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THE EFFECT OF COVERING AND MULCHING ON THE TEMPERATURE AND MOISTURE OF SOIL AND BROCCOLI YIELD

Edyta Kosterna

Faculty of Agriculture, Siedlce University of Natural Sciences and Humanities
ul. B. Prusa 14, 08-110 Siedlce,
e-mail: edyta.kosterna@uph.edu.pl

Abstract. Soils in Poland are characterised by relatively low available water reserves. Soil mulching is one of the methods which positively influence soil moisture and structure, reduce negative effects of erosion, and help to decrease fluctuations of soil temperature. The experiment was carried out in the years 2010-2012 at the Experimental Station of the Siedlce University of Natural Sciences and Humanities as a split-block design with three replicates. The study aimed to determine the effect of plant covering (without cover, under polypropylene fibre) and soil mulching with different kinds of straw (rye, corn, rape, buckwheat) on changes in soil temperature and moisture as well as on the yield of broccoli. Soil temperature at a depth of 10 cm in covered plots was higher than in plot without cover. Soil temperature in the plots without straw, irrespective of whether a covering was used, was higher than in plots with straw. The lowest fall in temperature compared to the control plot was observed in plots mulched with buckwheat straw. This phenomenon was a result of lower intensity of light reflection of this straw which absorbed more sunlight than straw of other species. All investigated kinds of straw caused an increase of moisture in the upper (0-20 cm) and lower (20-40 cm) soil layers after cover removal and before broccoli harvest, in the cultivation without cover and under polypropylene fibre. Application of covers and simultaneous soil mulching had more favourable influence on water content in the soil than only mulching. Significantly the highest total yield of broccoli in the cultivation under cover was achieved from plots mulched with buckwheat straw. In non-covered objects slightly higher yields compared to remaining kinds of straw, but significantly higher than in control plot, were noted for soil mulching with corn straw.

Keyword: polypropylene fibre, mulch, straw, moisture, temperature

INTRODUCTION

Soils in Poland are characterised by relatively low available water reserves (Walczak *et al*. 2002). The management of such resources in vegetables production, is becoming more and more of a problem. Rainfall is the main source which replenishes water reserves. However, over the recent years precipitation has been highly variable. The greatest shortages of rainfall occur in May and August, as well as April and July. Water losses due to evaporation are the primary problem in summer months (Radzka *et al*. 2007).

Retention of organic matter as mulch on the soil surface is one of the ways of limiting the water loss. Application of mulches beneficially influences soil structure, reduces negative effects of wind and water erosion, and decreases soil warming in summer months as well as helps to decrease fluctuations of soil temperature, resulting in an increase of crop yields (Duppong *et al*. 2004, Farrukh and Safdar 2004, Giordani *et al*. 2004, Ramakrishna *et al*. 2006, Chakraborty *et al*. 2008).

Olasantan (1999) found that the use of straw mulch prevents water evaporation and helps maintain a constant soil temperature. This was confirmed in studies by Kęsik and Maskalaniec (2005), in which mulch with rye straw was used effectively as an insulator and protected the soil from overheating. Studies by Shangning and Unger (2001), Włodek *et al*. (2003), Dahiya et al. (2007), Pabin *et al*. (2007) and Sinkevičienė *et al*. (2009) showed that the application of mulch increases soil water retention.

The application of plastic covers can have a significant influence on changes in thermal and humidity conditions in the immediate vicinity of plant. Covering of plants has the effect of changing the microclimate, which influences the growth and development of plants and increases the yield of vegetables (Kosterna 2006, Hamouz *et al*. 2007, Cholakov and Nacheva 2009, Majkowska-Gadomska 2010).

The study aimed to determine the effect of plant covering with polypropylene fibre and soil mulching with straw (rye, corn, rape, buckwheat) on changes in soil temperature and moisture as well as on the yield of broccoli cv.'Milady F_1'.

