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HUMIC SUBSTANCES IN THE ENVIRONMENT

Seasonal changes in the content of dissolved organic matter in arable soils

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Abstract

Purpose The aim of this paper has been to determine the seasonal changes in the content of dissolved organic matter (DOM) in the soils under agricultural use based on assaying changes in dissolved organic carbon (DOC) and dissolved nitrogen (DNt) as well as determining the factors which can define the DOM in soils.

Materials and methods The research has involved the soils under agricultural use sampled in the Kujawsko-Pomorskie province (Poland). Phaeozems and Luvisols were sampled from the depth of 0–30, 30–60, and 60–100 cm, November 2011 through September 2013, in November, March, May, July, and September. The soil samples were assayed for the grain size composition, pH, dry weight content, content of total organic carbon, and total nitrogen. Dissolved organic matter was extracted with 0.004 mol dm^3 $CaCl_2$; in the DOM extracts, the content of dissolved organic carbon (DOC) and dissolved nitrogen (DNt) were assayed. The research results were statistically verified.

Results and discussion It has been demonstrated that in the first year of research, the content of dissolved organic carbon in the soils was changing throughout the year. The highest differences in the content of that carbon fraction occurred across the soil sampled in autumn and the soil sampled in spring. In the second year of research, an inverse dependence was noted. DOC was migrating to deeper layers of the soil profile; yet, the migration got more intensive in summer. The content of dissolved nitrogen was not changing significantly throughout the year. Higher DNt content in the surface layer, in general, resulted in a higher content of dissolved nitrogen in deeper profile layer, which could have been due to leaching of the nutrient deep down the soil profile.

Conclusions The content of dissolved organic carbon was significantly related to the content of total organic carbon and total nitrogen. Significant changes in the content of dissolved forms of nitrogen were reported in the profile of Phaeozems due to mineral fertilization and irrigation. The soils where irrigation and higher nitrogen rates had been applied demonstrated a higher content and share of soluble forms of nitrogen, as compared with the soils non-irrigated and the soils where lower nitrogen rates had been supplied.

Keywords Cultivated soils · Dissolved nitrogen · Dissolved organic carbon · Luvisols · Phaeozems

1 Introduction

Dissolved organic matter (DOM) is a heterogeneous phase which includes simple short-chain organic compounds representing a group of non-specific humus substances (fatty acids, organic acids, amino acids, sugars) as well as water-soluble substances, being humus compounds in nature (Moore 2003; Silveira 2005). DOM as a highly reactive and most mobile and fast-decomposing humus fraction controls a number of chemical, physical, and biological processes which occur in the soil environment (Zsolnay 1996, 2003; Gonet et al. 2002; Bolan et al. 2011). Although DOM frequently accounts for less than 1% of the total organic matter, it plays a very important role in biogeochemical cycling of carbon, nitrogen, and phosphorus as well as in nutrients transport. Besides, it is a factor stabilizing colloids and soil aggregates

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as well as controlling mineral weathering (Kalbitz et al. 2000; Neff and Asner 2001). DOM, on the other hand, participates in transporting pollution in the soil profile (Kalbitz et al. 2000; Gonet et al. 2002) and mobilizes metal ions and thus their availability and toxicity (Staunton et al. 2002) as well as enhances the solubility of hydrophobic pollutions (Sabbah et al. 2004).

According to, e.g., Zsolnay (1996), Kalbitz et al. (2000), Chantigny (2003), as well as Chow et al. (2006), the formation and mobility of dissolved organic matter in the soils under agricultural use depends on many environmental factors (climate, hydrological conditions, microbiological activity) and anthropogenic factors (tillage, mineral fertilization, organic fertilization and/or natural fertilization, liming).

Changes in the content of DOM in soils can be due to a natural temperature variation which occurs throughout the year (Chapman et al. 1995; McDowell et al. 1998; Scott et al. 1998; Tipping et al. 1999; Andersson et al. 2000). As reported by Chapman et al. (1995), Guggenberger et al. (1998), McDowell et al. (1998), Nadany and Sapek (2004) as well as Jaszczyński et al. (2008), in the meadow and forest soils, the concentration of DOM in soil solution is higher in summer than in winter and early spring. At the same time, one should stress that the changes concern the surface layers, in deeper soil profile layers; changes in the concentration of dissolved forms of organic carbon compounds are much lower (Chapman et al. 1995); or nonsignificant changes are not found at all (Qualls et al. 1991; Qualls and Haines 1992).

Guggenberger et al. (1998) as well as Worall et al. (2003) report on an effect of temperature fluctuations on the content of soluble forms of organic carbon in soil throughout the year being mostly indirect. The higher the temperature, the more favorable the conditions for the development of microorganisms, thus increasing the microbiological activity of soils. A higher microbiological activity, however, intensifies the processes of organic substance decomposition and, as a result, intensifies the process of releasing dissolved forms of organic carbon.

Gaelen et al. (2014), based on the correlations between the dissolved organic carbon (DOC) content and the volumetric water content, found that one of the most essential factors affecting the DOM content in soils under agricultural use is soil moisture. However, as reported by Guggenberger and Zech (1994), under field conditions, the soil moisture does not have a significant effect on the amount of soluble forms of organic carbon compounds. Kalbitz et al. (2000) claim that changes in the DOM content in soils, next to moisture, are also due to the amount and dynamics of precipitation. Jaszczynski et al. (2008) did not identify a direct effect of precipitation on the DOC content in research soils. Gaelen et al. (2014) received negative values of the correlation between the DOC content and the intensity of precipitation. However, in the laboratory conditions, they revealed a few-fold DOC increase after 42.9 mm precipitation per hour.

Soil reaction is an important factor affecting the content and solubility of organic matter is soil (Andersson and Nilsson 2001; Kemmit et al. 2006). The solubility of organic matter was considerably increasing in the horizons of soils with pH below 4–4.5 (Gruba 2009). Due to an increase in dissociation of functional groups in acids, an increase in the solubility of organic matter can also occur at higher pH values (Andersson et al. 2000). The research performed under field conditions by Chapman et al. (1995), Xi et al. (2007) as well as Filep and Rekasi (2011) did not confirm the effect of pH on the content of soluble compounds of organic carbon in soil, and the reports by Kalbitz et al. (2000) show that under field conditions, the effect of pH on DOC dynamics is inconsiderable.

