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QUALITATIVE CHARACTERISTICS OF WHITE MUSTARD AND TANSY PHACELIA GROWN AS STUBBLE CATCH CROPS DEPENDING ON SOIL CULTIVATION AND SOWING METHODS

Edward Wilczewski✉

Department of Agronomy, UTP University of Science and Technology in Bydgoszcz
prof. S. Kaliskiego 7, 85-796 Bydgoszcz, **Poland**

ABSTRACT

Background. The aim of this study was to determine the dependence of the qualitative characteristics of the green mass of stubble catch crops on the soil cultivation and sowing methods.

Material and methods. A field study was carried out in a randomized split-plot design in 2010–2012 at the Research Station of the Faculty of Agriculture and Biotechnology of the UTP in Mochełek near Bydgoszcz. The first factor of the experiment was the method of soil cultivation and sowing: traditional (T) – plowing, seedbed preparation with a combined tillage unit, seed sowing with a drill; simplified (S) – stubble disking, broadcasting seeds, harrowing; simplified+ (S+) – stubble disking, broadcasting seeds with a 20% increased sowing rate, harrowing; zero (Z) – broadcasting seeds into ripening winter wheat; zero+ (Z+) – broadcasting seeds with a 20% increased sowing rate into ripening winter wheat. The second factor was the crop species grown as the stubble catch crop: white mustard 'Bamberka' and tansy phacelia 'Anabela'. Sowing seeds in variants T, S and S+ was carried out between August 16-18, and in variants Z and Z+ on July 20.

Results. A significant effect of the experimental factors on the quality characteristics of white mustard and tansy phacelia grown as stubble catch crops was found. White mustard contained significantly more total nitrogen and crude fiber in the dry aboveground mass than tansy phacelia, which was more abundant in phosphorus, potassium, calcium and magnesium. The use of simplified tillage resulted in obtaining the aboveground biomass of catch crops with a higher total nitrogen and phosphorus content than was the case in traditional (plowing) soil cultivation and in zero tillage with the use of seed broadcasting into ripening winter wheat. The aboveground biomass of catch crops obtained as a result of the use of zero tillage contained more crude fiber than in the variants with traditional and simplified tillage.

Conclusion. Simplifying soil cultivation for stubble catch crops has a significant impact on the quality characteristics of the aboveground biomass they produce.

Key words: broadcasting, crude fiber, macronutrients, simplified tillage, stubble catch crop

INTRODUCTION

Stubble catch crops are currently grown mainly to obtain biomass used for green manure, especially in crop rotations in which they are an important element improving soil biological activity (Herrera and Liedgens, 2009; Jaskulska and Gałęzewski, 2009; Dopka *et al*., 2012; Piotrowska and Wilczewski, 2014). However, the use of their biomass for green manure does not always result in an improvement in the yield of poaceae cereals grown after them (Herrera and Liedgens, 2009; Dopka *et al*., 2012; Wrzesińska *et*

✉ edward@utp.edu.pl

al., 2017). Considering the uncertain yield-formation effect of catch crops in cereal crop rotations, it is justified to use their green mass for feed purposes. It is of particular importance in areas with a high cattle stocking rate and a shortage of permanent grassland. Currently, the largest demand for green fodder produced on arable land is in the Kuyavian--Pomeranian and Greater Poland voivodships, where the cattle stocking rate per 100 ha of permanent grassland is 393 and 360 units, respectively (GUS, 2018). An important purpose of stubble catch crops is to absorb and protect against leaching of fertilizer components remaining in the soil after harvesting poaceae cereals. In such pro-environmental approaches to growing catch crops it is recommended to abandon the use of mineral fertilizers in these crops (Duer, 2009). This leads to environmental protection and when allocating the green mass for feed purposes, to obtain feed with a low concentration of macronutrients.

Both the quantity of yield as well as the quality characteristics of the green mass of stubble catch crops depend on the development phase they reach, which is conditioned by the sowing date and the length of their growing period. Sowing stubble catch crops after winter wheat or spring barley harvest enables, under current conditions, a growing period of 2–3 months (Kisielewska and Harasimowicz-Hermann, 2008 b, Kisielewska, 2010; Pastuszka, 2016). By omitting after harvest soil cultivation as well as by sowing seeds into ripening cereals the growing period of a stubble catch crop can be extended by 2–4 weeks, however, in conditions of precipitation deficiency this can result in the extension of the germination stage and a reduction in the field emergence capacity.

Under current conditions, plant cultivation methods that reduce energy consumption and production costs while protecting soil are sought. According to Holland (2004) it is very important to reduce the intensity of soil cultivation as this would enable a significant reduction in energy consumption and a reduction in carbon dioxide emissions. However, Peigne *et al*., (2007) and Derpsch *et al*., (2010) stated that zero tillage does not loosen the soil sufficiently, which often results in a reduction in plant root growth. Zero tillage and even simplified cultivation may lead to a decrease in plant density after emergence (Wilczewski *et al*., 2019). To obtain optimum plant density it is justifiable to increase the number of seeds sown. This is especially important in catch crop cultivation, which is characterised by a substantially shortened growth period compared to main crops.

