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ORIGINAL PAPER

CHEMICAL COMPOSITION OF STUBBLE CROP BIOMASS DEPENDING ON A CROP PLANT SPECIES AND TILLAGE SYSTEM*

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Abstract

The aim of this study was to compare the macro- and micronutrient content in the biomass of stubble crops grown in a three-year spring wheat monoculture under conventional plough tillage and no-tillage (reduced tillage) systems. This research tested the suitability of the following plants grown as stubble crops: white mustard, lacy phacelia, and a mixture of legumes (faba bean + spring vetch). The study was conducted over the period of 2013-2015, at the Czesławice Experimental Farm belonging to the University of Life Sciences in Lublin. The chemical composition of cover crop biomass was analyzed (the content of the following nutrients: N, P, K, Mg, Ca, Cu. Zn, Mn, and Fe). For this purpose, at the end of stubble crop growth, plant samples were taken from an area of 0.25 m^2 of each plot (plants cut right above the soil surface). It was proven that the chemical composition of stubble crop biomass was primarily determined by the cover crop plant species. The individual stubble crops showed different degrees of accumulation of macro- and micronutrients. The highest content of N, Mn, and Fe was found in the biomass of the mixed legume crop, Fe – in white mustard biomass, while Zn – in lacy phacelia biomass. In comparison with plough tillage, conservation tillage (no-till) practices contributed to a decrease in the content of the studied nutrients in cover crop biomass (this decrease was significant in the case of N, K, Mg, and Mn), as linked to monoculture duration. To sum up, the content of macro- and micronutrients in the biomass of stubble crop is more closely related to species characteristic of the plant than to agrotechnical factors. It was proven that the stubble crops beneficially affected spring wheat productivity, whereas white mustard biomass ploughed into soil in autumn had the greatest beneficial effect. Under the soil and climate conditions of the Lublin region, white mustard was characterized by the best and most reliable yields.

Keywords: stubble crops, biomass, chemical composition, plough tillage, conventional tillage, monoculture.

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INTRODUCTION

One of the methods to mitigate the effects of adverse crop sequencing is to grow cover crops, which perform a significant phytosanitary role (Abdin et al. 1997, Akemo et al. 2000). Cover cropping also reduces erosion processes, improves the quality of the soil environment (its physical, chemical, and biological properties), and is a factor that reduces soil nitrogen losses (Jensen 1991, Kuś, Jończyk 2000, Gondek, Zając 2003). Cover crops left over winter as mulch ensure favourable soil temperature and maintain the soil moisture content at a higher level (Bruce et al. 1990).

Assessment of the effectiveness of cover cropping varies, and it largely depends on soil quality and initial nutrient availability (Kołodziejczyk et al. 2017). Beneficial after-effects of plant residue predominantly depend on the rate of its decomposition and the amount of nutrients released from the residue, and this is directly related to biomass quality, i.e. the macro- and micronutrient content, C/N ratio, and lignin content (Hauggard-Nielsen et al. 2001). Kołodziejczyk et al. (2017) give the following content of the amount of nutrients absorbed by potato plants: the share of N accumulated from 5% to 34%, P from 6% to 38%, K from 5% to 36%, Ca from 27% to 190% and Mg from 12% to 55%.

In this study the authors hypothesized that individual stubble crop plant species would be characterized by varying content of chemical components, regardless of a tillage system. Furthermore, an assumption was made that reduced tillage (no-tillage) could contribute to negative changes in the macro- and micronutrient content of stubble crop biomass. It was also assumed that stubble crops sown every year in a spring wheat monoculture would show variation in the biomass chemical composition related to weather conditions during the study period and to the increasingly negative effect of the cereal monoculture duration.

The aim of this study was to determine the impact of tillage practices (plough tillage and no-tillage) on the macro- and micronutrient content in the biomass of selected plant species used as stubble crops sown in a three-year spring wheat monoculture.

MATERIALS AND METHODS

Results of a field experiment on stubble cropping were collected over the period 2013-2015 (stubble crops were sown as intercrops in a three-year spring wheat monoculture). This experiment was located at the Czesławice Experimental Farm, belonging to the University of Life Sciences in Lublin. It was run on loess soil with the grain-size composition of silt loam (PWsp), and classified as good wheat soil complex (soil class II). The soil contained

1.44% of humus, pH = 6.2, while the total content of P, K, and Mg was, respectively, 160, 284, and 64 mg kg^{-1} soil. The experiment was set up in a split-plot design, with 5 replicates, on 27 m^2 plots.

