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Original Research

Microbiological Parameters of Soil under Sugar Beet as a Response to the Long-Term Application of Different Tillage Systems

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Abstract

Traditional ploughing cultivation can contribute to soil erosion as well as to other symptoms of soil degradation, leading to a decline in its biological and production potentials. An alternative to conventional tillage is offered by simplified cultivation systems consisting of shallower and less intensive interference into the soil physical structure or even complete abandonment of cultivation treatment. The aim of the performed investigations was to ascertain the impact of a long-term application of simplifications in soil tillage on select soil chemical and microbiological properties under sugar beet cultivation employing two watering combinations: natural distribution of precipitation and sprinkling. Conventional ploughing tillage was treated as reference. The research hypothesis assumed that the application of simplifications in the pre-sowing soil cultivation of sugar beets contributes to the increase in soil organic carbon content and soil fertility. Its microbiological activity and sprinkling also can modify this effect.

Experiments were carried out for a period of four years in conditions of long-term application of three tillage systems (conventional tillage, simplified cultivation, and direct sowing). Select soil chemical (pH, $C_{org.}$, total N) and microbiological (total bacterial counts, numbers of oligotrophs, copiotrophs, actinomycetes and fungi, plus activity of dehydrogenases and acid phosphatase) parameters were analyzed.

The microbiological indices analyzed in this study nearly always spoke in favour of simplifications in soil tillage or complete abandonment of cultivation treatments. In successive years of experiments, almost all the analyzed parameters assumed the lowest values in conditions of ploughing cultivation and the highest ones in direct sowing. Sprinkling and fertilization modified this rule, whereas the level and directions of this impact varied and depended on weather conditions.

Keywords: microbiological activity of soil, soil protection, simplifications in soil tillage, sugar beet, sprinkling

Introduction

The scale and extent of the impact of farming on the natural environment are so wide-ranging that in many places on our planet, and especially in Europe, an ever growing pressure is being exerted on limiting or eliminating negative effects of this impact. Actions in this sphere adopted a concept of so-called sustainable farming, which combines production objectives with the requirements of environmental protection thanks to the application of integrated plant pro-

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tection plans, optimal utilization of the natural production potentials of soils, prevention of soil erosion, application of appropriate principles of rotation systems, etc. [1].

Agrotechnical treatments associated with soil cultivation constitute one of the essential elements through which agriculture can influence the soil environment. In many situations, traditional ploughing cultivation can contribute to soil erosion and other symptoms of its degradation as a result of soil opening, aeration, and drying as well as depriving it of its plant cover, leading to a deterioration of its biological and production potentials. Simplified cultivation systems involving shallower and less intensive interference in the soil physical structure frequently without translocation of soil layers in the soil vertical profile (reduction tillage, conservation tillage) or even complete abandonment of cultivation treatments (no-tillage, direct sowing) offer an alternative to the traditional ploughing cultivation across the entire depth of the soil humus horizon. The above-mentioned simplifications, irrespective of their economical consequences, are also associated with various repercussions of a physico-chemical, biological, and ecological nature [1-4].

One of the most essential soil biological elements decisive with respect to its functioning but also acting as an important indicator of its fertility is soil microbiological activity. In this study, the authors adopted numbers of the most important taxonomic-ecological groups of soil microorganisms and soil enzymatic activity as the measure of this activity. In addition, the effects of the method of the applied cultivation on such soil properties as the content of organic carbon, total nitrogen and pH also were analyzed.

The aim of the performed investigations was to determine the impact of long-term application of simplifications in soil tillage on select chemical and microbiological soil properties under sugar beets at two watering treatments: sprinkling and absence of sprinkling. Traditional ploughing cultivation was used as a reference to the employed simplified systems. The research hypothesis assumed that the system of soil pre-sowing tillage is a factor affecting soil organic carbon content, soil fertility, and its microbiological activity, and that the effects of this action are becoming increasingly stable in consecutive years of the application of the given system of tillage.

Experimental Procedures

Investigations were carried out in 2008-11 on the basis of a static crop-rotation experiment established in 1996 on the fields of the Didactic Experimental Station in Gorzyń of the Department of Soil and Plant Cultivation of Poznań University of Life Sciences, Branch in Złotniki on grey brown podzolic soils of a very good and good rye complex. The soil is relatively high in phosphorus and potassium and medium in magnesium.

Sugar beet cultivar Zawisza was grown in a 4-year rotation: sugar beet, spring triticale, pea, winter wheat. Two levels of irrigation and three tillage systems were arranged in a randomized block design in four replications.

