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SOIL AND WATER CONSERVATION ENGINEERING TECHNIQUES TO MODIFY THE RHIZOSPHERE CLIMATE OF CUCUMBER (CUCUMIS SATIVUS L.) FOR IMPROVING WATER USE EFFICIENCY AND YIELD

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ABSTRACT

The research was conducted to study the performance of cucumber under protected conditions with different plastic mulches. This experiment was conducted in a split plot design, having irrigation levels as main plot and mulches as subplots. The study revealed that mulching helped to maintain the soil moisture higher than bare soil and black mulch showed higher soil temperature and soil moisture (23.3%) under 100% irrigation. Plant height and yield was also influenced by mulching. Plant height and yield decreased in relation to reduction of the irrigation level. The highest water use efficiency (WUE) was found under 50% irrigation and black mulch plot (32 kg·m^{-3}). In conclusion, black mulch with 100% irrigation performed well among the treatments because of higher moisture and favourable soil temperature. In consideration of WUE, black mulch with 50% irrigation performed well.

Introduction

Soil and water are dominating factors in the existence and survival of all terrestrial organisms. They contribute to the requirement for production of food, feed, fuel, and fibre for livelihood of humans. Soil acts as a medium for plant growth and development (Eswaran et al., 2001). It is a non-renewable natural resource. Weather and climate play an important role in agricultural production. They have a profound influence on the crop growth, development and yield as well as on the water needs and fertilizer requirements (Manivannan et al., 2017). In the future view, living organisms and agricultural production systems are at risk due to continuously depleting aquifers and ground water as per projected climate change scenarios. Climate change is about to increase the demand for water needed for irrigation globally by about 40% (Fischer et al., 2007). Hence, under the emerging scenario of acute water shortages and land degradation, we must focus our effort on the development and adoption of efficient approaches for soil and water conservation as well as for agricultural sustainability.

Mulching is a conventional soil and water conservation practice used by farmers to reduce the soil degradation and enhance the crop growth. Mulch is any organic or non-organic material that is used to cover the soil surface to protect the soil from being eroded away, reduce evaporation, increase infiltration, regulate soil temperature, improve soil structure, and thereby conserve soil moisture (Jabran, 2019). Profitable production of crops and efficient use of water require a microclimate suitable for the plant growth (Kaur and Singh 2020). A microclimate can be modified by a farmer by the use of mulching and protected cultivation structures. Plastic mulches are used in many horticultural crops to suppress weed growth, conserve soil moisture and to alter a temperature in the rhizosphere. One of the main benefits associated with plastic mulching is the modification of the microclimate around the plant (Job, 2018). Mulched plots showed a higher soil moisture content than bare soil plots, which had a positive effect on vegetative and yield parameters of vegetables (Mahadeen, 2014; Singh and Kamal, 2012). Mulching improved the yield and plant growth parameters such as plant height and leaf area of many crops (Rashidi et al., 2010; Berihun, 2011; Bhatt et al., 2011; Hatami et al., 2012; Kumar et al., 2012).

Cucumbers (*Cucumis sativus* L.) are high yielding summer vegetables but are extremely sensitive to sudden weather changes. Cucumber is a thermophilic and frost susceptible crop, growing best at a temperature above 20˚C. A cucumber crop grows successfully under conditions of high light, high humidity, high soil moisture, temperature, and fertilizers in green houses (El-Aidy et al., 2007). Cucumber needs more water than grain crops and it was found that changes in the soil moisture in the root zone throughout the growing season significantly affect the yield and quality of cucumber (Mao et al., 2003). Water is a dominant limiting factor in the production and quality of cucumber because of its sparse root system. About 85% of the root is occupied in the upper 30 cm soil layer (Wang and Zhang, 2004). Scheduling irrigation is very crucial, as excessive irrigation water reduces the yield, while the inadequate supply causes water stress as well as yield reduction. One method to extend the production season and start early production of cucumbers is using a poly house (Nair et al., 2013).

Therefore, this study evaluates changes in the microclimatic parameters under poly house caused by the use of plastic mulching and drip irrigation in case of cucumber to improve the production and quality of fruits and also to identify the optimum rootzone microclimate of the crop.

