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PRODUCTIVITY OF WINTER WHEAT CULTIVARS AND CHANGES IN THE RICHNESS OF SOIL FERTILIZED WITH STRAW ASH

Mariusz Piekarczyk, Iwona Jaskulska, Lech Gałęzewski,
Karol Kotwica, Dariusz Jaskulski
University of Science and Technology in Bydgoszcz

Abstract. The aim of the study was to estimate the effect of winter wheat cultivar and mineral fertilization, taking into consideration the use of ash from wheat straw, on the biomass production of winter wheat. Moreover, changes in pH and the content of the assimilable forms of macro- and microelements in typical lessive soil (Luvisols) after three years of applying varied doses of ash from winter wheat straw were also evaluated. Research was carried out in years 2010-2012 at the Research Station in Mochełek (53°13' N; 17°51' E). Three-factor microplot experiment was carried out, in which interdependent interaction between diversified nitrogen-phosphorus fertilization NP ($g \cdot m^{-2}$): 8 + 1.31; 8 + 2.62; 16 + 1.31; 16 + 2.62 and the impact of ash from winter wheat straw ($g \cdot m^{-2}$): 0; 25; 50; 75; 100 on the biomass production of two cultivars of winter wheat ('Muszelka' and 'Batuta') was evaluated. Ash from winter wheat straw used in the experiment was characterized by alkaline reaction (pH in KCl 1 $mol \cdot dm^{-3}$ = 9.8). Total content of elements in $g \cdot kg^{-1}$ amounted to: P 5.8, K 75.0, Mg 5.3, and Ca 64.9, and in $mg \cdot kg^{-1}$: Cu 25.6, Mn 607, Zn 64.9, and Fe 3158. The study found that grain productivity of cultivar 'Muszelka' was higher and straw yield lower than those of cultivar 'Batuta'. Tested cultivars did not differ significantly, however, regarding the produced amounts of post-harvest residue biomass, and therefore had a similar quality for cultivation in the conditions of straw management for non-agricultural purposes, as a potential source of soil organic matter. High nitrogen and straw ash fertilization was conducive to the biomass production of both winter wheat cultivars, excluding post-harvest residue. Ash from wheat straw used at the dose of 100 $g \cdot m^{-2}$ after three years of application did not cause significant changes in soil richness but made it possible to keep nearly unchanged pH and the contents of available macro- and microelements.

Key words: macroelements, microelements, grain and straw yield, soil acidity

Corresponding author: dr inż. Mariusz Piekarczyk, Department of Plant Production and Experimenting of the University of Science and Technology in Bydgoszcz, ks. A. Kordeckiego 20C, 85-225 Bydgoszcz, e-mail: mapiek@utp.edu.pl

INTRODUCTION

Degradation process of cultivated soil is a significant threat for plant productivity and nutritional security of the world. Slow decrease in soil richness in humus and nutrients, as well as increasing souring and erosion, often lead to the total devastation of soils [Deen and Kutaki 2003]. The use of cultivated plant biomass for energy reasons deepens organic matter deficit in the soil, which results in the deterioration of its physical and chemical properties. In recent years, increasing interest in straw as a source of energy has been observed. During its combustion, loss of organic matter and some macroelements occurs. As a result, it makes carbon sequestration impossible in the soil and exterminates its basic source, in particular on farms with no animal production [Kraska and Pałys 2003].

Ash that is formed during straw combustion may be a valuable fertilizer. It is characterized by high content of potassium, as well as other macro- and microelements necessary for plants, and also alkaline acidity (pH 10-13) [Kowalczyk-Juśko 2009, Ciesielczuk *et al*. 2011]. Like organic waste [Szulc *et al*. 2009, Stępień and Wojtkowiak 2011] and combustion waste from plant biomass [Kalembasa 2006], it is a valuable mean that increases soil fertility but is not a threat to the environment because of very low natural contents of heavy metals [Yeledhalli *et al*. 2008, Piekarczyk *et al*. 2011b].

Study hypothesis assumed that by cultivar choice and the use of straw ash for soil fertilization, grain yield and post-harvest residue mass of winter wheat may be affected. It was also assumed that the nutrients present in the ash from wheat straw, supplemented with mineral fertilization, would make it possible to sustain, and even increase soil richness and affect favourably its acidity.

