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SOIL MULCHING WITH STRAW IN BROCCOLI CULTIVATION FOR EARLY HARVEST

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ABSTRACT
All treatments which protect soil from degradation and use of plant protection methods, other than chemicals are of great importance in the cultivation. This effect is attributed, among others, to organic mulches. By limiting the growth of weeds, maintaining proper moisture and reducing daily temperature fluctuations, mulch improves soil conditions for plant growth and development. The experiment was carried out between 2010 and 2012 at the Experimental Farm in Zawady as a split-block design with three replicates. The effect of the kind of straw (rye, corn, rape, buckwheat) and its dose (10 and 20 $t \cdot ha^{-1}$) applied as a mulch on the yield and quality of broccoli 'Milady F_1' cultivated for early harvest was investigated. The effect of straw was compared to a control plot without mulch. Weather conditions in the successive years of the study had a significant influence on the yield and quality of broccoli. The highest yields with the best parameters were obtained in 2010 and 2012, which were characterized by sufficient rainfall for broccoli. It was not found significant differences in the yield level and weight of head between particular kinds of straw, however, all kinds of straw investigated in the experiment, irrespective of dose, contributed to a significant increase in the yield and favourably influenced the biometric features of broccoli compared to that achieved from cultivation without straw. Soil mulching with corn straw was most favourable to yield and its parameters.

Keywords: yield, quality, broccoli, kind of straw, dose of straw.

INTRODUCTION

Soil mulching is one of the elements of ecological cultivation of vegetables. The effect of mulching on the soil properties and plant yield depends on the climatic and soil conditions, agrotechny and the kind of mulch. This treatment gives better results in less favourable soil conditions, in areas with a high abundance of weeds and at lower soil nutrients [Iwuafor, Kang 1994, Dobromilska et al. 1995, Zibilske, Makus 2009].

By limiting the growth of weeds, maintaining proper moisture and reducing the daily temperature fluctuations, mulch improves soil conditions for plant growth and development, resulting in a positive effect on vegetable yield [Swaider et al. 1992, Schonbeck, Evanylo 1998, Feldman et al. 2000, Ghosh et al. 2006, Dahiya et al. 2007, Nakhone, Tabatabai 2008, Saeed, Ahmad 2009]. According to Gill et al. [1996], the increase in yield due to mulching is higher for species grown for early harvest.

In the study by Jabłońska-Ceglarek et al. [2006] and Zaniewicz-Bajkowska et al. [2009], the application of rye straw as a mulch in cabbage and onion cultivation influenced the increase of total and marketable yield of these vegetables as compared to cultivation without mulch. An increased yield as the result of organic mulch application was found by Grassbaugh et al. [2004] as well as Rahman et al. [2006] (tomato), Law et al. [2006] (paprika), Jamil et al. [2005] (garlic), Adetunji [1990] (lettuce), Kar and Kumar [2007] (potato) and Johnson et al. [2004] (melon). In the study by Döring et al. [2005], mulch

with straw applied to organically grown potatoes had no significant influence on the yield or tuber size fractions.

This study aimed to determine the effect of mulch with different kinds of straw on the yield and quality of broccoli.

MATERIALS AND METHODS

The experiment was carried out between 2010 and 2012 at the Experimental Farm in Zawady, which is 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 content of plant-available nutrients was lower than that specified by Sady [2000] for optimal content for broccoli (Table 1). In the autumn, soil liming at the rate of 2 t CaO·ha^{-1} (calcium carbonate fertilizer) was performed.

The experiment was established as a split-block design with three replicates. The effect of this kind of straw (rye, corn, rape, buckwheat) and its dose (10 and 20 t·ha^{-1}) applied as a mulch on the yield and the quality of broccoli 'Milady F_1' cultivated for early harvest was investigated. The effect of straw was compared to a control plot without mulch. The area of one plot for harvest was 12 m^2.

The forecrop for broccoli was triticale. In the autumn preceding broccoli cultivation, 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 seedlings were planted, disc harrowing was applied to loosen the upper soil layer and prepare it for planting. After that, mineral fertilizers 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 fertilizers were applied in the form of ammonium nitrate, triple superphosphate and 60% potassium salt. Directly before planting broccoli seedlings particular kind of straw in appropriate doses was application.

Broccoli seedlings were grown in a non-heated greenhouse. Seeds (10 g) were sown in the successive study years on the 19th, 18th and 20th of March in multi-trays (54 holes). The seedlings were produced using peat substrate. Before planting, seedlings were moved outdoors. Plants were planted on the 19th, 18th and 23th of April, at a spacing of 50×50 cm. Three weeks after planting, 50 kg N·ha^{-1} in the form of ammonium nitrate was applied (topdress).

