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IMPACT OF LONG-TERM TILLAGE SYSTEMS AND DIFFERENT NITROGEN FERTILIZATION ON CHEMICAL AND BIOLOGICAL PROPERTIES OF SOIL AND SUGAR BEET YIELD

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Abstract. The aim of this study was to determine the effects of long-term use of three tillage systems (conventional tillage – CT, reduced tillage – RT and no-tillage – NT) in sugar beet cultivation. Chemical (pH, organic C and total N), microbiological (heterotrophic bacteria, oligotrophs and copiotrophs, actinomycetes and fungi) and enzymatic activity (dehydrogenases and acid phosphatase) properties of soil were tested as well as yield of sugar beets (roots, biological sugar, technological sugar) in the background of different nitrogen fertilization (0 and 160 kg N·ha^{-1}). The research was carried out between 2008 and 2011 and was based on a static field experiment set up in 1997 in Złotniki Experimental Station belonging to Poznań University of Life Science (Poland) in temperate climate. Soil samples were collected from 0–10 cm layer. Simplified tillage systems (RT and NT) contributed to an increase in pH, organic C and total N content, and all analyzed biological parameters. Simplified tillage system also led to a decrease in the yield of sugar beets. Actinomycetes reacted weakest on the tillage system, and particularly strong – dehydrogenase activity, which in conditions of RT or NT system was half lower than under CT system. Fertilisation with 160 kg N·ha^{-1}, in comparison with no-nitrogen fertilisation, in general, contributed to an increase in numbers of microorganisms as well as higher soil enzymatic activity and, predictably, to increased sugar beet yields. Only in the case of oligotroph and copiotroph counts and the activity of acid phosphatase, the influence of fertilisation levels turned out to be statistically non-significant. Furthermore, no significant interactions were observed between fertilisation and the employed tillage system. Nevertheless, the impact of simplifications in soil tillage (RT and NT) on numbers of oligotrophs and copiotrophs and, above all, on dehydrogenase activity was particularly conspicuous at the absence of nitrogen fertilisation (N0), while on numbers of fungi – when 160 kg N per 1 ha was applied. It should be noted that the activity of soil enzymes and number of microorganisms compared to the technological sugar yield were mainly inversely correlated. Only in the case of oligotrophs and fungi correlations were positive.

Key words: sugar beets, tillage systems, soil chemical and biological properties

INTRODUCTION

Soil cultivation is one of the main factors of agricultural influence on soil environment. Before industrial means of production were introduced into the farming practice, the basic task of soil tillage was to create the most favourable conditions for the development and growth of crop plants which, as a result, would lead to obtaining satisfactory yields. These objectives were achieved by employing a traditional soil ploughing tillage system, which – apart from some obvious advantages – can, in some cases, also exert a negative pressure on the soil environment.

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Another important issue is the economic aspect – the soil ploughing system is one of the most energy-consuming agrotechnical element of annual crop plants [Jaskulski et al. 2013, Kordas 2005].

One of the directions of activities limiting unfavourable phenomena accompanying traditional ploughing management is introduction of simplifications into soil ploughing tillage. At the present time, there are numerous possibilities allowing modification and simplification of soil tillage or even complete elimination of this treatment in the agrotechnical process in favour of the direct seeding. Such actions, frequently, better than traditional ploughing tillage, harmonize with new challenges and tasks of modern agriculture such as soil protection against water and wind erosion or maintenance of their fertility and biodiversity. However, many aspects associated with the impact of long-term application of different soil tillage systems on physical, chemical and biological soil properties in the context of various crop plant species and agrotechnical variants such as fertilisation, sprinkling, row spacing etc. are poorly recognized, while literature data are frequently contradictory or ambiguous [Bielińska and Mocek-Płóciennik 2012, Januauškaite et al. 2013, Małecka et al. 2015, Reji et al. 2012, Swędrzyńska and Grześ 2015, Twardowski 2010].

Most scientific papers on soil tillage systems are devoted to economical aspects as well as to optimization of agrotechnical practices and crop yields – both with respect to their quantity as well as quality. In the context of the effect of tillage systems on the environment, especially on soil, researchers discuss issues connected with the application of herbicides as well as restricting erosion together with limitation of the intensity and depth of soil tillage. Among primary indicators of soil environment condition and soil fertility are biological parameters such as microbiological biomass carbon (MSC) and microbiological biomass nitrogen (MSN) content, number of taxonomical-ecological groups of soil microorganisms, soil enzymes activity or the soil respiration [Bielińska et al. 2012, Piotrowska and Charzyński 2012, Zuber and Villamil 2016].

The aim of the study was to determine the effect of long-term use of the three tillage systems and different nitrogen fertilisation used in cultivation on chemical and biological properties of the soil and on the yield of sugar beets.