Another factor affecting the content of dissolved organic matter is the tillage method. According to Leinweber et al. (2001), an intensive plow tillage stimulates the microbiological decomposition of post-harvest residue, thus increasing the content of DOM. Andruschkiewitsch et al. (2013) and Liu et al. (2014) claim that plowless tillage combined with an adequate plant selection in crop rotation can lead to an increase in DOC in soil. Liu et al. (2014) reported a twofold higher DOC content in the 0–5 cm soil layer with plowless tillage, as compared with the soil with plow tillage.

The effect of mineral fertilization on the content of DOM is not definite (Zsolnay and Gorlitz 1994; Kalbitz et al. 2000; Chantigny 2003; Embacher et al. 2008). Mineral fertilization, with nitrogen mostly, can decrease the content of DOM by stimulating the microbiological activity which, in turn, increases the consumption of soluble organic carbon compounds (Chantigny 2003) or it can increase the DOM content due to organic matter decomposition processes (Kalbitz et al. 2000). According to Liu et al. (1995), applying mineral ammonium and urea fertilizers results in a temporary increase in the content of DOM due to a change in the soil pH value, whereas Embacher et al. (2008) claim that nitrogen fertilization stimulates an increase in crop biomass, which in turn, increases the content of post-harvest residue and, as a result, an increase in the content of DOM in soil (Gregorich et al. 2000).

Another important source of both the total and dissolved organic carbon in soils are organic and natural fertilizers (Zsolnay and Gorlitz 1994; Rochette and Gregorich 1998; Embacher et al. 2008; Kwiatkowska-Malina 2011; Singh et al. 2014; Jokubauskaite et al. 2015). Many of those researchers reported on an increase in DOC following the application of natural fertilizers (farmyard manure (FYM) mostly), e.g., Rochette and Gregorich (1998), after the FYM application at the rate of 100 Mg kg^{-1}, reported an increase in the content of DOC by 130 mg kg^{-1} of soil. As stressed by, e.g., Gregorich et al. (2000), Gonet et al. (2002) and Haynes

(2005), an essential factor affecting the DOM content in arable soils is the amount and kind of post-harvest residue introduced into soil. One shall note that DOM from post-harvest residue as well as present in organic and natural fertilizers is highly biodegradable and quickly used up by microorganisms, and so, it can result in only a temporary increase in the DOM content in soil (Singh et al. 2014). Similarly, Rochette and Gregorich (1998) in their field experiments observed a very fast increase in soluble forms of organic carbon compounds right after the FYM application and then a gradual decreasing throughout the vegetation period.

Generally, it is assumed that changes in the DOM content can be an important indicator of changes which occur in soils, especially due to anthropogenic factors (Bolan et al. 2011).

With the above in mind, the present paper is an attempt at determining seasonal changes in the content of dissolved organic matter in soils under agricultural use by assaying the changes in the DOC and dissolved nitrogen (DNt) as well as determining the factors which could affect the DOM content in soils.

2 Materials and methods

2.1 Research material

The research has involved the soil under agricultural use sampled at Gniewkowiec (the Kujawsko-Pomorskie province, Poland, Table 1). The Phaeozem samples (samples nos. 1, 5, 6, 10, 11, and 20) and Luvisols (samples nos. 2, 4, 7, 8, 14, 15, and 16) were taken from the depth of 0–30, 30–60, and 60–100 cm, November 2011 through September 2013, in November, March, May, July, and September. The grain size composition of the soil samples is presented in Table 2. For a variation in precipitation and mean monthly temperature (Zarski et al. 2010), see Fig. 1. The Phaeozem sampling locations varied in terms of the irrigation and mineral nitrogen fertilization rates applied (Table 1). In the locations with irrigation, vegetable crops and, in the non-irrigated locations, cereal crops and rape were grown. The Luvisol sampling locations differed in terms of the rates of natural and organic as well as mineral nitrogen fertilization applied (Table 1). In the research years in Luvisol cereal crops, rape and sugar beet were grown. In all the soil sampling locations, plow tillage was applied.

2.2 Research methods

In the soil samples right after sampling, the *content of dry weight* (W_{dm}) was assayed with the weighing method.

For air-dry soil samples, the following analyzes were made:

- *Grain size composition* was determined applying the aerometric method;
- *pH*—in the suspension of distilled water and soil with the pH meter MultiCal pH 540 GLP WTW;
- *The content of total organic carbon (TOC) and total nitrogen (Nt)*. The content of organic carbon and total nitrogen

Table 1 List of samples and types of agrotechnical practices

Sample no.	Soil type	Irrigation (l m^2 season^{-1})		Mineral fertilization (kg N ha^{-1})		Natural and organic fertilization	
		2011–2012	2012–2013	2011–2012	2012–2013	2011–2012	2012–2013
5	Phaeozems	200	150	126	161	–	–
10	Phaeozems	200	100	161	184	–	–
20	Phaeozems	100	150	182	160	–	–
1	Phaeozems	–	–	102	115	–	–
6	Phaeozems	–	–	95	108	–	–
11	Phaeozems	–	–	155	155	–	–
7	Luvisols	–	–	58	63	20,000 l ha^{-1}[a]	20,000 l ha^{-1}[a]
8	Luvisols	–	–	131	160	25,000 l ha^{-1}[b]	25,000 l ha^{-1}[b]
15	Luvisols	–	–	83	95	40 t ha^{-1}[c]	–
2	Luvisols	–	–	146	143	–	–
4	Luvisols	–	–	108	115	–	–
14	Luvisols	–	–	135	155	–	–
16	Luvisols	–	–	135	155	–	–

