

Effect of mulching with various films on the yield quality of butterhead lettuce and celery stalks with special reference to nitrate metabolism

Renata Wojciechowska¹, Piotr Siwek², Andrzej Libik²

¹Department of Plant Physiology, ²Department of Vegetable Crops
Faculty of Horticulture, Agricultural University in Kraków
29 Listopada 54, 31-425 Kraków, Poland
e-mail: rwojciechowska@bratek.ogr.ar.krakow.pl

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ABSTRACT

The results of two-year studies (2005 – 2006) on the effect of soil mulching with transparent, white and black film made from original and recycled materials on the selected yield quality ratios of ‘Melodion’ lettuce and ‘Tango’ celery stalks have been presented. Plants cultivated on mulches were generally characterized with lower contents of ascorbic acid, soluble sugars, ammonium ions, free amino acids and dry matter in comparison with non-mulched plants. Soil mulching with transparent and white film, regardless of the material it was made from, had significant effect on nitrate content decrease in lettuce heads in comparison with the control treatment. Least nitrates were accumulated by stalks of the celery cultivated on white films. On the other hand, the plants of both species cultivated on black films were characterized with highest NO₃⁻ content. In respect to the yield quality of celery stalks, best effects were obtained in the case of mulching with original rather than recycled film.

INTRODUCTION

Soil mulching around plants is a common agricultural procedure effectively increasing vegetable yield (Lamont 1993). The causes of the yield increase of vegetable crops cultivated in this manner were already discussed in the earlier study (Siwek et al. 2007). Available literature informs on few studies on the effect of soil mulching upon the quality of vegetables, in particular regarding leafy vegetables (Siwek 2002). The quality aspect is closely related not only to high content of favourable compounds in vegetables but also low level of substances harmful to the consumer's health, such as for example, nitrates. This problem is particularly important in the case of leafy vegetables such as lettuce or celery, which are capable of high NO_3^- accumulation (Elkner and Kaniszewski 2001, Premuzic et al. 2002).

Apart from nitrogen fertilization, factors such as lighting, water and thermal conditions during vegetation period have effect on nitrate intake and NO_3^- reduction in plant tissues, which is catalyzed by nitrate reductase enzyme (Lillo et al. 2004, Wojciechowska 2004). It was demonstrated earlier that mulching with films of different colours changes microclimate around plants (Siwek et al. 2007). Moreover, the authors also demonstrated the effect of the material from which the film was made (original or recycled) on optical properties of the film and the yield of butterhead lettuce and celery. Therefore, it was interesting to investigate to what degree the effect of soil mulching with various types of films can modify nitrate levels and the transformations of these compounds in the mentioned vegetables. Another aim of the study was to analyze the contents of ascorbic acid, soluble sugars and dry mass in lettuce and celery stalks.

MATERIAL AND METHODS

The study was carried out in 2005 and 2006 at the Experimental Station of Agricultural University in Kraków and concerned 'Melodion' lettuce and 'Tango' celery grown in the spring season. Details concerning the cultivation of both vegetable species, yields and the materials from which mulching films were made have been described in the work of Siwek et al. (2007).

Treatments were made by various kinds of films used in mulching: (1) control plants (without film), (2) transparent film from original material, (3) transparent film from recycled material, (4) white film from original material, (5) white film from recycled material, (6) black film from original material and (7) black film from recycled material.

From each of four replications (4 x 40 plants) three plants were taken for the chemical analyses. Nitrate reductase activity (NR) was determined in accordance to

the method described by Jaworski with the modifications of Rożek (1982). NO_3^- and NH_4^+ ion content in plant material was determined using ORION ion-selective electrodes working together with UNICAM-9460 ionometer (samples were 0.02M $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ extracted). Free amino acid content was determined in accordance with the procedure described by Korenman (1973). Total sugars were determined with Luffa-Schoorl method modified by Scales, and L-ascorbic acid with Tillman's method. In order to determine dry matter content, samples of plant material were dried at 95°C. All data were subjected to analysis of variance in Statistica program and the Neumann-Keuls test was used to estimate the significance of difference between the means at $p = 0.05$.