MATERIAL AND METHODS

The described field experiments with sugar beet cv. "Zawisza" were carried out in years 2008–2011, based on a static field experiment set up in 1997 at the Experimental Station in Złotniki (52°29′ N, 16°49′ E), which belongs to Poznań University of Life Sciences. Sugar beets were cultivated after winter wheat. Soil on which sugar beets were cultivated is classified as very good and good IVa and IVb rye complex quality class, rich in phosphorus and potassium of slightly acid reaction. Such soil is developed from loamy sands and light boulder clays containing 0.98–1.00% humus and 13–17% silt and clay fraction, including 3–4% colloidal clay. Thickness of the plough-humus horizon amounted to approximately 28 cm. Sugar beets were sown with 45 cm row spacing and seeds in rows were sown with the distance of 6 cm in the second decade of April. Sprinkling was applied when soil moisture content dropped to below 70% of field water capacity. Sugar beets were harvested in the first decade of October. The remaining agrotechnical treatments were conducted in accordance with principles of proper agrotechnology.

Experiments were carried out strictly in a split-plot design with two factors in four replications field. The first factor was tillage system and the second nitrogen fertilization. Three soil tillage systems were analyzed: conventional tillage system – CT (standard tillage with deep

plowing), reduced tillage system – RT (shallow plowing – up to 10 cm) and no-tillage system – NT (direct seeding without mechanical cultivation of soil) with two levels of nitrogen fertilization in the form of ammonium nitrate: 0 and 160 kg $N \cdot ha^{-1}$.

Soil samples for chemical analyses (except pH) were collected before the launch of the experiment in 2008. The replication plot was represented by a mean sample consisting of 10 individual samples collected from the depth of 0–10 cm. Soil was dried and manually crushed and sieved through a 2-mm sieve. Organic carbon was determined using the Tiurin method (K dichromate oxidation), total N using Kjeldahl method and pH in 1 mol $KCl \cdot dm^3$ [Mocek and Drzymała 2010].

Soil samples for biological analyses and pH were collected four times during each of the growing seasons: I term – 6-7 leaves unfolded (16–17 BBCH), II term – leaves cover 90% of ground (37–39 BBCH), III term – root development granary (42–43 BBCH) and IV term – after harvesting the roots of beets (BBCH – 49) the same way as the samples for chemical analyses. Microbiological analysis was performed by serial dilution method and involved determination of (using selective substrates, in four replications) the number of colony forming units ($CFU \cdot g^{-1}$ d.m. soil) of heterotrophic bacteria, oligotrophic and copiotrophic bacteria, actinomycetes and fungi. Examination of soil enzymatic activity in conditions of different tillage systems was based on the determination of the activities of dehydrogenases and acid phosphatase. Detailed methodology of the count determination of individual groups of microorganisms as well as activities of the examined soil enzymes was published earlier [Swędrzyńska and Grześ 2015].

Root quality analyses were performed annually in the laboratory of sugar refining factory in Środa Wielkopolska.

Weather conditions during the study period were very diverse (Table 1). In 2008 rainfall was scarce (only 203.8 mm) with an average air temperatures. Years 2009 and 2011 had similar average long-term temperature, which were approximately 2°C higher than the average multi-

Table 1. Mean daily air temperatures and precipitation sum in vegetation periods – Experimental Station Złotniki (2008–2011)

Year	Month								Mean/ Sum
	III	IV	V	VI	VII	VIII	IX	X	
Temperature (°C)									
2008	3.8	10,0	16.2	20.6	22.2	15.5	10.3	9.6	13.5
2009	3.9	14.2	15.1	16.7	21.7	21.4	17.0	10.2	15.0
2010	4.2	10.5	12.0	19.2	23.0	19.6	13.4	6.9	13.6
2011	4.5	12.7	15.3	18.4	17.5	18.9	15.0	19.1	15.2
1951–2007	3.3	8.5	14.2	17.4	19.1	18.4	13.8	9.1	13.0
Precipitation (mm)									
2008	32.1	77.5	9.5	8.4	46.6	29.5	5.6	21.6	230.8
2009	28.6	42.7	45.2	50.0	65.2	64.3	50.9	37.0	383.9
2010	33.8	38.5	134.6	26.6	100.9	132.4	68.5	7.2	542.4
2011	15.2	4.1	17.5	62.4	214.8	38.0	28.6	21.8	402.4
1951–2007	30.0	31.3	48.0	57.8	74.5	54.2	45.8	34.8	376.4

year temperature from the other years. In addition, there was an exceptionally wet month in July 2011 with precipitation reaching 214.8 mm and the air temperature lower by approx. 1.5° C. In contrast, 2010 was characterized by slightly higher average air temperatures, except for May when the temperature was lower by 2.2° C, while rainfall was higher by 166 mm. Thus, during the period of study supplemented balance sprinkler rainfall in 2009 and 2013 was used in the amount of 30 mm, and in 2008 – 90 mm.

