https://doi.org/10.17221/84/2019-RAE

Changes of root zone temperature, growth and productivity of broccoli cultivated with coloured plastic mulches

*El-Sayed Khater, Ramy Hamouda, Harby Mostafa**

Department of Agricultural and Biosystems Engineering, Faculty of Agriculture, Benha University, Qalyobia, Egypt

**Corresponding author: Harby.mostafa@fagr.bu.edu.eg*

Citation: Khater E., Hamouda R., Mostafa H. (2020): Changes of root zone temperature, growth and productivity of broccoli cultivated with coloured plastic mulches. Res. Agr. Eng., 66: 112–121.

Abstract: The main aim is to find out the influence of using coloured plastic mulches (blue, white, green, red, black and white on black) compared with a mulch-free treatment on the root zone temperature, growth and productivity of broccoli. The results indicated that the highest and lowest mean root zone temperatures were recorded the in the dark-coloured mulches (blue, green, red and white on black) and in the light-coloured mulches (white), respectively, in both the winter and spring seasons. The average shoot length, leaf number and root volume of the broccoli for all the treatments was higher in the spring season compared with those of the winter season. The highest marketable head fresh weight values were 449.6 and 451.0 g found in the black mulch, while the lowest values were 391.4 and 397.5 g found in the winter and spring seasons for the red mulch, respectively. The N, P, K, Ca and Mg concentrations in the broccoli heads ranged from 2.0 to 2.8%, 0.9 to 1.0%, 2.7 to 3.6%, 1.9 to 5.9% and 0.5 to 0.89%, respectively, for all the treatments.

Keywords: soil cover; soil heat; plant root; nutrients uptake

Broccoli is a cool-seasoned plant that can either be grown as a spring or a fall crop. Broccoli is a high-quality source for fresh use and is a popular frozen vegetable. This vegetable is a healthy source of vitamin A, calcium, and riboflavin (or vitamin B_2). The edible portion of the broccoli plant consists of the tender stem and the unopened flower buds. Sprouting broccoli should not be confused with broccoli-raab (or the Italian turnip), which is grown for early leafy greens and has much smaller flower shoots (Thompson et al. 2002).

Commercially, plastic mulches have been used to produce vegetables since the 1960s (Lamont 2005). Plastic mulches are presently used throughout the world to protect plants from adverse conditions caused by weather, insects, and birds. Plastic was first used in cold regions, where it was used to shield plants from the frost, but now, plastic is used in various climates, soils and seasons, as it provides many advantages besides an increase in temperature (Kasirajan, Ngouajio 2012).

Mulching is a popular agronomic pursuit of agriculture and it has many merits, including: preventing the loss of soil moisture, controlling weeds by tenting them and diseases by preventing soil contact with the plant foliage, regulating the soil temperature, either keeping it cool or keeping it warm, adding to the soil richness and increasing the soil organic matter content when organic mulch is used and retro gradation takes place. Some mulch materials, such as the reflective mulches, are efficient in holding off insects (AVRDC 1990).

The application of mulches helped the crop to mature 0.7–15 days earlier and it also affects the plant's height, leaf area index, and dry matter, while the application of a plastic mulch treatment improved the yield and water use efficiency in comparison to the non-mulch treatments (Zhao et al. 2012; Mostafa 2014).

https://doi.org/10.17221/84/2019-RAE

Plastic mulches alter the plant micro-climate by influencing the soil energy balance by changing the soil temperature (Tarara 2000; Díaz-Pérez, Batal 2002; Lamont 2005; Ibarra-Jimenez et al. 2006). In warm environments, however, plastic mulches may cause high root zone temperature (RZT) conditions which may be deleterious to the growth and yield of vegetables (Díaz-Pérez, Batal 2002; Ibarra-Jimenez et al. 2008). The RZT influences the physiological processes such as the plant growth, gas exchange, and uptake of water and mineral nutrients (Dodd et al. 2000).

Light colours affect the growth and yield of plants dramatically, they influence the maturity and control weeds and diseases. This study aims at determining the influence of light colours on the root zone temperature, growth and productivity of broccoli grown during the winter and spring seasons.

MATERIAL AND METHODS

The experiment was carried out at the Agriculture Research and Experiment Center, Faculty of Agriculture, Moshtohor, Benha University (latitude 30°21'N and 31°13'E), during the period of the November 2018 to April 2019 seasons.

Six mulches were used: a blue mulch, a white mulch, a green mulch, a red mulch, a black mulch and a white mulch on a black mulch. The transmissions of blue, white, green, red and black plastic were 450–500, 400–700, 500–570, 620–700 and 655–735 nm, respectively. The system consisted of seven treatments (six plastic film mulches and a control) refrigerators, raysoniculture. The cultivated area for each treatment was 7 m^2 (10 m long × 0.7 m wide). All the mulches were 1.2 m wide and had 35 μm thickness.

Six-week-old broccoli seedlings were planted in the field on the 20th of November 2018 (winter season) and the 25th of February 2019 (spring season), and a 30 cm spacing between the plants within the row. A drip irrigation system was used. The water consumptive use (mm·day^{-1}) was calculated and applied according to the climate data using the Penman-Monteith method described by (FAO 1991), and according to the local weather station data, which is located in Moshtohor. After the soil preparation, 1 m^3 of compost was added. The fertiliser requirements of broccoli were applied as recommended by the Agronomy Research Institute (ARC) Ministry of Agriculture and Land Reclamation. The mechanical and chemical analysis of the experimental soil before transplanting are shown in Table 1 according to Cottenie et al. (1982). After soil bed preparation, mulch was spread on the soil surface uniformity and fixed on the ground by putting some soil on the ends of the cover. The treatments were arranged in a completely randomised design with three replications and seven treatments [T1 – blue mulch, T2 – white mulch, T3 – green mulch, T4 – red mulch, T5 – black mulch, T6 – white mulch on black mulch and T7 – without cover (control)]. The plastic mulches were blue, white, green, red, black, white on black and control.

