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The effect of wheat straw quality on the rate of its mineralisation in soil

Abstract: The aim of this study was to assess the effect of straw of two spring wheat cultivars, Tybalt – with the culm filled with pith, and Ostka Smolicka – with the hollow culm, added to light textured soil, on the mineralisation rate of organic matter. The incubation experiment was established under laboratory conditions and comprised three experimental combinations: K1 was soil with an addition of pith-filled culms, K2 – soil with an addition of straw with hollow culms, and K0 – the control with no straw added. In all the combinations, mineral fertilisation was applied in the form of urea. Incubation lasted for 14 months. At specific dates the amounts of CO_2 released within 24 h and pH values were recorded. The rate of organic matter mineralisation was expressed in mg $CO_2 \cdot d^{-1}$. Analyses showed that the addition of straw, both with pith-filled and hollow culms, significantly influenced the mineralisation of organic matter in the first months of incubation. Mineralisation was most intensive in the soil incubated with straw with hollow culms. The large amount of released carbon dioxide in the first days of incubation caused a decrease in pH both in the control soil and in soils with the addition of straw. The change in the soil reaction to its initial value was recorded at day 222 for the soil combination K0 and at day 250 of incubation in soils fertilised with straw.

Keywords: mineralisation, wheat straw, CO_2, soil reaction

INTRODUCTION

The primary factor determining the physical, chemical and biological properties of soil is its organic matter content. Apart from its positive effect on soil fertility, numerous authors mention several other advantages, e.g. improvement of sorption and buffering properties, water capacity of soil and resistance to degradation (Rutkowska and Pikuła 2013, Pikuła 2015, Szopka et al. 2016). Moreover, organic matter is a structure forming material rich in macro- and micronutrients, which is a valuable source of food for a wide spectrum of beneficial soil microorganisms (Thangarajan et al. 2013). The high microbial activity in the decomposition of organic matter (mineralisation and humification) contributes to the formation of the crumb structure of soil, which results e.g. in the improvement of water and air properties. At the same time, mineralisation and humification processes taking place in organic matter lead to constant changes in its overall balance in soil (Pikuła 2015). In recent years, apart from the depletion of natural resources, we have also been observing a deterioration of agricultural soil quality and disturbance in its functions. A significant role in the case of soil degradation is played by loss of organic matter. According to Jakubus et al. (2013), such an effect is to a considerable degree influenced by the progressing urbanisation (a change in land use, drainage), intensification of agricultural production, monoculture and a lack of organic fertilisation. Maintenance of the level of organic matter or increasing its amounts in soil is justified not only from the point of view of broadly understood environmental protection, but first of all the need high productivity of agriculturally utilised land. Application of natural fertilisers (manure, slurry, liquid manure), organic fertilisers (composts) or harvest residues is a common method to improve soil quality in agroecosystems. Leaving harvest residue biomass in soil has been playing an increasingly important role mainly due to the decrease in the cattle population in Poland and the elimination of the bedding management system, resulting in the decreased manure production (Kaczyński, Siebielec 2015). In view of the above, it is justified to apply straw to the soil in order to maintain organic matter balance over a constant level (Kuś, Kopiński 2012). According to Harasim (2011), and Kaczyński et al. (2015) straw is an underestimated source of organic matter. The mature form of straw contains approx. 90% dry matter, high carbon content and a low amount of nitrogen. Cereal cultivars differ not only in yields or disease resistance, but also – as

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it is the case with wheats – culm filling. Wheat straw cultivars with pith-filled culms are characterised by a greater lodging resistance or resistance to pests (Nawracała et al. 2015). According to Kong et al. (2013), wheat with pith-filled culms have high contents of lignin and cellulose, which from the point of view of biochemical and microbiological changes may be an obstacle slowing down the processes of organic matter decomposition.

