POLISH JOURNAL OF SOIL SCIENCE
VOL. LII/2 2019 PL ISSN 0079-2985

DOI: 10.17951/pjss/2019.52.2.183

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CONTENT AND CHANGES IN DISSOLVED ORGANIC MATTER IN MEADOW AND ARABLE SOILS OVER TIME

Received: 14.09.2018
Accepted: 27.05.2019

Abstract. Considering the discrepancies in the reports on seasonal changes in the content of dissolved organic carbon, this paper concerns the research which aimed at defining the content and seasonal changes in dissolved organic matter (DOM) in arable and meadow soils in moderate climate conditions. The research has involved the soils sampled in the Kujawsko-Pomorskie province (Poland). Gleic Phaeozems (meadow soils), Brunic Arenosols and Eutric Cambisol were sampled from the depth of 0–30 cm, 30–60 cm and 60–100 cm, in November 2011 through September 2013. The soil samples were analyzed for dry weight content, pH, content of total organic carbon and total nitrogen. DOM was extracted with 0.004 mol·dm^{-3} $CaCl_2$. In the extracts the content of dissolved organic carbon (DOC) and dissolved nitrogen (DNt) were assayed. The share of DOC and DNt was determined by the soil management. The analysis of variance did not show significant differences in the content of TOC and Nt across the soil sampling dates. There were recorded changes in DOC and DNt between successive sampling dates; for topsoil for DOC – from -12.06% to 13.34% (meadow soils) and for DNt – from -40.84% to 47.44% (arable soils).

Keywords: meadow and arable soils, TOC, TNt, dissolved organic matter

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INTRODUCTION

The presence of organic matter is one of the most important soil features, which is related to the key role played by humus in most processes which occur in pedosphere. In the organic matter resources in soil one can distinguish dissolved organic matter (DOM), which is the most mobile and fast-decomposing (Haynes 2000, Gonet *et al.* 2002). DOM often accounts for less than 1% of the total organic matter, however, it affects the chemical, biological and physical soil properties considerably (Chantigny 2003). DOM plays an essential role in the biogeochemical cycling of carbon, nitrogen and phosphorus and it can provide nutrients and energy for microorganisms (Haynes 2000, Kalbitz *et al.* 2000). DOM components, mostly low-molecular fractions of humus substances, act as a stimulator of plant growth and development (Gonet *et al.* 2002). DOM is chemically and physically bonded, it participates in the transport of pollutions in the soil profile (Kalbitz *et al.* 2000, Gonet *et al.* 2002, Staunton *et al.* 2002).

The formation and mobility of dissolved organic matter in soil depends on many environmental and anthropogenic factors. The first group of factors includes e.g. temperature, soil moisture (level of groundwaters and amount of precipitation) as well as microbiological and enzymatic activity, while the anthropogenic factors – agrotechnical treatments (tillage, fertilisation) and land management (forest, meadows and arable land) (Kalbitz *et al.* 2000, Chantigny 2003, Gonet and Dębska 2006).

Changes in the content of DOM in soils can be, as already mentioned, related to the natural variation in temperature throughout the year (Chapman *et al.* 1995, McDowell *et al.* 1998, Scott *et al.* 1998, Tipping *et al.* 1999, Rosa and Dębska 2018). The applicable literature (McDowell *et al*. 1998, Nadany and Sapek 2004, Jaszczyński *et al.* 2008) demonstrates that, in general, the concentration of DOM in soil solution is higher in summer than in winter. Besides, e.g. Qualls *et al*. (1991) found that in deeper soil profile layers the concentration of DOM remains at a relatively constant level.