The applied sprinkling levels were as follows: 1) without sprinkling; 2) with sprinkling, when soil moisture content dropped to below 70% of field water capacity – the applied dose ranged from 35-40 mm, which amounted, in consecutive years, to the following total quantities during the vegetation season: 2008 – 160 mm, 2009 – 35mm, 2010 – 145mm, 2011 – 70 mm.

The tillage systems consisted of:

1) Conventional tillage with mouldboard ploughing in autumn to a normal depth (30 cm), followed by seed bed preparation and sowing (CT)
2) Reduced tillage with mouldboard ploughing in autumn shallower depth of 10cm followed by seed bed preparation and sowing (RT)
3) No-tillage – no pre-planting mechanical seedbed preparation and direct sowing by means of a disc coulter drill (NT); fertilization was uniform for all tillage systems and each experimental year (160 kg $N \cdot ha^{-1}$, 80 kg $P \cdot ha^{-1}$, 100 kg $K \cdot ha^{-1}$).

Weeds in sugar beets were controlled chemically. In the case of combinations with direct sowing, Roundup 360 SL in a dose of 3 l/ha was applied before sowing. After sowing, weeds were controlled in the same way in all combinations. Directly after sowing, Pyramin Elite 274EC (4.0 l/ha) in a mixture with Dual Gold (1.3 l/ha) was used, whereas after seedling emergence, weeds were controlled twice – the first spraying was applied at the phase of 2 leaves (BBCH – 12) using Betanal Elite 274 EC and Goltix 700SC in doses of 1.0 and 1.0 l/ha, and then after successive 14 days using identical doses and chemicals.

Soil samples for chemical analyses (C_{org}, N) were collected after harvesting beets in 2008. The replication plot was represented by a mean sample consisting of 10 individual samples collected using an Egner sampler from the 0-20 cm layer. After drying the soil was crushed by hand and sieved through a 2-mm sieve. Organic carbon was determined by the Tiurin oxidation method, total N by Kjeldahl method, and pH in 1 mol $KCl \cdot dm^3$.

Soil samples for biological analyses and pH were collected four times during the growing season (I term – 16-17 BBCH, II term – 37-39 BBCH, III term – 42-43 BBCH and IV term – after harvesting the roots of beets – BBCH – 49) in each years in the same way as the samples for chemical analyses.

The number of microorganisms was determined by the plate method on adequate agar substrates (in four replications). The mean number of colonies was converted into soil dry matter:

- Total bacteria counts were determined on a ready-to-use Merck-Standard count agar medium following five days of incubation at 25ºC [5]
- Oligotrophic bacteria ($CFU \cdot g^{-1}$ d.m. soil) were counted on diluted nutritive broth at 28ºC after 21 incubation days [6]
- Copiotrophic bacteria ($CFU \cdot g^{-1}$ d.m. soil) were determined on nutritive broth at 28ºC after 7 days of incubation [6]
- Actinomycetes ($CFU \cdot g^{-1}$ d.m. soil) were counted on Pouchon nourishing substrate at 28ºC [7]

Table 1. Mean daily temperatures of air and sum of precipitation in vegetation periods of sugar beet in 2008-11 and 1951-2008.

Month	Mean temperatures (°C)					Sum of precipitation (mm)				
	2008	2009	2010	2011	1951-2008	2008	2009	2010	2011	1951-2008
March	3.8	3.9	4.2	4.5	3.3	32.1	28.6	33.8	15.2	30.0
April	10.0	14.2	10.5	12.7	8.5	77.5	42.7	38.5	4.1	31.3
May	16.2	15.1	12.0	15.3	14.2	9.5	45.2	134.6	17.5	48.0
June	20.6	16.7	19.2	18.4	17.4	8.4	50.0	26.6	62.4	57.8
July	22.2	21.7	23.0	17.5	19.1	46.6	65.2	100.9	214.8	74.5
August	15.5	21.4	19.6	18.9	18.4	29.5	64.3	132.4	38.0	54.2
September	10.3	17.0	13.4	15.0	13.8	5.6	50.9	68.5	28.6	45.8
October	9.6	10.2	6.9	19.1	9.1	21.6	37.0	7.2	21.8	34.8
Mean or sum	13.5	15.0	13.6	15.2	13.0	230.8	383.9	542.5	402.4	376.4

- Fungi (CFU·g^{-1} d.m. soil) were counted on Martin's nourishing substrate at 24ºC [8]

The performed examination of soil enzymatic activity in conditions of different tillage systems was based on the determination of the activities of dehydrogenase and acid phosphatase (in four replications).

