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The influence of crop residues type on their decomposition rate in the soil: a litterbag study

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Abstract

The aim of the study was to evaluate the effect of crop residue type, chemical composition and amount of micro-organisms on residue decomposition rate in the soil. Different residues types of winter and spring oilseed rape, winter wheat and red clover were incorporated into the soil in a field experiment.

The decomposition rates of crop residues incorporated into the soil were found to depend on plant species, residue type, and chemical composition; the most important indicators were proved to be the C:N ratio and lignin concentration. The research findings showed that winter and spring oilseed rape threshing remains as well as stubble of winter wheat and red clover decomposed very intensively within the first 2.5 months after their incorporation into the soil. Decomposition of these crops roots and oilseed rape stubble was more intensive later on (2.5–26 months). Multiple regression analysis indicated that the decomposition rate of crop residues depended on the complex of their chemical composition: C:N ratio, N and lignin concentration. Decomposition rate correlated with the amount of micro-organisms only during the initial stages of decomposition up to 14.5 months; later on (14.5–26 months) no significant correlation was estimated.

Growth of different groups of micro-organisms (mineral N assimilators, ammonificators, micromycetes, and cellulose degraders) depended on the decomposing substrate and period of crop residues incubation in the soil. Threshing remains of winter and spring rape and also stubble and roots of red clover were a more favourable substrate for growth of the investigated groups of micro-organisms than stubble and roots of winter and spring rape, and winter wheat.

Key words: crop residues, decomposition, chemical composition, micro-organisms.

Introduction

In sustainable agriculture, one of the most relevant objectives is maintenance and restoration of soil fertility. Increase of the organic matter as the source for humus formation is one of the means to sustain soil fertility. The amount of soil organic matter depends on the balance between its synthesis and degradation. In agricultural systems mainly, it depends on the crops grown and organic residues that they leave. Usually, crop residues are incorporated into the soil where they start to decompose. Knowledge on the mineralization of crop residues added to the soil is of the utmost importance to address soil management practices aimed to maintain and restore soil organic matter (SOM) and to predict long term trajectories of SOM. The rate and extent of residue transformation in the soil depend on type, quantity, and quality of residues produced and how and when residues are treated (Magdof, Weil, 2004). Post-harvest residues tend to positively affect soil physical properties and especially air permeability (Feizienė et al., 2007).

The decomposition of crop residues is the result of complex microbial processes controlled by numerous factors (Тейт, 1991). Functional diversity of the microbial community and other early decomposing soil organisms can be determined by native SOM, organic inputs and their interaction (Bending et al., 2002; Georgeva et al., 2005). Even the C:N ratio in crop residues is generally considered sufficient to induce differences in the nature of decomposer organisms (Cheshire et al., 1999).

Plant materials are basically composed of similar components, but differ in their proportions which influence the decomposition of residues (Hadas et al., 2004). The biochemical composition of plant material has been identified by ecologists and agronomists as a decisive factor in the rate of decomposition of recently incorporated organic matter (Heal et al., 1997; Martens, 2000). The quality of residues depends on the plant species. Furthermore, at harvest crop residues are composed of heterogeneous materials (roots, pod walls, leaves, and stems) with different biochemical characteristics (Trinsoutrot et al., 1999; Magdof, Weil, 2004). Morphological properties of residues affect decomposition and interact with biochemical composition to influence decomposition rates (Jensen,

1994; Wolf, Snyder, 2003). Even the decomposition of dicot and monocot materials differs (Magid et al., 2004). Machinet et al. (2009) showed that C mineralization kinetics differs markedly between the genotypes of maize. It is indicated, that decomposition rate of organic matter in the soil is determined by the ratio of C:N in plant residues (Jenkinson, 1965; Тейт, 1991). The rate of crop residues decomposition in the soil cannot be sufficiently explained by the carbon to nitrogen ratio alone. A more complete answer to these questions can be given by investigations into the change of the lignin content (Тейт, 1991; Sjöberg, 2003; Bertrand et al., 2006). The concentrations of readily dissoluble components and lignin, as well as their ratio in decomposing material influence the rate of crop residues decomposition (Тейт, 1991; Wolf, Snyder, 2003). Decomposition of various residues is different and only detailed investigations under specific soil and climate conditions and soil management practice can explain the patterns of transformation. The data of investigations can be used to predict the influence of those processes on soil fertility.

The most common method to determine residues decomposition rate is the litterbag technique which allows experimental decomposition studies under field conditions. The method is simple and inexpensive and therefore widely used (Berg, McClaugherty, 2003).

The aim of our study was to evaluate differences among crop residues decomposition rate in the soil influenced by residue type, chemical composition and amount of different groups of micro-organisms.

Materials and methods

Site and soil. Field experiments on winter oilseed rape (*Brassica napus* L. ssp. *oleifera biennis* Metzg.), spring oilseed rape (*Brassica napus* L. ssp. *oleifera annua* Metzg.), winter wheat (*Triticum aestivum* L.), and red clover (*Trifolium pratense* L.) post-harvest residues decomposition were carried out at the Experimental Station of the Aleksandras Stulginskis University (former Lithuanian University of Agriculture) (54°53′ N, 23°50′ E) during the period of 2004–2006. The soil of the experimental site according to the FAO-UNESCO soil classification is drained moraine loamy *Endocalcari-Epihypogleyic Cambisol* (sicco) (*CMg-p-w-can*). The main soil properties were: soil pH_{KCl} 6.7, humus content in the arable layer 2.1%, total N 1.47 g kg^{-1}, base saturation >90%, available phosphorus (P_2O_5) 119 mg kg^{-1}, available potassium (K_2O) 100 mg kg^{-1}, available sulphur (SO_4^{2-}) 15.4 mg kg^{-1}. Soil texture in the arable layer (0–25 cm) was dominated by silt 55.3% and sand 33.8%, while clay particles amounted to 10.9%. The C:N ratio was 9.2.

