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Impact of crop residues and biopreparations on nitrogen changes in Haplic Luvisol – model experiment

Abstract: Agroecosystem crop residues are considered to be a primary resource of organic substances, and are subject to the different transformation processes in the soil environment. The decomposition processes of organic substance can be also regulated by the application of the different biopreparations. The decomposition of organic substances in soil also causes changes in nitrogen content and its forms. It is essential for farmers to know about these processes in order flexibly to regulate and affect the transformation processes of the applied crop residues via the biopreparations directly in the production conditions. The changes of content and forms of nitrogen and its calculated parameters in Haplic Luvisol influenced by the applied crop residues (wheat – WR, rape – RR) and biopreparations (Betaliq, Trichomil) were monitored in the small-pot experiment carried out at the Department of Soil Science (FAFR, SUA-Nitra). The laboratory experiments were established for the incubation period 4, 7, 14, 28, 60, 90 and 180 days. The applied crop residues had statistically significant impact on the contents of total nitrogen (N_t) and potentially mineralizable nitrogen (N_{pot}) and inorganic forms N, similarly also the values of labile nitrogen (L_N) and nitrogen pool index (NPI). The biopreparations affected statistically significantly the average values N_{pot}, L_N, nitrogen lability index (NLI) and nitrogen management index (NMI). During the incubation period, the contents N_{pot} and values L_N and other calculated indexes of nitrogen fluctuated significantly.

Keywords: Betaliq, Trichomil, Luvisol, Crop residues of wheat and rape oil

INTRODUCTION

In Slovakia the Luvisols represent some of the most utilised soils in the agricultural production. Their area is 265.4 thousand ha, which is 10.8% of the agricultural soil found in the Slovak Republic (SR). If the correct principles of cultivation and fertilization are followed, these soils become a good production type, suitable for growing common agricultural crops. In comparison with Chernozems and Mollic Fluvisols (the most productive soils in SR), they are more shallow, have a lower content of humus of worse quality, acid even slightly acid soil reaction and a higher content of clay under the A-horizon (Bielek 2017). This soil type requires increased care in order to improve or preserve its positive qualities. One of the most substantial factors, which can eliminate the negative impact of anthropogenic soil degradation, is sufficiency of the quality organic substances. In the course of the last two decades, Slovakia has been confronted with the serious problems, predominantly as a result of the radical decrease of animal production leading to the insufficient production of the high quality organic fertilizers, thus there is an imbalance of organic substance in agricultural soils (Green Report 2014). According to the latest information (Kobza et al. 2017) published in "Partial monitoring system – Soil" after the previous decrease the content of the soil organic substance and humus – mainly on the arable soil – has recently stabilized and even increased slightly (mainly in Fluvisols, Mollic Fluvisols, Chernozems, Podzols, and Leptosols) compared with the beginning of the soil monitoring in Slovakia as a result of the dramatic drop in the production of organic fertilizers. In the following monitoring period, the next possible growth of the organic substance could be associated with the subsidy policy of the SR Government in order to increase the organic substance in soil. Taking into consideration the quantity, the biggest primary source of the organic substance are after-harvest and root residues of the grown crops in the agroecosystems (Váchalová et al. 2016). The level of impact of crop residues on the formation of soil fertility depends not only on their

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quantity but also chemical composition. The application of crop residues into soil leads to the increase of carbon (Šimanský et al. 2008) and nitrogen content (Galantini and Rosell 2006), however, the other soil characteristics can also change. The regular supply of the organic substances into soil results in the increased quality of soils (Šimanský et al. 2008). In the future, the regulation processes of transformation of organic intakes into soils will intensively use different adjuvants, substrates, additives, mineral fertilizers or biopreparations, which enhance the positive humification processes in soils (Zaujec and Šimanský 2006). The biopreparations are organo-mineral substances that stimulate the different physiological processes and improve the ecological soil environment via some natural components or microorganisms, and also supply plants with macro- and micronutrients (Basak 2008). Biopreparations through improved microbial activity support the decay of crop residues (Šimanský et al. 2006a, 2006b; Šimanský and Szombathová 2011), at the same time they have also the positive impact on the yield of the cultivated crops (Černý et al. 2018), via the improvement of nutrient intake from soil (Pačuta et al. 2017).