RESULTS AND DISCUSSION

The results of qualitative indicators in 'Melodion' lettuce leaves are presented in Table 1. Generally, the type of film used for mulching did not affect ascorbic acid content in lettuce leaves. In 2005 the level of this compound was significantly higher in the control plants as compared to mulched plants. High total sugars and dry matter levels in non-mulched lettuce, observed particularly in 2006, might have been connected with the low yield harvested from this stand (Siwek et al. 2007). In both years of the experiment a positive effect of film made from recycled material on soluble sugar accumulation in lettuce leaves was determined, the exception being transparent film mulches. However, it is worth stressing that lettuce cultivated on transparent film was characterized, on average, with lowest nitrate level in comparison with other treatments.

Mulching with transparent and white film, regardless of the material the film was made from, had a significant effect on decreasing nitrate content in lettuce heads in comparison with the control treatment. However, in the case of plants cultivated on black film, NO_3^- concentration was similar to that of the control. Such an effect might have been connected with weed elimination under black film. In the case of other films, weeds effectively competed with lettuce for nitrate. Dobrzański et al. (2004) quote the results of experiments in which NO_3^- content in vegetables increased in effect of destroying weeds growing around such plants. In the studies on soil mulching with black film, Benoit and Ceustermans (1992) demonstrated a significantly higher nitrate content in lettuce grown on mulched soil as compared to non-mulched cultivation.

In the present study considerable differences in NR activity in lettuce leaves between 2005 and 2006 were demonstrated. However, it is worth stressing that the activity level of this enzyme was, in particular years, proportional to nitrogen ion content. A similar dependence was found in the case of celery stalks (Table 2).

Table 1. The effect of kind of plastic film used for soil mulching on ascorbic acid (mg AA 100 g⁻¹ f.w.), total sugars (mg 100 g⁻¹ f.w.), dry matter (%), nitrates (mg NO₃⁻ kg⁻¹ f.w.) content, nitrate reductase activity (NR, μmol NO₂⁻ g⁻¹ f.w. h⁻¹), ammonium ions (μmol NH₄⁺ g⁻¹ f.w.) and free amino acids (mg N 100 g⁻¹ f.w.) content in lettuce leaves in 2005 – 2006

Kind of plastic film	Ascorbic acid		Total sugars		Dry matter		Nitrates		NR		Ammonium ions		Free amino acids	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Control	36.47cB ³	25.13aA	1160cC	1297bC	5.62bAB	6.80dD	1104.6eC	254.0dC	888.5bB ³	86.4bC	29.46eC	15.88eC	11.65eC	8.18dD
Transp. ¹ original	23.87ab	22.83a	893b	937a	5.47a	5.36a	676.4a	187.8a	514.2a	63.5a	23.77a	12.48c	6.96b	6.49c
Transp. recycling	23.90ab	23.77a	780a	1040a	5.59b	5.53ab	754.7b	206.3b	460.3a	64.8a	25.29b	12.78c	7.38cd	6.64c
Mean for transp.	23.89A	23.30A	837A	988A	5.53A	5.45A	715.6A	197.1A	487.3A	63.9A	24.53A	12.63B	7.17B	6.56C
White original	27.00b	26.97a	1270d	1050a	6.18c	5.91c	840.4c	229.7c	473.7a	69.7a	27.45d	11.03b	7.05bc	5.87b
White recycling	22.07a	24.23a	1467e	1143ab	5.40a	5.52ab	662.8a	195.1ab	485.9a	72.8ab	26.52cd	9.87a	6.61a	6.54c
Mean for white	24.5A	25.60A	1368D	1097AB	5.80B	5.71B	751.6B	212.4B	479.8A	71.3AB	26.98B	10.45A	6.83A	6.20B
Black original	20.73a	27.37a	903b	1000a	5.60b	6.00c	1158.6f	235.5c	387.6a	66.6a	28.86e	13.65d	7.24cd	6.44c
Black recycling	22.97ab	22.37a	1097c	1277b	5.61b	5.65b	1051.6d	259.4d	430.2a	87.0b	25.57bc	11.55b	7.47d	5.59a
Mean for black	21.85A	24.87A	1000B	1138B	5.61AB	5.82C	1105.1C	247.5C	408.9A	76.8B	27.22B	12.60B	7.35B	6.01A
Original ²	23.87X	25.72X	1022X	996X	5.75Y	5.76X	891.81Y	217.68X	458.49X	66.63X	26.69Y	12.39Y	7.08X	6.27X
Recycling ²	22.98X	23.46X	1115Y	1153Y	5.53X	5.60X	823.03X	220.27X	458.82X	74.70Y	25.79X	11.40X	7.15X	6.26X