As for anthropogenic factors, one must consider nitrogen fertilisation and liming which can stimulate the production and consumption of DOC at the same time; thus, it is very difficult to determine the effect of mineral fertilisation on DOM content in field conditions (Chantigny 2003, Embacher *et al.* 2008). Dissolved organic matter from post-harvest residues and present in organic and natural fertilisers is highly biodegradable and quickly used up by microorganisms and it can result in a momentary increase in the content of DOM in soil (Pezzolla *et al.* 2013, Singh *et al.* 2014). According to Singh *et al.* (2014), the content of DOM in the soils with regularly applied natural and/or organic fertiliser is higher than in non-fertilised soils. As it is seen from the research performed so far, the content of dissolved organic matter is higher in forest and meadow soils than in arable soils (Zsolnay 1996) and it is proportional to the content of total organic matter. Generally, the content of DOM in soils decreases with an increase in the intensity of use (Chantigny 2003).

Considering the discrepancies in the reports on seasonal changes in the content of dissolved organic carbon, this paper concerns the research which aimed at defining the content and seasonal changes in DOM in arable and meadow soils in moderate climate conditions.

MATERIALS AND METHODS

The research involved the soils under agricultural use sampled at Gniewkowiec (the Kujawsko-Pomorskie province, Poland) (Table 1). Gleic Phaeozems samples (no. 17, 18, 19, meadow soils), Brunic Arenosols (9, 13) and Eutric Cambisol (3) were taken from the depth of 0–30 cm, 30–60 cm and 60–100 cm, in November 2011 through September 2013, in November, March, May, July, September. The soil sampling locations varied in terms of the doses of mineral nitrogen fertilisation and the cultivated plant (Table 2). In all arable soil sampling locations, plough tillage was used. In the soil samples immediately after sampling, the content of dry matter (W_{dm}) was determined with the weighing method.

Table 1. Soil types according to WRB and particle size distribution

Sample no.	Soil type	particle size distribution (%)		
		2–0.05	0.05–0.002	<0.002
		(mm)		
Meadow soils				
17	Gleic Phaeozem	61	25	14
18	Gleic Phaeozem	67	20	13
19	Gleic Phaeozem	54	32	14
Arable soils				
3	Eutric Cambisol	75	15	10
9	Brunic Arenosol	89	6	5
13	Brunic Arenosol	90	7	3

For the air-dried soil samples the following analyses were performed:

– pH – in the suspension of distilled water and soil with the use of pH-meter MultiCal pH 540 GLP WTW;

– the content of total organic carbon (TOC) and total nitrogen (Nt) were assayed with analyser Vario Max CN provided by Elementar (Germany). The content of TOC and Nt is given in $g \cdot kg^{-1}$ d.m. of soil;

– content of dissolved organic carbon (DOC) and dissolved nitrogen (DNt) were assayed in the solutions derived by extracting soil sample with 0.004 $mol \cdot dm^{-3}$ $CaCl_2$, at the soil sample: extrahent ratio 1:10. The extraction was performed for 1 hour and then the solution was centrifuged from above the sediment. For the extracts the following were assayed: the content of DOC and DNt with analyser Muli N/C 3100 Analityk Jena. The content of DOC and DNt was expressed in mg·kg^{-1} d.m. of soil sample and as their percentage share in the pool: TOC and Nt, respectively.

Table 2. List of types of agrotechnical practices

Sample no.	Mineral fertilization (kg N·ha^{-1})		Cultivated plant		
	year		year		
	2011–2012	2012–2013	2011	2012	2013
17	-	-	grass	grass	grass
18	-	-	grass	grass	grass
19	-	-	grass	grass	grass
3	158	90	oat	asparagus	asparagus
9	258	146	spring barley	maize	spring barley
13	240	141	maize	maize	rye

To determine the significance of differences in the content of TOC and Nt across the soils studied and the soil sampling dates, a two-factor analysis of variance was performed with the Tukey test, at the significance level of α=0.05. The differences in the content of DOC and DNt between the soil sampling dates were evaluated by calculating single base indices. Statistical analyses were performed by the Excel spreadsheet applied.