The soil environment is different in terms of its chemical, physical or biological parameters. It is apparent that the effect of crop residues and biopreparations will be different in the different soil types. Based on this, we assumed that (i.) as crop residues and biopreparations have the different composition, their effect would be different, (ii.) the biopreparations would stimulate the decay of crop residues, which would be reflected in the changes of individual forms of nitrogen in soil, and (iii.) the calculated nitrogen indexes (according to the calculated carbon indexes – Blair et al. 1995) would react more sensitively to the applied crop residues or the tested biopreparations in Luvisol than the determinated total nitrogen via their stronger differences between the individual monitored periods.

The objective of this study was to acquire information about the mutual relationship: crop residues – biopreparations – soil, where we emphasized predominantly the impact of crop residues and biopreparations on the changes of nitrogen and its forms as one of the most significant indicators of soil quality. The innovation of this study is the appraisal of changes of calculated nitrogen indexes after the application of crop residues or biopreparations.

MATERIALS AND METHODS

The soil for establishing the incubation experiment was taken from plough layer of Haplic Luvisol (HL) from the locality Golianovo (Slovakia). Before this experiment, the soil had slightly acid active soil reaction (6.47 pH), low content of organic carbon (1.08%), very strong hydrolytic acidity (23 mmol kg^{-1}), lower average cation exchange capacity (189.4 mmol kg^{-1}) and saturated sorption complex (87.8%). The soil was supplied by the after-harvest wheat residues (WR) in ratio straw : roots = 2:1; the element composition: C = 450 g kg^{-1}; N = 9 g kg^{-1}; C:N = 50 and rape (RR) in ratio straw:roots = 1:1; the element composition: C = 440 g kg^{-1}; N = 11 g kg^{-1}; C:N = 40. In the experiment, the following biopreparations were tested Betaliq (Redam, Ltd., Smržice, CzR) and Trichomil (product of Bioma, Ltd. Trnava, SR). More information about biopreparations (composition, properties) was published by Zaujec and Šimanský (2006).

The following treatments of the experiment were established:

HL – control (Haplic Luvisol)
HL +WR – Luvisol + wheat residues
HL +WR+B – Luvisol + wheat residues + Betaliq
HL +WR+T – Luvisol + wheat residues + Trichomil
HL +RR – Luvisol + rape residues
HL +RR+B – Luvisol + rape residues + Betaliq
HL +RR+T Luvisol + rape residues + Trichomil

The laboratory experiments were carried out in the pots of the volume 0.22 dm^3. 200 g of soil and 4 g of crop residues were weighed and put into the prepared pots with the sieve and filter paper at the bottom (three replications) with the duration of 4, 7, 14, 28, 60, 90 and 180 days. In order to adapt the ratio C:N in the treatments with crop residues, N was applied, equal the usage in practice, i. e. 1 kg N per 100 kg of crop residues, in the form of $(NH_4)_2SO_4$ and 1% of their solution was used in the treatments with biopreparations (10 ml for Betaliq and 12 ml for Trichomil). The experiment was located in the incubation room, where optimal conditions were maintained (temperature 23–25°C, humidity 50–60% FWC) for the decay of organic substances. After the completion of incubation the individual soil samples of the established treatments were analyzed. The individual contents and forms of nitrogen were detected: content of total nitrogen – by Kjeldahl method (Peterburskij 1963), content of potentially mineralizable nitrogen (N_{pot}) (Standford and Smith 1978), content of ammonium nitrogen (NH_4^+) – colorimetrically with Nessler´s reagent in extract 1% K_2SO_4 and content of nitrate nitrogen (NO_3^-) – colorimetrically with phenol disulphonic acid in extract 1% K_2SO_4 ($NH_4^+ + NO_3^- = N_{an}$). The following indexes for nitrogen were also calculated (equations 1–5):

Calculation of nitrogen lability (L_N)

$N_{NL} = N_t - N_{pot}$ (1)

$L_N = N_{pot}/N_{NL}$ (2)

where:

N_{pot} – potentially mineralizable nitrogen, N_{NL} – non-labile nitrogen, N_t – total nitrogen content.