¹Transparent film

²Mean for the kind of material

³Statistical analysis concerns each year separately; values designated with the same letters do not differ significantly; small letters concern interaction kind of material × color of film, capital letters – color of film, X, Y – kind of material

Table 2. The effect of kind of plastic film used for soil mulching on ascorbic acid (mg AA 100 g⁻¹ f.w.), total sugars (mg 100 g⁻¹ f.w.), dry matter (%), nitrates (mg NO₃⁻ kg⁻¹ f.w.) content, nitrate reductase activity (NR, μmol NO₂⁻ g⁻¹ f.w. h⁻¹), ammonium ions (μmol NH₄⁺ g⁻¹ f.w.) and free amino acids (mg N 100 g⁻¹ f.w.) content in celery stalks in 2005 – 2006

Kind of plastic film	Ascorbic acid		Total sugars		Dry matter		Nitrates		NR		Ammonium ions		Free amino acids	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Control	12.57dC ³	21.37dB	910abA	1937dC	5.57cA	11.03dC	759.9dC	92.89bB	19.09bB ³	3.46aB	32.42eD	22.61dC	5.87dC	5.88dD
Transp. ¹ original	9.40b	13.50bc	1003b	1637bc	5.50c	8.05c	757.7d	71.04a	14.16a	3.00a	24.91c	16.50c	5.27c	4.01b
Transp. recycling	9.17ab	12.40a	997b	1460a	5.30b	7.50a	573.2b	65.89a	16.65ab	3.06a	23.57b	13.91ab	3.53b	3.68a
Mean for transp.	9.28A	12.95A	1000B	1548AB	5.40A	7.77B	665.5B	68.51A	15.40A	3.03A	24.24B	15.21B	4.40B	3.84A
White original	11.87c	13.73c	1343c	1763c	6.32d	7.81b	403.9a	60.77a	26.01cd	4.42 b	27.94d	14.74b	3.16a	5.41c
White recycling	9.30b	12.80ab	1020b	1513ab	5.55c	7.38a	649.6c	64.96a	23.12c	3.13a	22.44b	13.67a	3.14a	5.26c
Mean for white	10.58B	13.27A	1182C	1638B	5.94B	7.60A	526.8A	62.87A	24.57C	3.77B	25.19C	14.21A	3.15A	5.34B
Black original	8.70a	13.03abc	850a	1437a	5.18a	7.57ab	1102.2e	87.54b	28.44de	4.46b	22.53b	14.69b	5.87d	5.93d
Black recycling	9.63b	13.50bc	1003b	1570ab	5.37b	7.59ab	1081.7e	124.81c	30.07e	4.84b	19.51a	14.96b	7.27e	5.35c
Mean for black	9.17A	13.27A	927A	1503A	5.28A	7.58A	1092.0D	106.18C	29.25D	4.65C	21.02A	14.83A	6.57D	5.64C
Original ²	9.99Y	13.42Y	1065Y	1612Y	5.67X	7.81Y	754.6X	73.12X	22.87X	3.53X	25.13Y	15.31Y	4.77X	5.12Y
Recycling ²	9.37X	12.73X	830X	1514X	5.41X	7.49X	768.2X	85.25Y	23.28X	4.09Y	21.84X	14.18X	4.65X	4.81X

^{1,2,3} See explanation in Tab. 1

This phenomenon results from the fact that NR is the enzyme induced in the presence of substrate, in this case NO_3^- ions (Lillo et al. 2004). Differences in nitrate content and metabolism in the studied vegetables, which occurred in both years of the experiment, might have been affected by the change of cultivation stand and different weather conditions during vegetation. In particular, very dry and hot weather in 2006 (Siwek et al. 2007) might have influenced the limitation of nitrate intake by plants.