RESULTS

Basic parameter of soils

In arable soils, irrespective of the soil sampling depth, the content of dry matter ranged from 90 to 94.5%. In meadow soils in topsoil the content of dry weight was, on average, 70%; in the 30–60 cm layer – 79.6% and in the 60–100 cm layer – 83%. The pH values in arable soils ranged from 6.0 to 7.2, and in meadow soils from 6.9 to 8.3. The pH values were higher in deeper layers of the soil profile.

The highest content of total organic carbon (TOC) of the Gleic Phaeozems sampled from the depth of 0–30 cm was recorded for sample no. 19 (Table 3). The content of TOC in the samples of the other meadow soils was, on average, 59.0 g·kg^{-1}. The lowest, although non-significant, mean content of TOC was reported for the soil sampled in May, the mean content of TOC in that month was 11.9% lower, as compared with its content in the other months. As for the samples taken from the depth of 30–60 cm and 60–100 cm, the highest content of organic carbon was recorded for sample no. 19, just like in the layer of 0–30 cm, and the lowest – sample no. 17 (Table 3). In the soil sampled from the

30–60 cm layer the highest difference in the content of TOC was noted between May and July. Soil samples no. 17 from the depth of 0–30 cm showed the highest nitrogen content and the samples from the layers 30 to 100 cm – the lowest (Table 3). There were recorded, however, no significant differences in the content of Nt across the soil sampling dates.

Table 3. Content of total organic carbon (TOC) and total nitrogen (Nt)

Parameter	TOC ($g \cdot kg^{-1}$)			Nt ($g \cdot kg^{-1}$)		
Depth (cm)	0–30	30–60	60–100	0–30	30–60	60–100
Term			Meadow soil			
XI	67.19	33.33	5.57	4.89	1.74	0.39
III	65.92	31.00	5.63	4.98	1.77	0.55
V	59.00	30.44	6.28	4.38	1.98	0.47
VII	66.02	36.70	6.52	4.75	1.96	0.46
IX	68.71	32.10	5.96	4.80	1.58	0.41
LSD*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Sample no.						
17	59.75	17.06	2.33	6.09	1.16	0.262
18	58.26	33.94	3.89	4.04	2.26	0.405
19	78.10	47.14	11.77	4.14	1.99	0.700
LSD	8.29	4.38	1.89	0.90	0.39	0.213
Term			Arable soil			
XI	6.38	3.35	1.58	0.72	0.48	0.23
III	6.38	3.80	1.83	0.74	0.53	0.21
V	6.24	3.99	1.62	0.70	0.59	0.25
VII	6.16	4.15	1.58	0.73	0.52	0.22
IX	6.65	4.40	1.76	0.78	0.58	0.24
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Sample no.						
3	6.40	3.98	1.88	0.77	0.61	0.27
9	6.62	4.71	1.44	0.78	0.58	0.25
13	6.07	3.12	1.70	0.65	0.47	0.17
LSD	n.s.	0.384	n.s.	0.10	0.139	n.s.

* low significant difference

In the arable soil samples (3, 9, 13) the content of TOC ranged from 6.07 to 6.62 $g \cdot kg^{-1}$; neither were there reported any significant differences across the soil sampling dates. The content of Nt was significantly higher in soil samples no. 3 and 9, as compared with soil no. 13, and it did not depend on the soil sampling date.

Content of dissolved organic carbon and dissolved nitrogen

The mean content of dissolved organic carbon (DOC) in the Gleic Phaeozems of meadow soils sampled from the depth of 0–30 cm ranged from 207.6 to 257.4 mg·kg^{-1} (Table 4). The DOC content was decreasing with depth. The content of DOC in topsoil accounted for 0.29 to 0.43% of the total content of TOC. The highest share of DOC was noted for samples no. 18 and 17 taken from the layer 60–100 cm. The content of DOC in topsoil depending on the soil sampling date ranged from 210.0 (July) to about 238 mg·kg^{-1} (May/ September), namely in May, September, it was about 13.7% higher as compared with the content of DOC in July. In the 30–60 cm layer the highest difference in DOC was noted between November and September and between November and May. The content of DOC in September was about 23% and in May – 19% higher. In the 60–100 cm layer the content of DOC ranged from 33.2 mg·kg^{-1} (September) to 41.5 mg·kg^{-1} (March), whereas the greatest difference in DOC expressed as a percentage share in the TOC pool was noted between November and September – 0.33 percent point. It must also be stressed that at the depth of 60–100 cm the increase in the DOC content was noted only between November and March and from March a successive decrease in the DOC content was observed (Table 4, Fig. 1).