MATERIALS AND METHODS

The experiment was carried out in the years 2010-2012 at the Experimental Station of the Siedlce University of Natural Sciences and Humanities, located in central-eastern Poland (52º03'N, 22º33'E), 115 km east of Warsaw. According to the international system of FAO classification, the soil was classified as a Luvisol (LV) (WRB FAO 1998). The soil organic matter content averaged 1.5% and its humus horizon reached a depth of 30-40 cm; the value of pH determined in H_2O was 5.4. The total contents of macroelements in mg dm^{-3} air dry matter amounted to 34 for phosphorus, 83 for potassium, 36 for magnesium, N-NO_3 – 14, N-NH_4 – 7, calcium – 260. The content of plant-available nutrients was lower than that specified by Sady (2000) as the optimal content for broccoli. Moisture of the upper soil layer (0-20 cm) prior to the experiment set-up was 11.72%, whereas for the lower layer (20-40 cm) it was slightly higher and equalled 13.29%.

The experiment was established as a split-block design with three replicates. Effects of the following factors were investigated: the plants covering (without cover, under polypropylene fibre), and the kind of straw applied for soil mulching (rye, corn, rape, buckwheat). The effect of straw was compared to a control plot without mulch. The effect of examined factors on soil temperature and moisture as well as yield of broccoli cv. 'Milady F_1' cultivated for early harvest was investigated.

The forecrop for broccoli was triticale. After triticale harvest, soil liming at the rate of 2 t CaO ha^{-1} (calcium carbonate fertiliser) was performed. In the autumn preceding broccoli cultivation, the soil ploughing was performed. At the same time, farmyard manure at a rate of 30 t ha^{-1} was incorporated. In the spring, two weeks before planting seedlings, disc harrowing was applied to loosen the upper soil layer and to prepare it for planting. After that, mineral fertilisers were applied in the amount of supplementary content to the optimal level for broccoli: 110 kg N, 98 kg P_2O_5, 220 kg K_2O per 1 ha. Mineral fertilisers were applied in the form of ammonium nitrate, triple superphosphate and 60% potassium salt. Directly before the seedlings were planted, a particular kind of straw at a dose of 10 t ha^{-1} was applied. Mulch with rye, rape, and buckwheat straw was in rather long (30-40 cm) pieces. These pieces were crumbled up, so it would be easy to spread them on the field. However, mulch with corn straw was chopped up into short pieces (20-30 cm). The thickness of the mulch layer depended on the type of mulch. In the case of rye and rape straw, the thickness of the mulch layer amounted, on average, to 7-8 cm. In the case of corn straw, the mulch layer amounted to about 5 cm, however for buckwheat straw the average was 8-10 cm.

Broccoli seedlings were grown in a non-heated greenhouse. Seeds (10 g) were sown in the successive study years on the 19^{th}, 18^{th} and 20^{th} of March in multi-trays (54 holes). Seedlings were produced using peat substrate. Prior to transplanting the seedlings were hardened off and then moved permanently outdoors. The seedlings were planted on the 19^{th}, 18^{th} and 23^{rd} of April, at a spacing of 50 × 50 cm.
After the seedlings were planted, suitable combinations were covered with polypropylene fibre Pegas Agro 17UV. The cover was removed after 4 weeks. After that, 50 kg N ha^{-1} in the form of ammonium nitrate was applied (topdressing).

During the plants covering period (27.04-18.05), measurements of soil temperature were performed at a depth of 10 cm in all experimental treatments, at 8.00 a.m. and 2.00 p.m. In the plant growing period, measurement of the intensity of light reflection from the surface of mulches and soil was performed four times. The measurement was executed by using the light intensity meter LXP-1 SONEL S.A.

Soil samples were taken from the central part of the 0-20-cm layer (at the depth of about 10 cm) and from the central part of the 20-40-cm layer (at the depth of about 30 cm) at two dates: immediately after polypropylene fibre

removal and before broccoli harvest. The soil samples were taken randomly from four different places of each plot with Kopecky cylinders (100 cm^3 volume).
Soil moisture was determined by the oven-drying gravimetric method. The samples were weighed using a MEDICAT LTD 160 M electronic scale to an accuracy of 0.01 g. Soil moisture was calculated by the following formula:

$$Sm = \frac{Kmw - Kmd}{Kmd - Km} \times 100 \quad (\%) \qquad (1)$$

where:
Sm – soil moisture (%)
Kmw – weight of cylinder with moist soil (g)
Km – weight of cylinder (g)
Kmd – weight of cylinder with soil after drying (g).

Broccoli were harvested by hand on 30 June 2010, and 28 June 2011 and 2012. After the harvest the total yield was specified.