The activity of dehydrogenases was identified by the spectrophotometric method, using as substrate 1% TTC (triphenyl-tetrazole chloride), after 24-hour incubation at 30ºC, and at wavelength 485 nm. Enzyme activity was expressed in µmol TPF·kg^{-1} DM of soil·24 h^{-1} [9].

The activity of acid phosphatase was determined using as substrate p-nitrophenylophosphate sodium, after one hour incubation at 37ºC with wave length 400 nm. Enzyme activity was expressed in µmol PNP·g^{-1} DM of soil·h^{-1} [10].

The results were tested by using standard variance analysis (ANOVA) for the randomized complete block. Mean separations were made for significant effects with LSD and Tukey tests at the probability of $P \leq 0.05$. Pearson correlation coefficient between chemical and biological properties were performed.

Results and Discussion

Weather Conditions

In the course of four years of experiments the results of which are presented in this study, weather conditions during the vegetation season were quite variable (Table 1). Temperatures were not very different from the last half-century period – most frequently upwards. Stressful conditions in this regard occurred undoubtedly during the major part of the vegetation season of 2008 as well as in the summer months of 2009-10. On the other hand, with respect to precipitation, considerable deviations from long-term averages during spring were observed, especially in 2001, when precipitation in the period from March to May was dramatically lower. Strong drought also occurred in May and June 2008, when low precipitation was further accompanied by high temperatures.

Despite variable weather conditions, the performed statistical analysis of the obtained results revealed an interaction between the examined factors taking place irrespective of years and, therefore, the results of a four-year long investigation were presented in the form of synthesis, and conclusions can be generalized for the entire climatic district.

Chemical Analysis of Soil

Table 2 presents the effects of the method of cultivation on pH. It turned out that long-term application of a given tillage system significantly modifies soil reaction and this impact depend on the employed water treatment. In sprinkling conditions, the soil cultivated traditionally exhibited the lowest pH, while the soil that was not subjected to any cultivation was characterized by the highest pH. In natural moisture conditions (without sprinkling), differences between the traditional and simplified cultivations were only slight but a distinctly higher pH occurred in the no-

Table 2. Effect of tillage system on soil pH in the two water variants.

Water variant	Tillage system	Sampling term				
		I	II	III	IV	Mean
Irrigated	Conventional tillage	6.74	6.63	6.82	6.68	6.71
	Reduced tillage	6.93	6.97	7.05	6.93	6.97
	No-tillage	7.05	7.10	7.19	7.17	7.12
Non irrigated	Conventional tillage	6.65	6.62	6.71	6.65	6.66
	Reduced tillage	6.63	6.66	6.68	6.62	6.64
	No-tillage	6.82	6.89	7.03	7.07	6.95
$NIR_{\alpha=0.05}$		0.162	0.206	0.235	0.214	0.204

Table 3. Some chemical properties of soil under conventional tillage, reduced tillage, and no-tillage systems at the different depths of soil profile.

Parameter	Tillage systems	Water variant	
		Irrigated	Non irrigated
Organic C ($g \cdot kg^{-1}$)	Conventional tillage	7.01	8.32
	Reduced tillage	7.34	8.85
	No-tillage	7.09	8.43
	$LSD_{0.05}$	0.208	0.341
Total N ($g \cdot kg^{-1}$)	Conventional tillage	0.66	0.78
	Reduced tillage	0.69	0.81
	No-tillage	0.70	0.82
	$LSD_{0.05}$	0.021	0.032
C:N	Conventional tillage	9.3	10.7
	Reduced tillage	10.6	10.9
	No-tillage	10.1	10.3
	$LSD_{0.05}$	0.61	0.46

tillage system. These results are in agreement with the results obtained by the authors in another experiment on a slightly different soil and using a different crop rotation system where tillage simplifications resulted in pH drop. However, research results were also published indicating that a very deep ploughing contributed to a pH decline by 0.2-0.6 units in comparison with normal ploughing [11]. In the context of soil biological life, these differences are relatively small and, at this stage of investigations, it would be futile to read into them some significant influence on soil microbiological status. Nevertheless, the observed significance and repeatability of these differences makes it possible to put forward an assumption that in consecutive years of application of different systems of soil cultivation these differences will become greater and their impact on soil microbiological life will become increasingly stronger and stronger. In addition, even small differences within the confines of a single parameter can create interactions with successive others and, in the end, their combined influence on soil microbiological activity may be quite strong. In the above-quoted study [11], a slight decline in pH caused an increase in fungal populations in relation to the populations of bacteria, especially to actinomycetes.