The root zone temperature (RZT) was measured between the plants within the row at 10 cm below the mulched soil surface. The RZT over the growing season was measured with a thermocouple thermometer (Model Digi-Sense 69202-30 – Range –250 to 1 800 °C, Producer, USA). The air temperature data were recorded by the local weather station data.

The soil heat accumulation, measured as the soil degree-days (DD_{soil}), was calculated as (Equation 1):

$$DD_{soil} = \sum_{i=1}^{i=n} \frac{1}{2} \times \left(\frac{RZT_{max} - RZT_{min}}{2} - RZT_{base} \right) \quad (1)$$

where: DD_{soil} – the soil degree-days; RZT_{max} – the maximum root zone temperature (°C); RZT_{min} – the minimum root zone temperature (°C); RZT_{base} – the base root zone temperature (10 °C) (Jenni et al. 1996).

Three plants were randomly selected from each replicate to be used for measuring the growth parameters. The shoot length and number of leaves

Table 1. The mechanical and chemical analysis of the experimental soil before transplanting

Clay (%)	Silt (%)	Sand (%)	Texture	pH	EC (dS·m^{-1})	$CaCO_3$ (g·kg^{-1})	OM (g·kg^{-1})	Available (mg·kg^{-1})		
								N	P	K
51	24.6	24.4	clayey	7.9	2.16	14.1	15.3	22.5	9.1	120
Trace elements			B	Fe	Zn	Mn	Cu	Cd	Ni	Pb
Total content (ppm)			15.15	54 574	89.73	935	64.65	0.154	60.56	9.16

EC – electrical conductivity; dS·m^{-1} – 640 ppm; OM – organic matter

https://doi.org/10.17221/84/2019-RAE

were measured weekly. The root volume, fresh and dry weight of the shoot, root and fruit were determined at the end of the experiment. For measuring the root volume, the water displacement technique was preferred. The measuring is undertaken in a special container with an overflow spout. This container is filled with water until it overflows from the spout. Then the fresh-washed roots, which have been carefully dried with a soft cloth, are immersed and the overflow water volume is measured in a graduated cylinder (Benjamin, Nielsen 2004). After measuring the fresh mass, the plants were oven dried at 70 °C until a constant weight was reached.

After digestion, the total content of the macro elements was evaluated (Chapman, Partt 1961). The nitrogen was determined by a Kjeldahl digestion apparatus (Bremmer, Mulvaney 1982). The total N includes all forms of inorganic N, such as NH_4, NO_3 and NH_2 (urea), and the organic N compounds, such as proteins, amino acids and other derivatives. Depending on the form of N present in a particular sample, a specific method is to be adopted for determining the total N value. While the organic N materials can be converted into a simple inorganic ammoniacal salt by digestion with sulfuric acid, the modified Kjeldahl method is adopted with the use of salicylic acid or Devarda's alloy to reduce the nitrates into an ammoniacal form. All the organic and inorganic salts are converted at the end of the digestion into an ammonium form, which is distilled and estimated using a standard acid. Since the method's accuracy depends on the complete conversion of organic N to NH4-N, the temperature and time of digestion, the solid-acid ratio and the type of catalyst used play an important role in the process. The optimum temperature for digestion is 320–370 °C. At a lower temperature, the digestion may not be complete, while above 410 °C, loss of NH_3 may occur. The salt : acid (weight : volume) ratio should not be less than 1 : 1 at the end of digestion. $CuSO_4$ and mercury (Hg) are widely used catalysts to accelerate the digestion process. Potassium sulfate is added to raise the acid's boiling point so that volatilisation prevents the loss of acid. The potassium, calcium and magnesium contents were determined by a photometer (Model Jenway PFP7 – Range 0–160 mmol·L^{-1}, Jenway, USA). The potassium present in the sample is extracted with a neutral ammonium acetate of 1 molarity. This is considered as the plant-available K in the samples. It is estimated with the help of a flame photometer. The calcium and magnesium contents are determined either by the ethylenediaminetetraacetic acid (EDTA) titration method or by using atomic absorption spectroscopy (AAS) after the removal of the ammonium acetate and organic matter (OM). The phosphorus (P) content was determined colorimetrically following the Murphy and Riley (1962) method. Olsen's procedure for neutral and alkali samples is the most widely used method for determining the available phosphorus in the samples. In these methods, specific coloured compounds are formed with the addition of appropriate reagents in the solution, whose intensity is proportionate to the estimated concentration of the element. The colour intensity is measured spectrophotometrically. In a spectrophotometric analysis, the light of the definite wavelength (not exceeding, say, 0.1–1.0 nm in bandwidth) extending to the ultraviolet region of the spectrum constitutes the light source.

RESULTS AND DISCUSSION

Root zone temperature. The results indicated that the average root zone temperature for all the treatments was higher than the average air temperature (Figure 1). The average root zone temperature values were 16.1, 14.5, 15.7, 16.3, 16.3, 15.4 and 14.3 °C for the blue, white, green, red, black, white on black coloured plastic mulches and without a cover, respectively, compared to 13.9 °C for the air temperature in the winter season. While, they were 22.1, 20.1, 21.4, 21.7, 22.1, 20.8 and 20.2 °C for the blue, white, green, red, black, white on black coloured plastic mulches and without a cover, respectively, compared to 20.0 °C for the air temperature in the spring season.