[a] Digestate from biogas plants

[b] Pig slurry

[c] Cattle manure

Table 2 Basic parameters of soils

Parameter		Phaeozems			Luvisols		
Deep (cm)		0–30	30–60	60–100	0–30	30–60	60–100
TOC	Mean	7.65	5.41	2.57	7.24	4.79	1.84
	Min	6.04	3.06	0.81	5.01	2.34	0.64
	Max	9.17	7.14	5.17	10.04	6.89	3.86
	SE	0.78	1.02	0.99	1.29	1.09	0.66
	CV (%)	10.2	18.9	38.7	17.7	22.7	36.3
Nt	Mean	0.87	0.67	0.39	0.82	0.59	0.26
	Min	0.63	0.40	0.15	0.62	0.27	0.11
	Max	1.13	1.00	0.68	1.11	0.94	0.60
	SE	0.12	0.15	0.12	0.11	0.14	0.10
	CV (%)	13.9	21.7	31.1	13.8	24.2	38.7
pH	Min	6.26	6.07	6.45	5.12	4.96	6.73
	Max	7.98	7.89	7.99	7.87	8.17	8.37
Grain size composition (%)							
Size (mm)		2–0.05	0.05–0.002	< 0.002	2–0.05	0.05–0.002	< 0.002
Mean		70.3	18.3	11.3	80.0	12.0	7.4
Min		64.0	7.0	6.0	73.0	6.0	4.0
Max		87.0	23.0	14.0	90.0	19.0	12.0
SE		8.4	5.9	2.9	5.8	4.4	2.4
CV (%)		11.9	32.3	26.0	7.2	35.2	32.8

SE standard error, *CV* coefficient of variation

were assayed with the Vario Max CN analyzer provided by company Elementar (Germany). The content of TOC and Nt was expressed in grams per kilogram of dry weight (d.w.) of soil;

- *the content of DOC and DNt*. Dissolved organic carbon and dissolved nitrogen were assayed in the solutions from the extraction of the soil sample of 0.004 mol dm^{-3} $CaCl_{2,}$ at the ratio of soil sample/extractant of 1:10. Extracting took 1 h, and then, the solution was centrifuged. In the extracts of dissolved organic matter, there the content of DOC and DNt with Multi N/C 3100 Analytik Jena analyzer was assayed. The content of DOC and DNt was expressed in milligrams per kilogram d.w. of the soil sample as well as the percentage share in the pool: TOC and Nt, respectively.

To determine the effect of soil sampling date on the values of the qualitative characters at respective depths, a single-factor analysis of variance was performed with the Tukey test, at the level of significance of $\alpha = 0.05$. The effect of anthropogenic factors (irrigation, natural, and organic fertilization as well as mineral fertilization) on varied selected qualitative parameters of soils was evaluated with the *t* Student test for dependent samples. The dependencies across the factors were determined with the Pearson correlation coefficient. For statistical calculations, the Excel spreadsheet and Statistica MS 2010 package were used.

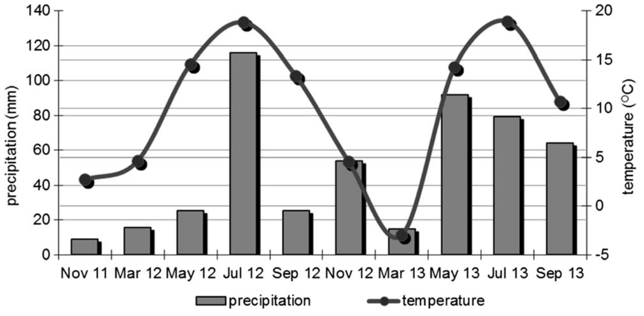


Fig. 1 Variation in precipitation and mean monthly temperature

3 Results and discussion

To define the seasonal changes in the content of dissolved organic matter (DOM), arable soil was sampled (Luvisols, Phaeozems, Table 1). The pH value of the soils was similar to neutral and it was slightly changing with depth (Table 2). The highest pH (6.45–7.99 for Phaeozems; 6.73–8.37 for Luvisols) was reported for the soil sampled from the 60–100 cm layer. The content of dry weight was changing from 80.4 to 95.9% (Figs. 2 and 3). In the first year of research, there were noted significant differences in the content of dry weight in the surface soil. The lowest content of dry weight was found for the soil sampled in November. For Luvisols there were also noted significant moisture differences in deeper layers. The content of dry weight in the samples of Phaeozems sampled from the 30–100 cm layers did not depend on the soil sampling date. The mean content of TOC in

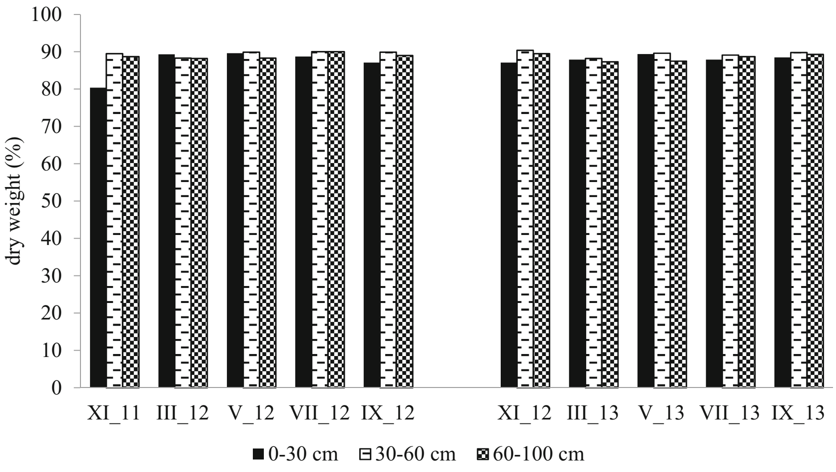


Fig. 2 Mean content of dry weight in Phaeozem samples depending on the sampling date. LSD for the first research year: 0–30 cm—7.0; 30–60 cm—n.s.; 60–100 cm—n.s.; LSD for the second research year—n.s

the Phaeozem surface samples was 7.65 g kg^{-1} and Luvisols—7.24 g kg^{-1}. The content of TOC was decreasing with depth; the lowest content—in the 60–100 cm layer was found in the Luvisol samples; the mean of 1.84 g kg^{-1} (Table 2). The mean content of TOC in Phaeozem samples from the deepest layer was 2.57 g kg^{-1}. The content of TOC did not depend on the soil sampling date. Significant differences across the soil sampling dates were not found for the total nitrogen content either. In the surface layer, the mean higher nitrogen content was found for Phaeozems—0.87 g kg^{-1} than the Luvisol sample —0.82 g kg^{-1}(Nt, Table 2). For Phaeozems sampled from the 30–60 cm layer, the mean content of Nt was 0.67 g kg^{-1}, and in Luvisols—0.59 g kg^{-1}. The mean Nt content in the 60–100 cm layer ranged from 0.26 g kg^{-1}—Luvisols—to 0.39 g kg^{-1}—Phaeozems.