Organic carbon is found in soil in the form of humus substances resistant to decomposition, i.e. humus, and non-humus substances, such as lipids, carbohydrates or lignins, from which humus is formed through chemical changes taking place in soil (Sapek 2009). As a result of mineralisation of organic matter, under aerobic conditions organic carbon is oxidised, as a result of which an inorganic, gaseous form of carbon is formed, i.e. CO_2. As it was reported by Krysiak et al. (2010), the content of carbon dioxide in soil air is much greater than in the atmospheric air. Those authors stressed that as much as 90% total amount of soil carbon dioxide may be the result of microbiological changes in the humus layer. Golka (2011) also confirmed that considerable amounts of CO_2 are released from arable soils as a result of excessive mineralisation of soil organic matter. According to Strosser (2010) and Kaczyński and Siebielec (2015), by measuring the level of released CO_2 we may determine the intensity of the mineralisation process.

The aim of this study was to assess the mineralisation rate of straw of two morphologically different spring wheat cultivars, i.e. Tybalt, with pith-filled culms (K1), and Ostka Smolicka, with hollow culms (K2), introduced to light soil. The control (K0) was soil with no straw added.

MATERIALS AND METHODS

Soil samples were collected from the topsoil of arable land. According to the Polish Soil Classification (PSC 2011) they were classified as lessive soils (in Polish: gleby płowe) of quality grade IVb, of good rye agricultural suitability complex and a particle size of sandy loam according to the Polish Soil Science Society classification (Polskie Towarzystwo Gleboznawcze 2009) and the FAO – WRB classification (IUSS Working Group WRB 2014)(Table 1).

TABLE 1. Soil texture

Percentage of fraction with diameter			Texture acc. to FAO and acc.to PTG 2008
sand (2–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)	
65	32	3	SL

Air-dried material was sieved through mesh size of 2 mm. Two wheat cultivars of quality class A were used in the experiment: one with pith-filled culms – Tybalt (S1), and another one with hollow culms – Ostka Smolicka (S2). Tybalt is a winter-and-spring wheat that produces short, stiff straw and exhibits high disease resistance. Ostka Smolicka is a high-yielding spring wheat of quality grade A. It is awned wheat of high disease and lodging resistance. Characteristics of straw are presented in Table 2.

TABLE 2. Characteristics of straw of cv. Tybalt (S1) and Ostka Smolicka (S2)

Properties	S1	S2
Corg $g \cdot kg^{-1}$(dry matter)	402	432
N_{total} $g \cdot kg^{-1}$(dry matter)	6.9	7.1
C:N	58:1	61:1

Straw of both cultivars was harvested at the full maturity stage of wheat. Straw was cut into fragments of 5 mm in length. Next, boxes of 0.5 dm^3 were filled with 400 g soil, which was mixed with 0.8 g dry matter of straw, separately for the cultivar with pith-filled culms (K1) and with hollow culms (K2). Amounts used in the experiment corresponded to the dose of 6 Mg straw per hectare under field conditions. The control in the experiment comprised soil with no straw added (K0).

In all the experimental combinations, urea was added at 0.03 g, which corresponded to a nitrogen dose of 12 kg N/t straw. The experimental design comprised three combinations (see Table 3). Characteristics of soil mixed with straw and soil without straw are presented in Table 4.

Each combination was performed in 40 replications. Soil in boxes was treated with distilled water to 60%

TABLE 3. Scheme of the experiment

Combination		Straw type	Mineral fertilisation
Control (K0)	lessive soil	–	urea
Combination 1 (K1)	lessive soil	S1	urea
Combination 2 (K2)	lessive soil	S2	urea

TABLE 4. Characteristics of soil mixed with straw and soil without straw

Properties	K0	K1	K2
pH	6.66	6.61	6.65
H_h $mmol(+) \cdot kg^{-1}$	6	5.25	3
S $mmol(+) \cdot kg^{-1}$	56	62	86
V %	90.3	92.2	96.6
N_{total} $g \cdot kg^{-1}$	0.420	0.408	0.406
Corg $g \cdot kg^{-1}$	4.92	7.82	7.82