The results were statistically analysed by means of analysis of variance, following the mathematical model for the split-block design. Significance of differences was determined by the Tukey test at the significance level of p=0.05. Calculations were performed by using a program based on the textbook “Methodology of agricultural experiments” (Trętowski and Wójcik 1991).

RESULTS AND DISCUSSION

Experiment conditions

Rainfalls during the years of the study were differentiated (Fig. 1). Years 2010 and 2012 were more favourable for broccoli growth and yield. These years were characterised by higher rainfalls and their more favourable distribution compared with 2011. A wet May and June favoured broccoli head growing up and, as a result, obtaining a higher yield. The least favourable conditions for broccoli growth were in 2011. The sum of rainfalls during the growing period amounted to only 106.2 mm and was lower than long-term mean by 55.6 mm.

Great differences in light intensity were found depending on the investigated surface (Tab. 1). The light intensity ranged from 2.6 lx in plots mulched with buckwheat straw to 16.4 lx in plots with rape straw. Depending on the kind of investigated mulch, the most light reflection was seen for corn and rape straw, at 9.6 and 9.7 lx, respectively, and the least for buckwheat straw, at 4.3 lx.

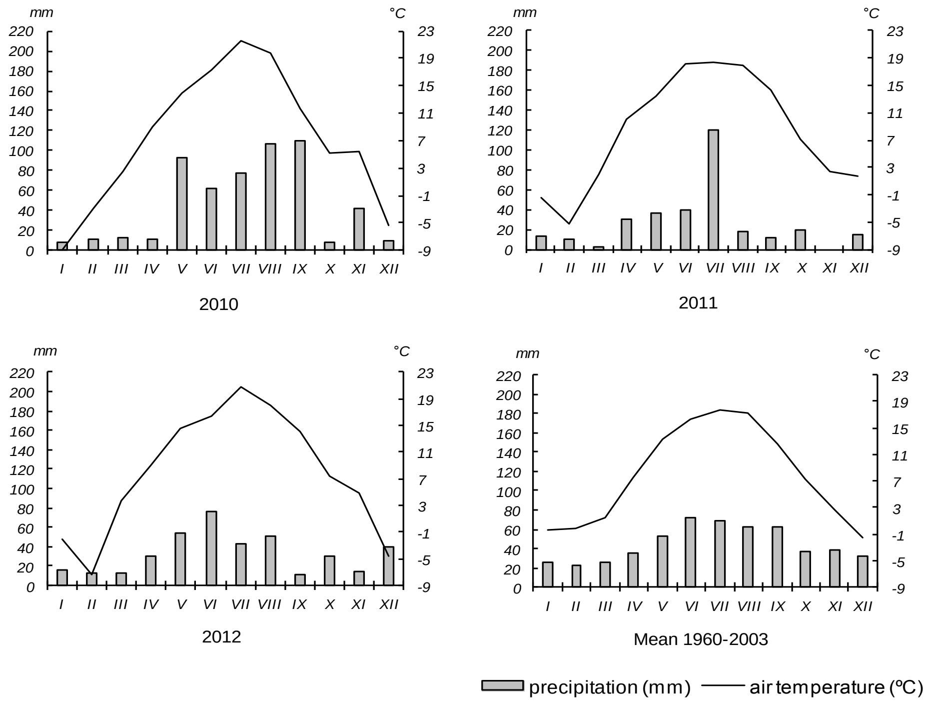

Fig. 1. Air temperature (ºC) and precipitation (mm) in the years of study in relation to long-term mean air temperature and precipitation

Table 1. Intensity of light reflection from the surface of mulches and soil (lx)

Date of measurement	Kind of straw				
	Control	Rye	Corn	Rape	Buckwheat
2.05	4.4	5.2	5.6	5.8	3.9
11.05	4.2	7.4	9.1	10.8	7.1
21.05	5.4	12.2	13.6	16.4	3.6
28.05	4.8	11.2	10.3	5.8	2.6
Mean	4.7	9.0	9.6	9.7	4.3

Soil temperature

Soil temperature at a depth of 10 cm in covered plots was higher than in plots without cover. The increase in soil temperature as a result of covering amounted to 1.2ºC at 8.00 a.m. and 1.8ºC at 2.00 p.m. (Fig. 2 and 3). In previous studies, the soil temperature under flat covers was higher by 1.9ºC in the morning and by

3.6ºC in the afternoon (Kosterna 2006). In the study by Cholakov and Nachev (2009), increase in soil temperature under polypropylene fibre at 8.00 a.m. amounted to 0.4-2.4ºC and at 2.00 p.m. to even 4.6ºC. Similarly, in the study by Hamouz *et al*. (2006) soil temperature under polypropylene fibre at a depth of 10 cm was higher by 1.8ºC and air temperature by 2.0ºC compared to that found in a plot without cover. According to Winiarska (2006) and Majkowska-Gadomska (2010), the covering reduces evaporation, decreases heat losses at night and, as a result, provides better plant growth.