Purpose and scope of work

The aim of the research was to assess the changes in the rhizosphere due to plastic mulching and an effect on the yield as well as the water use efficiency of the cucumber crop.

Materials and methods

The research was conducted to study the performance of cucumber (*Cucumis sativus* L.) under the protected conditions with different plastic mulches. This experiment was conducted in a poly house along with different plastic mulches at Tamilnadu Agricultural University, Coimbatore during the period from April 2021 to June 2021 (summer) and January 2022 to March 2022 (winter). Location of the experimental site on the globe is between 11.011' N latitude, 76.939' E longitude and at an altitude of 411 m above the mean sea level. Soil characteristics of the experiment field were given in Table 1.

Table 1.
Soil physical and chemical properties

Sl. No	Properties	Values
	1. Texture	
1	Sand (%)	48.2
2	Silt (%)	12.4
3	Clay (%)	32.3
4	Texture (%)	Sandy clay loam
	2. Physical Properties	
1	Bulk density ($g \cdot cc^{-1}$)	1.1
3	Field capacity (%)	19.8
4	Permanent wilting point (%)	13.7
	3. Chemical properties	
1	Soil (pH)	7.7
2	Electrical Conductivity ($dS \cdot m^{-1}$)	1.45
3	Available N ($kg \cdot ha^{-1}$)	213
4	Available P ($kg \cdot ha^{-1}$)	33
5	Available K ($kg \cdot ha^{-1}$)	555
6	Organic carbon (%)	0.45

The poly house (approximately 20x20 m size) was constructed with a polyethylene film of 200 µm thickness as a cladding material on a GI frame. Shadenet of green colour was used inside the polyhouse to reduce high intensity radiation. Foggers, cooling pads and exhaust fans were installed inside the poly house to control humidity and temperature. The experiment comprised two factors; Factor A is a plastic mulch of different colour viz. black, silver, yellow, red, white and no mulch as control and factor B is drip irrigation in three levels that are 100 PE (Pan Evaporation), 75 PE and 50 PE following a split plot design with two replications. Treatments details were provided in Table 2.

Table 2.
Treatment carried out for the experiment

Factor A (Sub-plot)	Factor B (Main-plot)
Different colour mulches	Different Irrigation levels
M1 Black	I1 100% PE
M2 Silver	I2 75% PE
M3 Yellow	I3 50% PE
M4 Red	
M5 White	
M6 No mulch	Replications 2

The size of a unit plot was 2.75x1.2 m. Two adjacent unit plots and blocks were separated by 0.3 and 0.2 m, respectively. Observations on height and yield were collected in the three randomly selected plants per each treatment plots. The fruit yield of cucumber in the greenhouse was compared to different mulching and irrigation conditions and correlated with other data. These investigations were carried out using eighteen treatments replicated two times. The treatments were tested in split plot Design. The spacing was maintained with row to row (0.60 m) and plant to plant (0.30 m). Different colour mulches of 25-micron thickness like black, silver, yellow, red, and white were cut as per the size of the plots. Healthy seeds of cucumber F1 hybrid (Malav) were used for sowing during third week of April 2021. Fertilizer was applied based on the recommendations of Tamilnadu Agricultural University (TNAU) crop production guide. Details of the fertilizer used were given in Table 3.

Table 3.
Schedule of fertigation of cucumber throughout the crop season

Sl.No	Crop Stage	Duration (days)	Fertilizer	Recommended ($kg{\cdot}ha^{-1}$)	Applied ($kg{\cdot}400\ m^2$)
1	Crop establishment Stage	10	19:19:19	19.7	0.8
			13:0:45	8.2	0.3
			Urea	22.1	0.9
2	Vegetative stage	20	12:61:0	9.2	0.4
			13:0:45	49.5	2.0
			Urea	95	3.8
3	Flowering	20	19:19:19	29.6	1.2
			13:0:45	20.6	0.8
			Urea	80	3.2
4	Harvesting	40	19:19:19	6.1	0.25
			13:0:45	66	2.6
			Urea	77	3.1

Crop protection measures were followed with spraying of neem oil (YK Neem 3000 ppm azardiractin) 5 $ml{\cdot}L^{-1}$ in 10 days interval from flowering stage. Sucking pests like black aphids and thrips were affected on 67^{th} day after sowing (DAS) and early management was done using systemic insecticide Imidacloprid 30.5% SC at the rate of 3 $ml{\cdot}L^{-1}$.