Broccoli was harvested by hand on 30 June 2010, and the 28 June 2011 and 2012. During the harvest, the following were determined: the marketable yield (t·ha^{-1}); average weight of marketable head (kg); weight of individual heads per plant – edible part of plant (kg); length of broccoli arc (cm); and stalk diameter (cm).

The results of the experiment were statistically analysed by means of the 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 $p = 0.05$.

Weather conditions in the study years varied (Table 2). Years 2010 and 2012 were characterized by a similar temperature during the growing period of the plant and favourable rainfall distribution for growing and development of broccoli. After seedlings were planted, there was abundant rainfall in the first and second 10-days of May. Also, two first 10-days of June were wet enough, what favoured broccoli heads formation and increased the yield. The least favourable conditions for broccoli

Table 1. Characteristic of soil conditions before experiment placing (available food components contents)

Years	pH	C–org.%	N–NO_3	N–NH_4	P	K	Ca	Mg
			mg·dm^{-3} air dry mass					
2010	5.7	1.7	8	7	32	70	220	24
2011	5.4	1.6	22	9	44	108	340	47
2012	5.0	1.3	13	6	27	70	220	37
Mean	5.4	1.5	14	7	34	83	260	36
Optimum content [Sady 2000]	6.2–7.0	–	105–120		50–60	160–190	1000–1500	45–55

Table 2. Mean air temperature and precipitation sums in the vegetation period of broccoli

Years	Decade	Temperature (˚C)			Precipitation (mm)		
		April	May	June	April	May	June
2010	I	7.8	12.7	18.6	5.9	30.3	12.5
	II	9.7	14.8	16.7	2.4	41.2	47.3
	III	9.2	14.6	16.9	2.4	21.7	2.8
Mean air temperature and precipitation sum		8.9	14.0	17.4	10.7	93.2	62.6
2011	I	8.6	8.5	20.5	9.8	17.9	8.7
	II	7.9	14.9	16.7	18.5	5.2	18.8
	III	13.7	17.0	17.1	2.7	13.0	11.6
Mean air temperature and precipitation sum		10.1	13.4	18.1	31.0	36.1	39.1
2012	I	3.0	15.1	13.9	4.6	17.3	26.4
	II	8.9	12.2	17.6	21.1	33.0	37.7
	III	14.9	16.4	17.5	4.2	3.1	12.1
Mean air temperature and precipitation sum		8.9	14.6	16.3	29.9	53.4	76.2
Mean long-term air temperature and precipitation sum		7.2	13.2	16.2	29.4	54.3	69.3

growth were in 2011, which was characterized by quite high mean air temperatures compared with the other study years but very irregular rainfall distribution. A dry period during the last 10 days of April (2.7 mm rainfall) contributed to poor seedling growth. Not much rain fell during the growth and development period of plants (second and third 10-days of May) and in the period of head formation (first and second 10-days of June).

RESULTS AND DISCUSSION

Weather conditions in the successive study years had a significant influence on the marketable yield, average weight of marketable head and weight of individual heads per plant (Table 3–5). The highest, marketable yield (18.78 t·ha^{-1}) and average weight of head (0.55 kg) was obtained in 2010, the most favourable for broccoli cultivation. In the least favourable year, 2011, the marketable yield was lower on

Table 3. Marketable yield of broccoli (t·ha^{-1})

Years	Dose of straw (t·ha^{-1})	Kind of straw				Mean
		rye	corn	rape	buckwheat	
2010	no straw	15.18	19.89	15.67	15.87	16.65
	10	22.45	23.86	18.33	20.70	21.34
	20	16.30	20.30	17.55	19.28	18.36
	Mean	17.98	21.35	17.18	18.62	18.78
2011	no straw	9.29	9.55	8.96	10.02	9.46
	10	14.35	14.60	14.22	14.33	14.37
	20	18.22	16.78	14.65	15.81	16.37
	Mean	13.95	13.64	12.61	13.39	13.40
2012	no straw	9.47	9.31	9.81	9.56	9.54
	10	19.45	21.34	23.23	22.45	21.62
	20	17.91	22.98	15.74	17.60	18.56
	Mean	15.61	17.87	16.26	16.54	16.57
Mean	no straw	11.31	12.92	11.48	11.82	11.88
	10	18.75	19.93	18.59	19.16	19.11
	20	17.48	20.02	15.98	17.56	17.76
Mean for kind of straw		15.85	17.62	15.35	16.18	16.25