The changes in the daily root zone temperature under the different coloured mulch throughout the season were related to the changes in the air temperature during both the winter and spring seasons. The highest value of the root zone temperature (16.3 °C) was obtained under the black mulch, while the lowest value of the root zone temperature (14.4 °C) was obtained under the white mulch compared to (14.3 °C) for the control in the winter season. In the spring season, the highest value of the root zone temperature (22.1 °C) was obtained under the black mulch, while the lowest root zone temperature (20.1 °C) was obtained under the white mulch compared to (20.2 °C) for the control which agreed with Lamont (2005) who found that the dark mulch had a higher mean root zone temperature.

https://doi.org/10.17221/84/2019-RAE

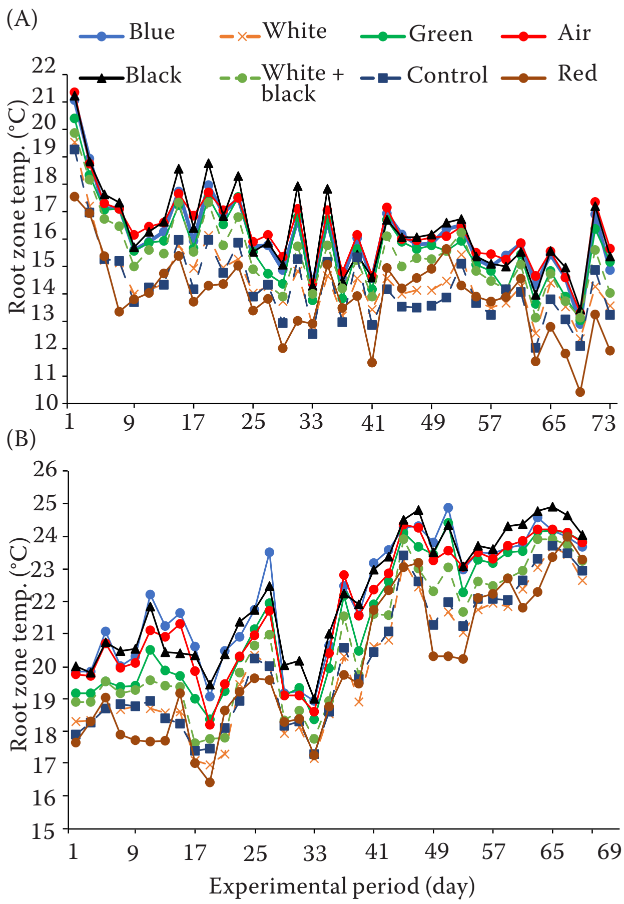

Figure 1. Air temperature and root zone temperature under plastic mulch for broccoli crop during (A) winter and (B) spring seasons

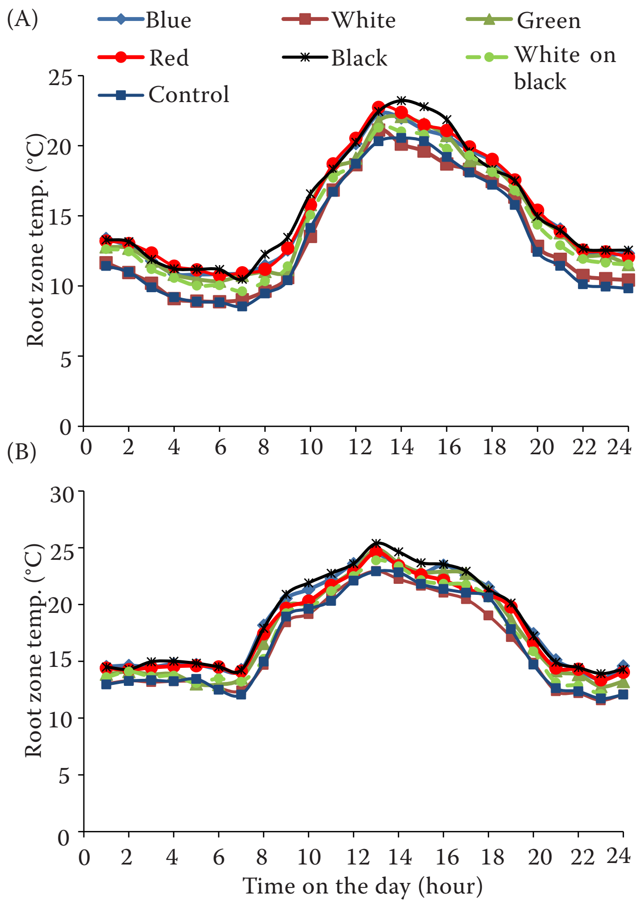

Figure 2. Average diurnal trends of root zone temperature under plastic mulch for broccoli crop during (A) winter and (B) spring seasons

The average diurnal trends of the RZT for each of the mulches during the three seasons are shown in Figure (2). The average hourly root zone temperatures ranged from 10.8 to 22.3 °C, 8.9 to 21.1 °C, 10.4 to 22.1 °C, 10.8 to 22.7 °C, 10.5 to 23.2 °C, 9.6 to 21.3 °C and 8.5 to 20.6 °C in the blue, white, green, red, black, white on black coloured plastic mulches and without a cover, respectively, in the winter season. While, they ranged from 13.4 to 24.4 °C, 11.6 to 23.0 °C, 12.8 to 24.9 °C, 13.4 to 24.6 °C, 13.9 to 25.4 °C, 12.1 to 23.9 °C and 11.7 to 22.93 °C in the blue, white, green, red, black, white on black coloured plastic mulches and without a cover, respectively, in the spring season.