In addition, small yet statistically significant and repeatable differences were found within such parameters as the content of organic carbon and total nitrogen determined after harvesting of plants (Table 3). In combinations without sprinkling, concentrations of organic carbon and total nitrogen in soils increased together with the limitation of soil tillage. On the other hand, sprinkling contributed to a considerable decline in the content of both organic carbon and total nitrogen in soils in all the applied systems of cultivation. Moreover, in sprinkling conditions, differences between the employed tillage systems associated with nitrogen disappeared, whereas in the case of those associated with organic carbon – a reversal in the tendency was recorded – in the no-tillage system, the content of carbon decreased significantly.

In the context of the development of a soil site, its fertility, etc., the observed differences in the content of organic carbon and total nitrogen are small but, as mentioned earlier, synergistic effects of such small differences occurring within different parameters may exert a significant influence on the population size of soil microorganisms as well as on soil enzymatic activity.

However, it should be remembered that the content of organic carbon as well as total nitrogen are determined after the harvest of plants in 2008. Although they are considered to be relatively stable, nevertheless temporary values, especially those resulting from a rapid supply of organic carbon in the form of after-harvest residues, etc., can differ from them and become more diverse in individual tillage systems as well as in different layers of the soil profile.

Microbiological Analysis of Soil

The number dynamics of select groups of soil microorganisms as well as the activity of the examined enzymatic processes taking place in the soil environment under sugar beets depending on the applied tillage system are presented in Figs. 1-7 and Tables 4-5.

Total bacterial counts (Fig. 1) turned out to be a poorly reliable parameter with respect to individual examined tillage systems. Nevertheless, statistically significant smallest counts of bacteria were determined most frequently in conditions of traditional cultivation, irrespective of the employed water variant. It is much more difficult to identify a tillage system that was especially favourable for total counts of bacteria. In this case, the applied water treatment was important. In sprinkling conditions, for the majority of dates, it was simplified cultivation involving shallowing pre-winter ploughing to 10 cm, while in the variant without sprinkling, it was direct sowing. Irrespective of sprinkling, total bacterial counts attained their highest values on the 2nd and 3rd terms, i.e. during the period of peak vegetation of plants.

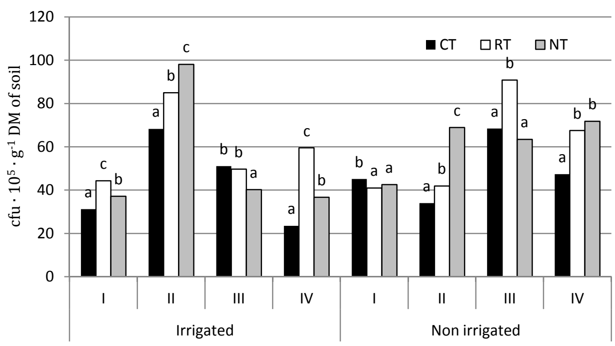

Fig. 1. Effects of tillage system on the total bacteria counts over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

Factors that are essential for the development of soil microorganisms include, among others: resources of organic matter as it supplies microorganisms with energy and nutrients as well as soil moisture content and aeration. The applied cultivation systems modify both organic matter content and soil water and aeration. Cultivation treatments translocate organic matter and soften soil and, therefore, together with the decrease of their frequency and depth of their execution, soil aeration decreases and, at the same time, soil moisture content and unevenness in the distribution of organic matter in the soil profile increases; the amount of organic matter decreases together with depth [11-16].

Interesting conclusions were drawn on the basis of the analysis of soil bacteria divided into oligotrophs and copiotrophs. The distribution of oligotroph counts (Fig. 2) reminds us somewhat of the distribution of total bacterial counts (Fig. 1), except that it is clearly more characteristic for individual tillage systems at consecutive dates. In sprinkling conditions the smallest numbers of oligotrophs nearly always were determined in soil cultivated traditionally, whereas in the treatment without sprinkling – in the soil subjected to simplified tillage. Undoubtedly the highest counts of oligotrophs were found in the soil deprived of cultivation treatments, with the exception of the last date of analysis in sprinkling combinations.

On average, oligotrophs constituted approximately 95% of all bacterial counts, which was more than the commonly given share of 80-85% [17]. Their numbers remained on a relatively stable level and organic matter was processed sparingly and they responded negatively to excessive concentrations of simple carbon compounds in the environment [18, 19]. This means that their high proportions in the soil indicated its low fertility [20].

