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INFLUENCE OF LONG-TERM SPRINKLING IRRIGATION AND NITROGEN FERTILISATION ON SOIL NITROGEN CONTENT OF A CEREAL CROP ROTATION

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Abstract: The paper presents results of investigations on the proportion contents of different nitrogen forms in the soil in conditions of a long-term cereal crop rotation. The experimental factors included sprinkling irrigation and nitrogen applied at various doses. It was found, among others, that the sprinkling irrigation failed to influence the content of the examined nitrogen forms in contrast to the nitrogen impact whose effect was statistically significant. A synergistic influence of both factors became apparent only in the case of the content of easily-hydrolysable nitrogen (N-EH).

Keywords: soil, cereal crop rotation, nitrogen forms, fertilisation

Nitrogen occurs in soils in various forms of which organic bonds prevail [1, 2] which, at the humic levels of soils, make up from 93 to 99 % of total nitrogen [3]. It is evident from investigations [4] that at least half of the content of nitrogen in soils is described as ‘unknown nitrogen’ which undergoes hydrolysis only to a very limited extent. It is very likely that this nitrogen is strongly bound with humins. However, nitrogen occurs also in the structures of humic and fulvic acids whose quantity and durability of bonds depend, among others, on the size of molecules [5]. The structure of these bonds is important from the point of view of the availability of the component to plants whose transformations in soils run along a complex circulation and in two cycles: internal and external. They take place simultaneously with organic matter changes due to their common microbiological character [6]. For this reason, properties of the organic matter introduced into the soil – primarily, the C:N ratio – exert a strong influence on

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the rate and directions of nitrogen compound transformations. In addition, this is also associated with the quantity of after harvest residues of plants characterised by varying amounts of carbon and nitrogen contents [7]. On the other hand, root bulk is determined, by fertilisation, mainly with nitrogen, and soil moisture content [8]. Activities of these factors, as well as properties of the soil itself, ultimately influence not only the dynamics of changes of nitrogen mineral forms [9, 10] but also other soil properties [11].

It is quite probable, that in under long-term conditions, a unique equilibrium develops between individual nitrogen forms which is a resultant of interactions between the above-mentioned factors.

This paper presents the results of long-term field experiments involving the impact of sprinkling irrigation and nitrogen fertilisation on soil nitrogen forms in conditions of a cereal crop rotation system.

Material and methods

The analyses were carried out on soil samples derived from a long-term field experiment situated in Zlotniki Experimental Station near Poznan (52^{o}29' latitude and 16^{o}50' longitude) which belongs to the Department of Soil and Plant Husbandry of Poznan University of Life Sciences. The field trial was established accordingly to a random schedule on a lessive soil classified as Albic Luvisols [12] developed from loamy sands underlained mostly at 40–60 cm depth. The soil on the humus horizon (0–25 cm) was characterised by 13–14 % content of fraction with < 0.02 mm diameter, including 3 to 4 % clay (< 0.002 mm) and pH(KCl) in the range 5.7 to 6.5. Soil samples were collected from the humus horizon following 26-year long-term cereal rotation experiment in which the following crop plants were grown: winter wheat, spring triticale, spring barley, and oat.

The first degree factor was sprinkling irrigation (sprinkle-irrigated objects – S and objects without sprinkling – NS) and the second degree factor – nitrogen fertilisation in different doses. The mean annual doses per crop rotation comprised [kg $\cdot$ ha^{-1}]: N_0 – 0.0; N_1 – 50.0; N_2 – 100.0; N_3 – 150.0. Mean doses of phosphorus (P) amounted to 35.0 kg $\cdot$ ha^{-1} and potassium (K) – 83.0 kg $\cdot$ ha^{-1}.

The employed cereal crop rotation system began with wheat which was fertilised in the case of each rotation series with farmyard manures in the amount of 30 Mg $\cdot$ ha^{-1}. All treatments were performed in four replications.

After drying and trituration, the soil material was screened through a sieve with 2 mm sieve mesh and results were expressed on a dry weight basis.