The aim of the study was the evaluation of the effect of mineral fertilization and straw ash application on grain and straw yield of two winter wheat cultivars, and also on the macro- and microelement contents in the soil and its acidity.

MATERIAL AND METHODS

In years 2010-2012 at the Research Station in Mochełek (53°13' N; 17°51' E), which is part of the University of Science and Technology in Bydgoszcz, three-factor microplot experiment was carried out as a split-plot split-block design in four repetitions. Plot area was 5.25 m^2, with 2 m^2 for harvest. Winter wheat was sown after winter rapeseed three times in crop rotation: winter rapeseed – winter wheat – spring barley. Every year during the three years, those three plants were sown simultaneously and straw ash was applied under each one. In the present experiment, the effect of diversified fertilization with nitrogen and phosphorus was determined, as well as of the ash of winter wheat straw burnt in a boiler room on the biomass production of two winter wheat cultivars, and changes in some soil properties after three years of its application. The experimental factors were as follows:

- I – cultivar: 'Muszelka', 'Batuta',
- II – nitrogen-phosphorus fertilization NP ($g \cdot m^{-2}$): 8 + 1.31; 8 + 2.62; 16 + 1.31; 16 + 2.62,
- III – ash from winter wheat straw ($g \cdot m^{-2}$): 0; 25; 50; 75; 100.

Winter wheat was sown at the density of 500 germinating seeds$\cdot m^{-2}$. Phosphorus and ash were introduced into the soil before sowing. Nitrogen dose of 8 N $g \cdot m^{-2}$ was applied in the spring at the onset of growth (BBCH 21-22), whereas the dose of 16 N g·m^{-2} was applied at two times: 10 N g·m^{-2} at the onset of growth (BBCH 21-22) and 6 N g·m^{-2} at the straw-shooting stage (BBCH 31-33). Weeds were controlled in the autumn at the 4-5 wheat leaf stage (BBCH 14-15) with herbicide containing isoproturon and diflufenican. Protection against disease was carried out at the earing stage (BBCH 50-52) with the use of methyl thiophanate and epoxiconazole. In the experiment, the amount of above-ground biomass (grain and straw) at the stage of full plant ripeness (BBCH 89) was evaluated. Moreover, from every microplot, the mass of the above- and underground parts of post-harvest residue was determined in cut-out soil monoliths 33 × 33 × 30 cm in size, from the area of which stubble mulch was uptaken, whereas the roots were separated from the soil with a flush of running water. The assigned biomass was dried and weighed.

The experiment was set up on typical lessives (Luvisols) [IUSS Working Group WRB 2014] with the granulometric composition of loamy sand according to PTG 2008: sand (2.0-0.05 mm) 75.5%, coarse dust (0.05-0.02 mm) 9.4%, fine dust (0.02-0.002 mm) 12.9%, and loam (<0.002 mm) 2.3%. Organic carbon content amounted to 8.1 g·kg^{-1}, total nitrogen 0.7 g·kg^{-1}, and the ratio C/N was 11.6. Ash from winter wheat straw used in the experiment had alkaline acidity (pH in KCl at the concentration of 1mol·dm^{-3} amounted to 9.8). Total element content in g·kg^{-1} amounted to: P 5.8; K 75.0; Mg 5.3; and Ca 64.9, and in mg·kg^{-1}: Cu 25.6; Mn 607; Zn 64.9; and Fe 3158.

Soil for the agrochemical study was uptaken after three years of research, in 2012, from every microplot. Analyses were carried out on 20 cumulative samples, and each ash fertilization level was represented by four samples. Soil pH and the contents of available elements were evaluated, namely: P, K, Mg, B, Cu, Mn, Zn, and Fe. Soil study was carried out at the Regional Chemical and Agricultural Station in Bydgoszcz. pH value was marked in KCl solution at the concentration of 1 mol·dm^{-3} with the potentiometric method, and the contents in the soil of available macroelements: phosphorus spectrophotometrically, potassium using flame photometry, and magnesium with atomic absorption spectrometer. Contents of the available forms of microelements were determined with atomic absorption spectrometer.