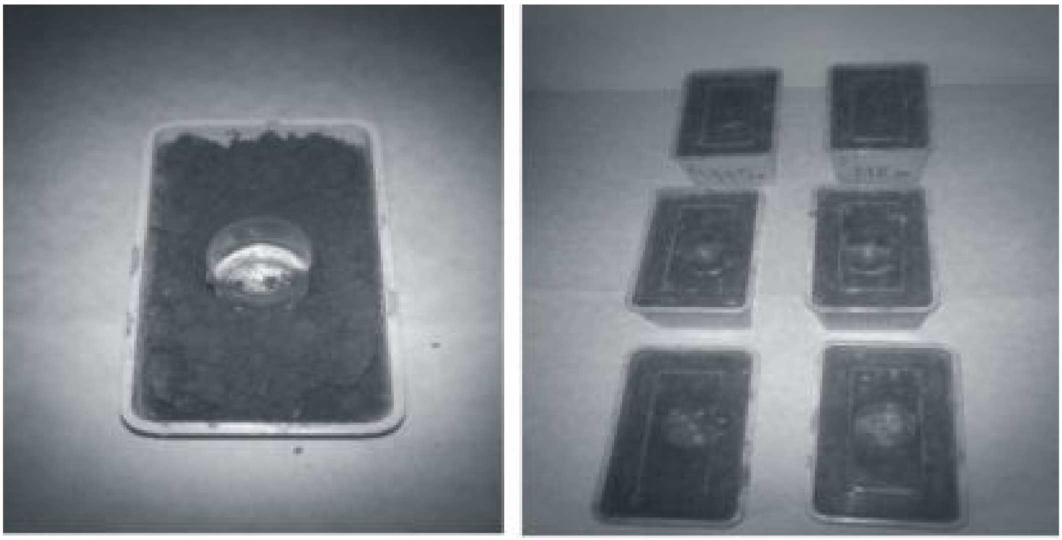

FIGURE 1. Boxes with soil and wheat, fragment of experiment

field water capacity and mixed. The intensity of microbiological changes was expressed in the amount of released CO_2. For this purpose, a beaker filled with 20 cm^3 0.5 $mol \cdot dm^{-3}$ NaOH was placed in each box (Figure 1). The boxes were sealed with plastic lids and incubated for 14 months (from 29.08.2014 to 16.11. 2015) at a temperature of 24±2°C.

Amounts of released CO_2 were measured at 23 dates, i.e. after 3, 6, 9, 16, 22, 29, 36, 50, 64, 78, 91, 112, 141, 169, 195, 222, 250, 285, 313, 335, 368, 403 and 445 days. For this purpose at each date 5 cm^3 of standard volumetric 0.5 $mol \cdot dm^{-3}$ NaOH solution were collected from beakers and titrated with the standard volumetric 0.5 $mol \cdot dm^{-3}$ HCl solution in the presence of phenolphthalein. Afterwards beakers were supplemented with a new portion of the standard volumetric 0.5 $mol \cdot dm^{-3}$ NaOH solution. Based on the recorded results the amount of CO_2, which was released and bound by NaOH in the beaker, was calculated. Moreover, at 20 dates, i.e. after 6, 16, 22, 36, 50, 64, 78, 91, 112, 141, 169, 195, 222, 250, 285, 313, 335, 368, 403 and 445 days, in the air-dried samples of soil pH was measured in 1 $mol \cdot dm^{-1}$ KCl applying the soil-eluent ratio of 1:2.5 and using a pH-meter with a glass electrode (Kabała et al. 2016).

Obtained data were subjected to statistical analysis. This paper presents mean values from replications and standard deviations (SD). Significance of differences between the means was determined using Tukey's test at $\alpha = 0.05$. Correlations coefficients between total amounts of released CO_2 (mg) at a given date and changes of pH values have a normal distribution and were calculated using Pearson's test. Data were analysed using the Statistica 10 and MS Excel software.