Soil heat accumulation. The amount of heat accumulated in the soil measured as the soil degree-days (DD_{soil}) or heat units differed among the seasons (winter and spring) and the plastic mulches (blue, white, green, red, black and white on black) and the control (Figure 3). The least amount of heat was accumulated in the soil during the winter season than during the spring season. It could be seen that the soil degree-days values were 112.7, 82.4, 106.1, 116.4, 116.7 and 99.2 for the blue, white, green, red, black and white on black coloured

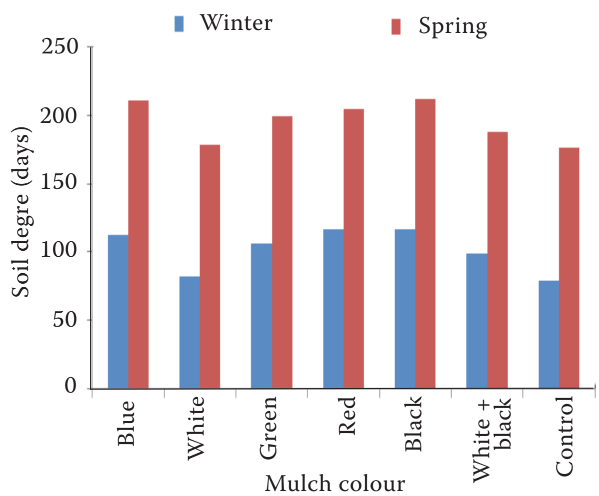

Figure 3. Soil degree-days under plastic mulch for broccoli crop during winter and spring seasons

https://doi.org/10.17221/84/2019-RAE

plastic mulches, respectively, compared to 79.5 without a cover (control) for the winter season. While, they were 211.0, 178.4, 199.0, 204.9, 212.5 and 188.1 for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 176.3 without a cover (control) for the spring season.

The highest value of the soil degree-days (116.7) was obtained under the black mulch, while the lowest value of the soil degree-days (79.5) was obtained in the control in the winter season. In the spring season, the highest value of the soil degree-days (212.5) was obtained under the black mulch, while the lowest value of the soil degree-days (176.3) was obtained in the control which agreed with Subramaniyan and Zhou (2008).

As shown in Figure 4, the soil degree-days increased with the increasing root zone temperature. It could be seen that the soil degree-days range from 79.5 to 116.7 and 176.3 to 212.5 for the winter and spring seasons, respectively.

The regression between the soil degree-days and the root zone temperature is expressed by the following Equations (2 and 3):

$$DD_{\text{soil}} = 18.509RZT - 185.11 \quad (2)$$

R^2 = 0.999 for the winter season

$$DD_{\text{soil}} = 14.523RZT - 207.88 \quad (3)$$

R^2 = 0.917 for the spring season

where: DD_{soil} – the soil degree-days; RZT – the root zone temperature (°C)

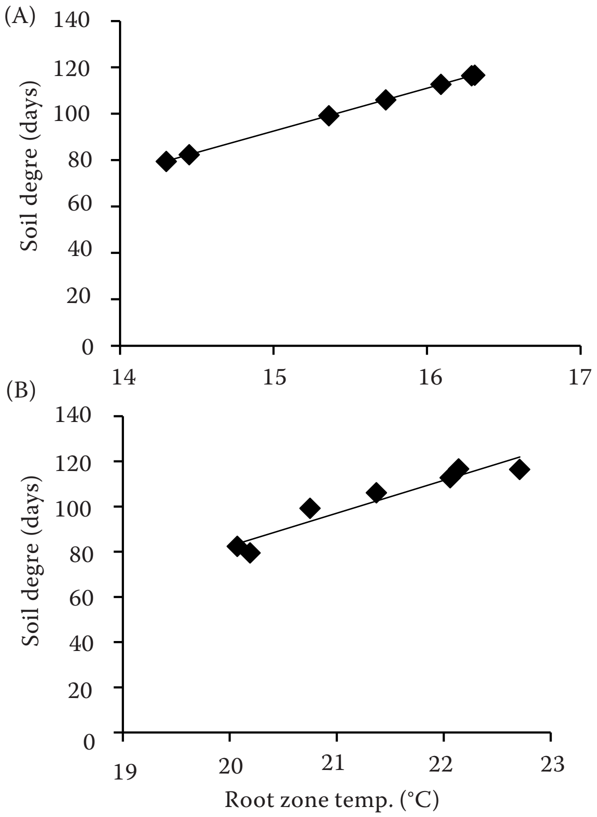

Figure 4. The relationship between soil degree-days and root zone temperature in (A) winter and (B) spring seasons

Shoot length. The average shoot length of the broccoli for all the treatments increased with the increasing plant age (Figure 5). The average shoot length of the broccoli at the end of experimental period was 48.3, 43.0, 45.3, 51.5, 43.7 and 48.7 cm for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 45.0 cm for without a cover in the winter season. While, it was 49.0, 44.7, 48.7, 46.0, 51.7, 47.7 cm for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 47.3 cm for without a cover in the spring season.

The results also indicated that the average shoot length of the broccoli for all the treatments was increased in the spring season and taller than those of the winter season. It could be seen, the highest value of the shoot length of the broccoli (51.5 cm) was found for the red mulch, while the lowest value of the shoot length of the broccoli (43.0 cm) was found for the white mulch in the winter season. In the spring season, the highest value of the shoot length of the broccoli (51.7 cm) was found for the black mulch, while the lowest value of the shoot length of the broccoli (44.7 cm) was found for the white mulch as obtained by Iqbal et al. (2009) who found that the highest value of the shoot length of hot peppers was found for a black mulch, while the lowest value of the shoot length of hot peppers was found under a clear mulch.