The obtained results were statistically processed with the analysis of variance. Significance of the differences between the average amounts of the analyzed characteristics was determined with the Tukey's test at the significance level of p = 0.05. Calculations were carried out with the use of the statistics program packet FR – ANALWAR 5.2. In the conducted research, no synergy of cultivars, nitrogen-phosphorus fertilization, and the dose of ash from winter wheat straw was found in the formation of biometric characteristics of winter wheat, and therefore only the effects of the main factors are presented.

Average annual air temperatures during the experiment were similar to the many-years' average from years 1996-2010 (Table 1). Only periods from April to June 2011 and from March to May 2012 ought to be counted as significantly warmer in comparison with average conditions. Research years were diversified in relation to precipitation conditions. During winter wheat growth in 2011 and 2012, precipitation distribution was not favourable. Significant precipitation shortages, in comparison with average conditions, occurred from March to May. On the other hand, precipitation higher than the many-years' average took place in July, August, September and November of 2010, as well as in June and July of 2011 and in 2012.

Table 1. Weather conditions in years 2009-2012
Tabela 1. Warunki opadowo-termiczne w latach 2009-2012

Years Lata	Miesiąc – Month											
	September wrzesień	October październik	November listopad	December grudzień	January styczeń	February luty	March marzec	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień
	Temperatura – Temperature, °C											
2009/2010	13.7	6.3	5.2	-1.1	-7.8	-2.7	2.4	7.8	11.5	16.7	21.6	18.4
2010/2011	12.2	5.5	4.1	-6.7	-0.6	-4.7	2.2	10.5	13.5	17.7	17.5	17.7
2011/2012	14.3	8.4	2.7	2.7	-0.3	-5.4	4.6	8.4	14.5	15.2	18.8	17.6
1996-2010	13.0	7.8	3.1	-1.0	-2.4	-0.8	2.0	7.9	13.0	16.2	18.6	17.9
	Opady – Precipitation, mm											
2009/2010	34.4	66.2	40.4	35.4	22.0	20.1	28.6	33.8	92.6	18.1	107.4	150.7
2010/2011	74.7	2.3	115.0	39.9	33.0	14.5	11.7	13.5	38.4	100.8	132.5	67.7
2011/2012	37.0	13.2	9.0	46.2	62.9	29.6	15.4	26.5	25.4	133.8	115.6	51.8
1996-2010	46.2	37.7	34.6	34.5	26.0	26.1	35.0	30.0	62.7	45.3	84.8	68.7

	Średnia temperatura – Mean temperature, °C January-December – styczeń – grudzień	Suma opadów – Precipitation sum, mm January-December – styczeń – grudzień
2009	8.0	532.4
2010	6.9	705.2
2011	8.5	517.5
2012	8.0	607.3
1996-2010	7.9	531.6

RESULTS AND DISCUSSION

No significant effect of nitrogen-phosphorus fertilization or the dose of straw ash introduced into the soil on plant number of both wheat cultivars per area unit was found (Tables 2-4). Plants of cultivar Batuta were higher on average by 19 cm (31.4%) than the ones of cultivar Muszelka (Table 2).

Table 2. Some characteristics of winter wheat depending on the cultivar
Tabela 2. Niektóre cechy pszenicy ozimej w zależności od odmiany

Specification Wyszczególnienie	Cultivar – Odmiana		$LSD_{0.05}$ – $NIR_{0,05}$
	Muszelka	Batuta	
Plant density – Obsada roślin, szt·m^{-2}	483	473	ni – ns
Plant height – Wysokość roślin, cm	60.6	79.6	16.01
Grain yield – Plon ziarna, g·m^{-2}	607	513	19.6
Straw yield – Plon słomy, g·m^{-2}	420	529	30.2
Air-dry root mass, g·m^{-2} Powietrznie sucha masa korzeni	348	327	20.3
Air-dry stubble mulch mass, g·m^{-2} Powietrznie sucha masa ścierni	240	219	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Table 3. Some characteristics of winter wheat depending on nitrogen and phosphorus fertilization
Tabela 3. Niektóre cechy pszenicy ozimej w zależności od nawożenia azotem i fosforem