The data were analyzed using standard variance analysis (ANOVA) for the randomised complete block. The obtained data from field experiments were subjected to the analysis of variance. Variability was assessed using t-Fisher test at the significance level of $\alpha = 0.05$, while the significance of inter-object differences was evaluated with the Tukey's test. Pearson correlation coefficients between chemical and biological properties were performed. All statistical analysis were performed using Statistica 7.1 software.

RESULTS AND DISCUSSION

The yielding (mass of roots, biological and technological yield of sugar) depended on the cultivation system and nitrogen fertilization and was independent from other factors (Table 2). With reducing the tillage the yield of sugar was decreased [Zimny 1997]. The use of minimum tillage compared to the conventional tillage resulted in a significant reduction of beet crops in the range 8.3–10.8%. Further reduction of tillage up to direct sowing contributed to the further, significant decline in yields. As a result, direct sowing, in comparison to the conventional tillage resulted in decrease of yield in the range of 15.9–16.8%. Similar relationships was reported by Dzienia at el. [2005], Zimny [1995], Zimny and Krzyśków [1996] and Kordas [2000].

The applied nitrogen fertilization resulted in a very high yield growth. The largest increase in beet yield was demonstrated for root yield, which increased by 21.5 $t \cdot ha^{-1}$, ie. by 62.0%, while biological and technological yield was 55.1 and 51.4%, respectively.

Table 2. The influence of tillage system and nitrogen fertilization on sugar beet yielding, $t \cdot ha^{-1}$ (mean 2008–2011)

Experimental factors	Yield		
	roots	biological sugar	technological sugar
Tillage systems			
Conventional tillage	50,0	9.80	8.56
Reduced tillage	44.6	8.99	7.85
No-tillage	41.6	8.24	7.14
$LSD_{0.05}$	2.2	0.63	0.50
Nitrogen fertilization			
0	34.6	7.06	6.24
160	56.1	10.95	9.45
$LSD_{0.05}$	3.7	0.65	0.64

The impact of nitrogen fertilization and tillage method on selected soil chemical parameters (C, N, pH) is listed in table 3. Nitrogen fertilization, as an independent experimental factor, caused a slight decrease of pH in each tillage system and contributed to a distinct increase in total N and organic C.

Table 3. Chemical properties of soil under conventional tillage, reduced tillage and no-tillage system at the two fertilization variants

Parameter	Tillage systems	Nitrogen fertilization (kg N·ha^{-1})	
		N 0	N 160
pH in KCl	conventional tillage	6.81	6.71
	reduced tillage	7.01	6.97
	no-tillage	7.25	7.12
	$LSD_{0.05}$	0.20	0.20
Organic C (g·kg^{-1})	conventional tillage	6.48	7.01
	reduced tillage	6.73	7.34
	no-tillage	6.59	7.09
	$LSD_{0.05}$	0.20	0.21
Total N (g·kg^{-1})	conventional tillage	0.59	0.66
	reduced tillage	0.60	0.69
	no-tillage	0.59	0.70
	$LSD_{0.05}$	ns	0.02
C:N	conventional tillage	11.0	10.6
	reduced tillage	11.2	10.6
	no-tillage	11.2	10.1
	$LSD_{0.05}$	ns	ns

ns – no significante differences

Long-term practice of soil tillage simplifications (RT and NT) resulted in a slight, albeit persistent increase in soil pH levels as well as organic C content in comparison with CT; the highest pH values were recorded in NT conditions, whereas organic C was found highest when RT was applied. These correlations as well as their scales were similar irrespective of the level of nitrogen fertilization. With regard to total N, the influence of the tillage system was also small, although statistically significant, assuming a similar system as in the case of pH, but only in conditions of N160. At the absence of N fertilization, the tillage system exerted no influence on the content of total N in soil. The impact of tillage systems on soil C and N content led to slight differences in the ranges of the C:N ratio. The direction of this influence depended on nitrogen fertilization. At the absence of nitrogen fertilization (N0) the C:N ratio attained the lowest value when CT was employed, whereas in conditions of N160 – when the NT system was applied.