The experimental design included the following factors:

I. Type of stubble crop in a spring wheat monoculture:
   A – white mustard (cv. Borowska);
   B – lacy phacelia (cv. Stala);
   C – faba bean + spring vetch (cv. Amulet + cv. Hanka).

II. Tillage practices used after harvest of the stubble crops and before sowing the cereal crop:
   1. Conventional plough tillage – after harvest of the spring wheat crop (first 10 days of August), skimming + seedbed conditioning, sowing of stubble crops (second 10 days of August); after harvest of the stubble crops (October), shredding of their biomass and ploughing in this biomass during autumn ploughing; in spring, the use of a seedbed conditioner, application of mineral NPK fertilization, and sowing of spring wheat using a seed drill.
   2. Conservation tillage (no-tillage) – after harvest of the spring wheat crop (first 10 days of August), a rigid tine cultivator (grubber) + + seedbed conditioning, sowing of stubble crops (second 10 days of August); after harvest of the stubble crops (October), their biomass was left in the field as mulch (until March 15); in spring – mixing the mulch with the soil using a disk harrow, smoothing the field with a spike tooth harrow, application of mineral NPK fertilization, and sowing of spring wheat using a seed drill.

In all treatments, mineral NPK fertilization was applied (adjusted to the requirements of the individual stubble crop species), and subsequently the cover crops were sown. Based on the soil availability of the major macronutrients before the experiment and taking into account “economical” crop protection to be used, the following doses of mineral fertilizers (kg ha^{-1}) were applied under the individual crops included in the field experiment: spring wheat N – 60, P_2O_5– 50, K_2O – 80, white mustard N – 40, lacy phacelia N – 40, faba bean + spring vetch N – 20.

Each year, the stubble crops were sown in the second 10 days of August. The seeding quantity was as follows, respectively: white mustard – 20 kg ha^{-1}, lacy phacelia – 5 kg ha^{-1}, faba bean + spring vetch – 100 + 40 kg ha^{-1}.

The chemical composition of stubble crop dry matter was analyzed to determine the content of the following nutrients: K, Ca, Mg, Zn, Fe, Cu, Mn (FAAS method), total N (Kjeldahl method), and P (spectrophotometrically). For this purpose, plants were sampled at the end of the cover crop growing season from a 0.25 m^2 area in each plot (the plants were cut just above the soil surface). After the samples were air-dried, they were delivered to the certified Central Agro-Ecological Laboratory, University of Life Sciences in Lublin, to perform chemical assays.

The study results were statistically analyzed (using Statistica software) and verified by the Tukey's test at a significance level of p = 0.05.

The weather conditions during the stubble crop growing season are shown in Tables 1 and 2. The annual total rainfall at the Czesławice Experi-

Table 1

Total rainfall and rainfall distribution (mm) in Czesławice during the period 2013-2015 in the months of the stubble crop growing season

Specification	Month			Annual total
	August	September	October	
Monthly total in 2013	147.1	137.5	11.1	778.0
Monthly total in 2014	60.5	80.4	25.7	5312
Monthly total in 2015	74.2	60.3	20.2	643.4
Long-term mean (1966-1996)	68.6	57.6	48.7	608.7

Table 2

Mean air temperature (°C) in Czesławice during the period 2013-2015 in the months of the stubble crop growing season

Specification	Month			Annual mean
	August	September	October	
Monthly mean in 2013	20.0	11.9	4.8	7.5
Monthly mean in 2014	18.6	10.8	4.8	6.8
Monthly mean in 2015	20.2	12.1	5.6	8.1
Long-term mean (1966-1996)	17.4	13.0	8.1	7.7

mental Farm in 2013 was 778 mm, and it was higher by 169.3 than the long--term mean. Thus, the year 2013 should be considered as a wet one. During the entire stubble crop growing season, the highest monthly rainfall totals were recorded in August (147.1) and in September (137.5). In turn, October 2013 proved to be exceptionally dry. The year 2014 should be considered as dry since the annual total rainfall was 531.2 mm, and it was lower by 77.5 mm than the long-term mean. The monthly total rainfall in August was similar to the long-term mean, in September it was higher by 22.8 mm relative to the long-term mean, whereas in October it was lower by 23 mm. Similarly to 2013, the year 2015 was a wet one. The highest monthly rainfall totals were found in August and September (74.2 mm and 60.3 mm, respectively), while October was a dry month relative to the long-term mean.