The aim of the present study was to assess the effect of soil cultivation and sowing methods on the content of macronutrients and crude fiber in the green mass of white mustard and tansy phacelia grown as stubble catch crops.

MATERIAL AND METHODS

The strict two-factor field experiment was performed in a randomized split-plot design in 2010–2012 at the Research Station of the Faculty of Agriculture and Biotechnology of the UTP in Mochełek near Bydgoszcz. Each harvest plot area was 14 m^2.
The experimental factors were:

1) the method of soil preparation for sowing:
   - traditional (T) - plowing, seedbed preparing with a combined tillage unit, seed sowing with a drill,
   - simplified (S) – stubble disking, broadcasting seeds, harrowing,
   - simplified+ (S+) – stubble disking, broadcasting seeds with 20% increased sowing rate, harrowing,
   - zero (Z) – broadcasting seeds into ripening winter wheat,
   - zero+ (Z+) – broadcasting seeds with 20% increased sowing rate into ripening winter wheat;
2) the crop species grown as a stubble catch crop:
   - white mustard ‘Bamberka’,
   - tansy phacelia ‘Anabela’.

The soil used in the experiment was a Luvisol (LV) with a fine sandy loam texture (IUSS Working Group WRB, 2007). The arable layer of the soil was very rich in absorbable phosphorus and rich in potassium and magnesium. It was slightly acidic. Sowing the catch crops was performed between August 16-18 in variants with traditional (T) cultivation, using row sowing and in variants with simplified (S) and simplified+ (S+) tillage, using broadcasting. In variants with zero (Z) and zero+ (Z+) tillage the seeds were broadcast before harvesting the previous crop (winter wheat), on July 20.

Seeds of the studied crops were sown in an amount of 15 kg·ha^{-1} in variants T, S and Z. To check the possibility of compensating for worse germination conditions of seeds, especially in the zero tillage variant, experimental objects with a 20% increased sowing amount (S + and Z +) were established, where 18 kg·ha^{-1} of seeds were sown. The sowing and harvesting dates and the number of days from sowing to harvesting the catch crops are presented in Table 1. Cultivation of the catch crops was carried out without the use of fertilizers.

Table 1. Sowing and harvesting date of catch crops

Soil cultivation and sowing variant	Year	Sowing date	Harvesting date	Number of days from sowing to harvesting
T, S, S+*	2010	16.08	18.10	63
	2011	16.08	16.10	61
	2012	18.08	26.10	69
Z, Z+	2010	20.07	18.10	90
	2011		16.10	88
	2012		26.10	98

*T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

After mowing the aboveground biomass of the catch crops the fresh mass yield was weighed and 0.5 kg of green mass from each plot was collected for chemical determinations. These samples were dried at 50^{o}C and then weighed again to determine the dry mass yield. The yield of fresh and dry mass was published in the work by Wilczewski *et al*. (2019). Chemical analyzes were carried out after grinding the dried plant material and after wet mineralization with perhydrol and sulfuric acid. The analysis included determination of the content of: crude fiber – with the modified Henneberg and Stohman method, total nitrogen – with the Kjeldahl method (Hermanowicz *et al*., 1976), phosphorus – the vanado-molybdenum method (Nowosielski, 1974), potassium and calcium – by flame photometry (Nowosielski, 1974) and magnesium – the colorimetric method with titanium yellow (Hermanowicz *et al*., 1976). Based on the content of macronutrients in the dry aboveground mass, the weight Ca : P ratio and the equivalent ratio of K : (Ca + Mg) were determined.

The study results were statistically analyzed by variance analysis. The significance of differences were determined by the Tukey confidence half interval, for the significance level P < 0.05. The relationships between the content of individual macronutrients and crude fiber in the biomass and the dry mass yield were determined by calculating Pearson's simple correlation coefficients. Statistical analysis of the results was performed using STATISTICA data analysis software system version 10 (StatSoft, 2011).

RESULTS

The mean total N content in the dry mass of the catch crops from the three years of the study was 17.2 g·kg^{-1} (Table 2). In variants with simplified and simplified+ tillage it was significantly higher than after using traditional, zero and zero+ tillage. In 2010 and on average over the three years of the study mustard contained significantly more total N than tansy phacelia, although in 2011 and 2012 the species did not differ in this respect. The method of soil cultivation and sowing in all years of the study affected the total N content in the dry mass of tansy phacelia. In two out of the three years of the study the total N content was also dependent on this factor for white mustard. Most often the highest values of this trait were found in plants from the simplified and simplified+ tillage and in the case of tansy phacelia in 2010 and 2011 they were comparable to the plants from traditional soil cultivation.