Meteorological conditions. Investigations were carried out during cold and warm periods (Table 1). The warm periods were characterized by a sharp shift of prolonged drought, higher air temperatures and rainfall.

Table 1. Duration of investigation periods and their meteorological conditions

No.	Duration of investigation period, months[x]	Date	Conditions during period			Average conditions for 3 successive days[xxx]		
			average temperature °C		precipitation mm	temperature °C		soil moisture %
			air	soil[xx]		air	soil[xx]	
1.	2.5	01 09 2004–11 11 2004	9.7	10.8	123.9	3.4	4.9	22.1
2.	7.5	11 11 2004–11 04 2005	−1.1	1.4	216.0	6.7	6.5	26.8
3.	14.5	11 04 2005–02 11 2005	13.4	15.0	399.0	2.3	3.2	21.6
4.	19.5	02 11 2005–24 04 2006	−2.0	0.5	157.0	8.1	7.5	21.7
5.	26.0	24 04 2006–02 11 2006	15.1	16.1	476.4	3.5	4.7	17.0

[x] – from initiation, [xx] – at a depth of 20 cm, [xxx] – before sampling

Experimental design. The experiment had a two-factor design. It was performed in four replications. Factor A – crop residues: 1) stubble of winter oilseed rape (30 cm from root collar), 2) threshing remains of winter oilseed rape (stems with branches and siliques), 3)stubble of spring oilseed rape (30 cm from root collar), 4) threshing remains of spring oilseed rape (stems with branches and siliques), 5) stubble of winter wheat (20 cm height), 6) stubble of red clover (20 cm height), 7) roots of winter oilseed rape, 8) roots of spring oilseed rape, 9) roots of winter wheat, 10) roots of red clover. Factor B – decomposition duration: 1) 0, 2) 2.5, 3) 7.5, 4) 14.5, 5) 19.5 and 6) 26 months.

Field experiment. The experiment was started on the 1st of September 2004. End-datum point of different duration decomposition periods was set up when average temperature in 20 cm soil depth for three successive days in spring was ≥ +5°C and in autumn ≤ +5°C. Samples of oilseed rape and wheat residues were prepared after harvesting. Sampling of residues of the second year red clover was done after the first cut. Collected crop residues were chopped in 2–3 cm size chaffs. Content of their dry matter (DM) was estimated. Litter bags (9 × 12 cm) of polychlorvinyl net with a mesh size of about 0.05 mm were filed with 20 g of natural humidity crop residues and incorporated into the soil of bare fallow at the 20 cm depth and at 20 cm distances. At the end of each decomposition period (factor B), a set of 40 litterbags was sampled. Chemical composition of decomposing crop residues, loss of their dry mass and spread of different groups of micro-organisms were determined.

Chemical and microbiological measurements. The content in the bag was dried out until air dry weight, ground, sieved through 1 mm separator. The following chemical analyses were performed on the samples: DM content was determined by drying in a thermostat at +105°C, the content of total nitrogen by the Kjeldahl, organic carbon by Tyurin, lignin by Klason methods.

Investigations of micro-organisms were performed at the Laboratory of Biodeterioration Research of the Institute of Botany. The ablution and direct dissemination methods were used for micro-organism isolation

(Билай, 1982). For different groups of micro-organisms different media were used: for N assimilators – starch-ammonia medium, for ammonificators – meat-peptone agar, for micromycetes – agar beer-mash medium (6 Bal.), for cellulose degraders – cellulose agar medium. Cultures were cultivated at +26 ± 2°C. The number of micro-organisms (colony forming units, cfu) was calculated in 1 g of dry substrate (Мирчинк, 1988).

Statistics. Significance of differences between treatments was determined by the analysis of variance (two-way *ANOVA*). Multiple regression analysis was applied to evaluate the influence of chemical composition and spread of micro-organisms on crop residues decomposition rate.

Results

Chemical quality characteristics of plant materials. Dry matter content in threshing remains of winter and spring oilseed rape, winter wheat and red clover stubble was much higher than that in oilseed rape stubble and all crops roots (Table 2). Red clover residues had high nitrogen concentrations and low C:N ratio, while the reverse was true for winter wheat stubble and roots. Winter wheat residues also had higher lignin concentrations than other materials while in the threshing remains of winter and spring oilseed rape and red clover stubble the lignin concentration was lower.

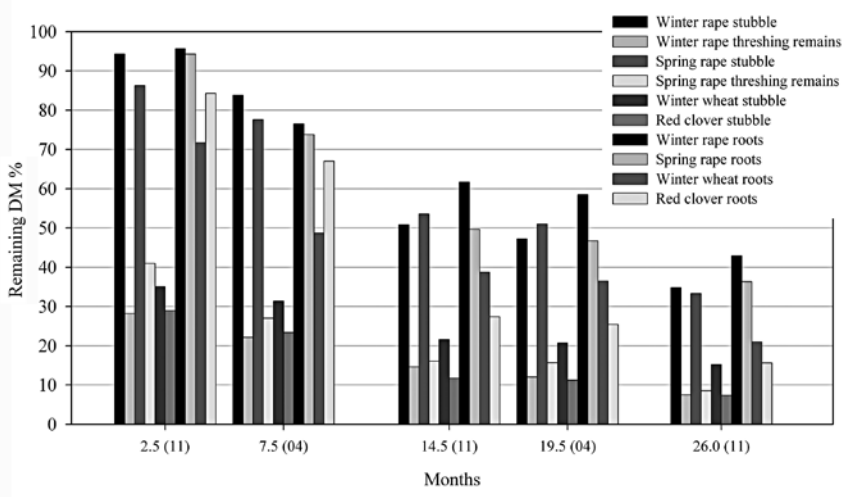
Table 2. Chemical quality characteristics of plant materials