Soil temperature and soil moisture were recorded inside the poly house daily at 7.30 AM and 2.30 PM. Soil moisture was recorded by using Lutron PMS 714 Soil Moisture Meter by Lutron electrical solutions and soil temperature were recorded using DS18B20 temperature sensor by Maxim integrated. Both sensors were calibrated using conventional methods. Vegetative growth parameters such as the plant height and total yield were also recorded.

Water required for irrigation of an individual plot was calculated using a pan evaporation method (PE) based on the central water commission guide (CWC 1984). Cumulative PE of 3 days was considered for estimation of irrigation water requirement. The formula used for estimating water requirement (CWC 1984) was given.

$$Wr\ (\text{litres}) = Cpe \cdot Kc \cdot Kp \cdot W.P \cdot Area \tag{1}$$

were:
- Wr – water requirement,
- Cpe – cumulative pan evaporation,
- Kc – crop co-efficient,
- Kp – pan co-efficient,
- W.P – wetting percentage,
- Area – plot area.

Pan co-efficient for tropical countries was estimated to be 0.7 (Allen et al., 1998) and wetting percentage of loamy soils for drip irrigation is taken as 0.8 (Finkel, 2019). Kc value of cucumber under different stages (Table 4) was taken as per recommended by Food and Agriculture Organization (FAO). This gives the water requirement of 100% PE irrigation level.

Water requirement for 75% and 50% were calculated by

$$75\, Wr = 0.75 \cdot Wr \tag{2}$$

$$50\, Wr = 0.5 \cdot Wr \tag{3}$$

Table 4.
Kc Value of cucumber under different stages

Stage and duration of crop	Crop coefficient (Kc)
Initial stage (10 to 15 days)	0.4 - 0.5
Mid- season stage (16 to 50 days)	0.85
Harvesting stage (51 to 90 days)	0.6 - 0.65

Statistical analysis of the observation done using R software using “Agricolae” and. “Doebioresearch” modules for split plot analysis. Correlation analysis was done using a “corrplot” method. Pooled data of the cropping seasons viz. Summer and winter were used for the statistical analysis.

Results and discussions

The surface soil temperature was measured under different colour mulches with different drip irrigation levels. The highest soil temperature was recorded in a black poly mulch with 50% irrigation and the lowest temperature was recorded in the control plot (No mulch) with 100% irrigation (Fig. 1).

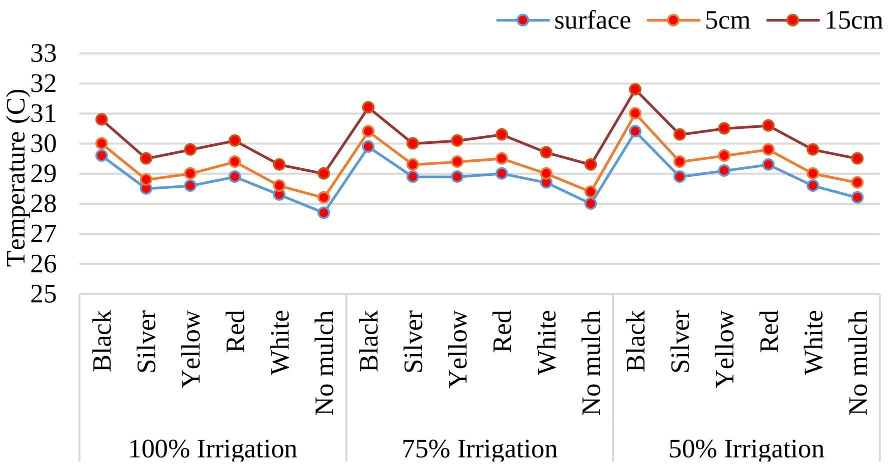

Figure 1. Soil temperature variation at 30 DAS and three different depths under different mulch and irrigation levels