Fig. 3 presents numbers of copiotrophs in the soils of the examined experimental combinations. The distribution of their numbers turned out very similarly to the distribution of oligotrophs' numbers but more unvarying in the course of the vegetation period, although less specific with respect to the employed method of cultivation. An exceptional situation was observed on the last date of the combinations without sprinkling, when numbers of copiotrophs

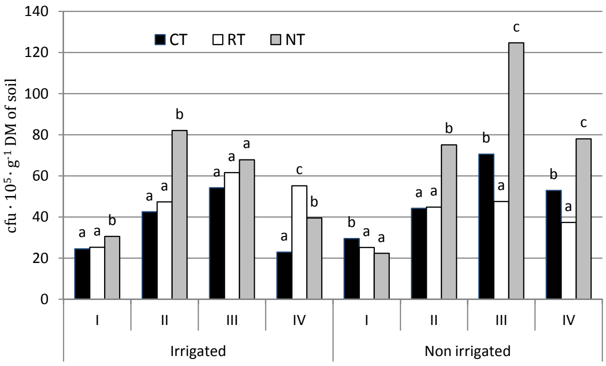

Fig. 2. Effects of tillage system on the oligotrophic bacteria counts over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

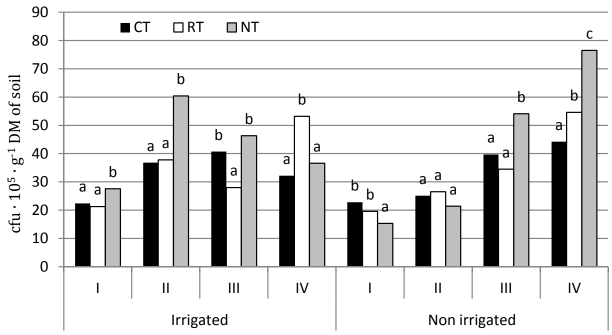

Fig. 3. Effects of tillage system on the copiotrophic bacteria counts over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

were the highest, while in the case of all the remaining microorganisms as well as soil enzymes, the greatest numbers and highest activity were always recorded either on the 2nd or 3rd dates. This can probably be attributed to the supply to the soil of fresh organic matter in the form of plant residues after harvest.

Copiotrophs are bacteria whose development is conditioned by the supply of fresh, easily-available organic matter. In contrast to indigenous oligotrophs, copiotrophic zymogens convert organic matter in a very wasteful manner at high carbon losses, and their counts decline relatively quickly once the easily-available nutrient substrate becomes scarce [18, 19, 21]. However, in this experiment copiotrophs turned out to be a group of microorganisms of relatively poorly differing numbers depending on the method of cultivation, watering treatment, or date of analysis – poorer than oligotrophs. Nevertheless, generally speaking, their numbers were significantly lower in the case of traditional or simplified cultivation and the highest in conditions of direct sowing. A similar lack of consistency but with respect to numbers of copiotrophs in successive years of application of different tillage systems was also observed in another study by the authors [22].

Also, proportions of oligotrophs to copiotrophs in individual tillage systems depended on the date and watering treatment. In the case of all soil combinations, the proportions of oligotrophs in soil microflora were dominant and the value of the O:C coefficient changed from 1.36 to 4.31 (Table 4). The above coefficient assumed the highest values most frequently in conditions of simplified cultivation. On the other hand, differences between traditional tillage and direct sowing turned out to be small and statistically non-significant, while in the case of traditional cultivation this ratio was significantly the smallest. The O:C ratio is particularly important from the point of view of the maintenance of organic matter in soil due to the economic processing of the energy substrate by oligotrophs. According to Weyman-Kaczmarkowa [19], the above-mentioned domination is essential to preserve a constant level of soil organic matter and testifies to the maintenance of soil biological equilibrium. From this point of view, simplified cultivation appears to be most advantageous.

Table 4. Ratios of the number of oligotrophs to copiotrophs (O:C).

Water variant	Tillage system	Sampling term				
		I	II	III	IV	Mean
Irrigated	Conventional tillage	1.82	1.96	1.55	2.63	1.82
	Reduced tillage	2.47	2.22	3.03	2.18	2.47
	No-tillage	1.57	1.72	1.36	2.56	1.57
Non irrigated	Conventional tillage	1.89	2.86	2.21	2.68	1.89
	Reduced tillage	2.71	2.66	2.61	2.13	2.71
	No-tillage	2.12	4.31	2.06	2.50	2.12
$NIR_{\alpha=0.05}$		0.162	0.22	0.32	0.17	0.25

Actinomycetes turned out to be a group of bacteria which responded worst to different systems of cultivation (Fig. 4). The recorded differences were small and frequently statistically non-significant, particularly in conditions of sprinkling. On the other hand, sprinkling contributed to the increase of actinomycetes during the peak of vegetation (the 2nd and 3rd sampling terms). In the treatment without sprinkling, the picture of the impact of the tillage system on counts of actinomycetes was clearer and easier to interpret; in other words, simplified cultivation and direct sowing did not differ from each other significantly, whereas in the case of traditional cultivation, numbers of actinomycetes were significantly smallest.