The mean content of dissolved organic carbon (DOC) in the surface samples of Phaeozems was 62.8 mg kg^{-1} and Luvisols—61.3 mg kg^{-1}. In the 30–60 cm layer, the mean DOC content was also slightly higher in the Phaeozem samples—54.0 mg kg^{-1}—than in the Luvosol samples—52.0 mg kg^{-1}. The lowest DOC content was recorded for the samples from the 60–100 cm layer, ranging from 33.3 mg kg^{-1}—Luvisols—to 38.5 mg kg^{-1}—Phaeozems.

DOC in the samples from the depth of 0–30 cm in the first year of research depended on the sampling date. The highest content of DOC was shown for the soil sampled in November and the lowest in March (Figs. 4 and 5), which points to a decrease in the content of that carbon fraction in winter.

In the second year of research, an inverse dependence was noted; the content of DOC in the soil sampled in spring was higher than in the soil sampled in autumn; however, the differences were not significant (Figs. 4 and 5). Chapman et al. (1995), Guggenberger et al. (1998), McDowell et al. (1998), Scott et al. (1998), Tipping et al. (1999), Nadany and Sapek (2004) as well as Jaszczyński et al. (2008) showed that in the forest and meadow soils, the lowest concentration of labile fractions of organic carbon occurred in winter and the highest at the end of summer and in early autumn. The data presented in the literature cited points to a continuous growing tendency

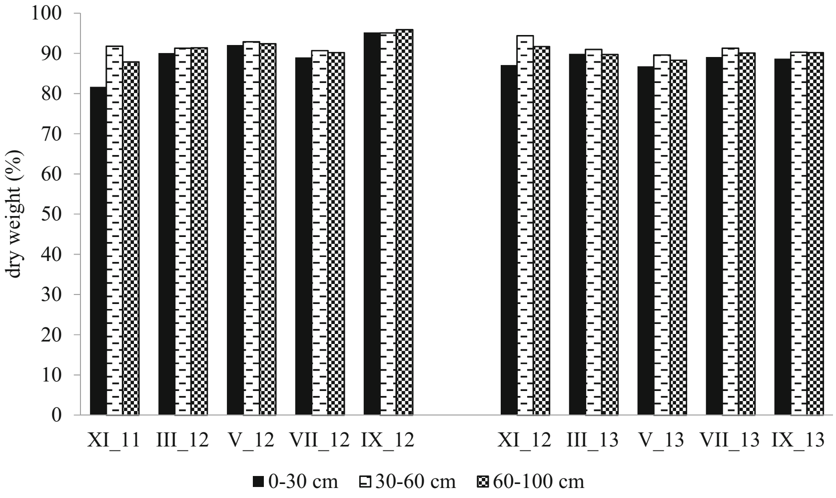
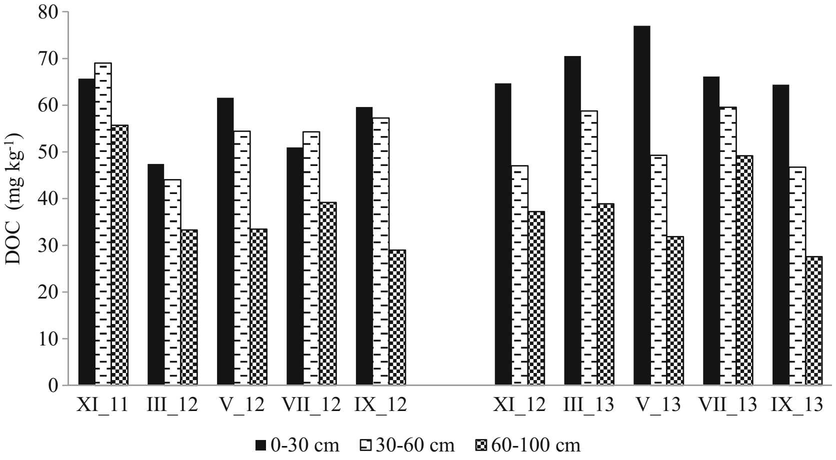


Fig. 3 Mean content of dry weight in Luvisol samples depending on the sampling date. LSD for the first year: 0–30 cm—4.9; 30–60 cm—3.1; 60–100 cm—5.8; LSD for the second year: 0–30—n.s.; 30–60 cm—4.3; 60–100 cm—n.s

Fig. 4 Mean DOC content in Phaeozem samples depending on the sampling date. LSD for the first research year: 0–30 cm—13.0; 30–60 cm—11.3; 60–100 cm—13.2; LSD for the second research year—n.s



of changes in the content of DOC than the lowest value in winter to the highest value in summer and early autumn. In the research discussed in that paper, there were observed DOC content fluctuations in summer and in autumn, which suggests that the content of that carbon fraction in arable soils changes with a different frequency than in meadow and forest soils. Tendencies of changes in the content of DOC in the samples of soils taken from the depth of 30–60 and 60–100 cm were similar as in the samples from the depth of 0–30 cm (Figs. 4 and 5). In these layers, a higher content of DOC in the first year of research was recorded for the samples taken in autumn and lower in spring. However, in the second research year in the soil samples of the 30–60 and 60–100 cm layers, a higher DOC content was found for the soil sampled in summer, as compared with the soil sampled in late autumn. Chapman et al. (1995), investigating the content of soluble forms of organic carbon compounds in forest soils from deeper horizon, recorded the lowest DOC content in the soil sampled in winter (February) and the highest one in late summer and early autumn (September). Also, Qualls et al. (1991) as well as Jaszczynski et al. (2008), researching the seasonal changes in the content of DOC in meadow and forest soils, observed that the samples taken in late summer and early autumn showed a higher content of soluble forms of organic carbon compounds than in winter.

