 13.4 t ha^{-1} for non-mulched treatment, 21.33 t ha^{-1} for black mulching treatment and 19.15 t ha^{-1} for blue mulching treatment. In present study, effects of black and blue water pillows and mulching materials were not significantly different.

3.2. Irrigation and water productivity

In the first year, 439 mm irrigation water was applied in drip treatments and 318 mm was applied in the other treatments. In the second year, 452 mm was applied in drip treatment and 328 mm was applied in the other treatments. The differences between drip treatment and water pillows and drip + mulching treatments was 121 mm in the first year and 124 mm in the second year. In both years, about 38% less water was applied in water pillows and drip + mulching treatments. Plant water consumption is the sum of transpiration from the plant surfaces and evaporation from the soil surface. It was calculated as 421 mm for drip treatment and 301 mm for the other treatments in the first year and respectively as 439 and 305 mm in the second year.

The difference in plant water consumptions between drip and the other treatments was measured as 120 mm in the first year and 134 mm in the second year. As the average of two years, plant water consumption was 30% lower in water pillows and drip + mulching treatments. Since mulching prevented evaporations from the soil surface, such a significant difference was encountered. Superior yields of water pillows and drip + mulching treatments to drip irrigation treatments indicated that there were not any water deficiencies in these treatments. Thusly, pre-irrigation soil moisture levels varied between 20% and 22% in these treatments and between 18% and 20% in drip irrigation treatments.

Kader et al. (2017) indicated that mulching largely prevented evaporation from the soil, thus reduced capillary rise from the lower layers and preserved soil moisture within the root zone for longer durations. Li et al. (2013) reported that plastic mulching materials reduced total plant water consumption of maize by about 35%. Present findings well comply with the results of earlier studies. Despite less water use, about 35% increase was achieved in yield of both cultivars.

Irrigation durations vary based on the applied irrigation water quantities. In drip irrigation treatments, average irrigation duration in 2018 and 2019 was respectively identified as 68 and 64 min and total duration was respectively identified as 1972 and 2048 min. In drip + mulching treatments, average irrigation duration was 57 min in the first year and 54 min in the second year. Total irrigation duration was 855 min in the first year and 864 min in the second year. The amount of energy used in drip + mulching treatments was 43% lower than the amount used in drip irrigation. Such an advantage was totally attributed to mulching material. Quite a short irrigation duration is the leading advantage of water pillows. In water pillows, the only thing an irrigator should do is to fill the water pillows. Irrigation duration was considered as the duration in which water was discharged from the drippers in drip irrigation and as the duration in which water pillows were filled with water in water pillows depending on water flow rate into the pillows. Therefore, irrigation duration is quite low in water pillows. In water pillow treatments, average irrigation and total seasonal duration were about 3 and 42 min in both years.

The amount of energy used in water pillows was about 2% of the energy used in drip irrigation. Such a value was 5% of the energy used in drip + mulching treatments. There is a vast saving in energy with water pillows. Since there is no contact between the water and the soil while filling water pillows, there is no problem of water erosion or surface runoff. This water then leaks through the holes provided on plastic pipes. Such a leakage may take 24 h in some cases. The issue to be pointed out here in is the much more energy use in drip and drip + mulching treatments and almost zero energy use in water pillows since water is discharged gravimetrically in water pillows as it was in surface irrigation. Therefore, there is no need for extra energy. Mulching is an option in drip irrigation and requires extra cost. In water pillows, plastic pipes serve both an irrigation tool and mulching material. Therefore, mulching is an inherent characteristic of water pillow irrigation method, thus does not constitute any extra costs. Such a case makes water pillows method more economic than drip method. Optimum use of energy is a significant issue in all sectors. To decelerate global warming and to mitigate potential effects of climate change, either solar or wind-like renewable energy sources should be used or efficiency of fossil fuels should be improved (Daniel et al., 2004). While there is a need for pump, thus energy to supply a constant pressure and flow in drip irrigation, there is no need for additional energy in water pillows (Gerçek et al., 2009a, 2009b; Gerçek et al., 2017).