Actinomycetes are extremely widespread in farming soils and are strongly associated with the rhizosphere zone. Due to the production of various enzymes (cellulases, chitinases, xylanases), they take part in the degradation of plant and animal residues as well as fungi, but they also strongly affect other soil microorganisms. Thanks to the production of antibiotics, they can protect plants against infestation with pathogens. In addition, they also form symbiotic associations with plants and fungi [23, 24]. The variability of actinomycetes in dry soils is small and their greatest numbers were isolated from fertile and moist soils [25].

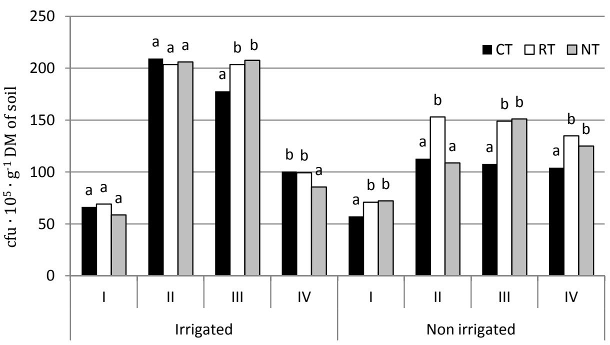

Fig. 4. Effects of tillage system on actinomycetes counts over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

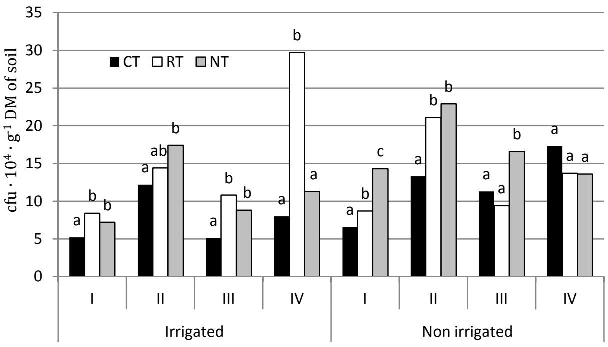

Fig. 5. Effects of tillage system on the fungi counts, over the growing period, in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

This probably explains the fact that their greatest numbers were determined in sprinkling conditions that levelled out the impact of the method of cultivation.

The impact of the soil tillage system on numbers of fungi depended, to a considerable extent, on the applied water treatment. In general, the number of fungi (Fig. 5) showed a similar distribution as the majority of the remaining microorganisms, i.e. it was the lowest in conditions of traditional tillage and the highest in conditions of direct sowing or shallow ploughing. Only on the 4th date of analysis did fungi achieve the highest numbers on experimental plots without sprinkling in the soil cultivated using the traditional method. On the remaining dates, in the case of combinations without sprinkling, the greatest numbers of fungi were determined in the soil without tillage (NT). On the whole, sprinkling contributed to decreasing the amount of fungi, with the exception of the combination with simplified cultivation in which their numbers were the highest.

Saprophytic fungi play an exceptional role in soil ecology since they stimulate the circulation of biogenic elements present in the dead organic matter. The increase in quantities of fungi in simplified systems might arouse concern if their ratio to bacteria also increased, which would be disadvantageous from the point of view of soil fertility and fecundity [26, 27]. However, this relationship in fact decreased because quantities of bacteria in these cultivation systems increased more significantly.

Enzymatic Activity of Soil

Soil enzymatic activity finds its reflection in the metabolic activity of soil microorganisms as well as other organisms of this environment. Simultaneously, soil enzymes take direct part in transformations of individual soil constituents. In this study, the authors analyzed the activity of dehydrogenases and acid phosphatase (Figs. 6 and 7).

The activity of dehydrogenases (Fig. 6) was a strongly variable feature depending on the method of soil cultivation, especially in conditions of the absence of sprinkling. At almost all dates of analyses, this activity was distinctly lower in the soil cultivated traditionally in comparison with simplified systems. The impact of the applied tillage system

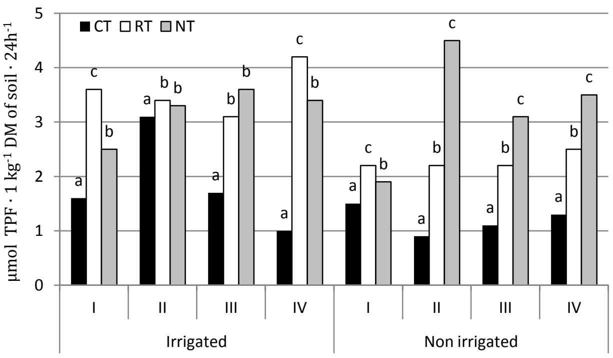

Fig. 6. Effects of tillage system on the activity of dehydrogenases over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