The studied plants contained in dry mass from 3.41 to 6.49 g·kg^{-1} phosphorus (Table 3). In two out of the three years and on average over the three years of the study, tansy phacelia contained significantly more of this component than white mustard. The highest amount of phosphorus was found in plants cultivated using simplified and simplified+ tillage, there was significantly less of it in the dry mass of plants from traditional cultivation, and the least from zero and zero+ tillage. However, in 2010 and 2011 no significant difference was found between traditional, simplified and simplified+ tillage. In 2011, the P content in the dry mass of white mustard did not depend on the soil cultivation and sowing variant.

Table 2. Total nitrogen content in aboveground dry mass of stubble catch crops (g·kg^{-1} d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	19.5 Aab*	16.3 Ba	17.9 ab
S	22.2 Aa	16.3 Ba	19.2 a
S+	16.0 Acd	17.5 Aa	16.8 bc
Z	15.5 Ad	11.7 Bb	13.6 d
Z+	19.0 Abc	11.7 Bb	15.3 cd
Mean	18.4 A	14.7 B	16.6
2011			
T	13.4 Ba	15.7 Aa	14.6 ab
S	14.3 Aa	14.6 Aab	14.4 ab
S+	15.2 Aa	14.6 Aab	14.9 a
Z	12.5 Aa	13.7 Aab	13.1 ab
Z+	12.8 Aa	12.0 Ab	12.4 b
Mean	13.6 A	14.1 A	13.9
2012			
T	16.6 Ab	18.4 Ab	17.5 b
S	24.8 Aa	12.7 Aab	23.8 ab
S+	26.8 Aa	26.2 Aa	26.5 a
Z	17.8 Ab	21.3 Aab	19.5 b
Z+	17.8 Ab	19.8 Ab	18.8 b
Mean	20.8 A	21.7 A	21.2
2010–2012			
T	16.5 Ab	16.8 Abc	16.7 b
S	20.4 Aa	17.9 Bab	19.2 a
S+	19.4 Aa	19.5 Aa	19.4 a
Z	15.3 Ab	15.6 Abc	15.4 b
Z+	16.5 Ab	14.5 Bc	15.5 b
Mean	17.6 A	16.8 B	17.2

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

Table 3. Phosphorus (P) content in aboveground dry mass of stubble catch crops (g·kg^{-1} d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	4.53 Aa*	4.39 Aa	4.46 a
S	4.40 Aab	4.59 Aa	4.49 a
S+	4.09 Bbc	4.70 Aa	4.39 a
Z	3.81 Ac	3.72 Ab	3.77 b
Z+	4.08 Abc	3.73 Bb	3.90 b
Mean	4.18 A	4.23 A	4.20
2011			
T	3.93 Ba	4.75 Aa	4.07 ab
S	3.88 Ba	4.51 Aa	4.19 a
S+	3.78 Ba	4.67 Aa	4.18 a
Z	3.49 Ba	3.98 Ab	3.74 bc
Z+	3.41 Aa	3.72 Ab	3.56 c
Mean	3.59 B	4.31 A	3.95
2012			
T	3.80 Bb	5.37 Ab	4.58 b
S	5.00 Ba	6.13 Aa	5.56 a
S+	5.50 Ba	6.49 Aa	5.99 a
Z	4.11 Bb	5.21 Ab	4.66 b
Z+	3.86 Bb	5.05 Ab	4.45 b
Mean	4.53 B	5.65 A	5.05
2010–2012			
T	3.91 Ab	4.84 Ab	4.37 b
S	4.43 Aa	5.08 Aa	4.75 a
S+	4.46 Aa	5.25 Aa	4.85 a
Z	3.81 Ab	4.30 Ac	4.06 c
Z+	3.78 Ab	4.17 Ac	3.97 c
Mean	4.08 B	4.73 A	4.40

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

Potassium was the component accumulated by the catch crops in the largest amount (Table 4). The potassium content in the dry mass of the catch crops varied significantly during the years of the study. The lowest concentration of this component was found in 2011 – on average 34.5 g·kg^{-1}, while the highest was in 2012 – on average 51.0 g·kg^{-1}. Tansy phacelia contained significantly more potassium than white mustard. The use of traditional, simplified and simplified+ tillage resulted in obtaining a dry mass yield with a higher potassium content than in variants where soil cultivation was not used and catch crop seeds were broadcast before harvesting the previous crop (winter wheat). An interaction was found between the research factors and the years regarding this trait. Most often the use of zero tillage negatively affected the potassium content. However, in 2011 this factor did not affect the potassium content in white mustard dry mass.

The calcium content in the dry mass of the studied plants was hardly modified by the method of soil cultivation and sowing. Only in 2011, in the dry matter of tansy phacelia grown using the traditional, simplified+ and zero+ method, a significantly higher content of this component was found than in the variant with zero tillage (Table 5). On average for the three years of the study the Ca concentration in the dry mass of tansy phacelia was significantly lower in the variant with zero tillage as compared with that obtained after using simplified+ and zero+ tillage. However, the method of soil cultivation and sowing did not affect the Ca content in the aboveground biomass of white mustard, which was also significantly less abundant in Ca in all years than was tansy phacelia.