The positive influence of nitrogen fertilization on the increase of organic C and total N was a result from increased plant biomass and microorganism production. On the other hand, the acidifying effect of the nitrogen fertilization was a result of intensified leaching process of basic ions in conditions of increased nitrate concentrations as well as from biological oxidation of ammonium cations causing hydrogen ions release [Filipek and Skowrońska 2013]. On the other hand, the recorded pH increase in conditions of soil tillage restrictions (RT and NT), in comparison with CT, requires comment. This situation occurred only in sugar beet cultivation. In terms of other cultivations, both the results of our own experiments [Małecka et al. 2012, Swędrzyńska et al. 2013, Swędrzyńska and Małecka-Jankowiak 2017] and other researchers [Mangalassery et. al. 2015, Myśków et. al. 1986] indicated a reverse relationship – simplifications resulted in a decline in soil pH, in particular in its top layer. One possible explanation could be a greater organic matter concentration in the upper soil layer and, as a consequence, intensification of mineralization processes. This in turn was accompanied by production of organic and inorganic acids, more intensive release of CO_2 as well as enhanced nitrification [Filipek and Skowrońska 2013, Kurek 2002]. The question arises then, why, in the case of sugar beet cultivation, the effect is reverse? It is difficult to give a final answer but it is possible that this was a result of completely different morphological structure and method of growth of sugar beet plants as well as different agrotechnology compared to cereals and pea. Hence, wide inter-rows used in sugar beet cultivation, slow initial growth of plants and thus the fact that soil was left uncovered for longer in comparison with cereals could contribute to observed differences. Such soil warmed up faster and its top layers dried faster and, therefore, organic matter mineralization and other microbiological processes occurred more rapidly. As a consequence, much more CO_2 was released but, at the same time at higher temperatures, its solubility in water significantly decreased and nearly all of CO_2 was passed into atmosphere. On the other hand, application of full soil tillage (CT), including deep ploughing, moved considerable amounts of organic matter into deeper soil profile. CO_2 produced in less heated, moister soil dissolved in water easier, forming carbonic acid (H_2CO_3). When it comes to cereals, inter-rows are covered by plants much earlier and faster and considerable proportion of CO_2 dissolves much faster in the soil and thus soil warms up slower irrespective of the applied tillage system. Because in simplified tillage (RT and NT) the intensity of organic matter mineralization in the surface soil layer is greater, more carbon dioxide is produced and, consequently, stronger acidification takes place. This hypothesis provides a good starting point for further research regarding the problem of different effect of simplifications in soil tillage on soil pH under sugar beets and other crop plants and will be further tested.

Tables 4, 5 and 6 show the influence of the sampling date, tillage system and nitrogen fertilisation on the biological parameters of soil. The analysis of the principle effect of individual factors revealed that this effect was nearly always very clear and statistically significant, both with respect to the population of soil microorganisms as well as to the enzymes activitie.

The majority of analyzed biological indicators (Table 4 and 5) reached their highest values on the 2nd date of analysis, i.e. during the period of the most intensive sugar beet growth, at approximately 80% of the soil cover by leaves (BBCH 37–39) despite the fact that weather conditions were not always very favourable, especially with respect to moisture conditions (Table 1). This correlation was particularly evident in the total counts of bacteria, oligotrophs and copiotrophs. Actinomycetes were very numerous also on the 3rd date, while fungi – on the 4th. With regard to soil enzymes, the effect of the sampling date on the differentiation of their activity was weaker, although also in their case, the highest activities were recorded on the 2nd date. All examined parameters showed distinctly lower values on the 1st date of analysis in comparison with the highest values nearly twice lower. This could probably be attributed to considerable raw spacing and the impact of small plants on the soil via root secretions or dying tissues.

Table 4. The number of soil microorganisms (CFU·g^{-1} DM of soil) depending on cultivation factors (mean 2008–2011)

Experimental factors	Bacteria (n·10^5)			Oligotrophs (n·10^5)			Copiotrophs (n·10^5)			Actinomycetes (n·10^5)			Fungi (n·10^4)		
	Nitrogen fertilization (kg N·ha^{-1})														
	N0	N160	Mean	N0	N160	Mean	N0	N160	Mean	N0	N160	Mean	N0	N160	Mean
Development phase of sugar beet (BBCH)															
16 – 17	34.6	37.6	36.1	31.7	30.1	30.9	23.6	23.7	23.7	72.9	64.7	68.8	8.2	6.9	7.6
37 – 39	55.4	83.8	69.6	59.5	57.3	58.4	42.3	45.1	43.7	119.8	206.3	163.1	12.0	14.7	13.3
42 – 43	32.9	47.0	39.9	46.6	51.2	48.9	34.9	38.3	36.6	140.0	196.3	168.2	9.0	8.2	8.6
49	38.0	39.9	39.0	40.9	39.3	40.8	29.2	40.6	34.9	77.2	95.1	86.2	10.6	16.4	13.5
$LSD_{0.05}$	14.7		6.9	ns		12.4	13.5		6.7	43.2		28.6	3.6		1.8
Tillage system															
CT	36.2	43.5	39.9	37.6	35.1	36.4	27.4	33.0	30.2	100.2	138.5	119.4	10.1	7.6	8.9
RT	41.0	59.6	50.3	45.2	46.2	45.7	37.2	35.1	36.2	104.4	143.9	124.1	9.3	15.8	12.6
NT	43.4	53.0	48.2	51.7	52.1	51.6	33.0	42.8	37.9	102.9	139.5	121.2	10.4	11.2	10.8
$LSD_{0.05}$	ns		8.1	ns		9.2	ns		5.9	36.1		ns	2.8		1.3
Nitrogen fertilization															
Mean	40.2	52.1	46.2	44.7	44.5	44.6	32.5	36.9	34.7	102.5	140.6	121.6	9.9	11.6	10.8
$LSD_{0.05}$	6.6		-	ns		-	ns		-	11.0		-	1.5		-