Specification Wyszczególnienie	Nitrogen and phosphorus fertilization Nawożenie azotowe i fosforowe N + P (g ·m^{-2})				$LSD_{0.05}$ $NIR_{0,05}$
	8 + 1.31	8 + 2.62	16 + 1.31	16 + 2.62	
Plant density – Obsada roślin, szt·m^{-2}	476	478	479	479	ns – ni
Plant height – Wysokość roślin, cm	68.1	68.6	71.4	72.2	1.52
Plon ziarna – Grain yield, g·m^{-2}	517	520	593	609	23.0
Grain yield – Plon ziarna, g·m^{-2}	425	450	506	517	22.8
Air-dry root mass, g·m^{-2} Powietrznie sucha masa korzeni	364	369	310	306	38.1
Air-dry stubble mulch mass, g·m^{-2} Powietrznie sucha masa ścierni	242	222	219	234	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Cultivar Muszelka gave higher grain yield by 94 g·m^{-2} (18.3%) in comparison with cultivar Batuta. Moreover, plants of cultivar Muszelka accumulated higher yield of air-dry root matter by 21 g·m^{-2} (6.4%) and lower straw yield by 109 g·m^{-2} (20.6%). Stubble mulch yields of both cultivars were similar (Table 2). Straw had the highest proportion in the total winter wheat biomass of cultivar Batuta. It oscillated around 33.3%, whereas the proportion of grain, roots, and stubble mulch in this cultivar amounted to 32.3%, 20.6%, and 13.8%, respectively. On the other hand, cultivar Muszelka was characterized by the highest proportion of grain, which oscillated around 37.6% of total biomass. Proportion of straw, roots, and stubble mulch of this cultivar amounted to 26.0%, 21.5%, and 14.9%, respectively.

Nitrogen dose of 16 N g·m^{-2}, regardless of phosphorus fertilization and the cultivar, in comparison with the dose of 8 N g·m^{-2}, caused a significant increase in grain and straw yield of winter wheat and a decrease in air-dry root mass. However, no effect of nitrogen fertilization dose on the amount of stubble mulch dry matter was found. Effect of an increased phosphorus dose on winter wheat productivity was also small. Only straw yield at the dose of 8 N g·m^{-2} was significantly higher after the application of 2.62 P g·m^{-2} than of 1.31 P g·m^{-2} (Table 3).

Application of straw ash at the dose of 100 g·m^{-2} caused a significant increase in grain and straw yield of winter wheat cultivars in comparison with the level with no ash, and the increase amounted to, respectively, 30 g·m^{-2} of grain (5.5%) and 21 g·m^{-2} of straw (4.5%). The application of ash did not affect, however, the amount of root biomass and the above-ground post-harvest residue of wheat (Table 4).

Table 4. Some characteristics of winter wheat depending on fertilization with ash from winter wheat straw

Tabela 4. Niektóre cechy pszenicy ozimej w zależności od nawożenia popiołem ze słomy pszenicy

Specification Wyszczególnienie	Ash dose – Dawka popiołu, g·m^{-2}					$LSD_{0.05}$ $NIR_{0,05}$
	0.0	25	50	75	100	
Plant density – Obsada roślin, szt·m^{-2}	472	480	476	483	478	ns – ni
Plant height – Wysokość roślin, cm	69.6	69.7	69.8	70.7	70.6	ns – ni
Grain yield – Plon ziarna, g·m^{-2}	549	546	559	566	579	29.5
Straw yield – Plon słomy, g·m^{-2}	470	461	468	481	491	19.8
Air-dry root mass, g·m^{-2} Powietrznie sucha masa korzeni	337	331	340	340	339	ns – ni
Air-dry stubble mulch mass, g·m^{-2} Powietrznie sucha masa ścierni	223	223	236	229	235	ns – ni

ns – ni – non-significant differences – różnice nieistotne

The results obtained in the study clearly confirm the favourable effect of increased nitrogen fertilization on the grain and straw yield of winter wheat [Piekarczyk *et al.* 2011a], as well as its negative effect on the mass of cereal root system [Buraczyńska and Ceglarek 2011, Piekarczyk *et al.* 2012]. Cereal cultivars with shorter straws usually produce higher grain yield than the taller ones [Descriptive list of cultivars 2008, 2009, Piekarczyk *et al.* 2012]. Small positive effect of straw ash application on the amount of biomass of winter wheat and the lack of unambiguously stimulating effect of phosphorus fertilization resulted probably from very high soil richness in assimilable phosphorus and average richness in assimilable potassium, and also from its slightly acidic acidity. Also small total content of macro- and microelements in the ash introduced into the soil was of great significance. Similar results were obtained in other studies [Piekarczyk *et al.* 2012].