The soil temperature was increased in all mulches when compared to the control plot. Among the five mulches, white mulch recorded a lower soil temperature than the others. There was an increasing trend of the soil temperature according to the irrigation levels. Drip irrigation with 100% PE recorded a low temperature and increased in 75% and the highest at 50% irrigation. The temperature increased from 0.6˚C to 1.5˚C in comparison to the control plot while using the mulch. Plastic mulches create a greenhouse effect under the ground level. It allows short wave radiation into the soil and arrests the long wave radiation from the soil and thereby increases the temperature below the mulch. However, Job et al., (2018) observed a higher soil temperature in a transparent mulch and silver mulch than in case of the black one. But he also concluded that the mulches increased the soil temperature about 1 to 9˚C in comparison to the control plot. Franquera (2015) reported a higher soil temperature due to coloured plastic mulches than in bare soil. Gordon et al., (2010) showed there was a difference in the soil temperature by coloured plastic mulches and a row cover. The reported impact of the coloured plastic mulches on the soil temperature by different researchers is variable from area to area and from crop to crop. The soil temperature under the plastic mulch depends on the thermal properties (reflectivity, absorptivity, or transmittance) of a particular material in relation to incoming solar radiation (Lamont, 1999).

Soil moisture is one of the necessities in the life of plants on which all their processes during their lifecycle depend. One of the major roles of plastic mulches include conservation of the soil moisture against the direct evaporation loss and increase the evapotranspiration of the crop. The soil moisture retention of different mulches under different level of irrigation were observed on 30 DAS DAS (Table 5). The table shows that the black poly mulch with 100% irrigation (I1) had the highest soil moisture content (M1 = 23.30%) followed by white (M5 = 22.45%) and silver (M2 = 21.25%). Irrigation plots of 75% (I2) and 50% (I3) level showed same trend in the moisture content but decreased according to irrigation levels. The irrigation levels I2 and I3 came under the same group and not much variation statistically. A daily soil-moisture content at 5cm depth was maximum under plastic mulching and minimum in the bare soil. The plastic cover prevented surface evaporation and, capillary flux from below the root zone might increase the soil moisture in comparison to the bare soil (Kader et al., 2017). Haapala et al., (2014) also agreed with the same results according to which mulching retained water in the upper soil layer (5 cm), which also helped to increase the soil moisture at the deeper layer (25 cm). The mulch reduced soil water evaporation and improved soil water retention (Mahadeen, 2014).

Table 5.
Effect of polymulches and drip irrigation on mean soil moisture at 5 cm depth (30DAS)

Treatments	Mean soil moisture % at 5 cm depth (30DAS)						
	M1 Black	M2 Silver	M3 Yellow	M4 Red	M5 White	M6 No mulch	Mean
I1 (100%)	23.30	21.25	21.05	21.05	22.45	19.00	21.35
I2 (75%)	21.25	19.40	19.45	19.70	20.80	17.05	19.60
I3 (50%)	20.40	19.05	18.50	18.85	19.70	16.90	18.90
Mean	21.65	19.90	19.66	19.86	20.98	17.65	
	Factor A	Factor B	Factor(B) at same levels of Factor A		Factor(A) at same levels of Factor B		
SEM	0.15	0.07	0.12		0.19		
CD at 5%	0.95	0.21	0.38		0.97		

The microclimate modified by mulching and protected cultivation significantly affected the plant characters. The plant height of cucumber at 45 days after sowing (DAS) has been mentioned in Figure 2.