Calculation of nitrogen lability index (NLI)

$NLI = L_{N\ CR}/ L_{N\ Co} \times 100$ (3)

where:

$L_{N\ CR}$ – nitrogen lability treatment with crop residues, $L_{N\ Co}$ – lability of control treatment without crop residues.

Calculation of nitrogen pool index (NPI)

$NPI = N_{t\ CR}/N_{t\ Co}$ (4)

where:

$N_{t\ CR}$ – N_t treatment with crop residues, $N_{t\ Co}$ – N_t control treatment without crop residues.

Calculation of nitrogen management index (NMI)

$NMI = NPI \times NLI$ (5)

The individual forms of nitrogen were evaluated in the program Statgraphics Centurion XV. I (Statpoint Technologies, Inc., USA) by multidimensional scatter analysis (ANOVA). The differences between the variants were further evaluated by LSD test with the minimal significance level $P < 0.05$. The dynamics of changes of the particular nitrogen forms were assessed via the simple linear analysis.

RESULTS AND DISCUSSION

After the completion of the incubation experiment, we detected that the applied crop residues significantly increased the values of total nitrogen (N_t) in soil. On the whole, the average values N_t were increased by 49% and 59% in variants RR and WR, or compared with the control (Table 1). The crop residues are considered to be the essential source of the organic substance (Naresh et al. 2017), therefore their application into soil is associated with the increased content C and also N in soils (Christensen et al. 1994). The changes after application of the crop residues into soil correspond with the chemical composition (Zaujec and Šimanský 2006) of the crop residues themselves. The tested biopreparations did not change the average values N_t significantly. On average, in all treatments the average values N_t were decreased statistically significantly by 143 mg kg^{-1} along with the period of incubation, which shows the occurring transformation processes in soil (Zaujec and Šimanský 2006). Of course, the dynamics of changes of values N_t during the whole incubation period was different (Figure 1A) and depended on the applied crop residues and the tested biopreparations. The values N_t in the control were not changed significantly, which proves the fact that N_t in soil is a relatively stable parameter, as its highest proportion is the organic N and only a low proportion of it is liable to a transformation (Ondrišík 2013, Kováčik 2014). All treatments either with the applied crop residues or biopreparations registered the drop N_t in the course of the incubation period. However, a significant (linear) decrease was recorded only in the cases of the applied wheat residues and the tested biopreparation Betaliq. In the treatments, where wheat residues were applied, the values N_t significantly decreased linearly at the rate 51.8 mg N per 1 kg of soil in 180 days during the monitored incubation period, which meant the drop by 10% N_t in soil. On average, the treatments with the tested Betaliq (B) proved the statistically evidential linear trend of decrease of content N_t, during the monitored incubation period because in this treatment the rate of drop N_t in soil was 47.8 mg N per 1 kg of soil in 180 days, which also mean the decrease by 10% N_t in soil (Table 3). The content of potentially mineralizable nitrogen (N_{pot}) can be dependent significantly on the quantity of the total N in soil (Doran 1987, Maková 2015), which was not approved completely by our results, as the negative, however, statistically insignificant correlation between N_t and N_{pot} was detected ($r = -0.142$, $P>0.05$). The content N_{pot} in soil can be influenced by the soil management with the equal reserves of the total N (Doran 1987), which is associated with the content of hydrolyzable N, which represents 52–84% out of N_t (Kováčik 2014, Bielek 2017). As the crop residues of the different chemical composition were applied into soil and two different biopreparations were tested, our assumptions were approved. On the whole, after the completion of the incubation experiment the average values N_{pot} changed significantly as a result of the application of the crop residues and also the application of Trichomil (Table 1). The average values N_{pot} were lower by 32 and 36 mg·kg^{-1} in the treatments WR and RR or compared with the control (HL). This fact shows that, on the one hand, the applied crop residues were subject to the transformation processes, on the other hand, their mineralization was eliminated significantly in comparison with the HL treatment. This information corresponds with the founding of Cayuela et al. (2009), who claimed that the applied crop residues in soil cause the immediate immobilization N, which eliminates the microbial growth, enzymatic synthesis