Application of ash from winter wheat straw for three years at the doses of up to 100 g·m^{-2} did not affect soil pH, which was from 5.85 to 5.98 (Table 5).

Contents of assimilable phosphorus forms in the soil on the control plot (no ash application) were very high (109 P mg·kg^{-1}). Application of ash in sequence after every plant in three-year long crop rotation at the dose of 100 g·m^{-2} increased the content of this element in comparison with the control plot by 12 P mg·kg^{-1}, that is by 11%, although the difference was not statistically proven. Introduction of straw ash into the soil, in spite of the lack of additional mineral fertilization with potassium and magnesium, did not cause a statistically confirmed increase in the contents of those macroelements. A tendency for increase in the contents of those forms was observed, respectively, by 11 K mg·kg^{-1} (10.1%) and 1.7 Mg mg·kg^{-1} (9.6%) at the ash dose of 100 g·m^{-2} (Table 5).

Table 5. pH and the contents of available forms of macroelements in soil fertilized with ash from winter wheat straw, mg·kg^{-1}
Tabela 5. pH i zawartość przyswajalnych form makroskładników w glebie nawożonej popiołem ze słomy pszenicy ozimej, mg·kg^{-1}

Specification Wyszczególnienie	Ash dose – Dawka popiołu, g·m^{-2}					$LSD_{0.05}$ $NIR_{0,05}$
	0.0	25	50	75	100	
pH in KCl – pH w KCl, mol·dm^{-3}	5.85	5.90	5.85	5.93	5.98	–
Phosphorus P – Fosfor, mg·kg^{-1}	109	114	111	116	121	ns – ni
Potassium K – Potas, mg·kg^{-1}	109	112	111	115	120	ns – ni
Magnesium Mg – Magnez, mg·kg^{-1}	17.8	17.5	19.2	18.3	19.5	ns – ni

ns – ni – non-significant differences – różnice nieistotne

After three years of straw ash application, no significant changes in the microelement content were observed. However, under the influence of yearly application of ash at the dose of 100 g·m^{-2}, in comparison with the lack of its application, the contents of the following assimilable forms in the soil increased by: boron 0.05 mg·kg^{-1} (15.2%), copper 0.42 mg·kg^{-1} (31.6%), manganese 16 mg·kg^{-1} (10.9%), and zinc 0.25 mg·kg^{-1} (5.0%) (Table 6).

Table 6. Contents of available forms of microelements in soil fertilized with ash from winter wheat straw, mg·kg^{-1}
Tabela 6. Zawartość przyswajalnych form mikroskładników w glebie nawożonej popiołem ze słomy pszenicy ozimej, mg·kg^{-1}

Specification Wyszczególnienie	Ash dose – Dawka popiołu, g·m^{-2}					$LSD_{0.05}$ $NIR_{0,05}$
	0.0	25	50	75	100	
Boron B – Bor, mg·kg^{-1}	0.33	0.30	0.37	0.35	0.38	ns – ni
Copper Cu – Miedź, mg·kg^{-1}	1.33	1.18	1.45	1.88	1.75	ns – ni
Manganese Mn – Mangan, mg·kg^{-1}	146	153	150	149	162	ns – ni
Zinc Zn – Cynk, mg·kg^{-1}	4.98	5.10	5.28	5.28	5.23	ns – ni
Iron Fe – Żelazo, mg·kg^{-1}	590	593	590	610	627	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Agricultural use of combustion waste from wheat straw is a very good method of its utilization. Its application also increases soil acidity [Sander and Andren 1997]. Poor deacidification effect of the ash applied in the research resulted probably from introducing relatively small doses into the soil, increased calcium and magnesium washing out into soil depth in light soils, and from ash acidity (pH 9.8). Combustion waste from plant biomass may be characterized by pH of even 12-13 [Hermann and Harasimowicz-Hermann 2005].