The maximum plant height was achieved in the black polymulch (174.05 cm) and 100% irrigation followed by the white mulch (170.30 cm) with same level of irrigation. The plant height increase was by 10.12 % and 7.5% more than that of the control plot, respectively. Among the irrigation treatments, the black and white mulches found to be better for the plant height followed by yellow, red, and silver. There was a significant difference between the mulched treatments and control plot. A maximum plant height obtained on the control plot was 158.60 cm in 100% irrigation whereas, the mulched treatments attained 5 to 10% extra height at the same level of irrigation. The plant height was highly influenced by the soil temperature, soil moisture and ambient temperature. Here, soil temperature and moisture were higher than in case of the control plots because of mulching effects. Higher soil moisture and temperature promoted the plant growth under the green house. A similar study using a plastic mulch has also reported an increased plant height in onion crop under a silver and transparent plastic mulch (Sarkar et al., 2019). A transparent plastic mulch showed higher performance than the black and blue one with regard to the growth and development of chilli (Ashrafuzzaman et al., 2011). Job et al., (2016). The reported plastic mulch has a significant effect on the plant height in okra. A vegetative growth improvement might be explained in view that plastic mulches improve moisture conservation and availability, which ultimately leads to the improvement of the plant growth. This could be explained in view of the soil temperature and moisture as previously reported by (Mahadeen, 2014).

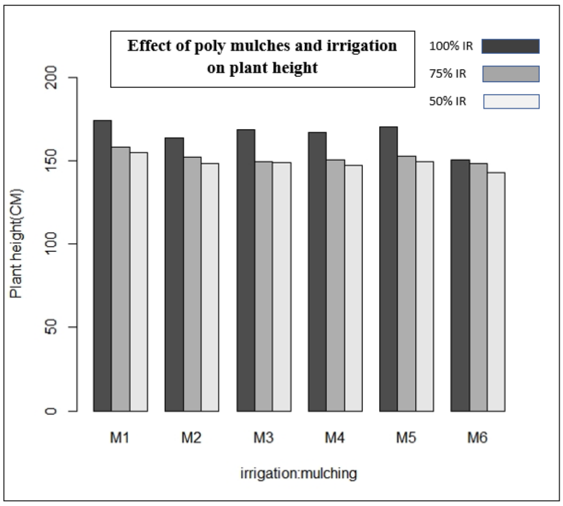

Figure 2. Effect of drip irrigation and colour mulches on cucumber plant height. Each combination of irrigation and mulch are significantly different at p= 0.05. Abbreviations: M1 - Black, M2 - Silver, M3 - Yellow, M4 - Red, M5 - White, M6 - No mulch

The total yield of cucumber was influenced by growing environment with mulch treatments. The average yield of cucumber has been presented in Table 6. From the table, it can be concluded that the black poly mulch with 100% irrigation attained the maximum yield of 36.1 $t{\cdot}ha^{-1}$. Followed by white (33.6 $t{\cdot}ha^{-1}$) mulch and silver mulch (32.1 $t{\cdot}ha^{-1}$) with the same irrigation levels. The per cent increase in yield was 38.3, 29.6, 26.3 and 10.2 for black, white, silver, yellow and red, respectively. The yield has decreased according to deficit irrigations in all mulches. The red and yellow mulches found to be on a par with each other.

Table 6.
Effect of polymulches and drip irrigation on yield of cucumber

Treatments	Average yield ($t \cdot ha^{-1}$)						Mean
	M1 Black	M2 Silver	M3 Yellow	M4 Red	M5 White	M6 No mulch	
I1 (100%)	36.11	32.10	31.50	28.33	33.64	26.00	31.28
I2 (75%)	30.34	26.81	28.57	25.42	29.75	24.45	27.54
I3 (50%)	28.26	26.44	23.68	23.00	26.91	22.23	25.14
Mean	31.51	28.20	28.63	25.62	29.62	24.21	
	Factor A	Factor B	Factor (B) at same levels of Factor A		Factor (A) at same levels of Factor B		
SEM	0.62	0.52	0.91		1.04		
CD at 5%	3.77	1.59	NS		NS		

The control plot yielded lower than all mulched treatments. There was a difference of 5 to 10 tonnes when compared to mulched treatments and control plots. The increased soil moisture percentage under mulched treatments enhanced the plant growth. The ambient temperature and RH were also maintained at an optimum level under a poly house. Extra soil temperature and moisture under mulching with the controlled environment under a poly house enhanced the yield of cucumber. Among the soil characteristics, the root zone temperature affects the physiology of plants such as plant growth, root development, aeration, water, and mineral uptake. This impact of the higher soil temperature promotes root activity on water and nutrient transportation, better penetration as well as root growth which significantly affects the yield of plants (Dodd et al., 2000). As per the observations of Job (2018), the black mulch attained the maximum yield in the tomato crop. It was observed that chilli plants grown under the black plastic mulch showed the highest amount of chlorophyll a and b, total chlorophyll contents, the highest number of fruits, and increased yield (Ashrafuzzaman et al., 2011). The result of Li et al., (2018) indicated that the yield of potato plant increased by 29.2% by plastic mulches than a bare land.