Table 4. Content and share of dissolved organic carbon (DOC) and dissolved nitrogen (DNt)

Parameter	DOC						DNt					
	mg·kg^{-1}			% of TOC			mg·kg^{-1}			% of Nt		
Depth (cm)	0–30	30–60	60–100	0–30	30–60	60–100	0–30	30–60	60–100	0–30	30–60	60–100
Term	Meadow soil											
XI	222.0	101.2	35.7	0.34	0.37	1.17	28.0	13.0	4.0	0.58	0.85	1.26
III	233.3	104.1	41.5	0.37	0.39	1.03	26.3	10.7	3.3	0.5	0.71	0.95
V	238.8	120.2	40.6	0.41	0.44	1.10	33.3	18.9	4.9	0.77	1.01	1.22
VII	210.0	110.5	37.3	0.32	0.33	0.98	27.5	14.4	5.8	0.59	0.73	1.28
IX	238.0	124.6	33.2	0.36	0.46	0.84	28.7	11.3	3.1	0.63	0.73	0.90
Sample no.												
17	257.4	93.4	35.9	0.43	0.55	1.66	31.2	11.7	2.9	0.51	1.07	1.27
18	207.6	148.7	42.2	0.36	0.44	1.10	34.7	20.8	7.2	0.84	0.92	1.69
19	220.3	94.2	35.0	0.29	0.20	0.31	20.4	8.4	2.6	0.49	0.43	0.40
Term	Arable soil											
XI	51.1	41.0	33.2	0.80	1.26	2.18	10.2	7.7	4.7	1.41	1.59	2.61
III	53.9	44.3	28.9	0.85	1.18	1.59	11.5	5.4	3.4	1.56	1.07	1.72
V	54.1	41.4	27.1	0.87	1.08	1.74	17.0	10.8	4.0	2.42	1.88	1.90
VII	49.8	40.9	30.5	0.81	1.02	1.98	10.0	11.9	6.0	1.38	2.22	3.04
IX	51.7	40.7	31.1	0.78	0.92	1.83	10.8	10.8	5.8	1.39	1.63	2.94
Sample no.												
3	56.5	45.4	33.2	0.89	1.17	1.78	10.4	10.9	5.4	1.34	1.83	2.25
9	57.7	45.5	29.1	0.88	0.98	2.09	15.7	11.4	5.0	2.02	1.96	2.42
13	42.1	34.1	28.2	0.70	1.13	1.72	9.6	5.7	4.0	1.48	1.25	2.66

