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PHACELIA AND AMARANTH CATCH CROPS IN SWEET CORN CULTIVATION. PART II. SELECTED COMPONENTS OF NUTRITIVE VALUE OF CORN

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Abstract. Sweet corn grain is rich in nutrients. There are many factors, fertilization being one of the most important, which influence the quality of the grain. A special role in improving soil fertility is ascribed to catch crop plants when they are incorporated into the soil. A field experiment was carried out in central-eastern Poland to investigate the effect of phacelia and amaranth catch crops used as green manures on dry matter, sugars and ascorbic acid contents in sweet corn kernels. Catch crops were sown at three dates: 21st July, 4th and 18th August, and incorporated in late October. Sweet corn was cultivated in the first year following manuring. The effect of the green manures was compared to farmyard manure applied at a rate of 40 $t \cdot ha^{-1}$ and a non-manured control. The highest average dry matter content (27.5%) was determined in corn kernels cultivated without manuring, significantly lower after farmyard manure (26.4%). Catch crops incorporation did not cause significant changes in dry matter content in corn. Corn cultivated after catch crops had higher or similar contents of sugars compared with cultivation after farmyard manure. The most total sugars (8.12% f.m.) were found in corn cultivated after phacelia sown on the 21st of July, the least (7.04% f.m.) in the non-manured control. The highest monosaccharides content was in corn following amaranth sown on the 21st of July and 4th of August (2.50% f.m.), it was significantly lower (2.27% f.m.) after farmyard manure. The highest ascorbic acid content was determined in corn after phacelia sown on the 4th of August (8.88 $mg \cdot 100^{-1}$ g f.m.) and in amaranth sown on the 21st of July (8.98 $mg \cdot 100^{-1}$ g f.m.). Significantly less ascorbic acid was found following phacelia sown on the 18th August and in the non-manured control. Ascorbic acid contents in corn from the remaining treatments did not differ significantly. 'Sweet Wonder F_1' was characterized by higher contents of dry matter and total sugars in kernels than 'Challenger F_1'.

Key words: organic manuring, green manure, *Phacelia tanacetifolia* Benth., *Amaranthus cruentus* L., *Zea mays* L. var. *saccharata*, dry matter, ascorbic acid, sugars

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INTRODUCTION

Sweet corn grain is rich in nutrients. It contains a lot of protein, sugars, and most of vitamins and microelements. There are many factors which influence grain quality, fertilization and weather conditions in the growing season of sweet corn being one of the most important. Mineral fertilization, nitrogen in particular, affects the chemical composition of vegetables in a special way [Kunicki 1996]. An inappropriate application of mineral fertilization quite often causes the decrease in yield and its quality. According to Venter [1983] and Biczak et al. [1998], increased rates of mineral fertilizer, whether applied prior to or after sowing, can decrease dry matter and sugars contents in vegetables. Organic manures are the factor which compensates for both the shortage and excess of nutrients in soil, which can be observed after high mineral fertilization. A special role in improving soil fertility is ascribed to catch crop plants when they are incorporated into the soil [Hruszka 1996, Jabłońska-Ceglarek et al. 2004, Clark et al. 2007, Tejada et al. 2008]. There is a paucity of literature on the subject of the effect of catch crops on the biological value of sweet corn.

The present work is an attempt to determine the effect of phacelia and amaranth catch crops, sown at three dates and incorporated as green manure on changes in the content of dry matter, sugars and ascorbic acid in sweet corn kernels.

MATERIALS AND METHODS

Results of the studies described in the present work came from a field experiment carried out over 2004–2007 at the Experimental Farm in Zawady, 25 km east of Siedlce (52°06'N, 22°55'E). There was investigated the secondary effect of phacelia and amaranth catch crops sown at three dates: 21st of July (PA1 – phacelia, AS1 – amaranth), 4th of August (PA2 – phacelia, AS2 – amaranth), and 18th of August (PA3 – phacelia, AS3 – amaranth) on the content of dry matter, total sugars and monosaccharides as well as ascorbic acid in sweet corn cv. 'Challenger F_1' and 'Sweet Wonder F_1'. The effect of the catch crop green manures was compared to farmyard manure applied at a rate of 40 t·ha^{-1} and a non-manured control (NOM).