TABLE 1. Effect of crop residues and biopreparates on total N and its forms content in soil

Factor			N_t (mg kg^{-1})	N_{pot}	N_{an}	NH_4^+	NO_3^-
Crop residues	*P-Value*		0.0000	0.0148	0.0000	0.0000	0.0000
		0	1432	108	37	26	11
		Wheat	2269	76	734	633	93
		Rape	2132	72	502	378	121
	±limits		117	24	93	99	42
Biopreparates	*P-Value*		0.3001	0.0769	0.5373	0.3443	0.5692
		0	1956	75	440	367	73
		Betaliq	1972	83	406	315	86
		Trichomil	1904	97	405	323	70
	±limits		91	19	72	77	33

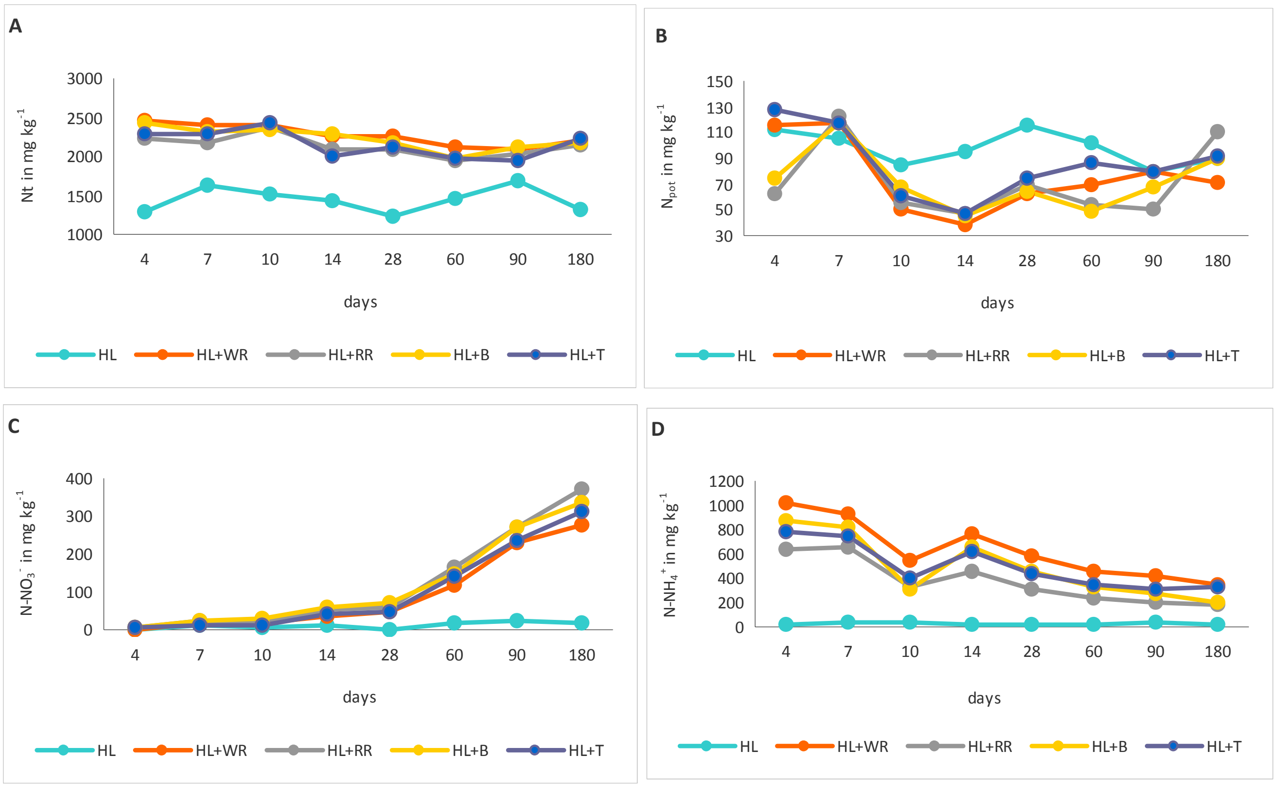

FIGURE 1. Changes of A – total nitrogen, B – potentially mineralizable nitrogen, C – nitrate nitrogen, and D – ammonium nitrogen in soil during 180 days of incubation
Treatments are mentioned in „Materials and Methods" section.

and the following mineralization. The next reason can be the application N in the form of ammonium sulphate, which corrects the ratio C:N for the acceleration and starting the decomposition processes of the after-harvest residues. The ratio C:N of the crop residues has a significant impact on the rate of the decomposition processes and mineralization (Gough et al. 2009). However, the microorganisms preferred markedly the supplied N in the form of ammonium sulphate. It is necessary to emphasize that these values (N_{pot}) represented 8%, 3.3% and 3.4% of N_t in HL, WR and RR treatments. Out of the biopreparations only the tested Trichomil (Table 1) increased the average values N_{pot} after the completion of incubation. During the monitored incubation period, when evaluating the dynamics of changes of values N_{pot}, we did not detected either a significant falling or rising trend (Table 3, Figure 1B), which refers to a considerable sensitivity of this parameter as a result of the different soil management. In spite of the fact that the inorganic nitrogen (N_{an}) represents only a small proportion in soil out of the total nitrogen about 1–2% (Vaněk et al. 2013), it has a substantial impact from the aspect of plants nutrition. However, the fundamental fact is that even this low quantity is liable to the considerable seasonal changes (Ondrišík et al. 2009, Ondrišík 2013), which are influenced apart from the climatic facts (Malhi et al. 2006) also by the soil management including soil fertilization (Vaněk et al. 2013). On the whole, the average values N_{an} were increased significantly as