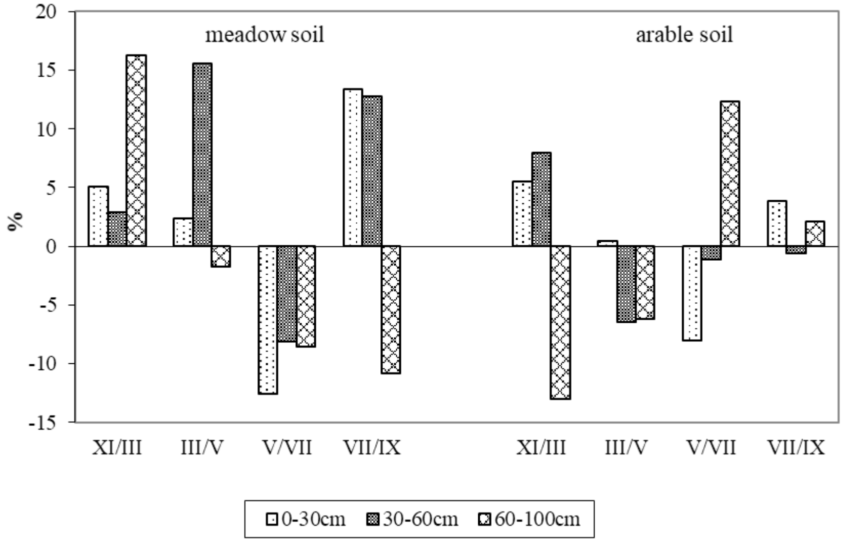

Fig. 1. Changes in the content of DOC between successive soil sampling dates

The content of DNt in the layers from 0 to 30 cm was significantly higher in samples no. 17 and 18, as compared with sample no. 19. The highest nitrogen content, irrespective of the depth, was recorded for the soil sampled in May or July. Besides, the highest increase in the content of DNt (and the share) was noted between March and May (Table 4, Fig. 2).

The content of DOC and DNt in the arable soil sampled from topsoil was lower than in the meadow soil samples about 4.4 and 2.4 times (Table 4). The

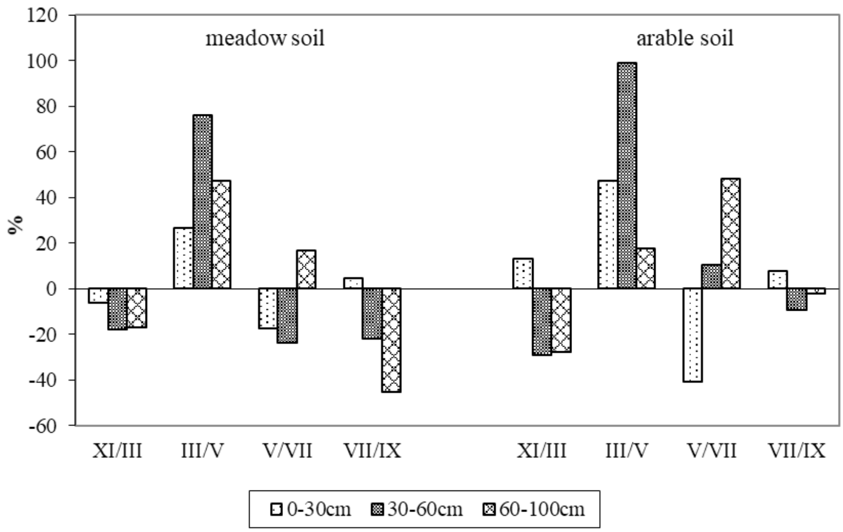

Fig. 2. Changes in the content of DNt between successive soil sampling dates

lowest content and share of DOC were observed for soil samples no. 13. The content of DOC in topsoil, depending on the soil sampling date, was changing from 49.8 (July) to 54.1 $mg \cdot kg^{-1}$ (May). It means that May through July recorded the greatest decrease in the content of DOC; by about 8.0% (Fig. 1), which corresponds to the share of DOC of 0.062 percent point (Table 4). In the 30–60 cm layer the decrease in DOC occurred also between March and May. In the 60–100 cm layer May to September an increase in the content of DOC, the highest one between May and July, was reported.

The content of DNt, similarly as DOC, was generally decreasing with depth. DNt changes over time mostly include, in topsoil, an increase in its content between March and May as well as between July and September; the highest, more than 47%, increase was recorded between March and May (Fig. 2). Between March and May there was noted also the highest increase in the content of DNt, accounting for 98.9%, in the 30–60 cm layer. In the soil sampled from the layer from 60 to 100 cm the highest increase in the content of DNt occurred between May and July.