Description of the study conditions and methods was presented in the first part of the work "Phacelia and amaranth catch crops in sweet corn cultivation. Part I. Corn yields".

Cobs were harvested at the stage of milk maturity of kernels. During the harvest the samples of 30 cobs from each plot were taken to perform chemical analyses. There was determined the kernel content of:

– dry mass – by drying to the constant weight at 105°C [Polish Standard PN-90/A-75101/03],

– total sugars and monosaccharides – by the Luff-Schoorl method [Polish Standard PN-90/A-75101/07],

– L-ascorbic acid content – by the Tillmans method modified by Pijanowski [Polish Standard PN-90/A-75101/11].

The results of the experiment were statistically analyzed 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.

RESULTS AND DISCUSSION

The average dry matter content in sweet corn kernels amounted to 26.7% (tab. 1). It was significantly affected by weather conditions in the consecutive study years. These sweet corn cultivated in 2005 and 2007 contained significantly more dry matter than in 2006. The years were characterized by significantly lower precipitation than 2006. In the sweet corn growing season (May–Aug) precipitation amounted to: 240.7 mm in 2005, 307.4 mm in 2006 and 219.4 in 2007 mm. In 2006 74% of precipitation in the corn growing season was recorded in August (227.6 mm). This year was also warmer than the others. Borowiecki [1988] has reported that soil water shortages negatively influence grain formation, number of grains per cob as well as dry matter content. Michałojć et al. [1996] have found that an increase in soil moisture is followed by increased dry matter content in sweet corn kernels.

Table 1. Dry matter contents in sweet corn kernels (%)
Tabela 1. Zawartość suchej masy w ziarniakach kukurydzy cukrowej (%)

Organic manures Nawożenie organiczne	Years – Lata			Cultivar – Odmiana		$\bar{x}$
	2005	2006	2007	Challenger F_1	Sweet Wonder F_1	
	średnio dla dwóch odmian mean for two cultivars			średnio dla lat mean for years		
Control (NOM) Kontrola	28.0 bc**	25.4 a	28.9 b	26.9 bc	28.0 b	27.5 b
Farmyard manure (FYM) Obornik	27.3 abc	24.9 a	26.9 a	26.3 abc	26.4 a	26.4 a
Phacelia 21.07 (PA1)* Facelia 21.07	27.8 abc	26.4 a	27.5 ab	27.4 c	27.1 ab	27.2 ab
Phacelia 4.08 (PA2) Facelia 4.08	27.8 abc	25.4 a	28.1 ab	27.0 c	27.2 ab	27.1 ab
Phacelia 18.08 (PA3) Facelia 18.08	26.0 a	26.2 a	27.9 ab	25.9 ab	27.5 ab	26.7 ab
Amaranth 21.07 (AS1) Szarłat 21.07	27.2 ab	25.3 a	28.1 ab	26.6 bc	27.0 ab	26.8 ab
Amaranth 4.08 (AS2) Szarłat 4.08	28.0 bc	25.3 a	26.7 a	26.4 abc	26.9 ab	26.6 ab
Amaranth 18.08 (AS3) Szarłat 18.08	28.1 c	24.8 a	27.1 ab	25.5 a	27.8 b	26.7 ab
Mean – Średnio	27.5 B	25.5 A	27.6 B	26.5 A	27.3 B	26.9

The highest average dry matter content (27.5%) was determined in sweet corn cultivated in NOM, significantly lower (26.4%) in farmyard manure-incorporated plots. The

catch crops investigated had an influence on the quantity of dry matter accumulated in corn kernels that was similar to farmyard manure. Jabłońska-Ceglarek et al. [2005] found that the effect of oat and field pea catch crops (in pure stand and mixture) on grain content of dry matter was similar to farmyard manure. After vetch, which produced less biomass than oat and field pea, the dry matter content was lower than after farmyard manure. Zaniewicz-Bajkowska et al. [2010] found that sunflower catch crop sown on the 21st of July and incorporated in the autumn increased the dry matter content in corn kernels compared with farmyard manure. Sunflower catch crop sown 2 and 4 weeks later had a similar effect on dry matter content to farmyard manure.