In the case of lettuce, in both years of the experiment high NR activities were found in the leaves of the control plants (Table 1). In 2005 no significant effect of the type of film on the activity of this enzyme was demonstrated. In the following year, the effect was evident in the mulched treatment, particularly in the case of black film made from recycled material, where reductase activity was significantly higher and proportional to higher NO_3^- concentration in the same tissues. In general, plants cultivated on mulches, in comparison with the control, demonstrated lower level of ammonium ions and free amino acids. This might indicate that the use of nitrate by these plants to increase plant biomass was better, the fact which might have been related to better water conditions under mulches and was reflected in higher yield.

The analysis of qualitative ratios in celery stalks (Table 2) showed that significantly lower yields in 2006 (Siwek et al. 2007) were accompanied with higher contents of ascorbic acid, soluble sugars and dry matter and significantly lower contents of nitrates as compared with the previous year of the experiment. The authors demonstrated that lowest levels of nitrates were accumulated by stalks of celery cultivated on white mulches. This fact might have been connected with the highest amount of light reaching these parts of leaves, particularly due to rays being reflected by film. The highest, in comparison with other films, reflectance (51.2% within 400-700 nm range) from white film made from original material was accompanied with lowest NO_3^- content but also relatively high reductase activity in both years of the experiment. Many authors have confirmed that nitrate content in plants decreases with the increase of light intensity (Wojciechowska 2004).

The observation, made in both years of the experiment, that the stalks of celery cultivated on mulch contained significantly less ascorbic acid than the control, usually regardless of film colour, seems to be of particular interest. Similar dependence was observed for dry matter content in 2006. These results are comparable to the results obtained by Najda and Dyduch (2005), who demonstrated that celery cultivated on black polyethylene mulch included less dry matter and L-ascorbic acid than non-mulched plants.

Summarizing, it may be stated that in respect to the yield quality of celery stalks, in comparison with other mulches, best effects were obtained for white film made from the original material. Cultivation on transparent and white mulches, regardless of the material they were made from, had effect on the decrease of nitrates in lettuce heads.

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WPLYW ŚCIÓŁKOWANIA RÓŻNYMI RODZAJAMI FOLII NA JAKOŚĆ
PLONU SAŁATY MASŁOWEJ I SELERA NACIOWEGO ZE SZCZEGÓLNYM
UWZGLĘDNIENIEM METABOLIZMU AZOTANÓW

Streszczenie: Przedstawiono wyniki dwuletnich badań (2005 – 2006) nad wpływem ściółkowania gleby folią bezbarwną, białą i czarną pochodzenia oryginalnego oraz recyklingowego na wybrane wskaźniki jakości plonu sałaty ‘Melodion’ oraz ogonków liściowych selera naciowego ‘Tango’. Rośliny uprawiane na ściółkach charakteryzowały się na ogół mniejszą zawartością kwasu askorbinowego, cukrów rozpuszczalnych, jonów amonowych, wolnych aminokwasów i suchej masy niż rosące bez ściółek. Ściółkowanie gleby folią bezbarwną i białą niezależnie od pochodzenia surowca w istotny sposób wpływało na obniżenie zawartości azotanów w główkach sałaty w porównaniu z kombinacją kontrolną. Najmniej azotanów gromadziły ogonki selera uprawianego na ściółkach białych. Natomiast rośliny obu gatunków uprawiane na ściółkach czarnych charakteryzował najwyższy poziom NO_3^- . Pod względem jakości plonu ogonków liściowych selera naciowego lepsze efekty uzyskiwano w uprawie ze ściółkowaniem gleby folią oryginalną niż recyklingową.

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