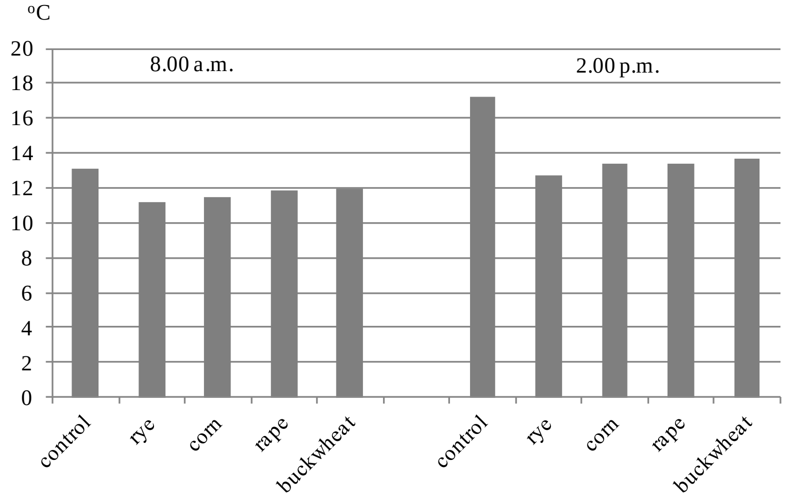

Fig. 2. Soil temperature at a depth of 10 cm (ºC) depending on the kind of straw, measured at 8.00 a.m. and 2.00 p.m. in the cultivation without cover (mean for period 27.04-18.05)

Soil temperature in the plots without straw, both in the morning (measurement at 8.00 a.m.) and in the afternoon (measurement at 2.00 p.m.), without cover and under polypropylene fibre, was higher than in plots with straw. The lowest fall in temperature compared to the control plot was observed in plots mulched with buckwheat straw. The reductions in soil temperature as a result of buckwheat straw mulching in treatments without cover at 8.00 a.m. amounted to 1.2ºC and at 2.00 p.m. to 3.6ºC, 0.5 and 3.0ºC, respectively (Fig. 2 and 3) in covered plots. The cause of smaller differences in soil temperature between the control object and objects with buckwheat straw mulch was lower intensity of light reflection (Tab. 1). The results of the study showed that, irrespective of whether a covering was used, soil mulching contributed to slower warming. This was confirmed in studies by Chakraborty *et al*. (2008), in which the temperature of soil mulched with rice straw was lower at a depth of 7 and 14 cm during all growing periods, especially at measurement at 2.30 p.m., as well as in those by Eruola et al. (2012), in which soil mulching with grass caused a significant reduction of temperature at a depth of 15 cm compared with the control. According to many authors, slower increase in soil temperature under mulches and also lower fluctuations of soil temperature in the growing period of plants contribute to better growth and development and, as a result, to obtaining a higher vegetable yield (Olasantan 1999, Kęsik and Maskalaniec 2005, Dahiya *et al*. 2007, Sinkevičienė *et al*. 2009). This phenomenon can be unfavourable for thermal plants, as confirmed in the findings of Borowy and Komosa (2003). They found that insufficient soil warming under rye mulch and the occurrence of frost after seedlings were planted contributed to significant damage of tomatoes. Tomato plants cultivated using traditional methods (without mulch) were not damaged by frost.