According to McDowell et al. (1998), the content of dissolved nitrogen (DNt) in soil, similarly as the content of DOC, changes seasonably. The mean DNt content in the Luvisol surface layer was 17.3 mg kg^{-1} and in Phaeozems—16.4 mg kg^{-1}. In the 30–60 cm layer, the DNt content was also higher in Luvisols—13.0 mg kg^{-1} than in Phaeozems—11.1 mg kg^{-1}. However, in the deepest layer, irrespective of the soil type, the mean DNt content was 7.7 mg kg^{-1}. The share of DNt in the total nitrogen pool ranged from 1.03 to 3.90% in the surface layer, from 0.94 to 3.34% in the 30–60 cm layer, and in the 60–100 cm layer it ranged from 1.84 to 5.85%. Generally, the results of the content and share of DNt did not differ significantly across the sampling dates (Table 3). One shall also stress that a higher DNt content, in deeper profile layers, could have been due to leaching of that nutrient deep the soil profile.

As reported by, e.g., Scott et al. (1998), Tipping et al. (1999), Andersson et al. (2000), Nadany and Sapek (2004) as well as Jaszczynski et al. (2008), changes in the content

Fig. 5 Mean content of DOC in Luvisol samples depending on the sampling date. LSD for the first research year: 0–30 cm—15.3; 30–60 cm—n.s.; 60–100 cm—9.9; LSD for the second research year: 0–30 cm—n.s.; 30–60 cm—n.s.; 60–100 cm—16.3

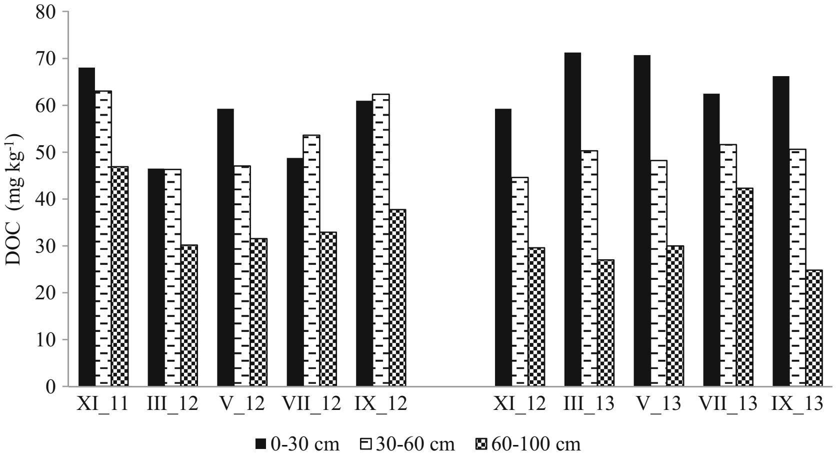


Table 3 Mean values of the content of dissolved nitrogen (DNt)

Parameter	DNt (mg kg^{-1})	DNt (%)	DNt (mg kg^{-1})	DNt (%)	DNt (mg kg^{-1})	DNt (%)
Term	0–30 cm		30–60 cm		60–100 cm	
Phaeozems						
XI_11	16.51 ± 12.6	1.90 ± 1.47	11.64 ± 9.2	1.62 ± 0.87	7.13 ± 5.4	1.90 ± 1.50
III_12	11.09 ± 11.8	1.26 ± 1.14	5.61 ± 1.6	0.94 ± 0.21	8.03 ± 7.3	2.28 ± 1.51
V_12	38.12 ± 40.4	4.11 ± 1.96	17.13 ± 10.8	2.18 ± 1.06	7.64 ± 3.7	2.24 ± 1.33
VII_12	14.31 ± 11.2	1.88 ± 0.91	12.82 ± 10.1	1.79 ± 1.03	10.11 ± 9.0	2.50 ± 1.39
IX_12	18.43 ± 11.0	1.95 ± 0.90	12.25 ± 4.0	1.78 ± 0.47	7.02 ± 3.4	1.84 ± 1.33
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
XI_12	10.63 ± 4.4	1.20 ± 0.32	13.23 ± 10.3	1.98 ± 1.09	7.37 ± 5.1	2.63 ± 2.09
III_13	18.30 ± 11.5	2.13 ± 1.18	12.35 ± 8.8	2.09 ± 1.06	7.87 ± 5.4	2.36 ± 1.43
V_13	14.09 ± 2.9	1.78 ± 0.52	8.25 ± 5.8	1.21 ± 0.82	6.59 ± 5.6	2.67 ± 1.90
VII_13	13.06 ± 4.5	1.43 ± 0.63	7.86 ± 1.8	1.25 ± 0.29	6.85 ± 3.2	2.12 ± 1.63
IX_13	9.10 ± 1.4	1.03 ± 0.21	9.97 ± 3.8	1.64 ± 0.57	7.98 ± 4.6	2.92 ± 1.59
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Luvisols						
XI_11	16.57 ± 10.6	2.22 ± 1.55	12.28 ± 7.6	2.28 ± 1.15	5.72 ± 1.6	3.02 ± 1.86
III_12	13.44 ± 18.6	1.73 ± 1.46	6.19 ± 2.8	1.16 ± 0.38	9.88 ± 1.9	3.94 ± 2.04
V_12	32.04 ± 30.9	3.90 ± 2.80	13.99 ± 13.8	2.24 ± 0.99	5.99 ± 2.7	2.54 ± 1.02
VII_12	13.59 ± 8.2	1.59 ± 1.00	16.44 ± 13.0	2.39 ± 0.92	10.08 ± 5.4	3.15 ± 1.88
IX_12	11.98 ± 3.7	1.37 ± 0.43	10.71 ± 3.4	1.48 ± 0.49	7.26 ± 3.9	2.47 ± 1.04
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
XI_12	12.24 ± 7.7	1.41 ± 0.76	9.73 ± 6.7	1.78 ± 0.83	5.90 ± 1.9	2.98 ± 1.70
III_13	25.13 ± 11.9	3.21 ± 1.77	22.79 ± 3.1	3.34 ± 1.14	5.94 ± 1.2	2.59 ± 1.35
V_13	23.08 ± 24.8	2.70 ± 1.52	14.57 ± 12.4	2.47 ± 0.95	4.49 ± 1.7	2.03 ± 1.10
VII_13	12.59 ± 6.7	1.43 ± 0.52	8.37 ± 2.9	1.48 ± 0.44	8.24 ± 6.2	3.92 ± 3.08
IX_13	12.12 ± 3.1	1.55 ± 0.38	14.86 ± 6.7	2.40 ± 0.77	13.29 ± 8.7	5.85 ± 4.08
LSD	n.s.	n.s.	n.s.	n.s.	8.5	n.s.