The distribution of mean temperatures throughout the entire growing period predictably varied. In August, the temperatures during the growth of the stubble crops were higher than the long-term mean, whereas in September and October they were lower relative to the long-term mean in each year of the study. To sum up, the mean annual air temperature in 2014 was lower than the long-term mean by 0.9°C, in 2013 it only minimally differed (by 0.2°C) from the long-term mean, whereas in 2015 it exceeded the long-term mean by 0.4°C.

RESULTS

The macronutrient content in stubble crop biomass was more dependent on a cover crop plant species than on tillage practice (Table 3). The nitrogen content was significantly highest in the biomass of the mixed legume crop compared to lacy phacelia and white mustard. At the same time, the statistical analysis showed a proven lower nitrogen content in the lacy phacelia biomass compared to white mustard. Apart from that, the biomass of the mixed legume crop was characterized by significantly the lowest potassium and calcium content relative to the other stubble crops. The content of the other macronutrients (P and Mg) in plant material of all the stubble crops analyzed was similar. When we analyzed the impact of tillage systems on the macronutrient content in stubble crop biomass, we found that on average it was statistically insignificant during the study period (Table 3).

Table 3

Macronutrient content in stubble crop biomass – on average during the study period

Specification		Macronutrient content (g kg^{-1} DM)				
		N	P	K	Ca	Mg
Plough tillage	white mustard	39.3 *a**	5.1 *a*	42.0 *a*	21.4 *a*	3.0 *a*
	lacy phacelia	32.1 *b*	5.0 *a*	48.5 *a*	26.6 *a*	3.4 *a*
	legume mixture	49.9 *c*	4.8 *a*	34.9 *b*	10.7 *b*	2.2 *a*
Conservation tillage	white mustard	38.6 *a*	5.3 *a*	40.1 *a*	23.6 *a*	3.0 *a*
	lacy phacelia	27.4 *b*	5.2 *a*	39.1 *a*	26.2 *a*	2.6 a
	legume mixture	45.4 *c*	4.4 *a*	34.6 *b*	10.0 *b*	2.4 *a*

* Means within a column followed by different letters (*a-c*) are significantly different.

The data contained in Table 4 show that year, as linked to the increasing duration of the spring wheat monoculture, generally contributed to a decrease in the macronutrient content in stubble crop biomass. Moreover, the reduction in the macronutrient content was more evident under reduced tillage conditions compared with the conventional plough tillage (it was statistically significant in the case of N and P, but particularly for Mg). Regardless of a tillage system, the highest decrease in the macronutrient content in stubble crop biomass occurred in 2015, as compared with 2013, with respect to nitrogen, magnesium, and calcium, while the lowest decrease (and even an increase in the white mustard biomass) was evidenced for potassium.

Table 4

Changes in macronutrient content in stubble crop biomass in 2015 – the 3rd year of spring wheat monoculture, relative to 2013 – the 1st year of spring wheat monoculture (macronutrient content in 2013 = 100%)

Specification		Changes in macronutrient content (%)				
		N	P	K	Ca	Mg
Plough tillage	white mustard	-5.1 *a**	-0.5 *a*	+0.4 *a*	-1.1 *a*	-3.9 *a*
	lacy phacelia	-7.0 *b*	-0.9 *a*	-0.7 *b*	-2.3 *b*	-4.5 *a*
	legume mixture	-8.1 *c*	-1.6 *b*	-0.9 *b*	-2.6 *b*	-4.2 *a*
Conservation tillage	white mustard	-6.9 *b*	-1.1 *b*	+0.1 *a*	-1.6 *a*	-7.2 *b*
	lacy phacelia	-8.0 *c*	-1.7 *b*	-0.8 *b*	-2.8 *b*	-7.6 *b*
	legume mixture	-8.6 *c*	-2.4 *c*	-1.0 *b*	-3.0 *b*	-7.9 *b*

* Explanations see Table 3

Table 5

Micronutrient content in stubble crop biomass – on average during the study period

Specification		Micronutrient content (mg kg^{-1} DM)			
		Cu	Zn	Mn	Fe
Plough tillage	white mustard	8.04 *a*	146.0 *a*	110.0 *a*	304.0 *a*
	lacy phacelia	6.85 *b*	24.3 *b*	138.0 *b*	350.0 *b*
	legume mixture	7.70 *a*	79.3 *c*	158.0 *c*	431.0 *c*
Conservation tillage	white mustard	7.35 *a*	128.0 *a*	71.8 *d*	326.0 *a*
	lacy phacelia	4.72 *b*	18.7 *b*	93.6 *e*	430.0 *c*
	legume mixture	7.50 *a*	84.4 *c*	132.0 *b*	506.0 *d*