Crop residue	DM g kg^{-1}	N g kg^{-1}	C:N ratio	Lignin g kg^{-1} DM
Winter rape stubble	279	6.5	55	170
Winter rape threshing remains	886	9.6	39	97
Spring rape stubble	246	7.0	50	158
Spring rape threshing remains	656	9.0	40	91
Winter wheat stubble	828	3.6	113	231
Red clover stubble	898	12.4	29	97
Winter rape roots	306	8.2	46	172
Spring rape roots	301	7.1	53	157
Winter wheat roots	441	3.1	104	219
Red clover roots	270	14.8	25	124

Decomposition rate. Within the first 2.5 months (September–November) more intensive decomposition of winter and spring oilseed rape threshing remains (DM-loss 72% and 59%, respectively), winter wheat and red clover stubble (DM-loss 65% and 71%, respectively) was recorded as compared with that of other residues (DM-loss 4–28%) (Figs 1 and 2). The slowest decrease of DM was recorded in the roots and stubble of winter and spring oilseed rape (accordingly 4% and 6%, 6% and 14%). Rape roots were decomposing significantly ($P \leq 0.05$) more slowly than those of wheat and clover.

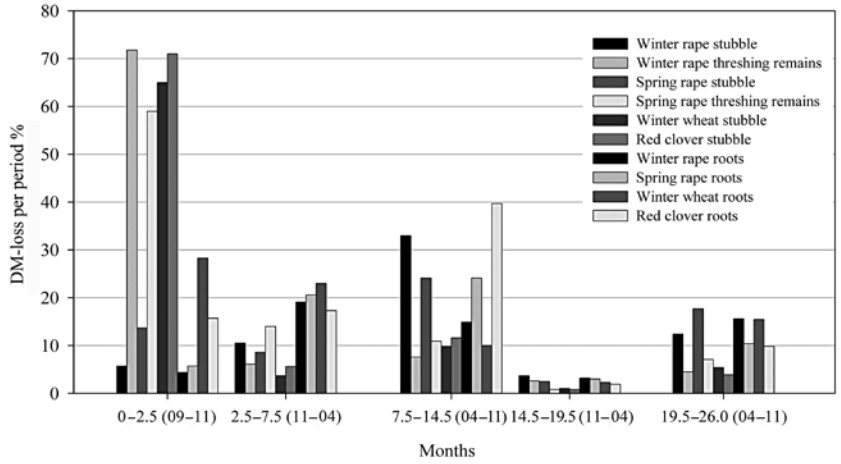
During the cold period of 2004–2005 (2.5–7.5 months), a slow organic matter decomposition process was going on. But winter oilseed rape stubble, roots of winter and spring oilseed rape started to decompose more intensively (DM-loss accordingly 10 and 19 and 21 %) than during the previous period, while decomposition of threshing remains of winter and spring oilseed rape and stubble of wheat and clover significantly ($P \leq 0.05$) slowed down (DM-loss accordingly 6% and 14%, 4% and 6%). During this cold period roots were decomposing significantly more intensively than above-ground biomass.

After 14.5 months, winter and spring oilseed rape roots and stubble were decomposed significantly less (DM-loss accordingly 38 and 49, 50 and 46 %) than other residues (61–88%). During this period red clover stubble, winter and spring rape threshing remains were decomposed significantly more than other residues.



Notes. In the brackets the calendar month is shown when sampling was done. The order of the crop residues in the label and in the columns is the same.

Figure 1. Decomposition of different crop residues in the soil ($LSD_{05} = 3.16$)



Notes. In the brackets the calendar month is shown when sampling was done. The order of the crop residues in the label and in the columns is the same.

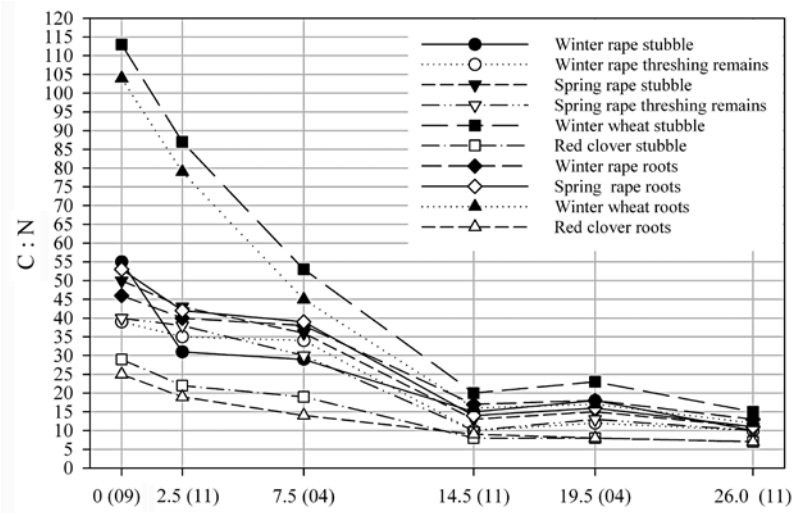
Figure 2. The decomposition rate per period of different crop residues in the soil (LSD_{05} = 4.50)

During the cold season of the second year (7.5–14.5 months) the decomposition rate slowed down considerably again (DM-loss 0.8–3.7%). The difference of the decomposition rate of all residues was not significant ($P \geq 0.05$).