The correlation analysis between the soil environment and plant growth was shown in Figure 3. Soil moisture correlated more than the soil temperature against the plant height and yield of cucumber. Soil moisture at 15 cm depth had highest correlation with the plant height (0.89) and yield (0.91). Moisture at 5 cm depth correlated with 0.87 to the plant height and 0.89 to the yield. The soil temperature showed less correlation. Soil temperature at 15 cm depth correlated more with the yield and plant height (0.26 and 0.31) than that of 5 cm and surface temperature.

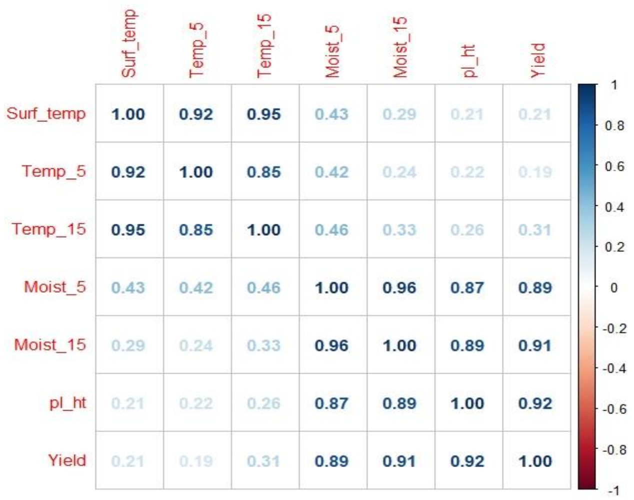

Figure 3. Correlation of soil temperature and soil moisture with plant height and yield

Previous studies also found good correlation between the plant growth and soil moisture (Onwuka and Mang, 2018; Job, 2018; Job et al., 2016).

The Water use efficiency (WUE) of cucumber was improved under the mulched condition over the bare soil (Fig. 4).

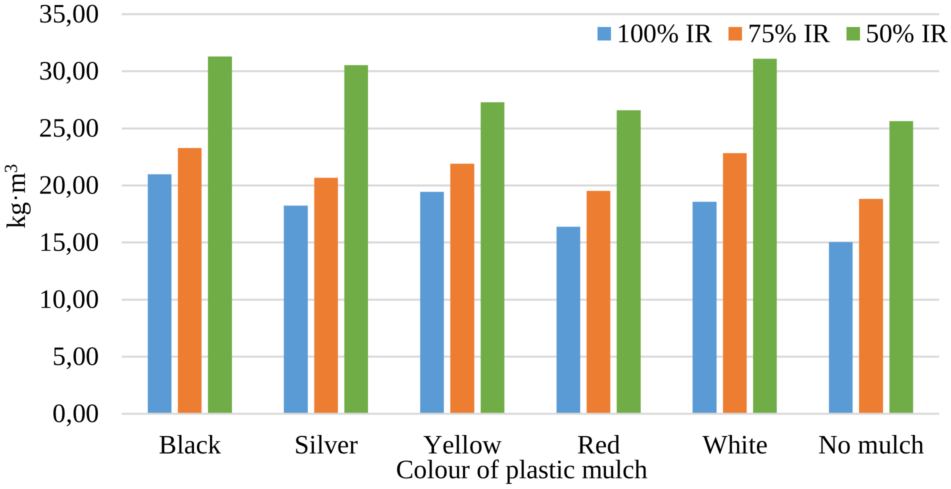

Figure 4. Effect of drip irrigation and colour mulches on Water use efficiency of cucumber. Each combination of irrigation and mulch are significantly different at p= 0.05