RESULTS AND DISCUSSION

Data given in Table 5 indicate that the addition of straw, both that with pith-filled culms and with hollow culms, significantly influenced the mineralisation rate of organic matter in the first months of incubation. The analyses showed that after 3 days of incubation the mean amount of CO_2 released within 24 h for combination K0 (6.34 mg $CO_2 \cdot d^{-1}$) was significantly smaller ($p=0.000113$) than the mean for combinations K1 (11.29 mg $CO_2 \cdot d^{-1}$) and K2 (12.43 mg $CO_2 \cdot d^{-1}$). At that date, we also observed that the mean amount of mg $CO_2 \cdot d^{-1}$ for combination K2 was significantly greater than the mean for combination K1, at $p = 0.000813$ (Table 5). According to Michalska and Ledakowicz (2012), the mineralisation rate of organic matter to a considerable extent depends on its morphological composition. As it was reported by Konga et al. (2013), straw with pith-filled culms (parenchyma) contains more lignin and cellulose, thus organic matter decomposition is slower than in the case of straw with hollow culms. For this reason it may be concluded that in the first days of incubation the mineralisation of organic matter was progressing the fastest during the incubation of the soil combination with straw with hollow culms (Figure 2). Mineralisation is a process, which depends among other things on moisture conditions, temperature, abundance and activity of microorganisms. A temporary reduction in one of the parameters could result in a decrease in the rate of mineralisation, which could result in a periodic absence of differences between the combinations (Zhou et al. 2013).

At the next date (after 6 days) the intensity of mineralisation was significantly greater for the experimental combinations K1 (7.41 mg $CO_2 \cdot d^{-1}$) and K2 (7.56 mg $CO_2 \cdot d^{-1}$) than for K0 after the same time (3.93 mg $CO_2 \cdot d^{-1}$). For the discussed combinations, the amounts of released CO_2 for K1 and K2 did not differ significantly (Table 5). Moreover, the process of mineralisation, in comparison to data recorded at previous dates, was much slower (Figure 2). As it was reported by Sapek (2009), cultivation measures such as ploughing or mixing biomass with topsoil increase access to oxygen and thus contribute to an increased emission of CO_2. Data presented in Table 5 indicate that the rate of carbon dioxide release from soil in combination K0 remained uniform (3–4 mg $CO_2 \cdot d^{-1}$) until as late as day 222 of incubation. At the next dates of incubation of the control soil, the rate of its release decreased systematically (Figure 2). In turn, combinations K1 and K2 up to day 22 of incubation were characterised by similar amounts of CO_2 at 6–7 mg $CO_2 \cdot d^{-1}$ (Table 5), while after day 29 we observed a decrease in the amounts of released $CO_2 \cdot d^{-1}$ to 4 mg, or even to 3–3.5 mg after day 64. After that time the amount of mg $CO_2 \cdot d^{-1}$ remained at the same level until day 368 of incubation, as evidenced by a lack of significant differences between combinations K0, K1 and K2 ($p>0.05$, Table 5). The last days of incubation in soil samples supplemented with both straw types resulted in a systematic decrease in released CO_2 and finally K0 released 2.3 mg $CO_2 \cdot d^{-1}$, while for K1 and K2 it was 2.15 mg $CO_2 \cdot d^{-1}$ at day 445 (Table 5).

In accordance with data given in Figure 3, differences in the total amounts of released CO_2 indicate that the process of mineralisation was most intensive

TABLE 5. Mean amounts of released CO_2 depending on time of incubation and experimental combinations