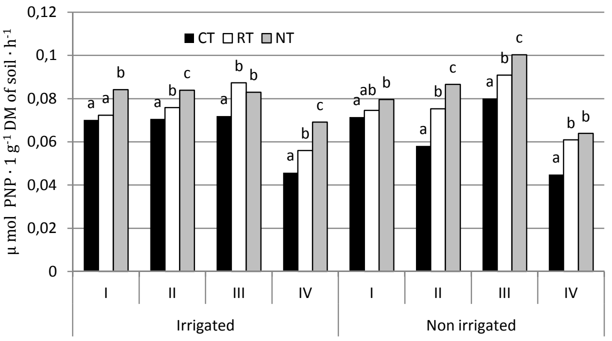

Fig. 7. Effects of tillage system on the activity of acid phosphatase over the growing period in the two water variants.
I, II, III, IV – sampling terms, CT – conventional tillage, RT – reduced tillage, NT – no-tillage.

on the activity of dehydrogenases was the most conspicuous and unequivocal in the soil under sugar beets grown without sprinkling. Dehydrogenases exhibited the highest activity in conditions of direct sowing and it was found to be even four times higher when compared with traditional cultivation. Sprinkling contributed to increased dehydrogenase activity in conditions of simplified cultivation, causing similar activity in conditions of direct sowing and in the case of the 1st and 3rd dates – even significantly higher.

Presumably, also in this case, the cause of differences between the applied systems of tillage and sprinkling can be sought in different distributions of organic matter in the soil profile as well as in different water-air conditions in the soil. Higher dehydrogenase activity in conditions of sprinkling (poorer soil aeration and faster compaction) and direct sowing (absence of soil softening, farmyard manure left on soil surface) corroborates interrelationships reported by Schulten et al. [28] that the activity of dehydrogenase increased together with greater quantities of organic matter and poorer soil aeration.

Since dehydrogenases are exclusively of microbiological origin, their activity is considered an indirect indicator of numbers and activity of microorganisms in the soil and, therefore, as an indicator determining the overall soil microbiological activity and its fertility [29-32].

The activity of acid phosphatase (Fig. 7) is considerably less varied than of dehydrogenases – both with respect to the method of cultivation and sprinkling. Nevertheless, the observed differences between the employed methods of tillage, although relatively small, were statistically significant, indicating high stability of this feature. Slightly greater differences between the methods of cultivation, but also very regular, were determined in conditions of sprinkling. Irrespective of sprinkling, the lowest activity of acid phosphatase was observed in the soil subjected to traditional ploughing cultivation, while the highest – the soil on which direct sowing was applied.

The obtained research results confirm conclusions drawn by other researchers about favourable influence of the resignation of traditional deep ploughing in favour of simplifications in soil cultivation, even its total abandonment on the activity of soil enzymes [33-35].

It should be emphasized that while the numbers of all analyzed microorganisms changed noticeably depending on the date of the performed analyses nearly always exhibiting the lowest level on the first date (beginning of vegetation) and the highest – on the 2nd or 3rd terms (peak of vegetation season), the soil enzymatic activity – especially with regards to acid phosphatase – remained on a uniform level. This indicates smaller sensitivity of this indicator of soil biological status to temporary factors associated with temperature, moisture content, or plant developmental phase, making it exceptionally useful for monitoring long-term activities. It is most probably connected with the fact that the activity of phosphatases is associated with, among other things, soil colloids and humic substances whose levels are not influenced by rapid changes [36]. Nannipieri et al. [37] reported that plant roots secrete acid phosphatase in conditions of shortage of available phosphorus. The current studies, however, have failed to confirm plant origins of acid phosphatase because its levels were similar both during the peak of the vegetative period and in spring, right after the emergence of plants. The observed higher activity of acid phosphatase in simplified systems, especially in direct sowing, was most likely determined, to the highest extent, by the quantities of organic matter which in these tillage systems was quite abundant in the near-surface soil layer than in conditions of ploughing cultivation [22]. Bearing in mind the above, this higher activity reflects not so much the status of available forms of phosphorus in soil [38], but rather points to potential possibilities of its mineralization [39]. Therefore, stimulation of the activity of acid phosphatase as well as of dehydrogenases by abandonment of the traditional ploughing cultivation is of great importance in processes aiming at improving nutrient availability for crop plants from forms unavailable for them [22, 34].