ns – no significante differences

Table 5. Mean activity of soil enzymes depending on cultivation factors (mean 2008–2011)

Experimental factors	Dehydrogenases (µmol TPF·kg^{-1} DM of soil·24h^{-1})			Acid phosphatase (µmol PNP·g^{-1}·DM of soil·h^{-1})		
	Nitrogen fertilization (kg N·ha^{-1})					
	N 0	N 160	Mean	N 0	N 160	Mean
Development phase of sugar beet (BBCH)						
16 – 17	2.14	2.57	2.35	0.064	0.076	0.070
37 – 39	2.75	3.27	2.91	0.075	0.077	0.076
42 – 43	2.70	2.80	2.75	0.070	0.076	0.073
49	2.68	2.87	2.84	0.066	0.057	0.062
$LSD_{0.05}$	0.51		0.26	0.011		0.007

Table 5. cont.

Tillage system						
CT	1.84	1.85	1.768	0.064	0.065	0.065
RT	2.74	3.58	3.208	0.070	0.070	0.070
NT	3.12	3.20	3.163	0.071	0.080	0.076
$LSD_{0.05}$	0.50		0.304	0.006		0.003
Nitrogen fertilization						
Mean	2.55	2.88	2.712	0.068	0.072	0.070
$LSD_{0.05}$	0.21		-	ns		-

ns – no significante differences

Table 6. The ratio between the number of oligotrophs to copiotrophs depending on experimental factors (mean 2008–2011)

Experimental factors	Nitrogen fertilization (kg N·ha^{-1})		
	N 0	N 160	mean
Development phase of sugar beet (BBCH)			
16 – 17	1.34	1.27	1.30
37 – 39	1.41	1.27	1.34
42 – 43	1.33	1.34	1.34
49	1.40	0.97	1.15
Tillage system			
CT	1.38	1.06	1.20
RT	1.22	1.32	1.27
NT	1.55	1.22	1.36
Nitrogen fertilization			
Mean	1.37	1.20	1.28

The effect of the date of sampling on soil microbiological indicators was important. Here, the decisive role was played by changes of soil moisture and temperature as well as plant developmental phase and hence quantitative and qualitative variability of their dying tissues and root secretions [Paul and Clark 2000]. This was in contrast to the other publications where it was shown that different time intervals were those in which soil microbiological activity was highest. Furczak and Turska [2006] reported that the highest soil microbiological activity expressed as the total number of bacteria and fungi under soybean cultivated in different soil tillage systems occurred usually in the autumn, shortly before plant harvest. Niewiadomska et al. [2010]

observed the highest enzymatic activity of lawn sward in the spring and autumn and explained this fact by the availability of nutrients for soil microorganisms. Gliński et al. [1986] in turn, reported a decline in dehydrogenase activity in June and its rapid increase in July, attributing this fact to the impact of changing soil moisture content. Moreover, Ajwa et al. [1999] found that the activity of dehydrogenases measured in August was by 30% higher in comparison with their activities recorded in April or June. Pawelczuk [1988] reported that temperature was the primary factor influencing the intensity of enzymatic processes in soil. The authors showed that in most cases it was the date of the full vegetative development of plants that was the one in which soil microbiological life was most intensive – root secretions, high soil temperature [Swędrzyńska et al. 2013, 2015, Swędrzyńska and Grześ 2015, Swędrzyńska and Małecka-Jankowiak 2017].

The performed analysis of the effect of the tillage systems applied in the experiment on soil microorganism counts and soil enzymatic activity indicated that, when the CT system was employed, all examined biological parameters attained significantly lower levels in comparison with the RT and NT conditions. The weakest response to the applied soil tillage systems was observed in the case of actinomycetes, whereas dehydrogenases activity responded particularly strong; in the case of CT, it was 50% lower than in RT or NT conditions.