The following nitrogen fractions were isolated with the assistance of sequential analysis:

– Water soluble and exchangeable nitrogen (inorganic N-inorg.) following soil shaking in 1 M NaCl solution for 2 hours; soil:solution – 1:5. The entire material was centrifuged and filtered into 100 cm^3 volume measuring flasks. Mineral N in samples was determined by the distillation method of Bremner [13] with MgO added for ammonium distillation followed by the addition of Devard alloy nitrate.

– *Easily-hydrolysable nitrogen* (NEH) using 0.25 M solution of H_2SO_4. The soil was hydrolysed at 1:5 ratio for 3 hours in a water bath at the temperature of 60 ^oC, centrifuged and the solution was filtered into 250 cm^3 volume measuring flasks. The residue was washed twice with hot distilled water and the filtrate after centrifugation was transferred into measuring flasks with acid extract.

– *Poorly-hydrolysable nitrogen* (N-PH) using 2.50 M solution of H_2SO_4. The soil was hydrolysed at 1:5 ratio for 3 hours in a water bath at the temperature of 60 ^oC, centrifuged and the solution was filtered into 250 cm^3 volume measuring flasks. The residue was washed twice with hot distilled water and the filtrate after centrifugation was transferred into measuring flasks with acid extract.

– *Non-hydrolysable nitrogen* (NNH) – it was calculated from the difference between the *total nitrogen* of soil (TN) content and the sum of isolated three fractions.

Total soil nitrogen (TSN) as well as the *nitrogen of fractions* (TNF) were determined by the Kjeldahl method using for this purpose 2300 Kjeltac Analyzer Unit apparatus.

Results were expressed in $mg \cdot kg^{-1}$ dry weight and subjected to the analysis of variance (STAT) using Duncan test for parametric evaluation at the significance level of $p \leq 0.05$.

Results and discussion

Transformations of soil nitrogen compounds run simultaneously with organic matter transformations. The dynamics of these transformations taking place within the framework of mineralisation and humification processes preconditions, among others, nitrogen availability to plants. Nevertheless, the rate of the occurring processes varies and depends on many factors. In the performed fertilisation trials [14], it was demonstrated that nitrogen and the type of the soil complex were among factors differentiating the content of mineral forms of nitrogen in the soil. According to Dechnik and Wiater [15], factors which influenced the dynamics of nitrate nitrogen(V) changes in the soil comprised: atmospheric conditions and, to a lesser extent, the type of the applied fertilisation. However, nitrogen introduced into the soil, irrespective of the form and source, always undergoes transformation into different forms, not only mineral ones [16].

The results collated in Table 1 concerning the distribution of nitrogen in soil samples comprising the entire long-term period during which both experimental factors were present revealed that the water factor (irrespective of the nitrogen fertilisation) did not exert a significant influence on the amount of the examined nitrogen forms in the soil. On the other hand, mineral nitrogen applied at various doses, irrespective of the applied sprinkling irrigation (Table 1) – with the exception of non-hydrolysable nitrogen forms (NNH) and total nitrogen – exhibited a significant impact as confirmed by mean nitrogen contents found in one uniform group (a).

Table 1

Independent impact of sprinkler irrigation and nitrogen fertilisation on the content of nitrogen forms in soil

Factor	Nitrogen of forms [$mg \cdot kg^{-1}$]				
	N_{min}[1]	NEH[2]	NDH[3]	NNH[4]	Total
S	37.10a	102.83a	247.20a	304.45a	691.67a
NS	35.06a	101.44a	244.99a	321.01a	702.50a
Test E, $p < 0.05$	0.19	0.13	0.03	0.12	0.08
Nitrogen doses					
N_0	26.60a	101.23a	284.38c	247.79a	660.00a
N_1	31.85ab	95.68a	258.67bc	328.80	715.00a
N_2	40.95ab	98.62a	200.67a	358.09a	698.33a
N_3	44.92b	113.02b	240.85b	316.21a	715.00a
Test E, $p < 0.05$	3.18*	4.02*	8.05*	1.04*	0.46

[1] – N_{min} (Inorganic) N; 2 – Easily hydrolysable N; 3 – Difficulty hydrolysable N; 4 – Non-hydrolysable N; * significant at $p < 0.05$.