Incubation time (days)	K0		K1		K2	
	mean mg $CO_2 \cdot d^{-1}$	SD	mean mg $CO_2 \cdot d^{-1}$	SD	mean mg $CO_2 \cdot d^{-1}$	SD
3	6.34^{a}	1.18	11.29^{b}	1.18	12.43^{c}	1.64
6	3.93^{a}	0.77	7.41^{b}	1.25	7.56^{b}	0.96
9	3.87^{a}	1.04	6.29^{b}	1.46	6.00^{b}	1.00
16	3.01^{a}	0.30	6.01^{b}	1.39	6.68^{c}	1.20
22	3.88^{a}	0.86	6.33^{b}	1.55	7.28^{c}	1.20
29	3.02^{a}	0.37	4.03^{b}	1.03	4.05^{b}	0.94
36	3.27^{a}	0.35	3.99^{b}	0.83	3.74^{b}	0.66
50	3.66^{a}	0.57	3.99^{b}	0.50	$3.84^{b.r.}$	0.58
64	$3.05^{b.r.}$	0.59	$3.14^{b.r.}$	0.53	$3.03^{b.r.}$	0.58
78	$3.34^{b.r.}$	0.42	$3.36^{b.r.}$	0.55	$3.36^{b.r.}$	0.51
91	$3.44^{b.r.}$	0.50	$3.46^{b.r.}$	0.54	$3.42^{b.r.}$	0.54
112	$3.35^{b.r.}$	0.32	$3.47^{b.r.}$	0.43	$3.42^{b.r.}$	0.35
141	$3.15^{b.r.}$	0.27	$3.07^{b.r.}$	0.28	$3.09^{b.r.}$	0.35
169	$3.23^{b.r.}$	0.34	$3.35^{b.r.}$	0.30	$3.19^{b.r.}$	0.30
195	3.22^{a}	0.22	3.52^{b}	0.28	3.59^{b}	0.30
222	$2.95^{b.r.}$	0.35	$3.01^{b.r.}$	0.24	$2.95^{b.r.}$	0.28
250	$2.79^{b.r.}$	0.42	$2.86^{b.r.}$	0.35	$2.78^{b.r.}$	0.23
285	$2.70^{b.r.}$	0.18	$2.73^{b.r.}$	0.15	$2.66^{b.r.}$	0.15
313	$2.70^{b.r.}$	0.25	$2.70^{b.r.}$	0.16	$2.78^{b.r.}$	0.17
335	2.68^{a}	0.38	3.11^{b}	0.11	3.32^{b}	0.27
368	$2.67^{b.r.}$	0.12	$2.78^{b.r.}$	0.13	$2.60^{b.r.}$	0.19
403	$2.39^{b.r.}$	0.13	2.30^{a}	0.16	2.56^{b}	0.13
445	2.31^{a}	0.05	2.15^{b}	0.04	2.15^{b}	0.03

a, b, c – statistically significant difference between combinations, homogeneous groups; b.r. – no statistically significant differences.

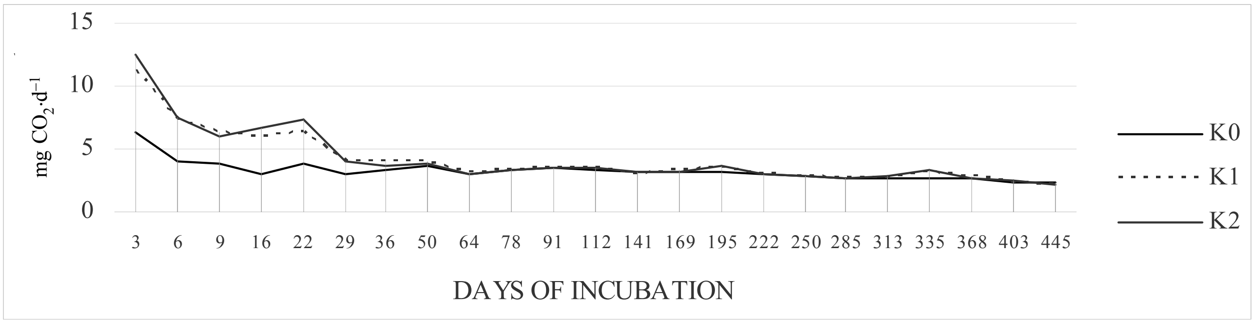

FIGURE 2. The rate of CO_2 release, $mg \cdot d^{-1}$, during incubation of the control soil (KO) and the combinations of soil with straw with pith-filled (K1) and hollow (K2) culms

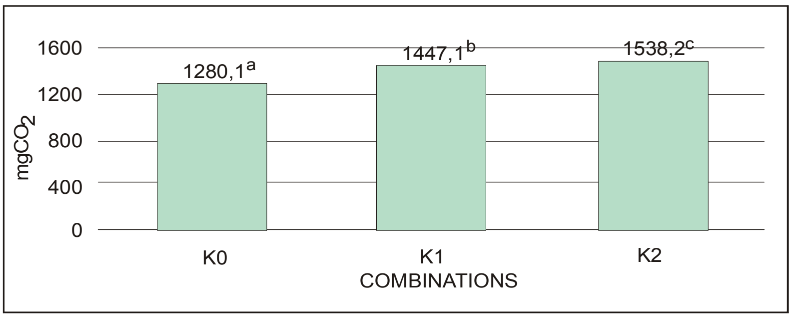

FIGURE 3. Total amounts of CO_2 released during a 445-days of incubation for experimental combinations K0, K1 and K2