The average Mg content in the aboveground dry mass of catch crops was 2.63 g·kg^{-1} (Table 6). It was significantly modified by the method of tillage and sowing. For white mustard it was significantly higher after the use of simplified tillage than after traditional or zero tillage. However, in 2011 no significant effect of this factor on the Mg content in the dry mass of white mustard was demonstrated. For tansy phacelia, both in 2011 and 2012, the method of tillage and sowing did not affect this characteristic, while in 2010 a significantly higher content of this component was found in the variants with simplified and simplified+ than with zero+ tillage. In all years of the study tansy phacelia contained significantly more Mg than white mustard.

Table 4. Potassium (K) content in aboveground dry mass of stubble catch crops (g·kg^{-1} d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	37.8 Ba*	43.9 Aab	40.8 a
S	37.5 Bab	46.4 Aa	41.9 a
S+	34.4 Bab	44.2 Aab	39.3 a
Z	30.1 Bb	38.7 Ab	34.4 a
Z+	33.0 Bab	37.8 Ab	35.4 a
Mean	34.6 B	42.2 A	38.4
2011			
T	28.1 Ba	56.1 Aa	42.1 a
S	27.3 Ba	47.6 Aa	37.4 ab
S+	30.0 Ba	53.4 Aa	41.7 a
Z	20.7 Ba	32.9 Ab	26.8 bc
Z+	18.2 Ba	30.9 Ab	24.5 c
Mean	24.8 B	44.2 A	34.5
2012			
T	37.6 Bab	71.8 Aa	54.7 ab
S	48.9 Ba	68.9 Aa	58.9 a
S+	45.9 Bab	60.6 Aab	53.2 ab
Z	41.1 Bab	58.4 Aab	49.8 ab
Z+	29.0 Bb	47.4 Ab	38.2 b
Mean	40.5 B	61.4 A	51.0
2010–2012			
T	34.51 Ba	57.2 Aa	45.9 a
S	37.9 Ba	54.3 Aa	46.1 a
S+	36.8 Ba	52.7 Aa	44.8 a
Z	30.6 Bab	43.4 Ab	37.0 b
Z+	26.7 Bb	38.7 Ab	32.7 b
Mean	33.3 B	49.3 A	41.3

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

Table 5. Calcium (Ca) content in aboveground dry mass of stubble catch crops (g·kg^{-1} d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	15.6 Ba*	21.4 Aa	18.5 a
S	17.5 Aa	21.3 Aa	19.4 a
S+	14.2 Ba	24.8 Aa	19.5 a
Z	15.2 Ba	19.9 Aa	17.5 a
Z+	15.1 Ba	20.3 Aa	17.7 a
Mean	15.5 B	21.5 A	18.5
2011			
T	15.7 Ba	28.1 Aab	21.9 a
S	17.0 Aa	20.5 Abc	18.7 a
S+	18.6 Ba	33.2 Aa	25.9 a
Z	20.4 Aa	15.6 Ac	18.1 a
Z+	21.9 Ba	30.5 Aab	26.2 a
Mean	18.7 B	25.6 A	22.1
2012			
T	19.6 Ba	30.8 Aa	25.2 a
S	27.1 Aa	33.2 Aa	30.2 a
S+	28.1 Aa	24.6 Aa	26.3 a
Z	20.8 Ba	32.2 Aa	26.5 a
Z+	23.0 Ba	33.6 Aa	28.3 a
Mean	23.7 B	30.9 A	27.3
2010–2012			
T	17.0 Ba	26.8 Aab	21.9 a
S	20.5 Ba	25.0 Aab	22.8 a
S+	20.3 Ba	27.5 Aa	23.9 a
Z	18.8 Ba	22.6 Ab	20.7 a
Z+	20.0 Ba	28.1 Aa	24.1 a
Mean	19.3 B	26.0 A	22.7

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

Table 6. Magnesium (Mg) content in aboveground dry mass of stubble catch crops (g·kg^{-1} d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	2.32 Ba*	2.62 Aab	2.47 ab
S	2.36 Ba	2.65 Aa	2.50 a
S+	2.14 Bab	2.68 Aa	2.41 ab
Z	1.98 Bb	2.46 Aab	2.22 b
Z+	2.22 Aab	2.33 Ab	2.28 ab
Mean	2.20 B	2.55 A	2.38
2011			
T	1.69 Ba	3.00 Aa	2.34 a
S	2.11 Ba	2.75 Aa	2.43 a
S+	1.88 Ba	2.83 Aa	2.36 a
Z	2.26 Ba	3.00 Aa	2.63 a
Z+	2.32 Ba	2.68 Aa	2.50 a
Mean	2.05 B	2.85 A	2.45
2012			
T	2.29 Bab	3.39 Aa	2.84 a
S	3.06 Aa	3.22 Aa	3.14 a
S+	3.04 Ba	3.72 Aa	3.38 a
Z	2.36 Bb	3.48 Aa	2.29 a
Z+	2.53 Bab	3.47 Aa	3.00 a
Mean	2.66 B	3.46 A	3.06
2010–2012			
T	2.10 Bb	3.00 Aa	2.55 a
S	2.51 Ba	2.87 Aa	2.69 a
S+	2.36 Bab	3.08 Aa	2.72 a
Z	2.20 Bb	2.98 Aa	2.59 a
Z+	2.36 Bab	2.83 Aa	2.59 a
Mean	2.30 B	2.95 A	2.63