LSD0,05 for: years = 4.13; kind of straw = n.s.; straw dose = 1.87; years × kind of straw = n.s.; years × straw dose = 3.24; kind of straw × straw dose = 1.19.

average by 5.38 t·ha^{-1} and average weight of head by 0.16 kg (Table 3-4). A significantly higher weight of individual heads was found in 2010 and 2012 compared to 2011 (Table 5). A high influence of weather conditions on the broccoli yields was also reported by Kałużewicz et al. [2010] and Karistsapol et al. [2013]. According to Birch et al. [2000], broccoli is highly responsive to climatic conditions, especially air temperature. Temperature has a strong impact on the plant's transition from the vegetative development-phase to the generative phase and yield [Kałużewicz et al. 2002].

The marketable yield and weight of broccoli head in the particular study years depended on the straw dose applied to soil mulching (Table 3-4). In 2010, higher marketable yield of broccoli as well as weight of head was obtained from the plots mulched with straw at a dose of 10 t·ha^{-1} compared to control object without straw. Higher yield and heads with higher weight compared to control without straw were also obtained from the plots with mulching with straw at a dose of 20 t·ha^{-1}. However, the differences were not statistically significant. In 2011 and 2012, soil mulching with straw irrespective of dose caused a significant increase in yield and average weight of marketable head compared with control plots without straw. In 2011 more favourable for broccoli yield influenced soil mulching with straw at a dose of 20 t·ha^{-1}, whereas in 2012 higher yields was obtained in the plots with straw at a dose of 10 t·ha^{-1}. The yield achieved from the plots mulching with straw at a dose of 10 t·ha^{-1} in 2012 was more than 2.0 times higher compared to control without straw. Gail et al. [1994] in studies regarding corn cultivation found that, with increasing straw dose applied to soil mulching, there was increased average weight and number of cobs per plant. However, the highest yield of seeds was obtained at a straw dose of 5.1 t·ha^{-1} compared to the control and mulching with straw at a dose of 1.7 t·ha^{-1}, 3.4 t·ha^{-1} and 6.8 t·ha^{-1}. Similarly, the study by Uwah and Iwo [2011] showed that increasing mulch dose from 2 to 8 t·ha^{-1} increased the height and number of leaves per maize plants. However, the highest yield of grain and the highest mass of cob was achieved at a mulch dose of 6 t·ha^{-1}. The authors also found that the yield of grain obtained with mulch at a dose of 6 and 8 t·ha^{-1} was more than twice that without mulching. Döring et al. [2005] did not find a significant influence of mulch with straw on the potato yield and tuber size. According to these authors, this could be caused by too low dose of straw applied for soil mulching. This relationship was confirmed in the studies by Stoner et al. [1996] and Edwards et al. [2000].

The study results showed a significant influence of the interaction between the kind and dose

Table 4. Weight of marketable head (kg)

Years	Dose of straw (t·ha^{-1})	Kind of straw				Mean
		rye	corn	rape	buckwheat	
2010	no straw	0.47	0.54	0.45	0.43	0.47
	10	0.68	0.66	0.54	0.60	0.62
	20	0.53	0.62	0.52	0.51	0.55
	Mean	0.56	0.61	0.50	0.51	0.55
2011	no straw	0.32	0.30	0.28	0.31	0.30
	10	0.42	0.42	0.40	0.39	0.40
	20	0.49	0.49	0.43	0.46	0.47
	Mean	0.41	0.40	0.37	0.39	0.39
2012	no straw	0.35	0.34	0.35	0.33	0.34
	10	0.58	0.61	0.65	0.61	0.61
	20	0.57	0.62	0.52	0.59	0.57
	Mean	0.50	0.52	0.51	0.51	0.51
Mean	no straw	0.38	0.40	0.36	0.36	0.37
	10	0.56	0.56	0.53	0.53	0.55
	20	0.53	0.58	0.49	0.52	0.53
Mean for kind of straw		0.49	0.51	0.46	0.47	0.49

LSD0,05 for: years = 0.09; kind of straw = n.s.; straw dose = 0.05; years × kind of straw = n.s.; years × straw dose = 0.09; kind of straw × straw dose = n.s.