During the last period of study (19.5–26 months), i.e. during the warm period of the second year, the decomposition of all crops roots and stubble of winter and spring rape became again more intensive (DM-loss 12–16%). The residues, which had been decomposing slowly during the first periods, started to decompose more intensively during the last period (19.5–26 months). During this period, winter and spring oilseed rape stubble decomposed more intensively (DM-loss accordingly 12 and 18 %) than other above-ground biomass residues (4–7%). After the period of 26 months winter and spring oilseed rape roots and stubble were decomposed significantly ($P \leq 0.05$) less than those of other plants.

The C:N ratio. In all investigated crop residues the most intensive organic carbon decomposition occurred during the warm period of the first year of investigation (7.5–14.5 months). About 50% of organic carbon decomposed during this period. The concentration of nitrogen in all crop residues was relatively increasing till 14.5 months of decomposition (Kriaučiūnienė, 2008). In the above-ground parts and roots of winter and spring oilseed rape there was significantly ($P \leq 0.05$) more nitrogen than in appropriate residues of winter wheat and less than that of red clover until 7.5 months of decomposition in the soil. Until 19.5 months, the concentration of N in red clover residues was significantly ($P \leq 0.05$) higher than that in other residues. After 26 months, the concentration of total nitrogen in the most decomposed residues (stubble and roots of red clover, threshing remains of winter and spring oilseed rape) was lower ($P \geq 0.05$) and in the least decomposed residues (roots of winter rape) – significantly ($P \leq 0.05$) higher than that in other investigated residues.

In winter and spring oilseed rape above- and below-ground residues after harvesting (Table 2), after 2.5 and 7.5 months of residues incubation, the C:N ratio (accordingly 29–55 and 40–50) was significantly ($P \leq 0.05$) lower than that of winter wheat (69–113) and significantly ($P \leq 0.05$) higher than that of red clover (14–29) residues (Fig. 3).



Note. In the brackets calendar month is shown when sampling was done.

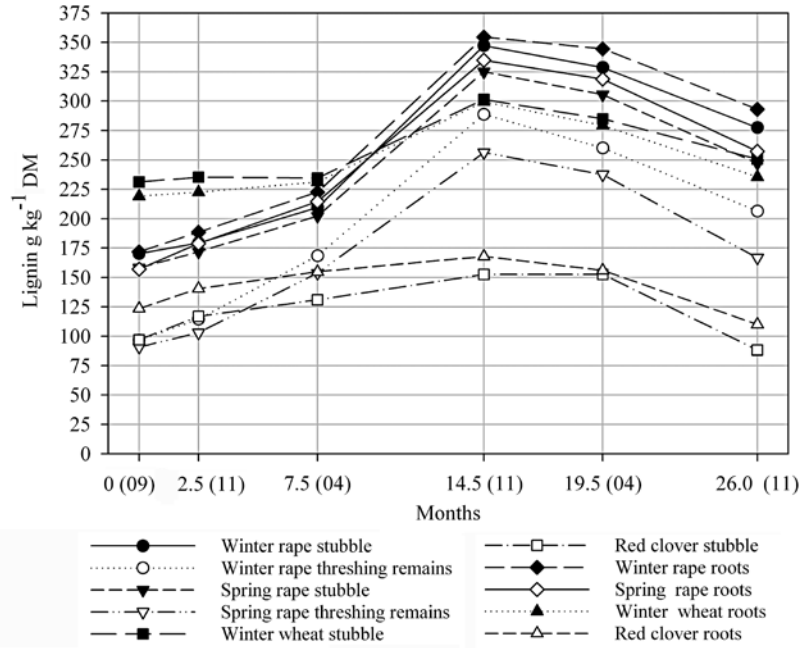
Figure 3. Changes in the C:N ratio in different crop residues during their decomposition in the soil (LSD_{05} = 4.89)

The C:N ratio most intensely decreased in crop residues (except for winter wheat) during the third (7.5–14.5 months) period which was warm. During the next period (14.5–19.5 months) which was cold, the C:N ratio in the crop residues slightly increased. During the warm period of the second year (19.5–26 months), a decrease in the C:N ratio was estimated in all crops residues, but it was significant ($P \leq 0.05$) only in winter rape and wheat stubble and all investigated crops roots, except for red clover.

After 26 months of decomposition, the C:N ratio in the residues of all crops roots was 7–13. The C:N ratio in the above-ground residues of oilseed rape did not differ significantly ($P \leq 0.05$) from that in red clover stubble and roots. The highest C:N ratio (15) was estimated in winter rape stubble. It did not differ significantly ($P \leq 0.05$) from the C:N ratio in winter and spring rape roots (it was accordingly 13 and 11).

Lignin. Before incorporation of crop residues into the soil, the highest concentration of lignin was recorded in winter wheat stubble and roots (accordingly 231 and 219 g kg^{-1}) and the lowest among the above-ground residues: in threshing remains of spring and winter oilseed rape (accordingly 91 and 97 g kg^{-1}) and stubble of red clover (97 g kg^{-1}); among roots: in red clover (124 g kg^{-1}) (Table 2). In roots of winter oilseed rape there was 9% more lignin than that of spring rape.

During 14.5 months of crop residues decomposition, the concentration of lignin in them was relatively increasing and after 14.5 months its concentration started to decrease (Fig. 4). After 19.5 months, it decreased significantly ($P \leq 0.05$) in the above-ground biomass residues (except for red clover), in roots (except winter wheat) the decrease was not significant ($P \geq 0.05$).