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

The content of crude fiber in the dry mass of the catch crops ranged from 176 $g \cdot kg^{-1}$ for tansy phacelia in 2010 with the use of simplified cultivation to 472 $g \cdot kg^{-1}$ for white mustard in 2012 in the variant with traditional cultivation (Table 7). On average, in the three year period, the most fibrous biomass was obtained after zero and zero+ cultivation. The fiber content was significantly lower after using traditional tillage and the lowest in the variant with simplified+ tillage. An interaction was found between the research factors and years with respect to this trait. There was no effect of the method of soil cultivation and sowing on the fiber content in the dry mass of white mustard in 2011 and tansy phacelia in 2010. In 2011, the fiber content in the dry mass of tansy phacelia was significantly higher in the variant with zero+ tillage than in traditional and simplified+, while in 2012 white mustard was more fibrous under traditional tillage than in zero and zero+.

The content of N and P in the catch crops dry mass was negatively correlated with their yield and positively correlated with the content of K and Mg (Table 8). The content of P, K, Ca and Mg in the catch crop dry mass was negatively correlated with the fibre content. Very significant positive correlations were also found between K, Ca and Mg content.

The Ca : P weight ratio was on average 4.76 for white mustard and 5.55 for tansy phacelia. It was the highest for both studied plants in the variant with zero+ tillage (Fig. 1). For white mustard the lowest values of this ratio were obtained after using traditional and simplified+ soil cultivation. For tansy phacelia the lowest value of the Ca : P ratio was found after the use of simplified and zero tillage.

The K : (Ca+Mg) equivalent ratio was from 0.6:1 for white mustard in the variant of zero+ tillage to 0.94:1 for tansy phacelia grown with the use of the simplified soil cultivation method (Fig. 2). Simplification of soil cultivation contributed to a significant reduction of the K : (Ca + Mg) ratio in the aboveground biomass of white mustard. For tansy phacelia the use of simplified tillage resulted in obtaining a similar K : (Ca + Mg) relation as in traditional cultivation. A reduction in the value of this ratio was obtained in the variant with simplified+, while the lowest K : (Ca + Mg) ratio was found in the variant with zero+ tillage.

Table 7. Crude fibre content in aboveground dry mass of stubble catch crops ($g \cdot kg^{-1}$ d.m.)

Soil cultivation and sowing variant	White mustard	Tansy phacelia	Mean
2010			
T**	363 Aa*	192 Ba	277 b
S	272 Ab	176 Ba	224 d
S+	304 Ab	189 Ba	246 c
Z	393 Aa	272 Ba	332 a
Z+	385 Aa	270 Ba	327 a
Mean	343 A	220 B	281
2011			
T	421 Aa	202 Bb	311 b
S	427 Aa	259 Bab	343 ab
S+	409 Aa	200 Bb	305 b
Z	418 Aa	271 Bab	345 ab
Z+	417 Aa	320 Ba	369 a
Mean	418 A	250 B	334
2012			
T	472 Aa	252 Ba	362 a
S	371 Ad	206 Bb	288 c
S+	308 Ae	181 Bb	244 d
Z	436 Ab	232 Ba	334 b
Z+	415 Ac	254 Ba	334 b
Mean	401 A	225 B	313
2010–2012			
T	418 Aa	215 Bc	317 b
S	356 Ab	214 Bc	285 c
S+	340 Ab	190 Bd	265 d
Z	416 Aa	258 Bb	337 a
Z+	406 Aa	281 Ba	343 a
Mean	387 A	232 B	309

*values marked with the same capital letters within the lines do not differ significantly for $P < 0.05$. Values marked with the same lowercase letters within columns for a given year and plant do not differ significantly for $P < 0.05$
**T – traditional; S – simplified; S+ – simplified+; Z – zero; Z+ – zero+

Table 8. Linear correlation coefficients between content of nutrients and dry mass yield of catch crops biomass (n = 30)

Variable	Dry mass yield	N	P	K	Ca	Mg	Crude fibre
Dry mass yield	–	***	**	ns	ns	ns	ns
N	-0.75	–	***	**	ns	**	ns
P	-0.49	0.82	–	***	***	***	***
K	-0.15	0.56	0.87	–	***	***	***
Ca	-0.08	0.36	0.62	0.68	–	***	*
Mg	-0.23	0.57	0.84	0.79	0.77	–	***
Crude fibre	-0.07	-0.22	-0.63	-0.70	-0.49	-0.66	–