Table 5. Weight of individual heads per plant (kg)

Years	Dose of straw ($t \cdot ha^{-1}$)	Kind of straw				Mean
		rye	corn	rape	buckwheat	
2010	no straw	0.42	0.36	0.35	0,37	0.38
	10	0.52	0.47	0.44	0.42	0.46
	20	0.36	0.44	0.36	0.38	0.39
	Mean	0.43	0.42	0.38	0.39	0.41
2011	no straw	0.37	0.24	0.32	0.28	0.30
	10	0.37	0.33	0.33	0.40	0.36
	20	0.42	0.37	0.31	0.44	0.38
	Mean	0.39	0.32	0.32	0.38	0.35
2012	no straw	0.38	0.38	0.35	0.37	0.37
	10	0.48	0.46	0.47	0.48	0.47
	20	0.49	0.49	0.44	0.43	0.46
	Mean	0.45	0.44	0.42	0.43	0.44
Mean	no straw	0.39	0.33	0.34	0.34	0.35
	10	0.46	0.42	0.41	0.44	0.43
	20	0.42	0.43	0.37	0.42	0.41
Mean for kind of straw		0.42	0.39	0.37	0.40	0.40

LSD0,05 for: years = 0.04; kind of straw = n.s.; straw dose = 0.05; years × kind of straw = n.s.; years × straw dose = n.s.; kind of straw × straw dose = 0.04.

of straw applied to soil mulching on the yield level and weight of individual heads per plant (Table 3 and 5). It was found that all kinds of straw investigated in the experiment irrespective of dose contributed to a significant increase in marketable yield. Significantly, the lowest yield was obtained from the plots without straw. Soil mulching with rye, rape and buckwheat straw at a dose of 10 $t \cdot ha^{-1}$ contributed to a significant increase in the marketable yield compared to plots mulched with straw at a dose of 20 $t \cdot ha^{-1}$. Increase in the marketable yield amounted to 1.27 $t \cdot ha^{-1}$, 2.61 and 1.60 $t \cdot ha^{-1}$, respectively. All straws at a dose of 10 $t \cdot ha^{-1}$ caused a significant increase in weight of individual heads per plants. Similar to the study by Sinkevičienė et al. [2009], the yield of vegetables depended on the kind of mulch application to soil mulching. These authors found that the highest yield was from soil mulching with grass. Yields of onion, reed beet, cabbage and potato from plots with straw and peat substrate mulch were similar – however, a less useful as a mulch was sawdust. This was confirmed in the study by Jamil et al. [2005] regarding garlic cultivation, in which mulch with straw contributed to a higher yield of bulb and a higher bulb weight compared to plots with sawdust mulch and control without mulch. The yield of bulb was higher by 1.68 and 2.76 $t \cdot ha^{-1}$, and weight of bulb by 74.13 and 111.10 g, respectively. Olfati et al. [2008] found that all organic mulches in the experiment contributed to increased total yield and average weight of carrot roots compared to cultivation without mulch. A similar dependence was found by Grassbaugh et al. [2004] and Saeed and Ahmad [2009] in tomato cultivation as well as Derek et al. [2006] in paprika cultivation. In the studies by Jabłońska-Ceglarek et al. [2006], mulch with rye straw in head cabbage growing increased the total and marketable yield compared to cultivation without mulch. Similarly, in the study by Zaniewicz-Bajkowska et al. [2009], yields of cabbage and onion cultivated after mulch with straw were higher than that obtained in the control without mulch. In the study by Feldman et al. [2000], the highest yields of cabbage and melon were obtained after soil mulching with organic mulch compared to synthetic mulch and without mulch. In turn, Díaz-Pérez [2004] in the study regarding onion cultivation, found that yield with straw mulch was significantly lower compared to the control. Gajc-Wolska et al. [2005] found that yields of paprika cultivated on the mulch with straw compared to polypropylene fibre mulch were lower.

Weather conditions in the study years had a significant influence on the length of broccoli head arc and stalk diameter (Table 6 and 7). The most favourable parameters were in 2012 (warm and moist). In

Table 6. Length of broccoli arc (cm)

Years	Dose of straw (t·ha^{-1})	Kind of straw				Mean
		rye	corn	rape	buckwheat	
2010	no straw	22.85	24.80	26.20	22.85	24.18
	10	28.50	24.50	24.35	24.00	25.34
	20	25.00	24.80	23.70	21.00	23.63
	Mean	25.45	24.70	24.75	22.62	24.38
2011	no straw	23.25	24.09	23.05	24.29	23.67
	10	24.78	21.56	22.22	23.22	22.94
	20	22.56	22.67	22.56	23.78	22.89
	Mean	23.53	22.77	22.61	23.76	23.17
2012	no straw	24.43	23.63	24.10	24.63	24.20
	10	27.57	27.23	27.10	26.20	27.03
	20	27.43	26.57	26.67	28.80	27.37
	Mean	26.48	25.81	25.96	26.54	26.20
Mean	no straw	23.51	24.18	24.45	23.93	24.02
	10	26.95	24.43	24.56	24.47	25.10
	20	25.00	24.68	24.31	24.53	24.63
Mean for kind of straw		25.15	24.43	24.44	24.31	24.58

LSD0,05 for: years = 0.87; kind of straw = n.s.; straw dose = n.s.; years × kind of straw = 1.92; years × straw dose = 2.09; kind of straw × straw dose = 0.91.