Changes in soil microorganisms, soil enzyme activity and soil pH are connected with one another. In order to analyze interrelationships taking place between the determined parameters, correlation analysis between them was carried out (Table 5).

The highest positive correlation coefficients were found between several of the analyzed biological parameters, particularly in terms of irrigation. A highly significant positive

Table 5. Correlation coefficients between the different soil chemical and biological properties.

		Oligotrops	Copiotrophs	Actinomycetes	Fungi	Dehydrogenase	Phosphatase	pH
Irrigated	Bacteria	0.655*	0.630*	0.643*	0.529	0.483	0.343	0.145
	Oligotrops		0.805**	0.758**	0.434	0.475	0.493	0.525*
	Copiotrophs			0.503	0.666**	0.407	0.014	0.316
	Actinomycetes				0.123	0.232	0.416	0.112
	Fungi					0.660**	-0.222	0.168
	Dehydrogenase						0.332	0.584*
	Phosphatase							0.599*
Non irrigated	Bacteria	0.446	0.510	0.516	-0.030	0.474	0.427	0.423
	Oligotrops		0.572*	0.553*	0.397	0.479	0.437	0.719**
	Copiotrophs			0.518	0.039	0.279	-0.173	0.518
	Actinomycetes				0.448	0.298	0.239	0.225
	Fungi					0.502	0.044	0.317
	Dehydrogenase						0.428	0.724**
	Phosphatase							0.456

*correlation coefficient significant at significance level = 0.05
**correlation coefficient significant at significance level = 0.01

correlation was determined between total bacterial counts, oligotrophic bacteria, copiotrophic bacteria, and actinomycetes, and between fungi and dehydrogenase activity. This, according to Quemada and Menacho [40], confirms a very high participation of microorganisms in soil total biological activity. The determined highly significant (r=0.805**) positive correlation between numbers of oligotrophic and copiotrophic bacteria deserves attention [22]. The pH of the soil highly significantly correlated with the counts of oligotrophs and activity of soil enzymes.

Analyzing the impact of the applied tillage systems on soil microbiological life, it should be remembered that different technologies employed in this area refer not only to quantities, type, and intensity of tillage, but also to a different system of weed control. In the case of no-tillage systems of this experiment, an additional spraying with a preparation containing glifosat was applied which, undoubtedly, must have affected microbiological indices. On the other hand, in the case of direct sowing, most of the post-harvest residues remained on the soil surface forming a layer of mulch. This means that organic matter from these residues finds its way into the soil much more slowly but, at the same time, it is more concentrated in the surface area. Furthermore, the mulch layer reduces warming up and drying of the soil, helps to maintain its structure, increases concentration of organic carbon and, consequently, activates more effectively its biological life close to its surface.

Soil biological life comprises not only microorganisms but also the so-called mesoflora and mesofauna, whose role in the soil is very important. For instance, earthworms are not only responsible for shaping soil structure and its aeration the transfer of organic matter in soil is not only associated with tillage treatments but also depends on the activities of such animals as earthworms whose numbers are greater in permanent agrocenoses (grasslands) and in soils that are not subjected to intensive tillage systems [41].

Crop plants, especially their root secretions (carbohydrates, amino acids, organic acids, nucleotides, flavonic compounds), change soil physicochemical properties and, indirectly, also exert some influence on the growth and development of soil microorganisms [42].

The influence of cultivation systems on the activity of soil microorganisms can follow many different pathways. Firstly through the transfer of organic matter or its accumulation in the surface layers, secondly through the influence of the condition of plants as well as the impact on numbers of soil mesofauna and – last but not least – via the effect on soil atmosphere. For example, in no-tillage systems soils are, generally speaking, much worse aerated and, consequently, CO_2 accumulation increases, which in turn favors the development of oligotrophs [43].

Conclusions

All in all, the obtained research results were in keeping with tendencies observed in other countries in different climatic and soil conditions. Many years of use of the specific tillage system significantly modified the number of different groups of soil microorganisms in sugar beet and soil enzyme activity, and the effect was dependent on the water variant.

In the vast majority of terms, counts of microorganisms and enzymatic activity of soil were significantly lowest under conventional tillage and highest for no-tillage systems.

The weakest expression of this relationship was observed in the case of actinomycetes, particularly in a irrigation variant, and strongest for the dehydrogenase activity in the absence of irrigation.

In all areas where soil protection against erosion or degradation is of prime importance (for example, in areas with deficiency of rainfall, whether on the restored grounds), careful consideration should be given to possibilities of the application of no-tillage systems.

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