The impact of the cooperation of the water factor with nitrogen also turned out to be small and, practically speaking, became apparent only with regard to the influence of easily-hydrolysable nitrogen content (Table 2). It is clear from the statistical evaluation utilising the uniform group parameter that the highest significant effect of experimental factors was observed in the case of easily-hydrolysable forms of nitrogen. However, no unequivocal direction of NEH quantitative changes were observed depending on the activity of these factors. Nevertheless, in the treatment with sprinkling irrigation, mean quantities of these nitrogen forms increased with N doses. This increase between the control treatment without nitrogen (N_0) and the N_3 dose amounted to 25.2 %. On the other hand, in the treatment without sprinkling, NEH quantities between the discussed nitrogen doses remained on a similar level. What was puzzling was the recorded absence of statistically significant differences between the experimental treatments with non-hydrolysable nitrogen (NNH) forms, despite quantitative differences found between treatments (Table 2).

However, it should be emphasised that higher nitrogen doses in conditions of increased moisture favoured the accumulation of the N-NH form in the soil. At average nitrogen doses of the order of 100 and 150 $kg \cdot ha^{-1}$ during the period of 26 years of the experiment, the content of the non-hydrolysable nitrogen on these objects amounted to 377.0 and 346.1 $mg \cdot kg^{-1}$, respectively, while on objects without sprinkling irrigation – 339.3 and 283.7 $mg \cdot kg^{-1}$.

The content configuration of individual nitrogen forms determined in this study indicates a relatively high stability of mineralisation and humification processes in the soil, especially, in view of the fact that according to some researchers [17, 18] all combinations of this element – including the non-hydrolysable ones – take part in processes of soil nitrogen transformations. Most nitrogen from this group has not been identified so far and the recognised forms indicate their heterocyclic structure [18].

Table 2

Impact of the cooperation of experimental factors on the content of nitrogen forms in soil humus horizon [mg · kg^{-1}]

Nitrogen forms	Water factor							
	S				NS			
	Nitrogen fertilization							
	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
N_{min}	26.8	30.7	49.0	32.0	16.2	32.4	32.8	50.5
Test F, p < 0.05–1.08								
NEH	89.9ab	107.3cd	101.5bcd	112.6cd	112.6cd	84.0a	95.7abc	113.4d
Test F, p < 0.05–6.30								
NDH	274.2b	279.9b	192.5a	242.6ab	294.6b	237.4ab	208.8a	239.1ab
Test F, p < 0.05–1.35								
NNH	225.8a	268.8a	377.0a	346.1a	269.9a	389.1a	339.3a	283.7a
Test F, p < 0.05–0.82								
NT	616.7a	686.7a	720.0a	743.3a	703.3a	743.3a	676.7a	743.3a
Test F, p < 0.05–2.74								
N-Sol*	390.9abc	417.9bc	343.0a	397.4abc	433.5c	354.2ab	337.3a	403.0abc
Test F, p < 0.05–1.08								
N-Sol in total [%]	63.4	60.9	47.6	52.1	60.2	47.6	49.8	59.7

* Sum of soluble nitrogen (N-Sol).

From the point of view of nitrogen availability for plants, easily soluble nitrogen fractions, whose dynamics affect the release of mineral bonds of this element, are the most important. The cooperation of the water and nitrogen factors in the NEH content testifies to the sensitivity of these bonds to soil transformations. It is quite probable that they affect mainly amides, a certain quantity of amines as well as part of the non-exchangeable nitrogen. Although their proportion in total nitrogen ranged only from 11.4 to 16.7 %, this form was characterised by a relatively high stability, irrespective of experimental factors (Fig. 1). Especially, that in the case of poorly--hydrolysable forms, the author observed a decrease in their proportions in total N in conditions of sprinkling and higher nitrogen doses. Without N fertilisation, this proportion amounted to 44.5 % in conditions of sprinkling irrigation, 41.9 % without sprinkling, while at the highest N dose – 32.6 and 35.3 % respectively. It is, however, more important that the highest drop in the proportion of this nitrogen form occurred at the average nitrogen dose of 100 kg · ha^{-1}. This proportion amounted to only 26.7 % in the case of the sprinkling irrigation treatment and to 30.9 % – for the non-irrigated one. However, this high decline in the discussed proportion was not only the result of losses of this constituent but also of its transformations to non-hydrolysable forms which in the case of these treatments amounted to 52.4 % and 50.2 % (Fig. 1), respectively.