LSD least significant difference, *n.s.* not significant

of DOM in the surface soil layers are related to temperature changes. The analysis of correlation did not confirm a significant effect of temperature on the content and share of DOC. Similarly in the research performed, e.g., by Qualls and Haines (1992), no effect of temperature on the DOM content was shown.

In the first research year, the lowest content of dry weight, and the highest DOC, in the soil sampled from the depth of 0–30 cm, occurred in November (Figs. 2, 3, 4, and 5). The dependence suggests an occurrence of the relationship between the soil moisture and the content of DOM. Unlike the results reported by Gaelen et al. (2014), in the research performed (for some variants), significant negative dependencies of correlation between the content and the share of DOC as well as DNt and the content of dry weight (W_{dm}) were reported (Table 4).

In the Luvisols sampled in the first research year, a significant negative correlation between the amount of precipitation and the content and share of DOC (from − 0.34 to − 0.49) was found. Besides, an increase in the content of DOC and with an increase in the amount of precipitation in the soil sampled in July from deeper soil profile layers (Figs. 1, 4, and 5) was observed. With the dependencies between the content and the share of DOC and the total precipitation, with some approximation, one can assume that hydrologic conditions modify the content of DOM, which was also reported by Kalbitz et al. (2000) and Chow et al. (2006).

Generally, the mean content and the share of DOC were significantly correlated with the mean content of TOC (Table 4). The dependencies coincide with earlier reports (Delprat et al. 1997; Gregorich et al. 2000; Gonet et al. 2002; Xi et al. 2007) and confirm the thesis that the key source of dissolved organic matter is soil humus (Filep and Rekasi 2011). Interestingly, in the soil sampled from the depth of 60–100 cm, the mean share of DOC fraction for Phaeozems was 1.65% and for Luvisols—1.98% and for the some variants was almost two- or even threefold higher, as compared with the mean share of that carbon fraction in the samples

Table 4 Values of the coefficients of correlation between the content and share of DOC (DNt) and the content of dry weight (W_{dm}) and TOC

Parameter		2011–2012			2012–2013		
		0–30 cm	30–60 cm	60–100 cm	0–30 cm	30–60 cm	60–100 cm
Phaeozems							
DOC (mg kg^{-1}) x	W_{dm}	− 0.46[a]	0.14	− 0.03	− 0.34	− 0.35	− 0.46[a]
	TOC	0.44[a]	0.44[a]	0.51[a]	0.28	0.37[a]	0.63[a]
DOC (%) x	W_{dm}	− 0.22	0.24	0.22	− 0.16	− 0.15	0.29
	TOC	− 0.10	− 0.58[a]	− 0.69[a]	− 0.31	− 0.65[a]	− 0.56[a]
DNt (mg kg^{-1}) x	W_{dm}	0.01	− 0.12	− 0.43[a]	− 0.01	0.22	0.02
	TOC	0.15	0.25	0.12	0.16	0.38[a]	− 0.22
DNt (%) x	W_{dm}	0.09	0.03	0.07	0.14	0.32	0.24
	TOC	0.15	0.09	0.07	− 0.08	0.21	− 0.57[a]
Luvisols							
DOC(mg kg^{-1}) x	W_{dm}	− 0.33[a]	− 0.10	− 0.21	− 0.42[a]	− 0.51[a]	− 0.09
	TOC	0.34[a]	0.42[a]	0.31	0.69[a]	0.73[a]	0.38[a]
DOC (%) x	W_{dm}	− 0.28	0.14	− 0.23	− 0.49[a]	0.18	0.15
	TOC	− 0.40[a]	− 0.68[a]	− 0.60[a]	0.09	− 0.48[a]	− 0.32
DNt (mg kg^{-1}) x	W_{dm}	− 0.09	− 0.15	− 0.02	− 0.56[a]	− 0.34[a]	0.02
	TOC	− 0.21	0.08	0.19	0.27	0.30	− 0.07
DNt (%) x	W_{dm}	− 0.06	− 0.12	− 0.09	− 0.45[a]	− 0.34[a]	0.04
	TOC	− 0.29	− 0.13	− 0.11	0.09	0.22	− 0.39[a]

W_{dm} dry weight

TOC total organic carbon

[a] significant correlation

from the depth of 0–30 cm (Figs. 6 and 7). As reported by Gonet et al. (2002), it is an effect of migration of dissolved organic matter deep down the soil profile.