Lack of proven significant increase in the concentration of the available for plant forms of macro- and microelements in light soil fertilized with ash is also a consequence of their uptake by plants. In other research [Piekarczyk *et al.* 2013], it was found that when straw ash with higher concentration of nutrients was introduced into the soil deprived of plants at the doses of 100-200 $g \cdot m^{-2}$, higher diversification in soil richness was caused.

CONCLUSIONS

1. Higher grain yield and lower straw yield were obtained from winter wheat cultivar Muszelka in comparison with cultivar Batuta. The evaluated cultivars did not differ in regard to the amounts of post-harvest residue biomass. In the conditions of straw harvest for non-agricultural purposes, they have, therefore, similar value, as a potential source of soil organic matter.
2. Increased nitrogen and straw ash fertilization was favourable to the accumulation of the above-ground biomass of both winter wheat cultivars, although it did not cause an increase in post-harvest residue mass.
3. Triple application in crop rotation of ash fertilization at the doses of up to 100 $g \cdot m^{-2}$ did not increase significantly soil pH as well as its richness in the available forms of chosen macro- and microelements.
4. Winter wheat straw ash is useful for agricultural purposes and may be recognized as a good and inexpensive potassium fertilizer with alkaline acidity.

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PRODUKCYJNOŚĆ ODMIAN PSZENICY OZIMEJ I ZMIANY ZASOBNOŚCI GLEBY NAWOŻONEJ POPIOŁEM ZE SŁOMY

Streszczenie. Celem badań było określenie wpływu odmiany i nawożenia mineralnego, uwzględniającego stosowanie popiołu ze słomy pszenicy, na produkcję biomasy pszenicy ozimej. Oceniono także zmiany pH oraz zawartości przyswajalnych dla roślin form makro- i mikroelementów w glebie płowej typowej (Luvisols) po trzech latach stosowania zróżnicowanych dawek popiołu ze słomy pszenicy. Badania przeprowadzono w latach 2010-2012 w Stacji Badawczej w Mochełku (53°13' N; 17°51' E). Wykonano trójczynnikowe doświadczenie mikropoletkowe, w którym oceniano współzależne oddziaływanie zróżnicowanego nawożenia azotowo-fosforowego NP ($g \cdot m^{-2}$): 8 + 1.31; 8 + 2.62; 16 + 1.31; 16 + 2.62 i stosowania popiołu ze słomy pszenicy ozimej ($g \cdot m^{-2}$): 0; 25; 50; 75; 100 na produkcję biomasy dwóch odmian pszenicy ozimej (Muszelka, Batuta). Użyty w doświadczeniu popiół ze słomy pszenicy ozimej charakteryzował się odczynem alkalicznym (pH w KCl o stężeniu $1 mol \cdot dm^{-3}$ – 9.8). Ogólna zawartość pierwiastków w $g \cdot kg^{-1}$ wynosiła: P – 5.8; K – 75.0; Mg – 5.3; Ca – 64.9 oraz w $mg \cdot kg^{-1}$: Cu – 25.6; Mn – 607; Zn – 64.9; Fe – 3158. Wyższe plony ziarna, a mniejsze słomy uzyskano z odmiany Muszelka w porównaniu z odmianą Batuta. Oceniane odmiany nie różniły się natomiast znacząco pod względem wytworzonej biomasy resztek pozbiorowych, a więc w warunkach zbioru słomy na cele nierolnicze miały podobną wartość jako potencjalne źródło glebowej materii organicznej. Zwiększone nawożenie azotem i popiołem ze słomy pszenicy sprzyjało produkcji biomasy nadziemnej obu odmian pszenicy ozimej, nie powodując zwiększenia masy resztek pożniwnych. Trzykrotne zastosowanie w zmianowaniu popiołu ze słomy w dawce do 100 $g \cdot m^{-2}$ nie zwiększyło istotnie zasobności gleby, ale pozwoliło utrzymać bez większych zmian jej odczyn oraz zawartość przyswajalnych dla roślin makro i mikroelementów.

Słowa kluczowe: makroelementy, mikroelementy, odczyn gleby, plon ziarna i słomy

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