a result of the application of the crop residues, at the same time it was reflected in the total increase N_{an} after the application of residues WR like RR. The biopreparations decreased overall the values N_{an}, but the differences between the variants were not significant (Table 1). During the whole incubation period the dynamics of changes registered the gradual drop in the values N_{an}, however, a significant linear decrease of values N_{an} was recorded only in the WR treatment. The average decline of the values N_{an} in this variant was 55 mg·kg^{-1} in 180 days, which means the drop 39% in comparison with the initial phase (the difference between the 4th day and 180th day of incubation). The total average content N-NH_4^+ increased significantly 25 and 15-times as much as a result of the application of after-harvest residues WR and RR, or compared with the control (HL). After the application of crop residues the average contents N-NO_3^- increased, in particular for the residues WR 8-times and for the residues RR 11-times in comparison with the control (Table 1). As we adjusted C:N by ammonium sulphate in all variants, we assumed that it would be reflected in the dynamics of changes of these inorganic forms N, by intensification of nitrification processes. N-NH_4^+ decreased more intensively in case of the crop residues WR than RR, on the other hand, N-NO_3^- increased more intensively in case of RR than WR (Table 3). This process can be inhibited by using inhibitors of nitrification (Zaman and Blennerhasset 2010, Slamka and Ložek 2017). As the biopreparations are the soil additives that regulate the transformation processes of the soil organic substance (Zaujec and Šimanský 2006), we anticipated that their effect would be associated also with the changes of N in soil. Despite the fact that the biopreparations did not have significant impact on the average values of these inorganic forms of N (Table 1), their dynamics was apparent (Figure 1C, D). N-NH_4^+ was decreased more intensively in case of the tested Betaliq than Trichomil. From the aspect of the evaluated biopreparations to the changes N-NO_3^-, similarly more intensive changes were detected with Betaliq than Trichomil, however, the tendency was adverse, i.e. the statistically linear increase of values N-NO_3^- during the incubation period (Table 3).