Between the content and share of DNt and the content of Nt, there were noted no such definite dependencies as for the content of TOC and its soluble forms. However, in the soil sampled in spring—right after the application of nitrogen fertilization (March, May)—a considerable increase in soluble nitrogen forms was observed. The mean content of DNt in the soil sampled in the month right after the application of fertilization (in the first year of research, in May, in the second year of research—in March), as compared with the content of DNt in November, was 131% for Phaeozems and 93% for Luvisols higher in the first research year and by 72% (Phaeozems) and 105% (Luvisols) in the second research year. An increase in the content of DNt, by an average of 66%, after the application of nitrogen fertilization was also recorded by Embacher et al. (2008). Besides, it was found (Table 5) that the level of mineral fertilization is an important factor determining the content and share of DNt. In the samples of

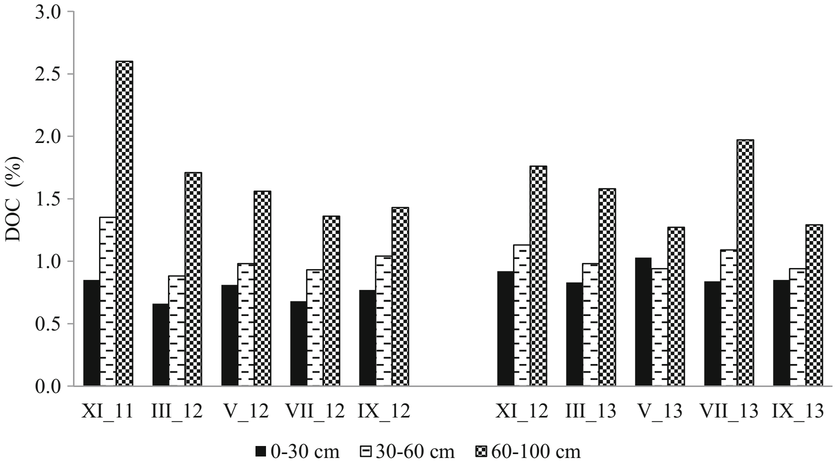
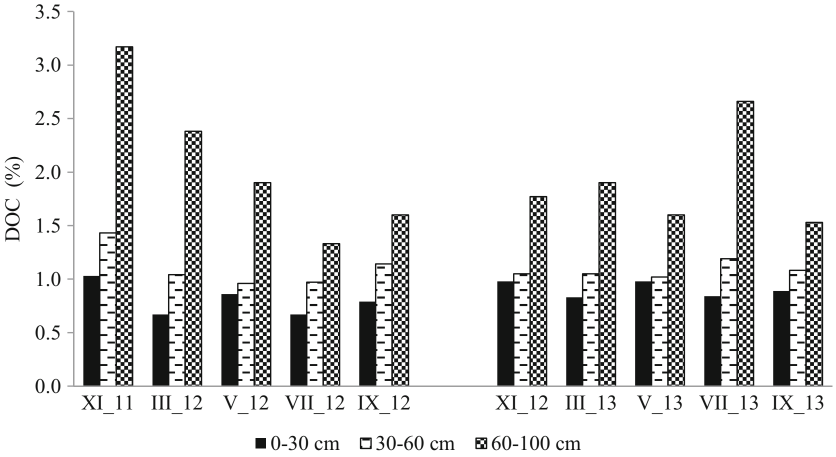


Fig. 6 Mean DOC share in the pool of TOC in Phaeozem samples depending on the sampling date. LSD for the first research year: 0–30 cm—0.17; 30–60 cm—0.34; 60–100 cm—0.98; LSD for the second research year—n.s

Fig. 7 Mean share of DOC in the pool of TOC in Luvisol samples depending on the sampling date. LSD for the first research year: 0–30 cm—0.22; 30–60 cm—0.33; 60–100 cm—1.08; LSD for the second research year: 0–30 cm—n.s.; 30–60 cm—n.s.; 60–100 cm—0.80



Phaeozems from the locations where higher rates of mineral fertilizers (> 120 kg ha^{-1}) had been applied, the content and share of DNt was higher than in the soil samples where lower rates (< 120 kg ha^{-1}) were provided. Such dependence was significant for both research years only for the soil sampled from the depth of 60–100 cm (Table 5). However, one shall note that in the soil sampled from the 0–30 cm layer after the application of higher fertilizer rates the mean content of DNt increased from about 29 to 46%, and in the 30–60 cm layer from about 61 to 87%.

Contrary to the results of research recorded by Embacher et al. (2008) and Jokubauskaite et al. (2015), mineral nitrogen fertilization was not observed to considerably affect the changes in the content of DOC (Table 5). A lack of significant effect of nitrogen fertilization on the content of DOC was also reported by Zsolnay and Gorlitz (1994) as well as McDowell et al. (1998). There was identified, however, a significant increase in the share of DOC accompanied by an increase in the rate of the nitrogen fertilization applied in the soil sampled from the depth of 60–100 cm.

As seen from the papers by Rochette and Gregorich (1998), Embacher et al. (2008), Kwiatkowska-Malina (2011), and Jokubauskaite et al. (2015), an important source of the total and dissolved organic carbon in soils are organic and natural fertilizers. Of the soils under study, organic or natural fertilization was applied in three fields (Luvisols, Table 1). The analyzes of the dependencies between natural or organic fertilization and the content and share of DOC and DNt show that the fertilization applied did not result in any changes in the content and share of DOC or DNt in the soils. As reported by Rochette and Gregorich (1998) as well as by Singh et al. (2014), an increase in soluble forms of organic carbon compounds is observed only right after applying organic fertilizers. Of all the Phaeozem samples, three sampling locations included the fields which had been irrigated (Table 1). The relationships provided in Table 6 show that irrigation was a factor significantly differentiating the content and share of DNt in deeper soil profile layers. The content and share of DNt in the irrigated soil samples was significantly higher than in the soil sampled from non-irrigated locations. In the 0–30 cm layer in the first research year, the soils sampled from the irrigated locations contained about 66% more DNt than non-irrigated soils. Besides, it was observed that in the irrigated locations, the greater the depth, the greater the share of DNt, which can point to a relatively strong leaching of soluble forms of nitrogen as affected by that factor.

A similar dependence was observed while evaluating the effect of irrigation on changes in the share of DOC in the soil sampled from the deepest layer studied (60–100 cm, Table 6). The share of DOC in the deepest layer was significantly higher in the soil sampled from irrigated locations, as compared with the non-irrigated ones.