Table 7. Stalk diameter (cm)

Years	Dose of straw (t·ha^{-1})	Kind of straw				Mean
		rye	corn	rape	buckwheat	
2010	no straw	4.19	3.72	4.72	4.59	4.30
	10	5.10	4.99	4.98	4.68	4.94
	20	4.67	4.64	4.17	4.79	4.56
	Mean	4.65	4.45	4.62	4.68	4.60
2011	no straw	4.32	4.31	4.46	4.23	4.33
	10	4.88	4.85	4.75	5.32	4.95
	20	4.77	4.99	4.95	4.54	4.81
	Mean	4.65	4.72	4.72	4.70	4.70
2012	no straw	3.73	3.67	3.60	3.80	3.70
	10	3.73	4.17	4.53	3.90	4.08
	20	4.70	4.63	4.40	4.33	4.52
	Mean	4.06	4.16	4.18	4.01	4.10
Mean	no straw	4.08	3.90	4.26	4.21	4.11
	10	4.57	4.67	4.76	4.63	4.66
	20	4.71	4.75	4.51	4.55	4.63
Mean for kind of straw		4.45	4.44	4.51	4.46	4.47

LSD0,05 for: years = 0.25; kind of straw = n.s.; straw dose = 0.43; years × kind of straw = n.s.; years × straw dose = n.s.; kind of straw × straw dose = 0.25.

this year, heads were characterized significantly by the highest length of arc and the lowest stalk diameter. The differences amounted to 1.82 and 0.50 cm compared to 2010, and 3.03 and 0.60 cm compared to 2011. Broccoli heads in 2010 were characterized by a significantly longer arc than in 2011.

The study results showed the effect of the kind and dose of straw in the successive study years on the length of broccoli arc (Table 6). In 2010, higher length of arc characterized heads from the plots mulched with rye, corn and rape straw compared to buckwheat straw. The dose of

straw applied to soil mulching had an influence on the length of head arc in 2012: the heads from plots with straw at a dose of 10 and 20 t·ha^{-1} were characterized by a significantly higher length of arc compared to controls without straw. The differences amounted to 2.83 and 3.17 cm.

The results showed a significant interaction between the kind and dose of straw on the investigated parameters of broccoli heads (Table 6 and 7). Application of rye straw, irrespective of dose, contributed to increased length of broccoli head arc compared to without straw. Length of arc was higher by 3.44 cm with rye straw at a dose of 10 t·ha^{-1} and 1.49 cm with rye straw at a dose of 20 t·ha^{-1}. A significant increase in the length of broccoli head arc in the combination with rye straw at a dose of 10 t·ha^{-1} was found compared to mulching with straw at a dose of 20 t·ha^{-1}. In the remaining combinations, the differences were lower and were not statistically significant (Table 6).

Broccoli heads with the lowest stalk diameter were obtained from the controls without straw (Table 7). In the plots with rape straw significantly lower stalk diameter were characterized heads at a dose of 20 t·ha^{-1} compared to 10 t·ha^{-1}. Olfati et al. [2008] showed that all organic mulches applied in the studies had a significant influence on the increased length of carrot roots compared to controls without mulch. However, the authors did not find significant differences in the height of plants or root diameter. This was confirmed by a study by Khan and Parvej [2010] regarding corn cultivation. The authors found that mulching enhanced the number of ears per plant, ear height, length and diameter, tassel length, number of seed rows and 1000-grains weight compared to cultivation without mulch.

CONCLUSIONS

1. Weather conditions in study years had a significant influence on the yield level and the quality of broccoli heads. The highest yield with the best parameters was obtained in 2010 and 2012, which were characterized by sufficient rainfall for broccoli.
2. It was found that all kinds of straw investigated in the experiment, irrespective of dose, contributed to a significant increase in the marketable yield, weight of marketable head and improved head quality compared to that achieved from cultivation without straw mulching.
3. Among the examined kinds of straw, the most favourable was corn straw at a dose of 20 t·ha^{-1}.

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