Number of leaves. The average number of broccoli leaves for all the treatments increased with the increasing plant age (Figure 6). The average number of the leaves at the end of experimental period was 12.3, 10.7, 12.0, 12.5, 12.0 and 12.3 for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 11.3 for without a cover in the winter season. While, it was 15.0, 14.3, 13.7, 14.0, 16.0 and 14.3 for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 14.0 for without a cover in the spring season.

https://doi.org/10.17221/84/2019-RAE

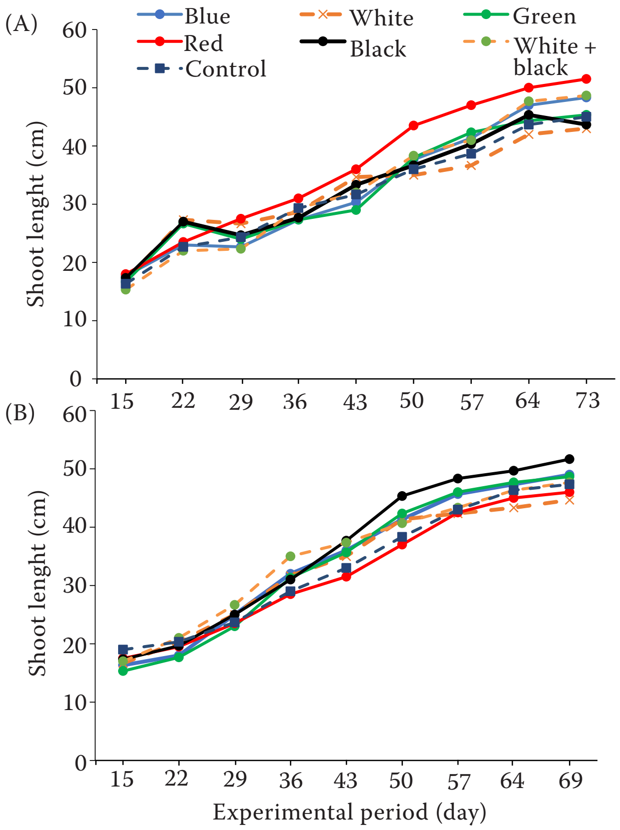

Figure 5. Shoot length of broccoli for plastic mulch during (A) winter and (B) spring seasons

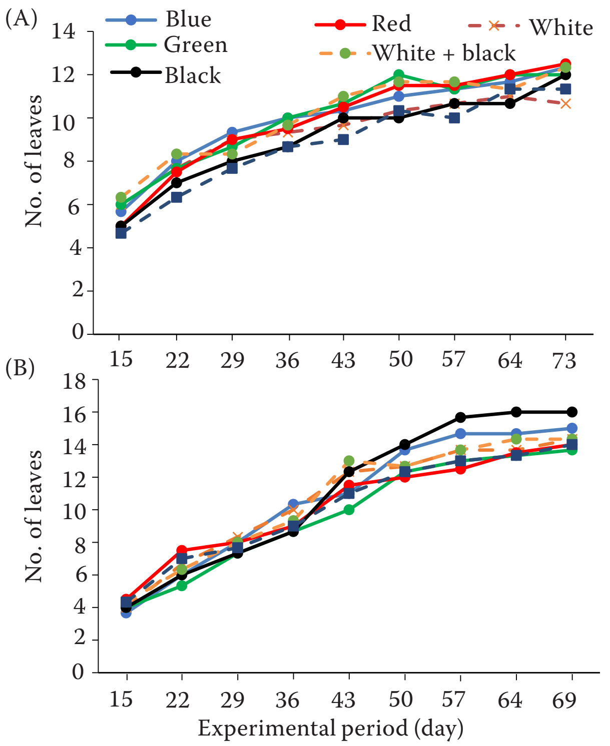

Figure 6. Number of leaves of broccoli for plastic mulch during (A) winter and (B) spring seasons

The results also indicated that the average number of broccoli leaves for all the treatments increased in the spring season more than those of the winter season. It could be seen that the highest value of broccoli leaves number (12.5) was found for the red mulch, while the lowest value (10.7) was found for the white mulch in the winter season. In the spring season, the highest value of broccoli leaves number (16.0) was found for the black mulch, while the lowest value (13.7) was found for the green mulch.

Root volume. The average root volume of the broccoli plant at the end of experimental period was 238.4, 228.1, 289.3, 239.0, 343.4 and 332.7 cm^3 for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 171.7 cm^3 for without a cover (control) in the winter season (Figure 7). While, it was 295.5, 260.2, 292.4, 272.4, 367.1 and 358.8 cm^3 for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 241.7 cm^3 for without a cover (control) in the spring season.

The highest value of the root volume (343.4 cm^3) was found for the black mulch, while the lowest value (228.9 cm^3) was found for the white mulch in the winter season. In the spring season, the highest value of the root volume (367.1 cm^3) was found for the black mulch, while the lowest value (260.2 cm^3) was found for the white mulch.

Fresh and dry weight of the shoot. It could be seen that the average fresh weight of the broccoli shoot at the end of experimental period was 991.0, 932.0, 921.5, 1 198.0, 783.5 and 1 281.5 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared

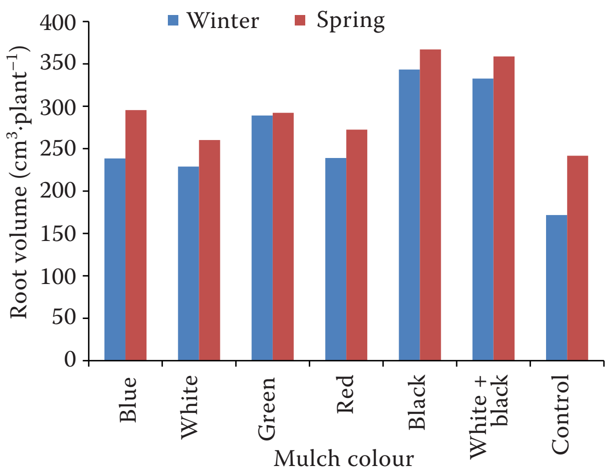

Figure 7. Root volume of broccoli plant for plastic mulch during winter and spring seasons

https://doi.org/10.17221/84/2019-RAE

to 638.5 g per plant for without a cover in the winter season (Figure 8). While, it was 1 160.2, 872.7, 795.4, 673.3, 1 290.8 and 1 105.6 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 779.4 g per plant for without a cover in the spring season. The increased the plant growth in the spring season may be attributed to the presence of the higher air and root zone temperatures in the spring than in the winter. These results agreed with those obtained by Tarara (2000).