In all the soil sampling locations, a crop rotation was applied, showing a neutral or depleting effect on the content of organic matter (cereal crops, vegetables, rape). In the research period, the crop species was not observed to modify the content of dissolved organic matter. It was found, however, that July through September, namely right after introducing post-harvest residue to soils, the content of DOC in the soil sampled from the depth of 0–30 cm was increasing, which coincides with the research results reported by, e.g., Gregorich et al. (2000) as well as Gonet et al. (2002). Interestingly, however, an increase in the content of DOC in soil in those months could have been also related to the application of tillage treatments or an effect of both.

A comparison, drawing on literature reports (Guggenberger et al. 1998; McDowell et al. 1998; Nadany and Sapek 2004; Jaszczynski et al. 2008), of changes in the content of dissolved organic matter in meadow and forest soils with the dynamics of changes in the arable soils identified that changes in the DOC content in arable soils are more intensive. As reported by Kalbitz et al. (2000), more frequent fluctuations in the content of DOC in the surface arable soil layer can be due to a direct effect of agrotechnical practices.

Table 5 Effect of mineral fertilization on selected quality parameters in Phaeozems

Parameter		0–30 cm		30–60 cm		60–100 cm	
		Rate < 120 kg ha^{-1} $n = 2$	Rate > 120 kg ha^{-1} $n = 4$	Rate < 120 kg ha^{-1} $n = 2$	Rate > 120 kg ha^{-1} $n = 4$	Rate < 120 kg ha^{-1} $n = 2$	Rate > 120 kg ha^{-1} $n = 4$
2011–2012							
TOC(g kg^{-1})	$\bar{x}$	7.76	7.51	5.76	5.40	3.58	2.12
	t_α	0.04[a]		0.17		0.001[a]	
DOC(mg kg^{-1})	$\bar{x}$	58.47	56.33	57.01	55.16	46.31	36.96
	t_α	0.54		0.63		0.004[a]	
DOC(%)	$\bar{x}$	0.76	0.75	1.00	1.05	1.37	1.91
	t_α	0.89		0.39		0.002[a]	
DNt(mg kg^{-1})	$\bar{x}$	14.60	21.30	7.38	13.92	5.44	9.41
	t_α	0.26		0.08		0.09	
DNt(%)	$\bar{x}$	1.58	2.41	1.03	1.97	1.20	2.67
	t_α	0.18		0.05[a]		0.01[a]	
2012–2013							
TOC(g kg^{-1})	$\bar{x}$	7.85	7.65	5.58	5.15	3.18	2.20
	t_α	0.35		0.07		0.002[a]	
DOC(mg kg^{-1})	$\bar{x}$	69.69	67.96	53.80	51.43	39.44	35.64
	t_α	0.56		0.32		0.06	
DOC(%)	$\bar{x}$	0.89	0.89	0.98	1.03	1.24	1.74
	t_α	0.91		0.42		0.02[a]	
DNt(mg kg^{-1})	$\bar{x}$	10.94	14.08	7.33	11.83	4.36	8.87
	t_α	0.25		0.09		0.003[a]	
DNt(%)	$\bar{x}$	1.28	1.63	1.07	1.91	0.91	3.37
	t_α	0.27		0.07		0.002[a]	

$\bar{x}$ mean value for the parameter calculated

[a] Significant difference at $t_\alpha < 0.05$

Table 6 Effect of irrigation on selected quality parameters in Phaeozems

Parameter		0–30 cm		30–60 cm		60–100 cm	
		Non-irrigation $n = 3$	Irrigation $n = 3$	Non-irrigation $n = 3$	Irrigation $n = 3$	Non-irrigation $n = 3$	Irrigation $n = 3$
2011–2012							
DOC (mg kg^{-1})	$\bar{x}$	50.5	54.6	55.08	56.46	41.71	40.92
	t_α	0.12		0.06		0.14	
DOC(%)	$\bar{x}$	0.78	0.73	1.08	0.99	1.58	1.88
	t_α	0.19		0.12		0.03[a]	
DNt (mg kg^{-1})	$\bar{x}$	14.2	23.6	7.2	16.5	4.5	11.7
	t_α	0.22		0.05[a]		0.02[a]	
DNt(%)	$\bar{x}$	1.58	2.68	1.05	2.27	1.08	3.29
	t_α	0.19		0.04[a]		0.01[a]	
2012–2013							
DOC (mg kg^{-1})	$\bar{x}$	69.6	67.5	50.9	53.5	41.7	38.4
	t_α	0.41		0.33		0.14	
DOC(%)	$\bar{x}$	0.90	0.89	1.04	0.99	1.39	1.75
	t_α	0.92		0.41		0.04[a]	
DNt (mg kg^{-1})	$\bar{x}$	12.4	13.7	6.9	13.7	4.6	10.2
	t_α	0.29		0.05[a]		0.001[a]	
DNt(%)	$\bar{x}$	1.43	1.60	1.07	2.19	1.05	4.05
	t_α	0.15		0.05[a]		0.01[a]	

$\bar{x}$ mean value for the parameter calculated

[a] Significant difference at $t_\alpha < 0.05$

4 Conclusions

1. The content of dissolved organic carbon (DOC) in the soils under agricultural use was changing throughout the year. The highest differences in the DOC content occurred between the soil sampled in autumn and the soil sampled in spring. Dissolved organic carbon was migrating to deeper soil profile layers.
2. The content of dissolved organic carbon was significantly related to the content of total organic carbon and total nitrogen. However, no direct effect of the organic/natural fertilization on the DOC content was found.
3. The content of dissolved nitrogen was not changing throughout the year. The soils which had been irrigated and treated with higher nitrogen rates showed a higher content and share of DNt, as compared with the non-irrigated soils and the soils with lower nitrogen rates.

The results have demonstrated that the seasonal changes in the content of dissolved organic matter in arable soils depend directly and/or indirectly on environmental and anthropogenic factors; some increase and others decrease the content of dissolved organic matter. For that reason, to evaluate the changes in the content of dissolved organic matter in field conditions, one should always consider the effect of their interaction.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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