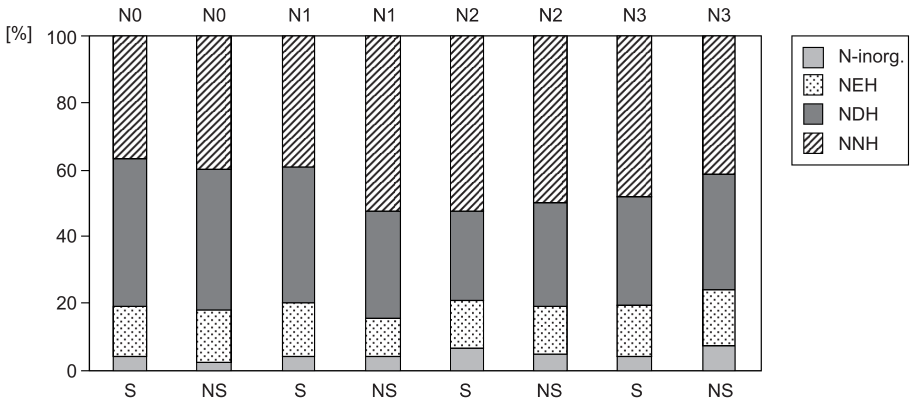

Fig. 1. Percentage share of nitrogen forms in soil as effected by sprinkling irrigation and nitrogen fertilization

Therefore in conditions of long-term cultivation of cereal plants alone a dynamic equilibrium developed between nitrogen forms on which the sprinkling level failed to exert a significant impact. Mineral nitrogen applied at doses of 100 kg $\cdot$ ha^{-1}, together with after-harvest residues as well as the plant root bulk, ensured optimal conditions for the formation of non-soluble nitrogen forms on the one hand and, on the other, soluble forms, potentially available for plants.

Conclusions

1. Sprinkling irrigation did not exert a significant influence on the content of investigated N forms in the soils, under experimental conditions.

2. Nitrogen fertilization significantly differentiated the contents of N mineral forms, easily and poorly hydrolysable N. In the case of total N as well as non-hydrolysable any influence was not observed.

3. Elevated nitrogen doses caused a significant increase of mean concentrations of the mineral forms of the element in the soil as well as significant differences in easily- and poorly-hydrolysable nitrogen but without unequivocal direction of changes.

4. A synergistic effect of sprinkling irrigation and nitrogen manifested its significant impact only with regard to the development of easily-hydrolysable nitrogen forms.

5. No unequivocal trend in changes of N fractions as induced by the water factor and nitrogen fertilization were revealed under conditions of the current field trial.

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WPŁYW WIELOLETNIEGO DESZCZOWANIA I NAWOŻENIA AZOTEM NA ZAWARTOŚĆ AZOTU W GLEBIE PŁODOZMIANU ZBOŻOWEGO

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Abstrakt: Przedstawiono wyniki dotyczące zawartości udziału różnych form azotu w glebie ukształtowane w warunkach wieloletniej uprawy w płodozmianie zbożowym. Czynnikami doświadczenia było deszczowanie i azot stosowany w różnych dawkach. Stwierdzono między innymi, że deszczowanie nie miało wpływu na zawartość badanych form N, w odróżnieniu od działania azotu, którego działanie było statystycznie istotne. Współdziałanie obu czynników ujawniło się tylko w kształtowaniu zawartości azotu łatwo hydrolizującego.

Słowa kluczowe: gleba, płodozmian zbożowy, formy azotu, nawożenie, deszczowanie