The black mulch with 50% irrigation showed a maximum WUE (32 $kg \cdot m^{-3}$ of water) followed by White (31 $kg \cdot m^{-3}$), Silver (30 $kg \cdot m^{-3}$), Yellow (28 $kg \cdot m^{-3}$), and Red (26 $kg \cdot m^{-3}$). The control plot showed a minimum WUE than other mulched plots in all irrigation levels. Under all levels of irrigation, the Black mulch had a higher efficiency. Yellow and red as well as white and silver were on a par with each other. The yield under all three irrigation levels had not much difference. Therefore, a higher yield under deficit irrigation led to the maximum water use efficiency under 50% irrigation. The poly mulch helped to retain the moisture under the deficit irrigation level and therefore the yield was sustained. However, the yield was decreased compared to the 100% irrigation but when calculated the yield per water applied 50 % irrigation with the black mulch gave a higher yield. The same results were observed by Mukherjee et al., (2010). He observed a higher WUE under deficit irrigation with the black mulch and this might be due to the enhancement of a deeper and more extensive rooting system because of the reduced irrigation. This would allow plants to use water and nutrient from deeper soil, thus increase both irrigation and nutrient use efficiency. Kumar et al., (2012) also reported a higher WUE under deficit irrigation and found the reduced WUE under 100% irrigation level. A higher WUE was observed also by Agrawal (2010) under the mulched conditions than in the controlled plots. Black mulch with 100% irrigation showed a maximum yield and plant height. Therefore, black mulches with 100% irrigation are recommended under the conditions of no water limit and the black mulch with 50% irrigation is recommended under the conditions of the limited water availability.

Conclusions

1. Mulching and drip irrigation can modify the microclimate of the root zone and influence soil physical properties such as soil moisture, temperature, and aeration. This directly influences the plant growth and enhanced yield..
2. During this experiment, plastic mulches have performed this job efficiently. The black plastic mulch restricts the light and increases the radiation in soil thereby increasing the soil temperature as compared to other colour mulches.
3. The white mulch reflects the light and radiation. Thereby resulting in the reduced temperatures in comparison to others. Silver performs intermediate between black and white.
4. Red and yellow mulches have also performed well compared to no mulch treatment.
5. Therefore, black mulches are recommended under temperate and sub tropic conditions and white mulches are recommended for tropical regions.

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TECHNIKI INŻYNIERII OCHRONY GLEB I WÓD W MODYFIKACJI KLIMATU RYZOSFERY OGÓRKA (*CUCUMIS SATIVUS* L.) MAJĄCEJ NA CELU POPRAWĘ EFEKTYWNOŚCI ZUŻYCIA WODY I PLONU

Streszczenie. Badanie zostało przeprowadzone w celu sprawdzenia wydajności uprawy ogórka w warunkach chronionych różnego rodzaju włókniną ogrodniczą. To doświadczenie zostało przeprowadzone w układzie “split plot”, gdzie poziomy nawodnienia stanowiły “main plot” a włókniny “subplots”. Badanie wykazało, że użycie włókniny pomogło zachować wilgotność gleby wyższą niż w przypadku samej gleby a zastosowanie czarnej włókniny wykazało wyższą temperaturę i wilgotność gleby (23,3%) przy 100% nawadnianiu. Mulczowanie za pomocą włókniny wpłynęło także na wysokość i plon rośliny. Wysokość i plon rośliny uległy zmniejszeniu wraz ze zmniejszeniem poziomu nawodnienia. Najwyższa efektywność zużycia wody (WUE) wystąpiła w przypadku 50% nawadniania i użycia czarnej włókniny (32 $kg \cdot m^{-3}$). Podsumowując, czarna włóknina przy 100 % nawadnianiu radziła sobie dobrze w odniesieniu do czynności z powodu wyższej wilgotności i dogodnej temperatury gleby. Biorąc pod uwagę efektywność zużycia wody, czarna włóknina przy 50% nawodnienia radziła sobie dobrze.

Słowa kluczowe: ogórek, mulcz, czarny mulcz, plon, woda