*correlation significant for $P < 0.05$; **correlation significant for $P < 0.01$; ***correlation significant for $P < 0.001$
ns – non significant

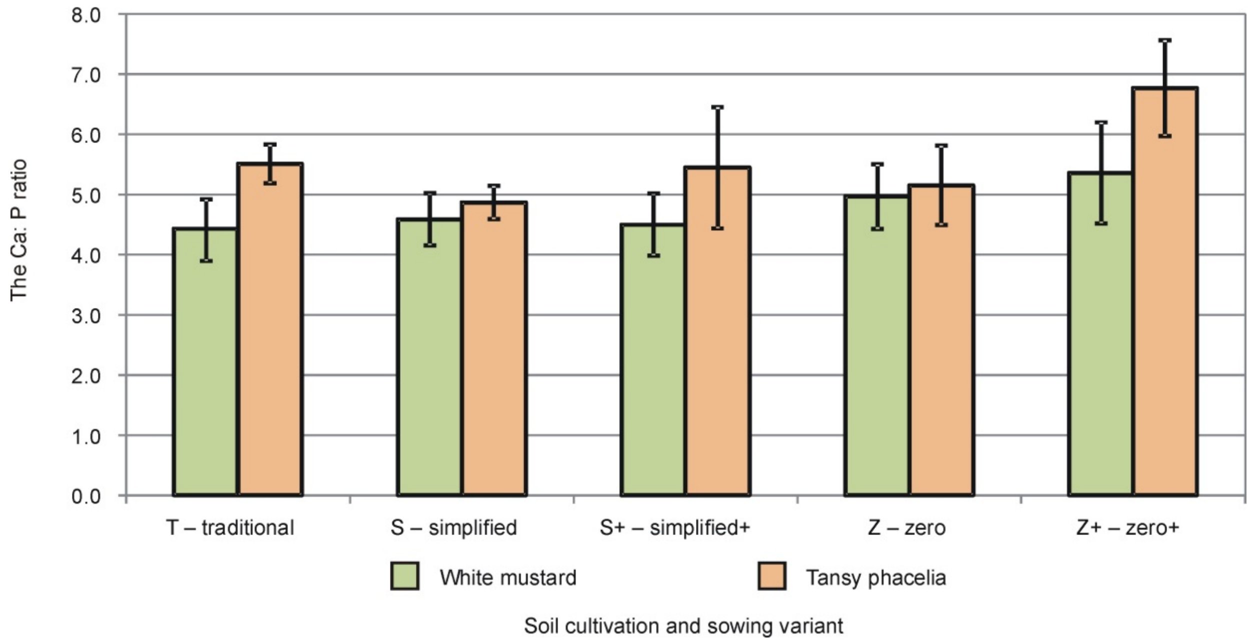

Fig. 1. The Ca : P concentration ratio in dry mass of catch crops – mean values for the years 2010–2012 (bars show standard errors)