The results also indicated that the average dry weight of the plant shoot at the end of experimental period were 78.3, 33.8, 54.9, 75.6, 36.5 and 78.4 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 40.0 g per plant for without a cover in the winter season. While, they were 112.6, 93.2, 74.8, 64.8. 123.3 and 111.2 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 88.3 g per plant for without a cover in the spring season.

The highest value of fresh weight of the plant shoot (1 281.5 g) was found for the white on black mulch, while the lowest value (783.53 g) was found for the black mulch in the winter season. In the spring season, the highest value (1 290.8 g) was found for the black mulch, while the lowest value (673.3 g) was found for the red mulch. These results agreed with those obtained by Díaz-Pérez (2009) who found that the highest value of the weight of the shoot of the broccoli plant was found for a black mulch, while the lowest value of the weight of the shoot of the broccoli plant was found under a blue mulch in the spring season.

Fresh and dry weight of the root. The results in Figure 9 indicate that the average fresh weight of the plant root at the end of experimental period was 339.7, 257.2, 248.1, 261.8, 351.3 and 307.9 g per plant

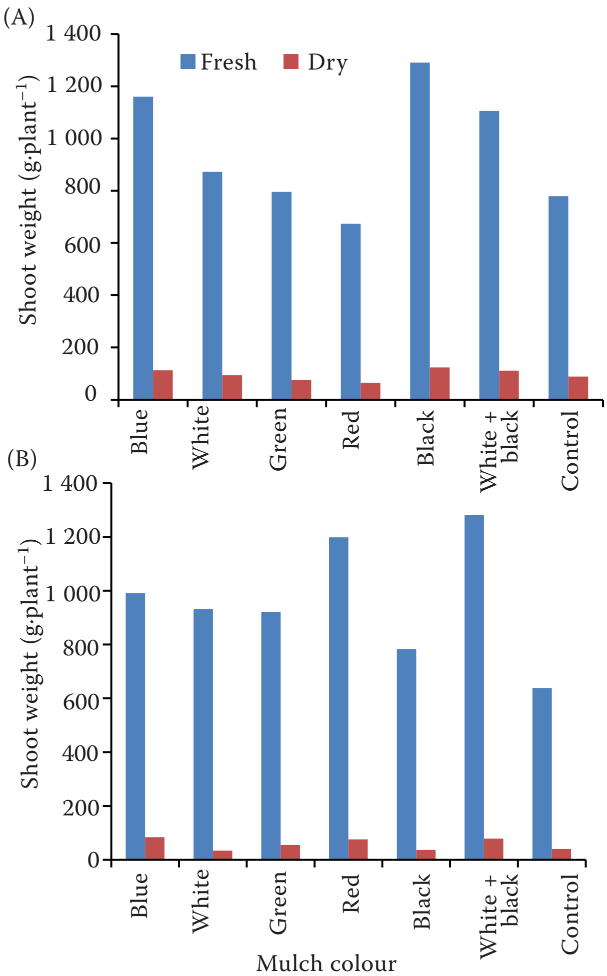

Figure 8. Fresh and dry weight of shoot of broccoli for plastic mulch during (A) winter and (B) spring seasons

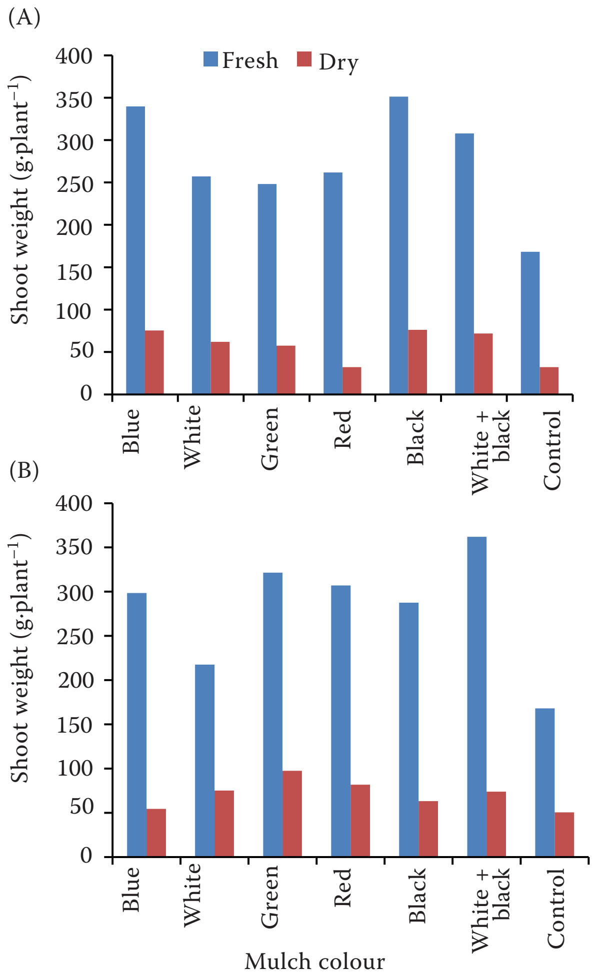

Figure 9. Fresh and dry weight of root of broccoli for plastic mulch during (A) winter and (B) spring seasons

https://doi.org/10.17221/84/2019-RAE

for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 167.1 g per plant for without a cover in the winter season. While, it was 298.5, 217.5, 321.5, 307.1, 287.5 and 362.0 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 168.0 g per plant for without a cover in the spring season.

The results also indicated that the average dry weight of the root at the end of experimental period was 75.3, 62.0, 57.5, 32.1, 76.1 and 71.8 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 32.0 g per plant for without a cover in the winter season. While, they were 54.4, 75.2, 97.5, 81.8, 63.2 and 74.0 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 88.3 g per plant for without a cover in the spring season.