Note. In the brackets the calendar month is shown when sampling was done.

Figure 4. Lignin concentration in different crop residues during their decomposition in the soil (LSD_{05} = 16.01)

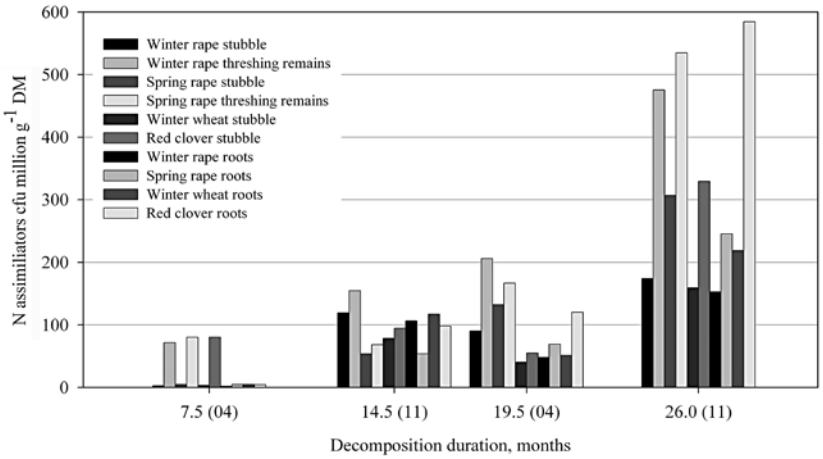
Lignin concentration in all crop residues significantly ($P \geq 0.05$) decreased (from its highest value after 19 months) after 26 months of decomposition. The highest amount of lignin degraded in red clover residues: in stubble 42%, in roots 34% and in spring and winter rape threshing remains 35% and 28%, respectively. The lowest decomposition rate of lignin was identified in the roots of winter rape and stubble of winter wheat: after 26 months its concentration declined only by 17% from the maximal value.

Micro-organisms. Micro-organisms isolated from crop residues decomposing in the soil were separated into four groups: mineral nitrogen assimilators, ammonificators, micromycetes and cellulose degraders.

Micro-organisms assimilating mineral nitrogen on decomposing crop residues were growing most abundantly. The highest number of them on all investigated crop residues was estimated after 26 months of incubation (Fig. 5). Most abundantly mineral N assimilators were growing on the threshing remains of winter and spring oilseed rape (accordingly 475 and 535 million cfu) and roots of red clover (584 million cfu).

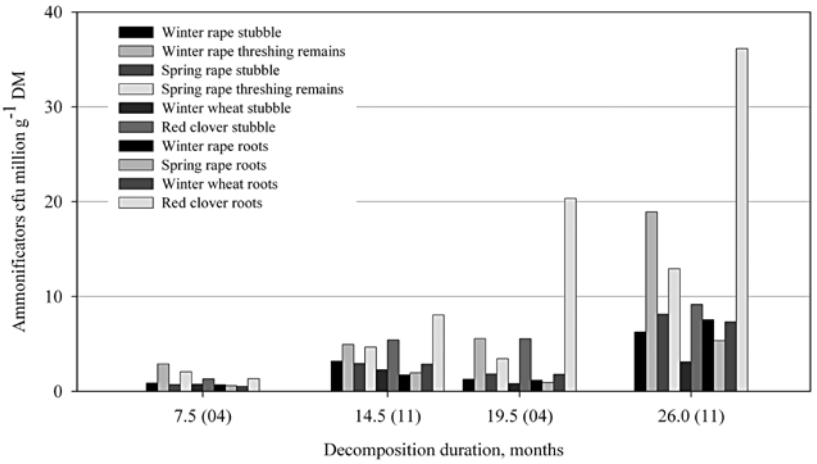
The number of ammonificators on crop residues was lower than that of N assimilators. The highest number of them on all crop residues was estimated also after 26 months of investigation (Fig. 6). Threshing remains of winter and spring oilseed rape and residues of red clover were the most suitable substrates for growth of this group of micro-organisms as well. The number of this group of micro-organisms on winter and spring threshing remains was 19 and 13 million cfu, on red clover roots it was 36 million cfu.

The highest activity of micromycetes on crop residues was estimated after 26 months of crop residues incubation in the soil (Fig. 7). The highest distribution of them was estimated on threshing remains of winter and spring oilseed rape (accordingly 2.6 and 2.8 million cfu) and stubble and roots of red clover (accordingly 2.8 and 5.1 million cfu).



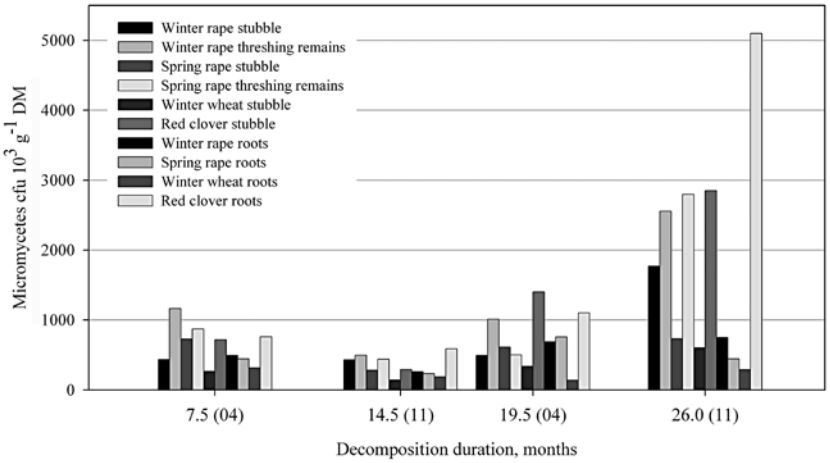
Notes. In the brackets the calendar month is shown when sampling was done. The order of the crop residues in the label and in the columns is the same.