The effect of organic manure type on dry matter content was different in the individual study years. In 2006, which was characterized by very wet August, when cobs formed and grew, the quantity and kind of organic matter incorporated had no effect on the dry matter content in kernels. In 2005 it was found that corn cultivated after amaranth sown on the 4th and 18th of August (AS2 and AS3) and in NOM contained significantly more dry matter compared with phacelia sown on the 18th of August (PA3).

The sweet corn cultivars examined had different dry matter contents depending on the organic manuring applied. 'Challenger F_1' (average d.m. content 26.5%) accumulated the most dry matter in kernels following catch crops PA1 and PA2, a similar quantity after AS1, AS2, FYM and in NOM, and significantly less after PA3 and AS3. 'Sweet Wonder F_1' (average d.m. content 27.3%) accumulated the most dry matter in NOM and after the catch crop AS3, significantly less after FYM.

Dry matter contents in corn kernels determined for individual combinations, fell within the range of optimal values (24–29%). The unique taste of sweet corn is associated with a high grain content of water-soluble polysaccharides. It is well established that an increased dry matter content, e.g. in maturing kernels, is followed by unfavourable changes in carbohydrates. The taste, quality and appearance of kernels deteriorated [Douglass and Juvik 1993, Michałojć et al. 1996, Marshall and Tracy 2003, Niedziółka and Szymanek 2005].

The total sugars content in sweet corn kernels differed significantly in the successive study years (tab. 2). It was found that corn cultivated in 2006 and 2005 contained the most and least total sugars (9.25 and 5.48% f.m., respectively). In 2005 organic manuring did not significantly affect the parameter investigated. In 2006 the highest total sugars content was determined in corn following phacelia PA1. Significantly the lowest total sugars content was recorded after FYM and catch crops AS1 and AS2. In 2007 corn cultivated after almost all the catch crops (except phacelia PA3) contained significantly more total sugars than after control NOM.

'Sweet Wonder F_1' contained significantly more total sugars (8.33% f.m.) than 'Challenger F_1' (6.66% f.m.). The cultivars investigated had different sugars contents depending on the organic manuring applied. 'Challenger F_1' contained the most total sugars (7.13% f.m.) after phacelia PA1, a similar quantity after amaranth AS2 and AS3, FYM as well as in the control NOM. Significantly lower was the sugars content in corn after phacelia PA2 and PA3. 'Sweet Wonder F_1' significantly the most total sugars accumulated after phacelia PA2 and PA1 (9.36 and 9.11% f.m. respectively), significantly the least (7.18% f.m.) in the control NOM. Corn following catch crops PA1, PA2, PA3 and AS1 contained significantly more total sugars than after FYM.

Table 2. Total sugars contents in sweet corn kernels (% f.m.)
Tabela 2. Zawartość cukrów ogółem w ziarniakach kukurydzy cukrowej (% św.m.)

Organic manures Nawożenie organiczne	Years – Lata			Cultivar – Odmiana		$\bar{x}$
	2005	2006	2007	Challenger F_1	Sweet Wonder F_1	
	średnio dla dwóch odmian mean for two cultivars			średnio dla lat mean for years		
Control (NOM) Kontrola	5.58 a**	9.11 ab	6.39 a	6.87 bc	7.18 a	7.03 a
Farmyard manure (FYM) Obornik	5.59 a	9.00 a	7.33 ab	6.79 bc	7.82 b	7.30 ab
Phacelia 21.07 (PA1)* Facelia 21.07	5.56 a	10.27 b	8.52 b	7.13 c	9.11 d	8.12 c
Phacelia 4.08 (PA2) Facelia 4.08	5.45 a	9.66 ab	8.21 b	6.19 a	9.36 d	7.77 bc
Phacelia 18.08 (PA3) Facelia 18.08	5.10 a	9.11 ab	7.54 ab	6.05 a	8.45 c	7.25 ab
Amaranth 21.07 (AS1) Szarłat 21.07	5.33 a	8.86 a	8.23 b	6.55 ab	8.39 c	7.47 abc
Amaranth 4.08 (AS2) Szarłat 4.08	5.74 a	8.84 a	8.02 b	6.94 bc	8.12 bc	7.53 abc
Amaranth 18.08 (AS3) Szarłat 18.08	5.52 a	9.15 ab	7.75 b	6.76 bc	8.18 bc	7.47 abc
Mean – Średnio	5.48 A	9.25 C	7.75 B	6.66 A	8.33 B	7.49