The highest value of the fresh weight of the root (351.3 g) was found for the black mulch, while the lowest value (257.2 g) was found in the white mulch in the winter season. In the spring season, the highest value of the fresh weight of the root (362.0 g) was found in the white on black mulch, while the lowest value of the fresh weight of the broccoli root (217.5 g) was found in the white mulch as mentioned by Díaz-Pérez (2009) who found that the highest value of the weight of the root of the broccoli plant was found for a black mulch, while the lowest value of weight of the root of the broccoli plant was found under a white mulch.

Broccoli yield. The average fresh and dry weight of the marketable head of broccoli for all the treatments increased in the spring season more than those in the winter season (Figure 10). It could be seen that the average fresh and dry weight of the marketable head of broccoli at the end of experimental period was 417.1, 401.4, 399.0, 391.4, 449.6 and 406.5 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 360.5 g per plant for without a cover in the winter season. While, they were 428.8, 402.4, 403.9, 397.5, 451.0 and 421.3 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 365.8 g per plant for without a cover in the spring season. The increased broccoli yield in the spring season may be attributed to the presence of the higher air and root zone temperatures in the spring than in the winter and these results agreed with Lamont (2005) and Ibarra-Jimenez et al. (2006).

The results also indicated that the average dry weight of the marketable head of broccoli at the end of experimental period was 48.7, 35.6, 33.3, 32.6, 50.6 and 36.1 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 29.6 g per plant for without a cover in the winter season. While, they were 39.0, 34.7, 35.3, 33.5, 51.6 and 37.8 g per plant for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 31.3 g per plant for without a cover in the spring season.

The highest values of the fresh weight of the marketable head of broccoli (449.6 and 451.0 g) were found for black mulch, while the lowest values of the fresh weight of the marketable head of broccoli (391.4 and 397.5 g) were found for the red mulch in the winter and spring seasons, respectively as obtained by Díaz-Pérez (2009) who found that the

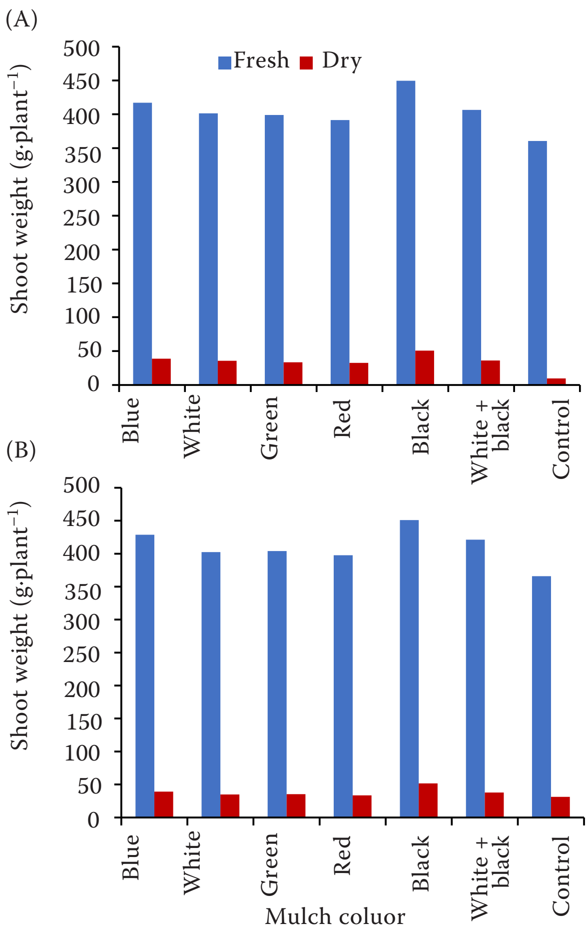

Figure 10. Fresh and dry weight of marketable head of broccoli for plastic mulch during (A) winter and (B) spring seasons

https://doi.org/10.17221/84/2019-RAE

highest value of the weight of the marketable head of broccoli plant was found for a black mulch.

Total nutrients uptake. The average nitrogen (N) in the broccoli head was 2.42, 2.16, 2.19, 2.33, 2.34 and 2.31% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 1.98% for without a cover in the winter season (Table 2). While, it was 2.57, 2.40, 2.35, 2.42, 2.81 and 2.53% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 2.06% for without a cover in the spring season.

The results also indicated that the average phosphorus (P) in the broccoli head was 0.89, 0.91, 0.92, 0.78, 0.90 and 0.94% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 0.87 % for without a cover in the winter season. While, it was 0.93, 0.93, 0.94, 0.83, 0.93 and 0.96% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 0.89% for without a cover in the spring season.

The potassium (K) in the broccoli head was 3.19, 2.89, 2.67, 3.33, 3.12 and 3.25% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 2.81% for without a cover in the winter season. While, it was 3.55, 2.90, 2.72, 2.71, 3.25 and 3.80% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 2.73% for without a cover in the spring season.

The calcium (Ca) in the broccoli head was 2.24, 1.96, 2.11, 2.12, 2.32 and 1.95% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 1.87% for without a cover in the winter season. While, it was 2.46, 2.23, 2.56, 2.51, 2.89 and 2.38% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 2.30% for without a cover in the spring season.

The magnesium (Mg) in the broccoli head was 0.89, 0.54, 0.84, 0.84, 0.75 and 0.78% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 0.72% for without a cover in the winter season. While, it was 0.81, 0.56, 0.81, 0.71, 0.80 and 0.71% for the blue, white, green, red, black and white on black coloured plastic mulches, respectively, compared to 0.69% for without a cover in the spring season.

CONCLUSION

The experiment was carried out to study the influence of using coloured plastic mulches (blue, white, green, red, black and white on black) compared with a non-cover (control) on the root zone temperature, growth and productivity of the broccoli grown in the winter and spring seasons. The obtained results can be summarised as follows:

In both the winter and spring seasons, the mean root zone temperatures were the highest (16.3 and 22.1 °C) in the dark-coloured mulches (blue, white, green, red and white on black) and the lowest (14.5 and 20.1 °C) in light-coloured mulches (white).