According to Blair et al. (1995) we calculated the following indexes: nitrogen lability (L_N), nitrogen lability index (NLI), nitrogen pool index (NPI) and nitrogen management index (NMI), which could be considered as their equivalents with carbon (Blair et al. 1995, Conteh et al. 1999, Szombathová 1999, Vieira et al. 2007, Šimanský and Polláková 2016) to

TABLE 2. Effect of crop residues and biopreparates on calculated nitrogen indexes

Factor			L_N	NLI	NPI	NMI
Crop residues	*P-Value*		0.0000	0.9312	0.6778	0.0001
		0	0.079	–	–	–
		Wheat	0.034	48	75	1.59
		Rape	0.035	49	71	1.48
	±limits		0.013	11	16	0.05
Biopreparates	*P-Value*		0.0998	0.0661	0.0865	0.1106
		0	0.045	42	63	1.55
		Betaliq	0.048	47	72	1.56
		Trichomil	0.056	57	85	1.50
	±limits		0.010	5	20	0.06

TABLE 3. Relationship between content of total N and its forms in soil and time of soil incubation (y = N and its forms; x = time of incubation)

Treatment	N_t		N_{pot}	
	Linear equation	R^2	Linear equation	R^2
HL	y = 0.82x + 1440	0.0001	y = -2.55x + 110	0.2375
HL+WR	y = -51.8x + 2502	0.7889	y = -4.85x + 97.1	0.1768
HL+RR	y = -29.8x + 2266	0.3120	y = -0.18x + 72.4	0.0002
HL+B	y = -47.8x + 2444	0.8085	y = -2.17x + 81.8	0.0532
HL+T	y = -40.8x + 2344	0.3257	y = -3.96x + 103	0.1343
	NH_4^+		NO_3^-	
HL	y = -0.81x + 29.3	0.0438	y = 2.33x + 0.81	0.5860
HL+WR	y = -91.9x + 1047	0.8334	y = 39.1x – 82.7	0.8345
HL+RR	y = -68.9x + 688	0.8431	y = 50.6x – 107	0.8339
HL+B	y = -90.5x + 893	0.7305	y = 46.9x – 94.0	0.8536
HL+T	y = -67.8x + 799	0.7718	y = 43.4x – 94.4	0.8314