The average monosaccharides content in sweet corn kernels amounted to 2.40% f.m. (tab. 3). Significantly most and least monosaccharides were determined in 2006 (2.77% f.m.) and 2005 (2.16% f.m.), respectively. Both corn cultivars were characterized by similar average monosaccharides contents.

The effect of organic manure type on the monosaccharides content in sweet corn depended on the study years and cultivars examined in the study. In 2005 there was found no significant influence of the factors investigated on monosaccharides contents. In 2006 corn cultivated after phacelia PA3 and amaranth AS1 contained more monosaccharides than after farmyard manure. In 2007 most monosaccharides were accumulated in corn after phacelia and amaranth at the first date of sowing (PA1 and AS1). Significantly less monosaccharides were found after amaranth AS3, phacelia PA2, FYM and in NOM.

'Challenger F_1' cultivated following PA1, PA2, AS1 and AS2 contained significantly more monosaccharides than in the remaining combinations. In 'Sweet Wonder F_1' the monosaccharides content after amaranth AS1 was significantly higher than after phacelia PA3 and PA2, FYM as well as in NOM. Corn cultivated after almost all the catch crops, except PA2, contained significantly more monosaccharides compared with FYM and in NOM.

Jabłońska-Ceglarek et al. [2005] have reported insignificant differences in sugar contents of sweet corn cultivated following the previous crops used as green manures (oat, field pea, vetch) and farmyard manure. The authors did not find any influence of

the quantity of catch crop mass incorporated on the accumulation of sugars by corn. Zaniewicz-Bajkowska et al. [2010] have not found a significant effect of sunflower catch crop sown at different dates (21st of July, 4th and 18th of August) on the content of total sugars in sweet corn. However, they have demonstrated that corn cultivated after a sunflower catch crop sown on the 21st of July was characterized by a higher content of monosaccharides compared with farmyard manure.

Table 3. Monosaccharides contents in sweet corn kernels (% f.m.)
Tabela 3. Zawartość cukrów redukujących w ziarniakach kukurydzy cukrowej (% św.m.)

Organic manures Nawożenie organiczne	Years – Lata			Cultivar – Odmiana		$\bar{x}$
	2005	2006	2007	Challenger F_1	Sweet Wonder F_1	
	średnio dla dwóch odmian mean for two cultivars			średnio dla lat mean for years		
Control (NOM) Kontrola	2.09 a**	2.72 ab	2.17 ab	2.33 a	2.32 a	2.32 ab
Farmyard manure (FYM) Obornik	2.13 a	2.52 a	2.15 ab	2.25 a	2.29 a	2.27 a
Phacelia 21.07 (PA1)* Facelia 21.07	2.10 a	2.68 ab	2.56 c	2.46 b	2.43 cd	2.45 ab
Phacelia 4.08 (PA2) Facelia 4.08	2.20 a	2.79 ab	1.96 a	2.27 a	2.36 abc	2.32 ab
Phacelia 18.08 (PA3) Facelia 18.08	2.27 a	2.88 b	2.21 abc	2.51 b	2.40 bc	2.45 ab
Amaranth 21.07 (AS1) Szarłat 21.07	2.02 a	2.92 b	2.55 c	2.48 b	2.52 d	2.50 b
Amaranth 4.08 (AS2) Szarłat 4.08	2.32 a	2.80 ab	2.39 bc	2.53 b	2.47 cd	2.50 b
Amaranth 18.08 (AS3) Szarłat 18.08	2.16 a	2.85 ab	2.17 ab	2.34 a	2.45 cd	2.39 ab
Mean – Średnio	2.16 A	2.77 C	2.27 B	2.39 A	2.40 A	2.40

Weather conditions in the successive study years influenced the ascorbic acid content in sweet corn kernels (tab. 4). Significantly most and least ascorbic acid was accumulated by corn in 2005 (9.40 mg·100^{-1} g f.m.) and 2006 (8.15 mg·100^{-1} g f.m.), respectively.