Dehydrogenases are enzymes found exclusively inside cells of soil microorganisms and constitute a numerous group of oxidoreductases residing in the cytoplasm or specific structures formed from membranes of cytoplasmatic cells of microorganisms. They are indicators of the intensity of soil microorganism metabolic respiration. Therefore, dehydrogenases activity indicates directly the number of physiologically active microorganisms and there is a positive correlation with counts of bacteria and actinomycetes [Brzezińska and Włodarczyk 2005, Górska and Stępień 2007, Kieliszewska-Rokicka 2001, Skawryło-Bednarz 2008]. For that reason, they are frequently treated as a unique indicator that determine total soil microbiological activity [Brzezińska 2006, Moreno et al. 2007, Nannipieri et al. 2003].

Phosphatases did not respond as strongly to the experimental factors as dehydrogenases, however the response to the date of analysis and the tillage system was statistically significant. The lowest acid phosphatases activity was determined when CT was applied and the highest – in NT conditions. Phosphatase activity is associated with soil colloids and humus substances which levels do not undergo rapid changes. Therefore they are particularly useful in monitoring long-term changes connected with the intensity of agricultural utilisation [Bielińska and Mocek 2009, Nannipieri et al. 1990].

Differences between simplified systems (RT and NT) were not statistically significant. In the case of four of the analyzed indicators (bacteria, actinomycetes, fungi, dehydrogenases), higher values were obtained in RT conditions, while in the case of the remaining three (oligotrophs, copiotrophs, acid phosphatase) – in NT conditions.

The impact of the soil tillage system on the examined soil biological indicators under sugar beets was comparable to that in cereal or pea cultivations as reported by others [Swędrzyńska et al. 2013, Swędrzyńska and Grześ 2015, Swędrzyńska and Małecka-Jankowiak 2017]. This refered to differences between CT and RT and NT systems. They resulted from the distribution of organic matter derived from the over ground after-harvest residues of the previous crop which, in the case of CT, was ploughed under and transferred into deeper layers of the topsoil, while in the RT and NT systems remained in the near-surface soil layer and it was just this layer that was analyzed in [Januauškaite et al. 2013, Madejón et al. 2006, Swędrzyńska et al. 2013]. The differences between RT and NT systems and promotion – by each of the two systems – different groups of microorganisms and modified enzymatic activity, a decisive role was presumably played by varied moisture conditions and near-surface aeration of 10 cm soil layer. In the RT system, the layer was loosened (therefore, more aerated) and the organic matter from the

previous crop that accumulated on the surface was mixed with it. Noteworthy, the application of the NT system only slightly disturbed the structure of the soil surface layer and considerable amounts of after-harvest residues remained on its surface [Kordas and Zimny 1998, Flis-Bujak et al. 2006].

Nitrogen fertilization modifies soil microbiological properties both directly and indirectly through its contribution to plant intensive growth leading to increased quantities of root secretions as well as after-harvest residues.

The influence of nitrogen fertilization on the level of analyzed biological indicators was clear, although not as strong as initially expected, bearing in mind the fact that the extent of levels of this factor was very large, from 0 to 160 kg $N \cdot ha^{-1}$. The dose of 160 kg $N \cdot ha^{-1}$ in comparison with the absence of nitrogen fertilization, in the majority of cases, contributed to the increase of bacterial counts and higher soil enzymatic activity. However, with respect to the numbers of oligotrophs, copiotrophs and acid phosphatase activity, the impact of fertilization levels turned out to be statistically non-significant.

The observed lack of oligotrophs response to nitrogen fertilization was a typical response of this group of microorganisms characterized by low dynamics of their population size to supplies of fresh organic matter [Reji et al. 2012, Weyman-Kaczmarkowa and Pędziwilk 1996, Wolińska et al. 2015]. There were also cases of a negative response of these microorganisms to excessive organic carbon concentrations, particularly in the form of amino acids and organic acids [Otha and Hatorii 1980].

Poor copiotrophs response to nitrogen fertilization was, most probably, the result of its delayed action. This can be traced by analyzing the response of copiotrophs to fertilisation in individual regrowth. Mineral nitrogen did not affect these microorganisms. The influence of fertilisation became apparent only on the 4th date, when the reserves of after-harvest residues decreased. At the absence of fertilisation, numbers of copiotrophs declined, while in the fertilised treatment, the numbers increased following higher supplies of root secretions or dead sugar beet tissues. Copiotrophs are zymogens whose numbers and activity in the soil environment is conditioned by availability of fresh organic matter.

Despite the fact that populations of oligotrophs and copiotrophs gave a weak response to the applied systems of soil tillage, O:C coefficient was calculeted (Table 6) which is considered to be an important indicator of maintenance of soil biological stability in the context of organic matter content [Weyman-Kaczmarkowa and Pędziwilk 1996]. Even though the differences were not statistically significant and the O:C ratio assumed relatively low values, it was noticed that this indicator was higher when no fertilisation was applied. A particularly strong difference occurred on the 4th date when, in the fertilised treatment, this indicator dropped below 1 as well as in conditions of the CT system.