Irrigation water productivity (IWP) and water productivity (WP) values varied with the years and cultivars (Table 4). In the first year, for Captain capia pepper, the highest and the lowest IWP values were obtained from drip + blue mulching and drip treatments, respectively. For Yellow Stone chili pepper, the highest and lowest IWP values were obtained from blue water pillow and drip treatments, respectively. The lowest WP value in Captain capia and Yellow Stone chili pepper cultivar was obtained from drip treatments and the highest respectively from drip + blue mulching and blue water pillow treatments. In the second year, in both pepper cultivars, the lowest IWP and WP values were obtained from drip treatments. The highest IWP value was obtained from black water pillow treatment in Captain capia pepper cultivar and from drip + black mulching treatment in Yellow Stone chili pepper cultivar. The highest WP value was obtained from black water pillow treatment in Captain capia pepper and from drip + black mulching treatment in Yellow Stone chili pepper. While there were significant differences in IWP and WP values of drip treatments and the other treatments, the differences in IWP and WP values of water pillow and drip + mulching treatments were not found to be significant ($P < 0.05$).

Present findings clearly revealed that mulching materials preserved soil moisture and improved yield levels. Therefore, as compared to drip without mulching, mulching materials yielded quite greater IWP and WP values. In a previous study conducted to investigate the effects of

Table 5
Average soil temperatures of 10 cm depth.

Treatments	May		June		July		August		Sept.		Oct.		Nov.	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Drip	20.1	20.5	25.8	26.2	30.2	29.1	30.3	29.0	25.1	25.7	13.9	14.1	12.5	12.6
Black water pillow	21.5	21.7	27.2	27.4	31.4	30.8	31.5	31.6	26.3	25.9	15.6	15.8	13.9	14.0
Blue water pillow	21.3	21.6	27.1	27.6	31.1	30.9	31.4	31.2	26.1	26.0	14.9	14.9	13.8	14.1
Drip + black mulching	21.6	21.8	27.3	27.5	31.4	31.0	31.3	31.5	26.3	26.0	15.4	15.5	13.8	14.1
Drip + blue mulching	21.4	21.5	27.2	27.5	31.1	30.9	31.3	31.4	26.2	26.1	15.0	15.0	13.9	14.0

Fig. 2. Undeveloped weeds under black mulching material.

water pillows and furrow irrigation on soybean, water productivity value was calculated as 2.70 kg ha^{-1} mm^{-1} for water pillows and 1.63 kg ha^{-1} mm^{-1} for furrow irrigation (Gerçek et al., 2009a). In another study on peppers, water productivity value of furrow and water pillows were respectively calculated as 18.2 and 33.8 kg ha^{-1} mm^{-1}. Mulching effect of water pillows increased water productivity by 60% as compared to furrow irrigation (Gercek et al., 2009b). Water productivity of non-mulched drip and furrow irrigation in pepper plants were respectively reported as 17.7 and 10.4 kg ha^{-1} mm^{-1} (Antony and Singandhupe, 2004). Liang et al. (2011) conducted a study with pepper plants under greenhouse conditions and reported water productivity value as 261 kg ha^{-1} mm^{-1} for drip + mulching and 132 kg ha^{-1} mm^{-1} for drip treatments. All these findings revealed that drip + mulching increased water productivity values by about 50–65%. Present findings agree with those earlier ones. Similar cases are also valid for irrigation water productivity.

3.3. Soil temperatures

Soil temperatures at 10 cm depth for all treatments are provided in Table 5. The lowest average soil temperature was measured in drip treatment and the highest values were measured in black water pillows and black mulching treatments. In both years, water pillow and drip + mulching treatments had higher soil temperatures than drip treatment. The average hottest temperatures were measured in July and August in both years. In the first year, the average temperature for these months was 30.2 °C for drip irrigation, while it was 31.1–31.4 °C for water pillows and drip + mulching treatments. There was 1.2 °C temperature difference between drip and black water pillow and drip + black mulching and 0.9 °C between drip and blue water pillow and drip + blue mulching treatments. Similar findings were also observed in the other months and the second year.