The effect of organic manure type on the ascorbic acid content in kernels depended on the study years and cultivars examined in the study. In 2005 most ascorbic acid was determined in corn cultivated after phacelia PA1 (9.80 mg·100^{-1} g f.m.) and PA2 (9.73 mg·100^{-1} g f.m.). Significantly less ascorbic acid was accumulated by corn after FYM and amaranth AS1 and AS2. In 2006 there was found no significant influence of organic manure type on the factor examined. In 2007 most ascorbic acid was determined in corn cultivated after amaranth AS1 (9.42 mg·100^{-1} g f.m.). A similar quantity was also found in corn after farmyard manure. Corn following phacelia PA2 and amaranth AS2 and AS3 accumulated more ascorbic acid than after phacelia PA1.

Table 4. Ascorbic acid contents in sweet corn kernels (mg·100^{-1} g f.m.)
Tabela 4. Zawartość kwasu askorbinowego w ziarniakach kukurydzy cukrowej (mg·100^{-1} g św.m.)

Organic manures Nawożenie organiczne	Years – Lata			Cultivar – Odmiana		$\bar{x}$
	2005	2006	2007	Challenger F_1	Sweet Wonder F_1	
	średnio dla dwóch odmian mean for two cultivars			średnio dla lat mean for years		
Control (NOM) Kontrola	9.34 ab**	7.92 a	8.30 ab	8.57 bc	8.47 a	8.52 a
Farmyard manure (FYM) Obornik	9.16 a	8.03 a	8.93 cd	8.50 ab	8.91 b	8.70 ab
Phacelia 21.07 (PA1)* Facelia 21.07	9.80 b	8.35 a	8.20 ab	8.90 c	8.67 ab	8.78 ab
Phacelia 4.08 (PA2) Facelia 4.08	9.73 b	8.18 a	8.73 bc	8.91 c	8.86 b	8.88 b
Phacelia 18.08 (PA3) Facelia 18.08	9.47 ab	7.93 a	8.13 a	8.18 a	8.84 b	8.51 a
Amaranth 21.07 (AS1) Szarłat 21.07	9.12 a	8.40 a	9.42 d	9.39 d	8.57 ab	8.98 b
Amaranth 4.08 (AS2) Szarłat 4.08	9.17 a	8.12 a	8.73 bc	8.93 c	8.41 a	8.67 ab
Amaranth 18.08 (AS3) Szarłat 18.08	9.43 ab	8.25 a	8.72 bc	8.69 bc	8.91 b	8.80 ab
Mean – Średnio	9.40 C	8.15 A	8.64 B	8.76 A	8.70 A	8.73

Significantly most ascorbic acid was accumulated by 'Challenger F_1' after amaranth AS1 (9.39 mg·100^{-1} g f.m.). When cultivated after phacelia PA1 and PA2 and amaranth AS2 the cultivar was characterized by a higher ascorbic acid content than after FYM and phacelia PA3. 'Sweet Wonder F_1' following FYM and AS3, PA2 and PA3 contained more ascorbic acid than after AS2 and in NOM. In other studies no differences were found in ascorbic acid content in corn cultivated after farmyard manure and sunflower sown on the 21st of July, 4th and 18th of August. However, they noticed that after sunflower sown in August corn accumulated more ascorbic acid compared with that which cultivation included an application of mineral fertilizers only. Warman and Havard [1998] claimed that it is difficult to indicate which sweet corn cultivation method, that is mineral fertilizer- or organic manure-based one, more favourably influences vitamin C content in sweet corn kernels. The vitamin C content can be influenced by grain maturity, fertility and moisture content in soil, cultivation, meteorological conditions and even time of the day [Shewfelt 1990].

CONCLUSIONS

1. The content of dry matter, sugars and ascorbic acid in sweet corn kernels depended on weather conditions in the study years. Corn cultivated in 2006, which received the greatest precipitation during the growing season, contained least dry matter and ascorbic acid and most total sugars and monosaccharides.