* Explanations see Table 3

The micronutrient content determined in stubble crop biomass depended on a plant species and tillage practice (Table 5). The content of copper (Cu) was significantly the lowest in lacy phacelia plant material compared with white mustard and the legume mixture, both under plough tillage and no-tillage conditions. The white mustard biomass exhibited significantly the highest content of zinc Zn – (128.0 - 142.0 mg kg^{-1} DM), while the lowest one was found in lacy phacelia (18.7 - 24.3 mg kg^{-1} DM). The content of manganese (Mn) and iron (Fe) was significantly the highest in plant material originating from the mixed legume crop, whereas the lowest one appeared in the white mustard biomass. It is worth noting that conservation tillage contributed to a significantly lower Mn content in the biomass of all the stubble crops as well as resulting in a significantly higher Fe content in the biomass of lacy phacelia and of the mixed legume crop (Table 5).

Decrease (-) or increase (+) in the micronutrient content in stubble crop biomass related to year and increasing monoculture duration were statistically insignificant for most of the nutrients (Table 6). The content of manga-

Table 6

Changes in micronutrient content in stubble crop biomass in 2015 – the 3rd year of spring wheat monoculture, relative to 2013 – the 1st year of spring wheat monoculture (micronutrient content in 2013 = 100%)

Specification		Changes in micronutrient content (%)			
		Cu	Zn	Mn	Fe
Plough tillage	white mustard	-0.2 *a**	-1.1 *a*	-2.7 *a*	-2.5 *a*
	lacy phacelia	-2.4 *b*	-3.3 *b*	-3.3 *b*	-4.4 *b*
	legume mixture	-2.5 *b*	-2.9 *b*	-3.9 *b*	-4.6 *b*
Conservation tillage	white mustard	-0.4 *a*	-1.8 *a*	-2.9 *a*	-3.0 *a*
	lacy phacelia	-2.8 *b*	-3.7 *b*	-5.7 *c*	-4.7 *b*
	legume mixture	-3.0 *b*	-3.1 *b*	-6.5 *c*	-4.9 *b*

* Explanations see Table 3

nese (Mn), which was significantly lower in 2015 than in 2013 (in the biomass of lacy phacelia and of the mixed legume crop), is the only exception in this regard. Furthermore, it is worth noting that white mustard proved to be the most stable species in terms of the content (+/-) of the micronutrients determined during the study period.

When we consider the final yield of stubble crop biomass (after cutting), we note that white mustard was characterized by the highest productivity, regardless of tillage practices (Table 7). An equally high dry matter yield was

Table 7

Stubble crop dry matter (t ha^{-1}) after harvest (third 10 days of October) – on average during the study period

Cover crop	Tillage system		
	plough tillage	conservation tillage	average
White mustard	4.06	4.01	4.03
Lacy phacelia	3.98	3.87	3.92
Faba bean + spring vetch	2.48	2.31	2.39
Average	3.5	3.4	-
$LSD_{(0.05)}$ for: tillage system (*a*) = n.s.; cover crop (*b*) = 0.356; interaction (*a* x *b*) = n.s.			

also obtained from lacy phacelia stubble cropping (lower by only 2.7% compared to that of white mustard). The legume mixture proved to be an unreliable cover crop because it produced an about 60% lower yield than the other species. The stubble crop dry matter yield in the conservation tillage treatments was lower on average by only 0.1 t (less than 3%) than that obtained in the treatment using the moldboard plough technology.