Less heat was accumulated in the soil during winter season than during the spring season. The highest values of the soil degree-days were 116.7 and 212.5, while the lowest values of soil degree-days were 79.5 and 176.3.

The highest values of the root volume of the broccoli (343.4 and 367.1 cm^3) and fresh weight of the marketable head (449.6 and 451.0 g) were found for the black mulch, while the lowest values of the root volume (228.9 and 260.2 cm^3) were found for the white mulch and the fresh weight of the marketable head (391.4 and 397.5 g) were found for the red mulch in the winter and spring season, respectively.

The fresh and dry weight of the shoot and root, shoot length and number of leaves of broccoli for all

Table 2. The mineral nutrient concentration in the broccoli heads as affected by the plastic film mulch

Mulch	N		P		K		Ca		Mg	
	winter	spring	winter	spring	winter	spring	winter	spring	winter	spring
Blue	2.42	2.57	0.89	0.93	3.19	3.55	2.24	2.46	0.89	0.81
White	2.16	2.40	0.91	0.93	2.89	2.90	1.96	2.23	0.54	0.56
Red	2.19	2.35	0.92	0.94	2.67	2.72	2.11	2.56	0.84	0.81
Green	2.33	2.42	0.78	0.83	3.33	2.71	2.12	2.51	0.84	0.71
Black	2.34	2.81	0.90	0.93	3.12	3.25	2.22	2.89	0.75	0.80
White on black	2.31	2.53	0.94	0.96	3.25	3.80	1.95	2.38	0.78	0.71
Control	1.98	2.06	0.87	0.89	2.81	2.73	1.87	2.30	0.72	0.69

https://doi.org/10.17221/84/2019-RAE

the treatments increased in the spring season more than those of the winter season.

The N, P, K, Ca and Mg concentrations in the broccoli heads ranged from 1.98 to 2.81%, 0.87 to 0.96%, 2.73 to 3.55%, 1.87 to 5.89% and 0.54 to 0.89%, respectively, for all the treatments.

The highest value of the fresh weight of the marketable head of the broccoli plant was found the for black mulch.

A future study is recommended to investigate the effect of the mulch colour on other exported crops.

REFERENCES

AVRDC (1990): Vegetable Production Training Manual. Taiwan, AVRDC Shanhua Talnau.

Benjamin J.G., Nielsen D.C. (2004): A method to separate plant roots from soil and analyze root surface area. Plant and Soil, 267: 225–234.

Bremmer M., Mulvaney S. (1982): Nitrogen-total. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Ed. Agronomy series No. 9 ASA. Madison, SSSA: 595–624.

Chapman D., Partt P. (1961): Methods of analysis of soils, plant and water. Berkeley, University of California: 150–200.

Cottenie A., Verloo M., Kiekens L., Velgh G., Camerlynch R. (1982): Chemical Analysis of Plants and Soils. Laboratory for Analytical and Agrochemistry. Ghent, State University.

Díaz-Pérez C., Batal D. (2002): Colored plastic film mulches affect tomato growth and yield via changes in root-zone temperature. Journal of the American Society for Horticultural Science, 127: 127–135.

Dodd C., He J., Turnbull N., Lee K., Critchley C. (2000): The influence of supraoptimal root-zone temperatures on growth and stomatal conductance in *Capsicum annuum* L. Journal of Experimental Botany, 51: 239–248.

FAO (1991): Localized irrigation. Irrigation and Drainage, Paper No. 36.

Ibarra L., Zermeno A., Lozano J., Cedeno B., Ortega H. (2008): Changes in soil temperature, yield and photosynthetic response of potato (*Solanum tuberosum* L.) under coloured plastic mulch. Agrochimica, 52: 263–272.

Ibarra L., Quezada R., Cedeno B., Rio D., de la Rosa M. (2006): Watermelon response to plastic mulch and row covers. European Journal of Horticultural Science, 71: 262–266.

Iqbal Q., Amjad M., Asi R., Ali A., Ahmed R. (2009): Vegetable and reproductive evaluation of hot peppers under different plastic mulches in in poly/plastic tunnel. Pakistan Journal of Agricultural Sciences, 46: 113–118.

Jenni S., Cloutier C., Bourgeois G., Stewart A. (1996): A heat unit model to predict growth and development of muskmelon to anthesis of perfect flowers. Journal of the American Society for Horticultural Science, 121: 274–280.

Kasirajan S., Ngouajio M. (2012): Polyethylene and biodegradable mulches for agricultural applications, a review. Agronomy for Sustainable Development, 32: 501–529.

Lamont J. (2005): Plastics: Modifying the microclimate for the production of vegetable crops. HortTechnology, 15: 477–481.

Mostafa H. (2014): Effective moisture conservation method for heavy soil under drip irrigation. Agricultural Engineering International: CIGR Journal, 16: 1–9.

Murphy J., Riley P. (1962): A modified single solution method for determination of phosphate in natural waters. Analytica Chimica Acta, 27: 31–36.

Tarara M. (2000): Microclimate modification with plastic mulch. HortScience, 35: 169–180.

Thompson L., Doerge A., Godin E. (2002): Subsurface drip irrigation and fertigation of broccoli: I. Yield, quality, and nitrogen uptake. Soil Science Society of America Journal, 66: 186–192.

Zhao H., Xiong C., Li M., Wang Y., Qiang C. (2012): Plastic film mulch for half growing-season maximized WUE and yield of potato via moisture temperature improvement in a semi-arid agroecosystem. Agricultural Water Management, 104: 68–78.

Received: December 25, 2019
Accepted: July 1, 2020
Published online: September 28, 2020