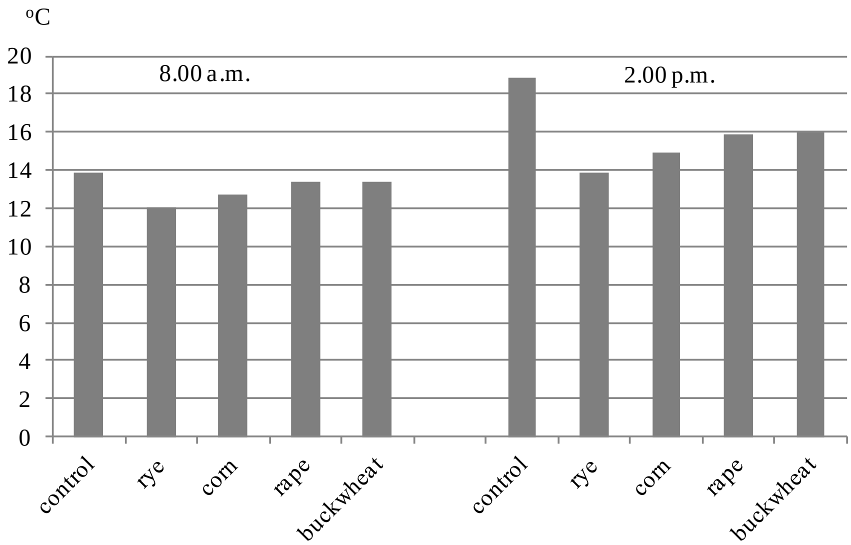

Fig. 3. Soil temperature at a depth of 10 cm (ºC) depending on the kind of straw, measured at 8.00 a.m. and 2.00 p.m. in the cultivation under polypropylene fibre (mean for period 27.04-18.05)

Soil moisture

The study results showed a significant influence of the interaction between plant covering and the kind of straw on the soil moisture in both the soil layers 0-20 and 20-40 cm immediately after cover removal and before broccoli harvest (Tab. 2 and 3). It was found that all kinds of straw investigated in the experiment caused an increase of moisture in the upper and lower soil layers on both dates of sampling (after cover removal and before broccoli harvest), in the combination without cover and under polypropylene fibre. This was confirmed in studies by Olasantan (1999) and Iles and Dosmann (1999), in which mulched soil was always characterised by higher moisture compared with non-mulched control. According to those authors, mulching protected the soil from water losses through evaporation, helped improve soil moisture and limited the penetration of water beyond the root system. Olasantan (1999) claims that mulching, irrespective of the time of mulch application, maintains the moisture in the upper soil layer because mulched soil dries more slowly. According to Sinkevičienė *et al*. (2009), soil moisture in mulched plots is not only higher compared with control plots, but also more stable during all growing period. Studies by Shangning and Unger (2001), as well as by Uwah and Iwo (2011), indicated that straw mulching increases soil moisture and causes an increase in the content of water in the soil with an increasing straw dose used for mulching.

Table 2. Soil moisture at a depth of 0-20 and 20-40 cm after cover removal (%) – mean for years 2010-2012

Kind of straw	Covering		Mean
	Without cover	Polypropylene fibre	
Soil layer 0-20 cm			
Control	11.21	12.28	11.74
Rye	12.82	12.60	12.71
Corn	12.66	13.80	13.23
Rape	12.31	12.94	12.62
Buckwheat	13.44	13.43	13.44
Mean	12.49	13.01	12.75
$SLD_{0.05}$ for: covering = n.s.; kind of straw = 1.45; covering x kind of straw = 1.07			
Soil layer 20-40 cm			
Control	11.54	12.67	12.11
Rye	13.26	13.30	13.28
Corn	13.09	13.60	13.34
Rape	13.59	13.41	13.50
Buckwheat	13.83	13.18	13.50
Mean	13.06	13.23	13.15
$SLD_{0.05}$ for: covering = n.s.; kind of straw = n.s.; covering x kind of straw = 0.73			

On the first date of soil sampling (after cover removal) in the covered plots, higher moisture of upper soil layer (0-20 cm) was characteristic of the soil mulched with corn straw compared with plots mulched with rye straw (Tab. 2). However, in the cultivation without cover, higher moisture in the 0-20 cm soil layer was found in plots mulched with buckwheat straw compared with rape straw, and in lower soil layer (20-40 cm) in plots mulched with buckwheat straw than mulched with corn straw.

When the soil moisture was determined before broccoli harvest, higher moisture of upper soil layer (0-20 cm) in non-covered objects was found in plots mulched with rye straw compared with corn and rape straw (Tab. 3). The plots mulched with corn and buckwheat straw were also characterised by higher soil moisture than those mulched with rape straw. However, mulching with rape straw contributed to significant increase water content in the lower soil layer (20-40 cm) compared to remaining kinds of straw. No significant differences were found in soil moisture for the successive kinds of straw in covered combinations in both the upper and lower soil layers.