One of the tasks set in the objectives of this study was the evaluation of interactions between nitrogen fertilization and other experimental factors (in particular, the tillage system) with reference to soil microbiological activity. The diagram (Fig. 1) presents the impact (expressed in percent) of simplified soil tillage systems (RT and NT) on the examined soil biological indices in relation to CT at two levels of nitrogen fertilization. The diagram illustrates not only the direction but also the scale of this effect. It shows that the numbers of nearly all populations of microorganisms and the activity of examined enzymes, the stimulating impact of RT and NT was very similar at both levels of N fertilization. At the absence of nitrogen fertilization (N0), the highest growth was determined for numbers of oligotrophs and copiotrophs and, first and foremost, of dehydrogenases – by nearly 70% in RT conditions and by over 80% in NT conditions. The lowest growth of only several percent was noticed for actinomycetes and fungi. For the latter, a slight decline in their numbers was observed when the RT system was applied.

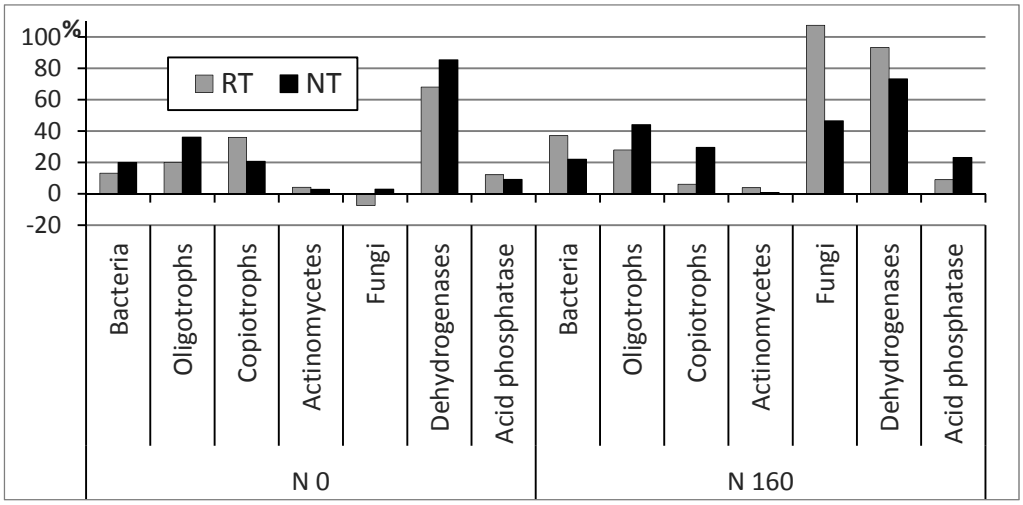

Fig. 1. The impact of simplified soil tillage systems (RT – reduced tillage and NT – no-tillage system) on the mean number of microorganisms and enzymes activity depending on fertilisation (N0 and N 160 kg·ha^{-1}) with respect to conventional tillage – CT (mean 2008–2011)

Furthermore, when nitrogen fertilisation (N 160) was used, the number of fungi turned out to be an indicator, which exhibited the highest growth in RT and CT conditions in comparison with CT – by 107% and 42%, respectively.

Our study shows the correlation between analyzed biological properties (at the thickening roots phase – time of intensive growth of sugar beets – BBCH 42–43 and at the time of harvesting – BBCH 49) and technological yield of sugar depending on the tillage system and nitrogen fertilization (Table 7). Most significant correlation was found in RT system. In the case of the number of oligotrophs, copiotrophs and fungi, these correlations occurred in both analyzed terms. It should be noted that the activity of soil enzymes and number of microorganisms compared to the technological sugar yield were mainly inversely correlated. Only in the case of oligotrophs and fungi correlations were positive.

CONCLUSIONS

1. It has been shown that the influence of tillage system and nitrogen fertilization on the analyzed parameters are independent.
2. Simplified tillage systems (RT – reduced tillage and NT – no-tillage) resulted to an increase in the pH of soil, organic C and total N content and biological activity of soil. Simplified tillage system also led to a decrease in the yield of sugar beets. Actinomycetes reacted weakest on the tillage system, and particularly strong – dehydrogenase activity, which in conditions of RT or NT system was half lower than under CT system.
3. Nitrogen fertilization usually caused an increase in numbers of microorganisms as well as higher soil enzymatic activity and contributed to increased sugar beet yields.
4. No significant interactions were observed between fertilisation and the employed tillage system. Nevertheless, the impact of simplifications in soil tillage (RT and NT) on numbers

Table 7. The correlation between biological properties of soil and technological yield of sugar depending on the cultivation system and nitrogen fertilization (mean 2008–2011)