2. Phacelia and amaranth catch crops sown at different times had a similar to farmyard manure effect on the dry matter content in corn kernels.

3. Corn cultivated after the catch crops examined in the study was characterized by a higher or similar content of sugars compared with farmyard manure. The most total sugars were determined in corn cultivated after phacelia sown on the 21st of July, and least in the control without organic manure. Corn after amaranth catch crop sown on the 21st of July and 4th of August contained most monosaccharides, and significantly less after farmyard manure.

4. The effect of catch crops and farmyard manure on ascorbic acid content was similar. Corn cultivated after amaranth sown on the 21st of July and phacelia sown on the 4th of August accumulated more ascorbic acid than after phacelia sown on the 18th of August and in the control without organic manure.

5. The sweet corn cultivars differently responded to organic manuring. 'Sweet Wonder F_1' contained more dry matter and total sugars, on average, than 'Challenger F_1'.

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MIĘDZYPLONY FACELII I SZARŁATU W UPRAWIE KUKURYDZY CUKROWEJ. CZĘŚĆ II. WYBRANE ELEMENTY WARTOŚCI ODŻYWCZEJ KUKURYDZY

Streszczenie. Ziarno kukurydzy cukrowej posiada bogate wartości odżywcze. Wpływ na jego jakość ma wiele czynników, wśród których ważniejsze to nawożenie. Szczególną rolę w podnoszeniu urodzajności gleby przypisuje się roślinom międzyplonowym uprawianym na przyoranie. Doświadczenie przeprowadzono w środkowo-wschodniej Polsce. Badano wpływ międzyplonowych nawozów zielonych z facelii i szarłatu na zawartość w ziarniakach kukurydzy cukrowej suchej masy, cukrów i kwasu askorbinowego. Międzyplony wysiewano w trzech terminach: 21 lipca, 4 i 18 sierpnia; przyorywano pod koniec października. Kukurydzę cukrową uprawiano w pierwszym roku po nawożeniu organicznym. Efekty stosowania międzyplonów porównano z obornikiem (40 t·ha^{-1}) oraz obiektem kontrolnym bez nawożenia organicznego. W latach 2005 i 2007 w ziarniakach kukurydzy stwierdzono więcej suchej masy niż w roku 2006. Najbogatsza w cukry okazała się kukurydza uprawiana w roku 2006, najuboższa w roku 2005. W roku 2005 stwierdzono natomiast najwięcej kwasu askorbinowego, a najmniej w roku 2006. Najwięcej suchej masy (27,5%) zawierały ziarniaki kukurydzy uprawianej bez nawożenia organicznego, istotnie mniej po oborniku (26,4%). Przyoranie międzyplonów nie powodowało natomiast istotnych zmian w zawartości suchej masy w kukurydzy. Kukurydza uprawiana po międzyplonach charakteryzowała się wyższą lub zbliżoną zawartością cukrów do uprawianej po oborniku. Najwięcej cukrów ogółem (8,12% f.m.) stwierdzono w kukurydzy uprawianej po facelii posianej 21 lipca, najmniej (7,04% f.m.) w kontroli bez nawożenia organicznego. Najwięcej cukrów redukujących zawierała kukurydza po szarłacie z siewu 21 lipca i 4 sierpnia (2,50% f.m.), istotnie mniej (2,27% f.m.) po oborniku. Najbogatsza w kwas askorbinowy okazała się kukurydza po facelii z siewu 4 sierpnia (8,88 mg·100^{-1} g f.m.) i szarłacie z siewu 21 lipca (8,98 mg·100^{-1} g f.m.). Istotnie mniejszą ilość kwasu askorbinowego stwierdzono po facelii posianej 18 sierpnia i w kontroli bez nawożenia organicznego. Zawartość badanego parametru w kukurydza z pozostałych obiektów nie różniła się istotnie. Odmiana 'Sweet Wonder F_1' charakteryzowała się wyższą zawartością suchej masy i cukrów ogółem w ziarniakach niż odmiana 'Challenger F_1'.

Słowa kluczowe: nawożenie organiczne, nawozy zielone, facelia, szarłat, kukurydza cukrowa, sucha masa, kwas askorbinowy, cukry

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