Table 3. Soil moisture at a depth of 0-20 and 20-40 cm before harvest (%) – mean for years 2010-2012

Kind of straw	Covering		Mean
	Without cover	Polypropylene fibre	
Soil layer 0-20 cm			
Control	7.36	7.92	7.64
Rye	10.10	10.87	10.48
Corn	9.51	10.86	10.19
Rape	8.77	10.95	9.86
Buckwheat	9.73	10.97	10.35
Mean	9.09	10.31	9.70
$SLD_{0.05}$ for: covering = 1.14; kind of straw = 1.12; covering x kind of straw = 0.38			
Soil layer 20-40 cm			
Control	8.05	8.64	8.35
Rye	10.05	11.03	10.54
Corn	9.43	10.46	9.94
Rape	11.29	11.12	11.21
Buckwheat	9.44	11.36	10.40
Mean	9.65	10.52	10.09
$SLD_{0.05}$ for: covering = n.s.; kind of straw = 2.05; covering x kind of straw = 1.24			

In the study by Sinkevičienė *et al*. (2009) the soil moisture in straw mulched plots was shown to be higher by 3.0-4.5% compared to the soil moisture in the control plots. The favourable influence of straw mulch on the reduction of water losses from the soil in potato cultivation was confirmed in a study by Kar and Kumar (2007). In a study by Ramakrishna et al. (2006) the amount of water in the soil profile to a depth of 90 cm was significantly higher in plots mulched with straw compared with non-mulched control. The moisture of soil mulched with rice straw in the study by Chakraborty et al. (2008), at a depth of 15-30 cm, after 67 and 85 days from sowing amounted to 8.9% and was significantly higher compared to non-mulched control (7.6%). At a depth 0-15 cm, the level of soil moisture under rice straw was moderate (13%), although the best maintenance of moisture in the rice straw occurred at a depth of 30-45 cm. Tomar et al. (1992) demonstrated higher soil moisture at the depth of 0-30 cm in mulched plots compared with the control. According to those authors, the effect of mulching was less pronounced at the 30-90 cm depth, but mulches retained relatively more moisture than the control. On the basis of the results obtained it was found that plant covering with polypropylene fibre and simultaneous soil mulching had a more favourable influence on water content in the soil than only mulching. This was confirmed in a study by Siwek (2002), regarding straw mulching in cucumber and celery cultivation. According to the author, plants growing for a few weeks under flat covers are in conditions of high humidity. Additional soil mulching protects the water in the soil and prevents losses through evaporation and, as a result, improves plant growth and development.

Broccoli yield

Irrespective of investigated factors, the total yield of broccoli amounted to 21.16 t ha^{-1} (Tab. 4). The results of the study showed a significant influence of the interaction between covering and kind of straw applied for soil mulching on the yield level of broccoli. It was found that mulching with all the kinds of straw contributed to a significant increase of yield compared with plot without straw, both in cultivation without cover and under polypropylene fibre. Significantly the highest yield in the cultivation under polypropylene fibre cover was achieved from plots mulched with buckwheat straw compared with other kinds of straw. The highest yield of broccoli heads on buckwheat straw could be a result of higher soil temperature during the whole growing period of plants. In the combination without cover, higher broccoli yield was obtained in plots mulched with corn straw. However, the difference was too small and it was not statistically confirmed. The yielding effect of organic mulches was confirmed in the studies by Sinkevičienė *et al*. (2009) in the cultivation of onion, red beet, cabbage and potato, by Jamil *et al*. (2005) in garlic, by Olfati *et al*. (2008) in carrot, by Saeed and Ahmad (2009) in tomato. The favourable effect of using covering on the yield level of broccoli was confirmed in a study by Kunicki *et al*. (1996). The author showed that the improvement of the microclimate in the plants' surroundings, as a result of the increase of temperature and moisture under perforated foil and polypropylene fibre, caused the yields of broccoli heads to occur 3-4 days earlier and to be significantly higher compared with the control object. In a study by Siwek (2002), the marketable yield of cucumber, as a result of soil mulching and plant covering, was higher on average by 276% than the yield from the plots without mulch and cover. According to Gordon *et al.* (2010), an increase in soil temperature and moisture under mulches will not always cause an increase in the yield of plants.