DISCUSSION

The macro- and micronutrient content in the biomass of white mustard, lacy phacelia and the mixture of legumes (faba bean + spring vetch) found in this study was similar to the content of these nutrients reported by other authors (Thorup-Kristensen 2004, Wilczewski, Skinder 2005, Kristensen, Zaniewicz-Bajkowska et al. 2013). Kassan et al. (2009), Vogeler et al. (2009), and Morris et al. (2010) observe that the macro- and micronutrient content in cover crop biomass is more clsely related to the species-specific characteristics of a plant than to agronomic factors (including tillage practices), and that this content may vary within a broad range, depending on weather conditions, soil type, and stage growth of the crop plant. Moreover, the amount of macronutrients taken up by cover crop plants depended on the cover crop sowing date and pluvio-thermal conditions during the crop growing season. The present study found that the macro- and micronutrient content in cover crop biomass in 2015 (3rd year of monoculture cropping) decreased relative to the results noted in 2013 (1st year of monoculture). It should be underlined that, among the three years of the study, the stubble crop growing season in 2015 was the most favourable one for the growth of cover crops (it was characterized by the optimum amount of rainfall in August and September, while a rainfall deficit was recorded only in October), and it was the warmest year throughout the study period. It should therefore be presumed that the decline in the macro- and micronutrient content in stubble crop biomass in 2015 was more likely to be attributable to the effect of the increasing duration of the spring wheat monoculture. Wilczewski (2007) did not find a significant difference in the three-year average content of nitrogen in post-harvest residue of stubble-cropped Fabaceae plants. Significantly the highest amount of this element was determined in the underground parts of serradella only in one year, while its lowest amount was found in lupin. The content of phosphorus, potassium and calcium varied over the study period. Generally, a lower content of these elements was found in the treatments where a higher biomass yield was obtained compared with the other treatments, which is partly confirmed by the present study.

When analyzing the effect of biomass of some stubble crops on yield and quality of carrot roots, Kwiatkowski et al. (2015) found that both lacy phacelia and a mixture of spring vetch + field pea contributed to the incorporation of similar amounts of macronutrients: P – 5.06-5.12 t ha^{-1}, K – 22.5-24.7 t ha^{-1}, Ca – 11.3-12.1 t ha^{-1}, Mg – 3.27-3.44 t ha^{-1}. An exception was nitrogen content because the mixed legume crop provided to the soil 58.6 t N ha^{-1}, whereas lacy phacelia – 50.4 t N ha^{-1}. Similar observations are also reported by Harasimowicz-Herman and Herman (2006) as well as by Kraska (2011*a*, *b*).

The present study showed white mustard to be the most stable species in terms of variation (decrease/increase) in the macro- and micronutrient content in plant biomass throughout the entire study period. On the other hand, the legume mixture was characterized by a significant decline in nitrogen content in 2015. Other authors note that the biomass of leguminous cover crops is characterized by the highest nitrogen content, but at the same time this content exhibits large year-to-year variations (Brandsćter, Netland 1999, Keatinge et al. 1999, Teixeira et al. 2005). Wilczewski and Skinder (2005) observed that oil radish and white mustard accumulated most nitrogen on average, whereas sunflower and oilseed rape accumulated least. The differences between the species were primarily due to the variation in yields of the crop plant studied. Thorup-Kristensen (1994) also demonstrated particularly high suitability of plants of the family *Brassicaceae* (fodder radish, white mustard) for protection of soil against the risk of mineral nitrogen leaching during the autumn and winter period because these plants have the highest ability to accumulate this nutrient.

This study reveals that the mixture of legumes (faba bean + spring vetch) was characterized by the highest nitrogen content among the cover crops studied, in spite of producing significantly the lowest biomass yield. Wojciechowski and Wermińska (2016) prove that the fertilizer value of cover crops was more dependent on the type of cover crop than on the amount of biomass produced by the respective cover crop. The mixed legume crop incorporated over twice as much nitrogen into soil, despite the fact that its dry matter yield was only slightly higher than that of mustard. This cover crop also accumulated more potassium and phosphorus. Zaniewicz-Bajkowska et al. (2013) noted that faba bean accumulated most nitrogen and phosphorus in cover crop dry matter compared to phacelia, amaranth, and sunflower. Wilczewski and Skinder (2005), on the other hand, found that among stubble-cropped non-Fabaceae plants, oil radish, winter oilseed rape, and white mustard were richest in nitrogen in their aerial parts.

CONCLUSIONS

1. The three-year laboratory analyses of the biomass of the selected stubble crops do not entitle us to conclude which of the respective cover crop species is characterized by the most favourable macro- and micronutrient content under the soil and climatic conditions of the Lublin region. But it was found that the mixed legume crop (faba bean + spring vetch) accumulated in its biomass significantly most nitrogen, manganese, and iron, with simultaneously the lowest accumulation of potassium and calcium. White mustard, in turn, had the highest content of zinc, and importantly, it showed the greatest stability of the chemical composition of biomass throughout the study period. Lacy phacelia biomass, on the other hand, was distinguished by the highest content of copper.

2. Over the three-year study period, conservation tillage practices adversely affected the chemical composition of stubble crop biomass, causing a decrease in the content of nitrogen, potassium, magnesium, and manganese compared to conventional (plough) tillage.

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