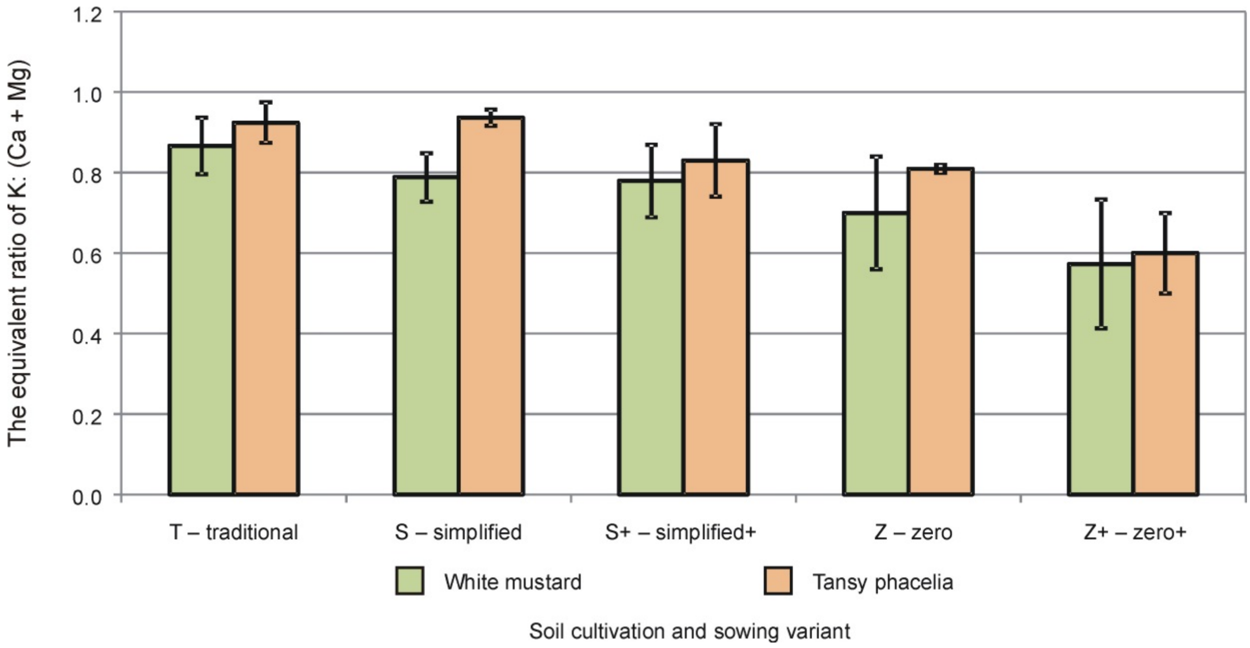

Fig. 2. The equivalent ratio of K : (Ca+Mg) in dry mass of catch crops – mean values for the years 2010–2012 (bars show standard errors)

DISCUSSION

The N content in the aboveground biomass of catch crops was relatively low (on average 17.2 g·kg^{-1}). In other studies carried out at the same location the mean N content in white mustard dry mass was on average 27.0-30.6 g·kg^{-1} (Kisielewska, 2010; Wilczewski and Szczepanek, 2018). The reason for the low content of this component in the present author's study may be the high total rainfall in the period preceding sowing the catch crops and in the initial period of their growth. The total precipitation in July in 2010, 2011 and 2012 was 107.4, 132.5 and 115.6 mm, respectively (Wilczewski *et al*. 2019). In addition, in 2010 there was also a very high total rainfall of 150.7 mm in August. Such conditions favor leaching of easily available forms of nitrogen from the soil (Jabloun *et al*., 2015, Huang *et al*., 2017). According to Huang *et al*. (2017), nitrogen leaching from the soil with a monthly rainfall of up to 100 mm is small, but significantly increases after exceeding this value. For stubble catch crops cultivated without mineral fertilization the deficiency of this component in the soil was an important limiting factor. This is also indicated by the relatively high content of macronutrients with lower susceptibility to leaching from the soil, such as phosphorus or calcium, whose content in the dry mass of white mustard was even slightly higher than in the studies cited above by Kisielewska (2010) or Wilczewski and Szczepanek (2018). In the present study, the content of N, P, K and Mg was the lowest in 2011 which was characterized by the highest rainfall in July and quite high rainfall in August, and was the highest in 2012 when there was a lower rainfall and a lower dry mass yield (Wilczewski *et al*., 2019).

The potassium content in the catch crop dry mass was moderately high for white mustard and very high for tansy phacelia. According to Hart *et al*. (1997) the K content in the dry mass of feed should not exceed 15 g·kg^{-1}. Therefore, despite the lack of fertilization of catch crops their aboveground biomass was too rich in potassium, especially in the case of tansy phacelia which exceeded the safe level of concentration of this macronutrient more than twice. An analysis of the scientific literature on this issue shows that excessive potassium accumulation in the aboveground biomass of stubble catch crops occurs frequently (Kisielewska, 2010; Wilczewski and Skinder, 2005). However, in the study by Zaniewicz--Bajkowska *et al*. (2013) the content of this component in tansy phacelia only slightly exceeded the desired values and decreased significantly with a sowing delay from July 21 to August 18. Therefore, when allocating the aboveground biomass of catch crops for feed purposes it is necessary to mix it with feed poorer in potassium. Simplified tillage variants resulted in aboveground biomass usually containing more N and K than when using traditional or zero tillage. This was probably due to a lower yield of aboveground dry mass in simplified tillage (Wilczewski *et al*., 2019). This was confirmed by the significant negative correlation coefficients between the content of these components and dry mass yield.

The high fiber content in the dry mass of the catch crops under conditions of zero and zero+ tillage was associated with the about 4 weeks longer growing season of the catch crops in these variants as compared with traditional or simplified tillage. Consequently, at the time of harvest mustard had already reached the phase of seed formation and phacelia had reached the beginning of or full flowering phase. In the variants with traditional and simplified tillage white mustard had reached the stage of silique formation and tansy phacelia the stage of budding or the beginning of flowering. In the study by Pastuszka (2016), delayed sowing of a stubble catch crop from August 1 to September 1 caused a significant decrease in the content of both the neutral and acidic fiber fraction. This was related to the weaker development of plants resulting from the delayed sowing. In the present study, diversification of the plant development stage was also the reason for the dependence of nitrogen, phosphorus and potassium content in plants on the method of soil cultivation and sowing. The study by Kisielewska and Harasimowicz-Hermann (2008a) shows that delaying the sowing date of white mustard from July 19–20 to August 16–24 results in a very significant reduction in the proportion of generative organs in the yield. However, in the present study white mustard development in the harvest period was much more advanced. This variation could have resulted from the mineral fertilization used in the cited study, in which 69 $kg \cdot ha^{-1}$ N, 50 $kg \cdot ha^{-1}$ P and 70 $kg \cdot ha^{-1}$ K were used, respectively. The availability of fertilizer components in the soil could have favored more intensive vegetative growth and delayed the formation of generative organs.