Figure 5. The amount of N assimilators on crop residues decomposing in the soil



Note. Explanations under Figure 5.

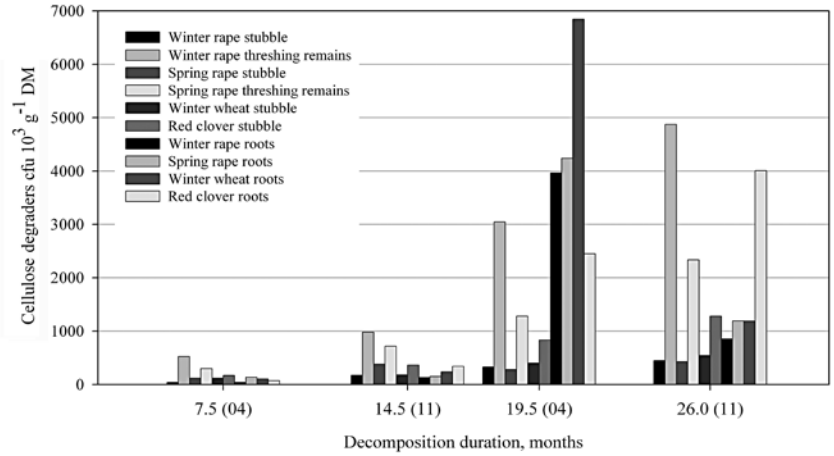
Figure 6. The amount of ammonificators on crop residues decomposing in the soil



Note. Explanations under Figure 5.

Figure 7. The amount of micromycetes on crop residues decomposing in the soil

With increasing incubation period the number of cellulose degraders also was increasing on all plants above-ground residues and roots of red clover (Fig. 8). On the roots of other plants, the highest number of those micro-organisms was estimated after 19.5 months of decomposition. They were growing most abundantly on decomposing roots (4.0–6.8 million cfu), threshing remains of winter and spring oilseed rape (accordingly 4.9 and 2.3 million cfu) and stubble of red clover (1.3 million cfu).



Note. Explanations under Figure 5.

Figure 8. The amount of cellulose degraders on crop residues decomposing in the soil

The best substrates for growth of all identified groups of micro-organisms were threshing remains of oilseed rape and residues of red clover. Cellulose degrading micro-organisms were growing also on roots of all investigated plants.

During the same year of investigation, more micro-organisms on crop residues were found in the autumn than in spring, except for the micromycetes during the first year of investigation (7.5–14.5 months) and cellulose degrading micro-organisms on roots during the second year of investigation (19.5–26 months). During the first year of decomposition, more micromycetes on crops roots were isolated in spring than in autumn. During the second year, more cellulose degrading micro-organisms on oilseed rape and wheat roots were found after the cold period compared with the warm one.

Discussion

Investigation showed that different residues decomposed at different rates and, therefore, the nutrients present in them were released at different times. Threshing remains of winter and spring oilseed rape, stubble of wheat and red clover decomposed rapidly, and might have had a positive influence on subsequent crops from the rapid release of nutrients present in them. Stubble of oilseed rape and roots of all crops decomposed more slowly and, therefore, on release their nutrients could be available for the subsequent crop later. Roots of winter oilseed rape were the slowest to decompose so they might be a potential nutrient source over a longer time. Furthermore they are rich in lignin, and because of that stable humic compounds could be formed. These differences in organic matter decomposition rates are influenced by the chemical composition of the crop residues. The most important indices are the C:N ratio, the content of lignin, and glucosinolates present in rape residues (Александрова, 1980; Тейт, 1991; Wolf, Snyder, 2003).

Within the first 2.5 months, fine above-ground biomass residues (threshing remains of winter and spring oilseed rape, stubble of red clover) decomposed most rapidly. They had higher contents of N, lower of lignin and lower C:N ratio. Although winter wheat stubble had different chemical composition, its decomposition rate was similar. It is well known that organic compounds that are readily accessible to micro-organisms, are first to decompose. Microbial cell synthesis requires nitrogen, so for residues with wide C:N ratios due to nitrogen deficiency, microbial activity is limited (Knapp et al., 1983). Under aerobic conditions, microbial activity and nitrogen immobilization are favoured on residues with high available carbon (Hadas et al., 2004), thereby conserving nitrogen. However, lower available nitrogen temporarily reduces soil microbial activity. In our investigation, micro-organisms quickly used the small amount of nitrogen present in the residues of winter wheat and started decomposing carbon. This resulted in a reduced C:N ratio, and lignin began to degrade, providing a more accessible carbon source for micro-organisms. It has been shown that soil fungi use lignin decomposition products as a carbon source (Microbiological deterioration of materials, 1997). Multiple regression analysis showed that decomposition rates during this period are not influenced by only one measured variable in the initial plant material (N, C:N ratio, lignin), but depend on all of these chemical features. A combination of N, C:N ratio and lignin concentration in crop residues explained decomposition rates by 83%, and 27% depending on the other factors such as plant type, part, environment etc. (Table 3).