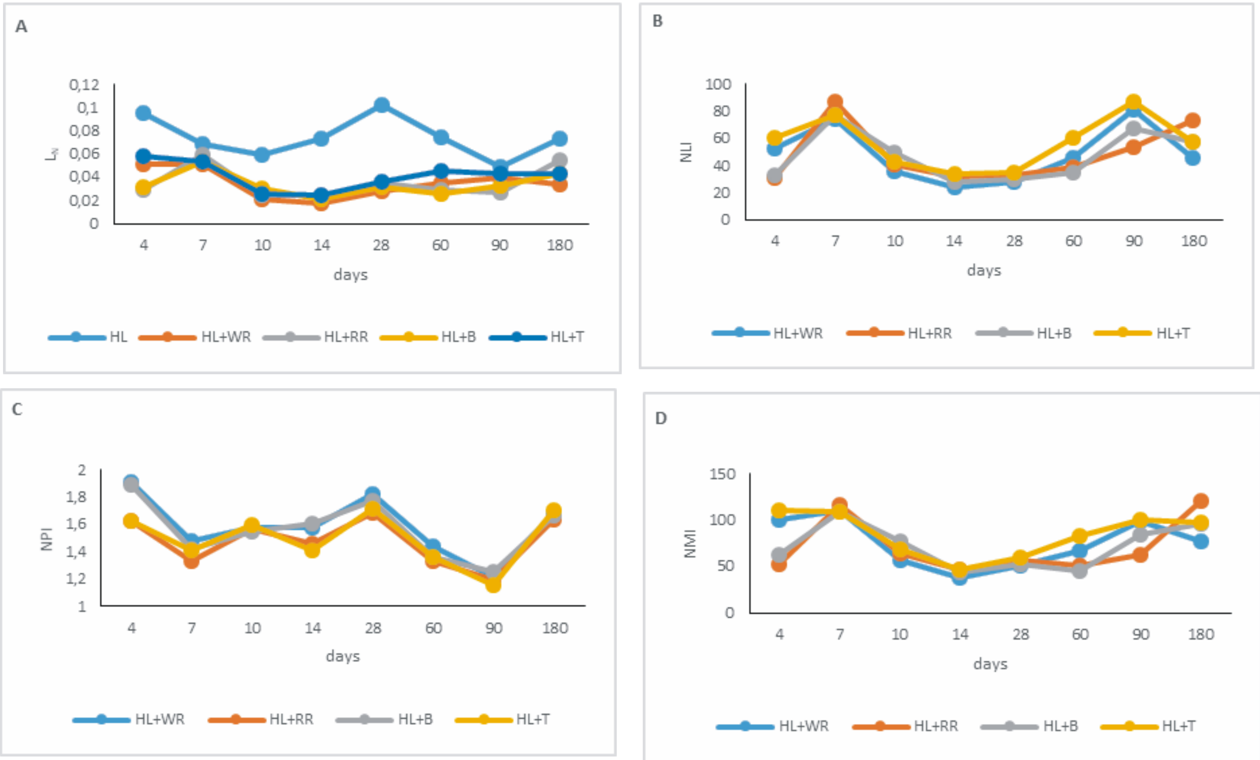

FIGURE 2. Changes of A – nitrogen lability, B – nitrogen lability index, C – nitrogen pool index, and D – nitrogen management index during 180 days of incubation
Treatments are mentioned in „Materials and methods" section.

be more sensitive indicators of the soil organic substance. The average higher values L_N were significantly influenced by the applied crop residues and also by biopreparations (Table 2). On the whole, the average values L_N in the treatments with crop residues were lower than in the control (HL), on the other hand, they were higher in the treatments with biopreparations. The stated average values proved a higher resistance of the applied crop residues to the decomposition by microorganisms, i.e. that the organic substance in the treatments of the crop residues were not subject to significant change. The change of the crop residues in soil was qualified by the addition of biopreparations. The apparent change of the crop residues and consequently also the degradation of organic substance by microbial activity was detected predominantly with Trichomil (statistically significantly increase of values L_N). During the monitored incubation 180-day period, the dynamics of changes of values L_N fluctuated considerably, therefore it was not possible to identify any positive or negative trend (Table 4). The values L_N positively correlated significantly with the values NLI (r = 0.887, $P<0.001$). The difference of the average values NLI between the variants with the crop residues was not significant, however, on the whole a significant difference was detected as a result of the application of biopreparations (Table 2). The values NLI were increased by 12% and 36% in the treatment B and T, or in comparison with the control (but it was statistically significant only with Trichomil). The stated information proves again the stimulative effect of biopreparations on the intensification of the transformation processes by the microbial activity (Šimanský et al. 2006a, 2006b). During the incubation the dynamics of changes in the values NLI fluctuated considerably, similarly to L_N, therefore it was not possible to identify any significant linear trend of their decrease or increase (Table 4). In the course of the monitored period, we identified two significant peaks of values NLI in all variants (apart from RR) after 7 and 90 days of incubation (Figure 2B). The application of the organic substance either in the form of organic fertilizers or crop residues results in the gradual increase of lability of organic substance (Shen et al. 2001, Šimanský and Tobiašová 2010) until the depletion of easily available (more labile) organic substances, which are liable to the rapid changes. Based on the average values NPI, it is clear that more intensive degradation of soil organic substance was detected in the treatments RR than WR. This fact refers to the composition of the crop residues because the after-harvest residues RR contain more easily degradable organic substances than the residues of wheat