In both years, greater soil temperatures were measured in black water pillow and drip + black mulching treatments than in blue water pillow and drip + blue mulching treatments. Black colored water pillows absorbed more solar rays than blue colored water pillows. Therefore, soil temperatures in black water pillow and drip + black mulching treatments were greater than in blue water pillow treatments. This difference had a positive effect on crop yields. Several researchers indicated that black mulching increased soil temperature and thus had positive effects on plant yields. Zhao et al. (2012) emphasized that soil temperature was 2.9 °C higher in black mulching treatments than in non-mulched treatments. Potato yield was found to be 1820 kg ha^{-1} higher than non-mulched treatments. Tesfaye et al. (2016) compared the effects of black, blue and clear mulches on tomato yield and soil temperatures with the control (bare) treatments and reported significant increases in soil temperature and yields with mulching treatments. In present study, soil temperatures both in water pillow and drip + mulching treatments were higher than in drip treatments without mulching. Then such increasing temperatures might have increased yields.

3.4. Weeds

Since black and blue mulching materials of water pillows and drip + mulching treatments did not pass sun light, photosynthesis of weeds was prevented and thus weed development was not observed in these treatments (Fig. 2). Zhang et al. (1992) reported that black plastic film mulch resulted in 100% control of all the weeds in maize that supported the present experimental result.

Weeds were encountered only in drip irrigation treatments. In present experimental greenhouse, Heliotropium europaeum L. Seteria glauca (L.) Beauv, Portulaca oleracea L., Amaranthus retroflexus L, Chenopodium album L., Agropyron repens (L.) Beauv, Poa annua L., Convolvulus arvensis L., Mercurialis annua L. and Tribulus terrestris L. weed species were encountered. These species are common species of the region encountered throughout the experimental season (Isık et al., 2009). Weed control was practiced manually with the use of simple mechanic tools and herbicides were not used. It is possible to damage pepper roots during the weed control. Plants spend extra energy to repair damaged roots and such an effort may have negative effects on yield. Thusly, in a previous study, significant differences were reported in root distribution of mulched and non-mulched irrigation treatments (Goyal et al., 1988).

Weed control is a laborsome and a costly process. Weeds also take up soil water and nutrients to grow and compete with main crops for water and nutrients, thus reduce yield levels. Ronchi et al. (2007) reported that weed roots competed with coffee roots, accordingly coffee roots stored more nutrients and such a case then negatively influenced coffee yields. Previous studies also reported prevention of weed growth with black and dark-colored mulching materials covering the soil surface (Rajablariani et al., 2012; Tolasa and Eshetu, 2014). Prevention of weed development was also reported in studies conducted with water pillows (Çömlekçioğlu et al., 2008; Gerçek et al., 2009a, 2009b; Gerçek et al., 2017; Altunlu et al., 2017; Gerçek and Demirkaya, 2020).

4. Conclusions

Optimum use of water resources is an essential component of sustainable agriculture. Pressurized irrigation methods and mulching materials should be used to improve water use efficiency. Drip irrigation systems have a high initial investment cost. Mulching also brings an extra cost to irrigation investments. Mulching is not an inherent component of drip irrigation; it is totally up to the farmer. Energy is an essential component of drip irrigation for system operation. Water pillows as a new method of irrigation have various advantages over drip irrigation. The yield values of drip + mulching treatments were similar with the values of water pillows. Present findings revealed that water pillows and drip + mulching treatments were clearly superior to drip irrigation. Although yield values of water pillows and drip + mulching treatments were not significantly different, no extra energy demand, inherent mulching characteristics and quite low labor costs have made water pillows more advantages over drip + mulching treatments. On the other hand, water pillows irrigation is quite cheaper and easier to apply than drip irrigation. Inhering mulching material nature of the water pillows undoubtedly makes the pillows a "pioneering method of irrigation". Previous studies also put forth the advantages of water pillows over furrow and drip irrigation. Further research is recommended to investigate the effects of water pillows on salt distribution within soil profile and the effects of saline irrigation waters through water pillows on yield and soil properties.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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