During the second investigation period (2.5–7.5 months) which was cold, crop root residues decomposed more rapidly than above-ground biomass residues. Decomposition of the crop residues, that decomposed rapidly during the first period (0–2.5 months), slowed down or was not significant ($P \geq 0.05$) during the second period. The roots of winter and spring oilseed rape and stubble of winter oilseed rape, that had decomposed significantly ($P \leq 0.05$) more slowly than other residues during the previous period, started to decompose more rapidly during this period (2.5–7.5 months). Multiple regression analysis showed that during this period chemical composition of crop residues had no significant influence on the decomposition rate (Table 3).

Table 3. The influence of the chemical composition of crop residues on their decomposition rate

Measured variables	N g kg^{-1}	C:N ratio	Lignin g kg^{-1} DM
Incubation period of residue decomposition (DM-loss %)			
0–2.5 months	–	Y = 106.162 + 1.692 C:N_0 − 1.095 LIGN_0 r = 0.870**, R^2 = (%) 75.74*	
	Y = 39.093 + 4.617 N_0 + 2.141 C:N_0 − 1.063 LIGN_0 r = 0.910*, R^2 = (%) 82.78*		
2.5–7.5 months	–	–	–
7.5–14.5 months	–	Y = −4.065 − 1.554 C:N_7.5 + 0.39 LIGN_7.5 r = 0.877**, R^2 = (%) 76.82*	
	Y = −18.763 + 0.627 N_7.5 − 1.259 C:N_7.5 + 0.377 LIGN_7.5 r = 0.885*, R^2 = (%) 78.36*		
14.5–19.5 months	–	–	Y = −1 + 0.01 LIGN_14.5 r = 0.695*, R^2 = (%) 48.32*
	Y = −7.497 + 0.222 N_14.5 − 0.08 C:N_14.5 + 0.027 LIGN_14.5 r = 0.958**, R^2 = (%) 91.73**		
19.5–26 months	Y = −6.874 + 0.205 N_19.5 − 0.093 C:N_19,5 + 0.026 LIGN_19.5 r = 0.962**, R^2 = (%) 92.57**		
0–26 months		Y = 114.046 + 0.695 C:N_0 − 0.494 LIGN_0 r = 0.852*, R^2 = (%) 72.66*	
	Y = 56.225 + 3.981 N_0 + 1.082 C:N_0 − 0.466 LIGN_0 r = 0.986**, R^2 = (%) 97.29**		

* $P \leq 0.05$; ** $P \leq 0.01$

During the cold period, the decomposition rate was mainly dependent on micro-organisms activity, which was influenced by temperature. Higher amounts of mineral N assimilators, ammonificators and cellulose degraders on crop residues were likely to have been responsible for more rapid decomposition during the period of 7.5 months. The activity of these groups of micro-organisms also micromycetes influenced decomposition rate by 81% (Table 4).

The C:N ratio in crop residues declined markedly during the third (7.5–14.5 months) warm period. That was influenced by the alterations in the organic carbon amounts and especially nitrogen in the crop residues during this period. During this period, the stubble of winter and spring oilseed rape and roots of red clover and spring oilseed rape decomposed most rapidly. Multiple regression analysis showed that residues with higher concentration of N and lignin and lower C:N ratio decomposed most rapidly (Table 3). A higher amount of micromycetes appeared to have the greatest influence on the rapid decomposition of crop residues during this period (Table 4).

Table 4. The influence of the amount of micro-organisms on crop residues on their decomposition rate

Measured variables	Mineral N assimilators (NA) cfu million g^{-1} DM	Ammonificators (AMM) cfu million g^{-1} DM	Micromycetes (MIC) cfu 10^3 g^{-1} DM	Cellulose degraders (CD) cfu 10^3 g^{-1} DM
Incubation period of residue decomposition (DM-loss %)				
0–7.5 months	Y = 32.394 + 0.559 NA; r = 0.791**, R^2 = (%) 62.50*	Y = 22.205 + 0.021 AMM; r = 0.635*; R^2 = (%) 40.38*	–	Y = 27.614 + 0.119 CD; r = 0.692*, R^2 = (%) 47.93*
	Y = 52.353 − 0.075 MIC + 0.531 NA + 0.014 AMM + 0.067 CD; r = 0.898*, R^2 = (%) 80.69*			
7.5–14.5 months	–	–	–	–
	Y = 13.166 + 0.088 MIC − 0.095 NA − 0.001 AMM − 0.035 CD; r = 0.937*, R^2 = (%) 80.69*			
14.5–19.5 months	Y = 1.773 + 0 MIC + 0.002 NA + 0 AMM + 0 CD r = 0.385, R^2 = (%) 14.85			
19.5–26 months	Y = 11.791 − 0.005 MIC + 0.007 NA + 0.001 AMM − 0.003 CD; r = 0.857, R^2 = (%) 73.38			

* $P \leq 0.05$; ** $P \leq 0.01$

The following period (14.5–19.5 months) of the investigation was cold (November–April) and decomposition rate of all crop residues declined significantly ($P \leq 0.05$). During 14.5 months of crop residue decomposition, lignin concentrations were increasing because of the more rapid decomposition of readily degradable components after residue incorporation into the soil. More intensive degradation of lignin in crop residues began

after 14.5 months and its concentration had decreased after 19.5 months of crop residues decomposition in the soil. After this period, the highest decrease in lignin concentration was estimated in winter and spring oilseed rape threshing remains (10% and 7%, respectively) and roots of red clover (7%). Decomposition rates during this period depended on lignin concentration (R^2 = 48%, $P \leq 0.05$) and lignin concentration combined with other chemical properties (N and C:N ratio) in the crop residues (R^2 = 92%, $P \leq 0.01$) (Table 3). No significant influence from the increased populations of micro-organisms on crop residues was detected (Figs 5–8, Table 4).