(Zaujec and Šimanský 2006). The tested biopreparations had a significant impacton the average values NPI as well (Table 2). More intensive microbial degradation was detected in the treatments with Trichomil, which corresponds with the other monitored parameters as L_N, NLI. The dynamics of changes fluctuated quite considerably and without any significant linear trend of decrease or increase during the monitored incubation period (Figure 2C). The effect of applied crop residues and added biopreparations was evaluated also by the calculated values NMI. Lower values NMI indicate more intensive changes of content of organic substance as a result of the soil management and a higher quantity of nitrogen released from soil. The after-harvest residues did not have any significant effect on the average values NMI. The biopreparation Trichomil had more than Betaliq on higher quantity N released into soil than control (Table 2). Similarly to other calculated parameters (L_N, NLI and NPI), the dynamics of NMI of these values also fluctuated considerably and without the statistically significant linear trend of increase or decrease (Table 4).

TABLE 4. Relationship between values of N indexes and time of soil incubation (y = N indexes; x = time of incubation)

Treatment	L_N		NLI	
	Linear equation	R^2	Linear equation	R^2
HL	y = -0.002x + 0.08	0.0789	–	–
HL+WR	y = -0.0014x + 0.04	0.0788	y = 0.12x + 47.4	0.0006
HL+RR	y = 0.0005x + 0.03	0.0079	y = 1.535x + 41.9	0.0318
HL+B	y = -0.0004x + 0.04	0.0072	y = 0.916x + 43.1	0.0141
HL+T	y = -0.0011x + 0.05	0.0510	y = 0.911x + 52.7	0.0135
	NPI		NMI	
HL	–	–	–	–
HL+WR	y = -0.036x + 1.75	0.1611	y = -2.05x + 83.9	0.0363
HL+RR	y = -0.013x + 1.54	0.0304	y = 2.10x + 61.9	0.0305
HL+B	y = -0.033x + 1.72	0.1444	y = 0.31x + 70.3	0.0010
HL+T	y = -0.013x + 1.56	0.0266	y = -1.01x + 89.4	0.0109

CONCLUSIONS

On the whole, after the completion of the incubation experiment, the crop wheat residues in Luvisol increased significantly in terms of total nitrogen, inorganic nitrogen, ammonium nitrogen and the values of nitrogen management index, on the other hand, they decreased considerably as regards nitrogen lability. The rape residues increased significantly in terms of potentially mineralizable nitrogen after the completion of the experiment, and their application into Luvisol had the statistically significant impact on the increase of nitrate nitrogen. The acquired results approved the significant effect of the tested biopreparations on the individual forms of nitrogen in Luvisol. The biopreparation Trichomil increased significantly the average values of the potentially mineralizable nitrogen and nitrogen lability and management indices. However, after the completion of the experiment it decreased significantly as regards the nitrogen pool index.

From the aspect of the dynamics of contents, considerable differences were detected in changes of individual forms of nitrogen depending on the applied crop residues and the applied biopreparations. The contents of the potentially mineralizable nitrogen and values of nitrogen lability indexes, but also other calculated nitrogen indexes, registered considerable fluctuation during the incubation period, and it was not possible to identify any positive or negative trend. The stated facts show and approve our assumption that these parameters are characterized by higher sensitivity to changes in soil management.

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