in soil supplied with straw with hollow culms (1538.2 mg), while smaller amounts of CO_2 were detected in soil from combination K1 (1447.1 mg), whereas for the control soil a total of 1280.1 mg CO_2 was recorded (Figure 3). Statistical analysis showed that the addition of straw had a statistically significant effect on the increase in the organic matter mineralisation rate ($p=0.000227$). Statistically significant differences were also manifested between the amounts of CO_2 released from soil of the experimental combinations with straw of the two cultivars ($p=0.000247$). Observed differences may be explained by the morphological structure of straw with pith-filled and hollow culms. As it was reported by Michalska and Ledakowicz (2012), wheat with pith-filled culms contains more cellulose and lignin, resulting in slower decomposition (mineralisation) than in the case of straw with hollow culms.

confirmed by mean amounts of CO_2 greater than at the other dates (Figures 2, 4). Data presented in Figure 4 indicate that in combination K0 pH values were within the range of 4–5 up to day 222 of incubation, followed by, a gradual increase, reaching 6.4 at day 250. The reaction of the control soil remained at a similar level to the end of incubation (up to day 445). In turn, for the experimental soil combinations with straw, the increase in soil reaction above pH 6.0 took place after approx. 250 days (Figure 4). Irrespective of the addition of straw, changes in soil reaction occurred in all the combinations, which may indicate advantageous buffering properties of soil – V over 90% (Table 4). The significance of the dependence between the total amounts of released CO_2 and pH values is confirmed by the high correlation coefficients (K0 – 0.87, K1 – 0.9, K2 – 0.91)(Table 6.).