In addition to the content of macronutrients, their mutual relationship is an important indicator of feed quality (Bobrecka-Jamro and Szpunar-Krok, 2002; Grzegorczyk and Gołębiewska, 2004; Kumar and Soni, 2014). The Ca : P ratio found in the present study was relatively high, especially for tansy phacelia, in the variant with zero+ tillage (6.6 : 1). This was due to the very high calcium content in the dry mass, resulting from the low biomass yield. According to Ruszczyc (1985), the optimal Ca : P ratio in a feed is 2 : 1, however, a problem with the use of these components appears after exceeding the value of 10 : 1. With potentially such a wide Ca: P ratio, adequate macronutrient supplementation may be needed for a feed to be appropriate for animals (McDowell, 1992).

A relatively low K: (Ca + Mg) ratio was found in the dry mass of the catch crops. In none of the studied variants it reached even half of the permissible value, which is 2.2 : 1 (Kidambi *et al*., 1989; Kumar and Soni, 2014). Favorable values of this indicator in the present study result from the high Ca content in the aboveground biomass of the catch crops with moderately high potassium content.

CONCLUSIONS

1. White mustard contained significantly more total nitrogen and crude fiber in the dry aboveground mass than tansy phacelia, which in turn was more abundant in phosphorus, potassium, calcium and magnesium.
2. The use of simplified soil cultivation resulted in obtaining the aboveground biomass of catch crops with a higher total nitrogen and phosphorus content than in traditional (plowing) tillage and in comparison with zero tillage using seed broadcasting into ripening winter wheat.
3. The above-ground biomass of catch crops obtained as a result of the use of zero cultivation contained more crude fiber than in variants with traditional and simplified cultivation.

4. The method of soil cultivation and sowing generally did not affect the content of calcium and magnesium in the aboveground parts of the stubble catch crops.

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CECHY JAKOŚCIOWE GORCZYCY BIAŁEJ I FACELII BŁĘKITNEJ UPRAWIANYCH W MIĘDZYPLONIE ŚCIERNISKOWYM W ZALEŻNOŚCI OD SPOSOBÓW PRZYGOTOWANIA ROLI I SIEWU

Streszczenie

Celem badań było określenie zależności cech jakościowych zielonej masy międzyplonów ścierniskowych od sposobu uprawy roli i siewu. Badania polowe wykonano w układzie losowanych podbloków w latach 2010–2012 w Stacji Badawczej Wydziału Rolnictwa i Biotechnologii UTP w Mochełku k. Bydgoszczy. Pierwszym czynnikiem doświadczenia był sposób przygotowania roli i siewu: tradycyjny (T) – orka, doprawienie gleby agregatem uprawowym, siew nasion siewnikiem rzędowym; uproszczony (S) – talerzowanie ścierniska, siew rzutowy nasion, bronowanie; uproszczony+ (S+) – talerzowanie ścierniska, siew rzutowy nasion ze zwiększoną o 20% ilością wysiewu, bronowanie; zerowy (Z) – siew rzutowy nasion w dojrzewającą pszenicę ozimą; zerowy+ (Z+) – siew rzutowy nasion w dojrzewającą pszenicę ozimą ze zwiększoną o 20% ilością wysiewu. Drugim czynnikiem był gatunek rośliny uprawianej w międzyplonie ścierniskowym: gorczyca biała ‘Bamberka’ oraz facelia błękitna ‘Anabela’. Siew nasion w obiektach T, S i S+ wykonywano w terminie 16–18 sierpnia, a w obiektach Z i Z+ – 20 lipca. Stwierdzono istotny wpływ czynników doświadczenia na cechy jakościowe gorczycy białej i facelii błękitnej uprawianych w międzyplonie ścierniskowym. Gorczyca biała zawierała istotnie więcej azotu ogółem i włókna surowego w suchej masie nadziemnej niż facelia błękitna, która była od niej bardziej zasobna w fosfor, potas, wapń i magnez. Stosowanie uproszczonej uprawy roli skutkowało uzyskaniem biomasy nadziemnej międzyplonów o wyższej zawartości azotu ogółem i fosforu niż w uprawie tradycyjnej (orkowej) oraz w porównaniu z uprawą zerową z wykorzystaniem siewu rzutowego nasion w dojrzewającą pszenicę ozimą. Biomasa nadziemna międzyplonów uzyskana w wyniku stosowania uprawy zerowej zawierała więcej włókna surowego niż w obiektach z uprawą tradycyjną i uproszczoną. Upraszczanie uprawy roli pod międzyplony ścierniskowe wywiera istotny wpływ na cechy jakościowe wytwarzanej przez nie biomasy nadziemnej.

Słowa kluczowe: makroskładniki, międzyplon ścierniskowy, siew rzutowy, uprawa uproszczona, włókno surowe