Table 4. Effect of plant covering and soil mulching with straw on the total yield of broccoli (t ha^{-1}) – mean for years 2010-2012

Kind of straw	Covering		Mean
	Without cover	Polypropylene fibre	
Control	13.24	20.13	16.69
Rye	20.16	23.40	21.78
Corn	20.85	23.18	22.02
Rape	19.61	22.30	20.95
Buckwheat	19.99	28.70	24.35
Mean	18.77	23.54	21.16
$SLD_{0.05}$ for: covering = 3.40; kind of straw = 2.42; covering x kind of straw = 3.15			

CONCLUSIONS

1. Application of polypropylene fibre cover contributed to an increase in soil temperature by 1.2ºC in the morning and by 1.8ºC in the afternoon. The highest soil temperature, irrespective of covering, was observed in the control object without straw. The research showed that mulching contributed to slower warming of soil.
2. Irrespective of whether a covering was used, all kinds of straw investigated in the experiment caused an increase of soil moisture in both the soil layers, 0-20 and 20-40 cm, immediately after cover removal and before broccoli harvest.
3. The increase of temperature and moisture as a result of soil mulching with straw and covering the plants caused a significant increase in broccoli yield compared to the control. In the cultivation under polypropylene fibre the highest yielding effect was achieved in the objects with buckwheat straw. In non-covered objects slightly higher yields, compared to remaining kinds of straw, but significantly higher than in control plot, were indicated for soil mulching with corn straw.

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WPŁYW OSŁANIANIA I ŚCIÓŁKOWANIA NA TEMPERATURĘ I WILGOTNOŚĆ GLEBY ORAZ PLONOWANIE BROKUŁU

Edyta Kosterna

Katedra Warzywnictwa, Wydział Przyrodniczy,
Uniwersytet Przyrodniczo-Humanistyczny w Siedlcach
ul. B. Prusa 14, 08-110 Siedlce
e-mail: edyta.kosterna@uph.edu.pl

Streszczenie. Gleby w Polsce charakteryzują się stosunkowo niskimi zasobami wody. Mulczowanie jest jedną z metod, które wpływają korzystnie na wilgotność i strukturę gleby, redukują negatywny wpływ erozji oraz pomagają zmniejszyć wahania jej temperatury. Eksperyment polowy przeprowadzono w latach 2010-2012 na terenie Stacji Doświadczalnej należącej do Uniwersytetu

Przyrodniczo-Humanistycznego w Siedlcach, w układzie split-blok w trzech powtórzeniach. Celem badań była ocena wpływu osłaniania roślin (bez osłony, pod włókniną polipropylenową) i mulczowania gleby słomą (żytnia, kukurydziana, rzepakowa, gryczana) na zmiany jej temperatury i wilgotności a także na plonowanie brokułu. Temperatura gleby na głębokości 10 cm w obiektach osłanianych była wyższa niż w obiekcie nieosłanianym. Niezależnie od osłaniania temperatura gleby w obiektach bez słomy była wyższa niż w obiektach mulczowanych słomą. Najmniejszy spadek temperatury w porównaniu do stwierdzonej w obiekcie kontrolnym zaobserwowano w obiektach mulczowanych słomą gryczaną. Zjawisko to było wynikiem niższej intensywności odbicia światła przez tę słomę, która absorbowała więcej promieni słonecznych niż słoma innych gatunków roślin. Wszystkie badane rodzaje słomy powodowały wzrost wilgotności wierzchniej (0-20 cm) i głębszej (20-40 cm) warstwy gleby po zdjęciu osłon i przed zbiorem róż, zarówno w uprawie bez osłony, jak i z włókniną polipropylenową. Zastosowanie osłon i jednoczesne mulczowanie gleby wpłynęło korzystniej na zawartość wody w glebie w porównaniu do mulczowania. Istotnie największy plon ogółem brokułu w uprawie pod włókniną zebrano z obiektów mulczowanych słomą gryczaną. W uprawie bez osłony nieznacznie większy w porównaniu z pozostałymi słomami, ale istotnie większy w porównaniu z obiektem kontrolnym plon dało mulczowanie gleby słomą kukurydzianą.

Słowa kluczowe: włóknina polipropylenowa, mulcz, słoma, wilgotność, temperatura