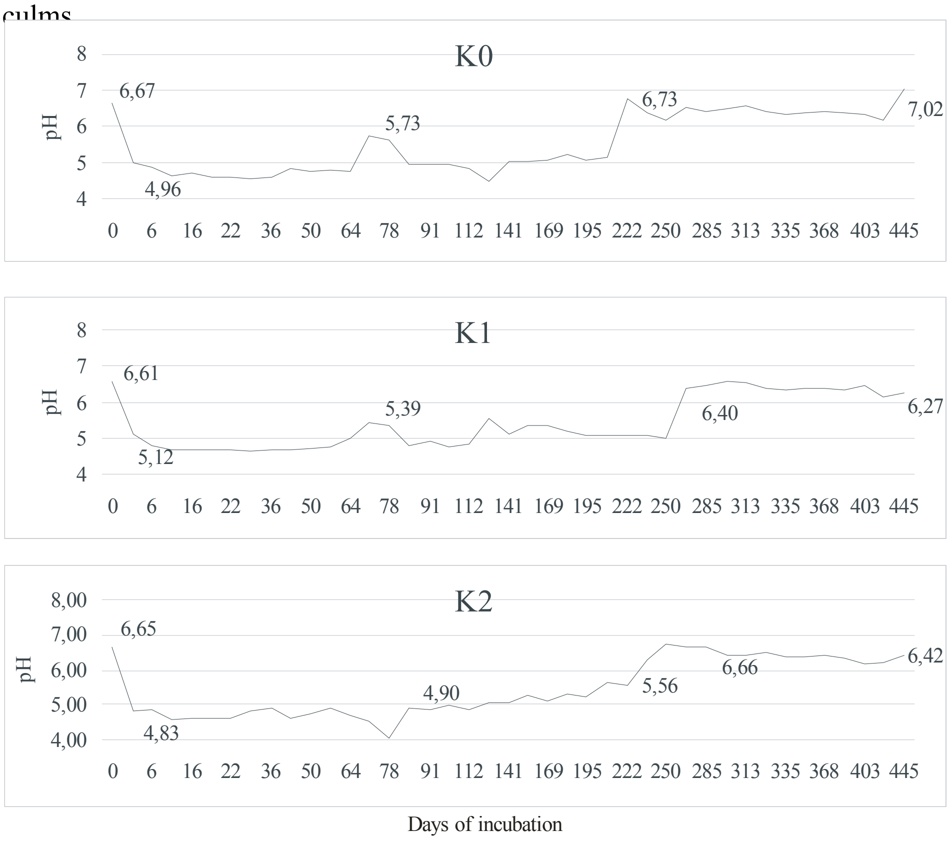

FIGURE 4. A graph of changes in pH values in time depending on the combination

Data given in Figure 4 show the course of changes in pH values for the experimental soil combinations K0, K1 and K2. The analysis showed that after 6 days of incubation in all the combinations a rapid decrease was observed for pH values (for K0 – down to pH 4.96, K1 – 5.12, K2 – 4.83). According to Koper and Lemanowicz (2008), soil acidification may be a result of applied nitrogen fertilisation consequently leading to a faster mineralisation rate in the first days of incubation and a high carbon dioxide concentration in soil in the first days of incubation, which was

With an increase in the total amounts of released CO_2 the soil reaction increased reaching the value close to the levels observed before the establishment of the experiment.

TABLE 6. Correlation coefficients between total amounts of released CO_2 at a given date and change of pH value

pH			
	K0	K1	K2
CO_2	0.87	0.90	0.91
$p<0.001$			

CONCLUSION

Addition of straw with pith-filled and hollow culms to soil resulted in an increase in the mineralisation rate of organic matter in soil in the first days of incubation. At the same time the greatest values of released $CO_2 \cdot d^{-1}$ were observed in the case of soil with straw with hollow culms, which contained less lignins and celluloses and as such was decomposed faster. In that case also the total amount of released CO_2 was greater for the experimental combination of soil with hollow straw in comparison to the amount recorded for the soil with pith-filled straw or the control. The slower decomposition of pith-filled straw may result in a higher level of organic matter being maintained in the soil, thus improving its properties. It needs to be stressed that up to day 6 of incubation in all the combinations we observed an increase in the mineralisation rate, resulting in a rapid decrease in pH at that time. As a consequence of the release of carbon dioxide from soil pH values increased systematically at successive incubation dates, which indicates advantageous buffering properties of the analysed soil.

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Wpływ jakości słomy pszenicy na tempo jej mineralizacji w glebie

Streszczenie: Celem pracy była ocena wpływu dodatku do gleby lekkiej, dwóch odmian słomy pszenicy jarej, Tybalt – z rdzeniem wypełnionym oraz Ostka Smolicka – z rdzeniem pustym, na tempo mineralizacji materii organicznej. Doświadczenie inkubacyjne przeprowadzono w warunkach laboratoryjnych i składało się z trzech kombinacji doświadczalnych: K1 stanowiła gleba lekka z dodatkiem słomy z wypełnionym rdzeniem, K2 – gleba lekka z dodatkiem słomy z rdzeniem pustym oraz K0, którą była kontrola bez dodatku słomy. We wszystkich kombinacjach zastosowano nawożenie mineralne w postaci mocznika. Inkubacja trwała 14 miesięcy. W określonych terminach dokonano pomiarów ilości wydzielonego CO_2 w ciągu doby oraz wartości pH. Ilość wydzielonego $CO_2 \cdot d^{-1}$ odzwierciedlała tempo mineralizacji materii organicznej. Badania wykazały, że dodatek słomy zarówno z pełnym, jak i pustym rdzeniem istotnie wpłynął na tempo mineralizacji materii w pierwszych miesiącach inkubacji. Mineralizacja najintensywniej zachodziła w kombinacji doświadczalnej gleby z dodatkiem słomy z pustym rdzeniem. Duża ilość uwolnionego dwutlenku węgla w pierwszych dniach inkubacji spowodowała zmniejszenie pH zarówno w glebie kontrolnej, jak i w glebie z dodatkiem słomy. Zmianę odczynu gleby na jej początkową wartość odnotowano w dniu 222 dla kombinacji gleby K0 i w dniu 250 inkubacji w glebach nawożonych słomą.

Słowa kluczowe: mineralizacja, słoma pszenicy, CO_2, odczyn gleby