During the last period of study (19.5–26 months), the residues that were decomposing slowly at the beginning (stubble of winter and spring oilseed rape, and roots of all crops), decomposed more rapidly, apparently because the non-lignified carbon had become more accessible to micro-organisms with the degradation of lignin (Paul, Clark, 1989; Microbiological deterioration of materials, 1997). Multiple regression analysis showed the dependence of the decomposition rates on chemical composition of crop residues (R^2 = 93%, $P \leq 0.01$; Table 3).

After 26 months of crops residues incubation in the soil, a significant ($P \leq 0.05$) decrease in lignin concentration in all crop residues was estimated. After this period, the highest amount of lignin was degraded in red clover residues: in stubble 42%, in roots 34% and in spring and winter rape threshing remains 35% and 28%, respectively. Accordingly, those residues were the most readily decomposed. Losses of root mass and lignin concentration of red clover were 84% and 34%, respectively; exceeding the losses from other plant residues. By contrast, the roots of winter rape and associated lignin were decomposed the least (57% and 17%, respectively). These differences may occur because of different quality of lignin in residues (Bertrand et al., 2006).

Multiple regression analysis of the decomposition rates of crop residues over 26 months showed that the C:N ratio and lignin concentration could explain 73% of the controlled variation, and when N concentration of crop residues was included in the analysis – 97%. Giller and Cadish (1997) concluded that no single index can characterise the quality of crop residues and predict the rate of decomposition. No significant relationship was established between the N concentration of residues alone and their decomposition, confirming the study of Trinsoutrot et al. (2000). Our data showed that decomposition rates correlated with the amount of micro-organisms only during the first stages of decomposition; later on no significant correlation was found.

On all the residues investigated, the highest distribution of micro-organisms assimilating mineral nitrogen, ammonificators and micromycetes was established after 26 months of incubating crop residues in the soil. The highest number of cellulose degrading micro-organisms was measured on the plant above-ground part residues and clover roots after 26 months and on oilseed rape and wheat roots after 19.5 months of decomposition.

Conclusions

1. Decomposition rates of crop residues incorporated into the soil depended on plant species and residues type because of their different chemical composition, whose most important indicators were the C:N ratio and lignin concentration.

2. Growth of different groups of micro-organisms (mineral N assimilators, ammonificators, micromycetes, and cellulose degraders) depended on the decomposing substrate and period of crop residues incubation in the soil.

3. Decomposition rate of crop residues and growth of micro-organisms on them during 26 months incubation in soil was not consistent. Thin above-ground biomass residues, as threshing remains of oilseed rape, stubble of red clover and winter wheat, decomposed more intensively at the beginning of their incorporation into the soil, while roots and tough above-ground residues, such as stubble of oilseed rape, started to decompose more intensively later.

4. The residues which had been decomposing more intensively within the first 2.5 months of incubation were decomposed most after 26 months and the highest content of lignin degraded in these residues also. They were the most suitable substrate for growth of micro-organisms.

5. The study showed that the influence of crop residues chemical composition on organic matter decomposition rate has to be studied as a complex of several indices.

6. The highest distribution of micro-organisms on crop residues was estimated during the last decomposition periods (19.5 and 26 months), it correlated with the decomposition rate only in the beginning of incubation (until 14.5 months).

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Skirtingų augalų rūšių liekanų skaidymosi intensyvumas dirvožemyje

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Santrauka

Tyrimų tikslas – nustatyti skirtingų augalų rūšių liekanų cheminės sudėties ir mikroorganizmų kiekio įtaką jų skaidymosi intensyvumui dirvožemyje. Vykdant lauko bandymą į dirvožemį buvo įterpta žieminių bei vasarinių rapsų, žieminių kviečių ir raudonųjų dobilų antžeminės dalies ir šaknų liekanos.

Nustatyta, kad į dirvožemį įterptų liekanų skaidymosi intensyvumas priklausė nuo augalo ir liekanų rūšies, cheminės sudėties, o svarbiausiais rodiklis buvo C:N santykis bei lignino koncentracija. Tyrimų rezultatai parodė, kad žieminių bei vasarinių rapsų kūlenos, žieminių kviečių ir raudonųjų dobilų ražienojai intensyviausiai skaidėsi per pirmuosius 2,5 mėn. po jų įterpimo į dirvožemį. Augalų šaknys ir rapsų ražienojai intensyviau skaidėsi vėlesniais laikotarpiais (2,5–26 mėn.). Daugianarė regresinė analizė parodė, kad augalų liekanų skaidymosi intensyvumas priklauso nuo jų cheminės sudėties – C:N santykio N ir lignino koncentracijos.

Skaidymosi intensyvumas nuo mikroorganizmų kiekio priklausė tik pirmaisiais skaidymosi laikotarpiais (iki 14,5 mėn.), vėlesniais laikotarpiais (14,5–26 mėn.) esminių koreliacijų nebuvo. Skirtingų grupių mikroorganizmų (mineralinį azotą asimiliuojančių, amonifikuojančių, celiuliozę skaidančių mikroorganizmų bei mikromicetų) paplitimas ant augalų liekanų priklausė nuo skaidomo substrato ir augalų liekanų inkubacijos dirvožemyje laikotarpio. Žieminių bei vasarinių rapsų kūlenos, raudonųjų dobilų ražienojai ir šaknys buvo tinkamesnis substratas tirtų grupių mikroorganizmams nei žieminių bei vasarinių rapsų ir žieminių kviečių ražienojai bei šaknys.

Reikšminiai žodžiai: augalų liekanos, skaidymasis, cheminė sudėtis, mikroorganizmai.