Biological properties	Technological sugar yield					
	CT		RT		NT	
	N 0	N 160	N 0	N 160	N 0	N 160
BBCH 42–43						
Bacteria	0.233	-0.021	0.016	-0.356	-0.093	-0.209
Oligotrophs	0.142	0.596*	0.642**	-0.230	0.423	0.054
Copiotrophs	-0.131	-0.491	-0.085	-0.556*	-0.448	-0.367
Actinomyces	-0.386	-0.611**	-0.402	-0.502*	-0.278	-0.237
Fungi	0.195	-0.172	0.603*	0.554*	0.300	-0.480
Dehydrogenases	-0.455	-0.374	-0.218	-0.366	-0.152	-0.182
Phosphatases	-0.155	0.099	-0.019	-0.575*	-0.288	-0.015
BBCH 49						
Bacteria	-0.316	-0.652**	-0.416	-0.655**	-0.238	-0.300
Oligotrophs	-0.401	0.198	0.810**	-0.430	0.288	-0.036
Copiotrophs	-0.255	-0.248	-0.460	-0.724**	-0.110	-0.110
Actinomyces	-0.413	0.096	-0.235	0.079	0.432	0.374
Fungi	0.379	-0.397	0.800**	0.490	0.460	0.392
Dehydrogenases	0.170	0.416	-0.576*	-0.671**	-0.630**	-0.500*
Phosphatases	0.253	0.157	0.100	0.414	0.194	0.393

BBCH – development phase of sugar beet
*correlation coefficient significant at significance level = 0.05
**correlation coefficient significant at significance level = 0.01

of oligotrophs and copiotrophs and, above all, on dehydrogenase activity was particularly conspicuous at the absence of nitrogen fertilisation (N0), while on numbers of fungi – when 160 kg N per 1 ha was applied.

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WPŁYW WIELOLETNIEGO STOSOWANIA SYSTEMÓW UPRAWY ROLI I ZRÓŻNICOWANEGO NAWOŻENIA AZOTEM NA WŁAŚCIWOŚCI CHEMICZNE I BIOLOGICZNE GLEBY ORAZ PLON BURAKÓW CUKROWYCH

Synopsis. W niniejszej pracy poddano analizie wpływ długoletniego stosowania trzech systemów uprawy roli (uprawy tradycyjnej – CT, uprawy uproszczonej – RT i braku uprawy – NT) na wybrane właściwości chemiczne (pH, zawartość węgla organicznego i azotu całkowitego), mikrobiologiczne (liczebność bakterii ogółem, oligotrofów, kopiotrofów, promieniowców i grzybów) i aktywność enzymatyczną (nitrogenaza i fosfataza kwaśna) gleby pod burakami cukrowymi oraz na plonowanie buraków, na tle zróżnicowanego nawożenia azotem (0 i 160 kg N·ha^{-1}). Badania prowadzono w latach 2008–2011 w oparciu o doświadczenie statyczne założone w roku 1997 w Zakładzie Doświadczalno-Dydaktycznym w Złotnikach należącym do Uniwersytetu Przyrodniczego w Poznaniu. Próby gleby pobierano z warstwy 0–10 cm. Uproszczenia w uprawie roli (systemy RT i NT) przyczyniały się do wzrostu odczynu gleby, zawartości węgla organicznego i azotu całkowitego w glebie, wzrostu poziomu wszystkich badanych parametrów biologicznych oraz do obniżenia plonowania buraków cukrowych. Najsłabiej na system uprawy roli reagowały promieniowce, natomiast szczególnie silnie – aktywność dehydrogenaz, która po zastosowaniu RT lub NT była o połowę niższa niż w warunkach CT. Nawożenie 160 kg N·ha^{-1} w porównaniu z brakiem nawożenia azotem przyczyniało się, na ogół, do wzrostu

liczebności drobnoustrojów i wyższej aktywności enzymatycznej gleby oraz, co oczywiste, do zwiększenia plonowania buraków. Jedynie w odniesieniu do liczebności oligotrofów i kopiotrofów oraz do aktywności fosfatazy kwaśnej, wpływ poziomów nawożenia okazał się statystycznie nieistotny. Nie zaobserwowano również znaczącej interakcji pomiędzy nawożeniem a systemem uprawy roli. Tym niemniej wpływ uproszczeń w uprawie roli (RT i NT) na liczebność oligotrofów i kopiotrofów, a przede wszystkim na aktywność dehydrogenaz był szczególnie wyraźny przy braku nawożenia azotem (N0), a na liczebność grzybów, po nawożeniu 160 kg N na 1 ha. Warto zauważyć, że aktywność enzymów glebowych i liczebności drobnoustrojów były najczęściej odwrotnie skorelowane z plonem technologicznym buraków. Jedynie w przypadku grzybów i oligotrofów korelacja była dodatnia.

Słowa kluczowe: buraki cukrowe, systemy uprawy roli, właściwości chemiczne i biologiczne gleby

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