DISCUSSION

As seen from those dependencies (Table 3), one of the key factors determining the content of organic matter is the soil use (one should bear in mind the fact that meadow soils were established on a different type of soil compared to arable soils). Further on, another basic factor which determines the content of organic matter in soils is the supply of fresh organic matter. A greater accumulation of carbon and nitrogen in meadow soils, as compared with arable soil is a result of humus production and the protective effect of the humus meadow soil horizon (Kusińska *et al.* 2004). The organic matter content of arable soils depends on the intensity of organic fertilization (manure, slurry) and the kind of crop rotation applied, which is connected with the quantity and quality of the post-harvest residues in the field. Additionally, in arable soils, agrotechnical practices, especially ploughing, considerably intensify the processes of organic matter mineralization (Kalbitz *et al.* 2000, Gonet and Dębska (2006). Interestingly, in the research period the crop rotation depleting the soil of organic matter was applied.

Chapman *et al.* (1995), Scott *et al.* (1998), Tipping *et al.* (1999) as well as Nadany and Sapek (2004) demonstrated that in forest and meadow soils the lowest concentration of labile organic carbon fractions occurs in winter, and the highest – at the end of summer and in early autumn. The results do not confirm the above research results unambiguously, however, an increase in the content of DOC between July and September both in meadow and arable soils was reported (Fig. 1). Similarly, Qualls *et al.* (1991) and Jaszczyński *et al.* (2008) found that, despite no significant variation throughout the year, the highest content of dissolved forms of organic carbon compounds occurred in the soil sampled in late summer and in early autumn.

In the 30–60 cm layer of meadow soils, the direction of changes in the content of DOC between the successive soil sampling dates was the same as in topsoil, which is also noted by Chapman *et al.* (1995). Other tendencies were observed in arable soils; in the 30–60 cm layer from March a regular decrease in the content of DOC, and in the 60–100 cm layer – an increase from May were noted. The results can point to DOC leaching to deeper soil layers, which, as seen from the present research, gets intensified in late spring and summer and it concerns arable soils.

Despite a lack of significant differences in the content of dissolved nitrogen (DNt) between respective sampling dates, an increase in dissolved nitrogen forms in the soil sampled in spring (March, May) was observed (Table 4, Fig. 2). The increase was much higher for arable soils, as compared with meadow soils, which is a consequence of the nitrogen fertilisation applied (Embacher *et al.* 2008, Jokubauskaite *et al.* 2015, Rosa and Dębska 2018). Irrespective of the soil management, March through July record a greater intensity of nitrogen leaching processes to deeper soil layers, which can be, as reported by Gaelen *et al.* (2014), a result of higher precipitation intensity.

Changes in the content of dissolved organic matter in soils can be due to the natural temperature variation throughout the year (Chapman *et al.* 1995, Scott *et al.* 1998, McDowell *et al.* 1998, Tipping *et al.* 1999). March through May, namely during the highest increase in mean temperature, an increase in and share of DOC was observed. However, May through July, namely over a further increase in temperature, a decrease in the content of DOM was already recorded. Qualls *et al.* (1991), Jaszczyński *et al.* (2008) as well as Rosa and Dębska (2018) also point to a lack of significant variation of dissolved organic carbon due to temperature.

CONCLUSIONS

1. Meadow soils showed a higher dissolved organic carbon (DOC) content, as compared with arable soils. However, the share of that carbon fraction in the total organic carbon pool was higher in arable than in meadow soils.
2. Share of DOC and DNt (dissolved nitrogen) was increasing with soil sampling depth. In arable soils the share of nitrogen was higher than the share of carbon.
3. The analysis of variance did not show significant differences in the content of TOC and Nt across the soil sampling dates. There were recorded changes as for DOC and DNt between successive sampling dates; for topsoil for DOC – from -12.06% to 13.34% (meadow soils) and for DNt – from -40.84% to 47.44% (arable soils).

4. In arable soils the highest increase in the content of dissolved organic matter in the 0–30 cm layer was recorded March through May; during the highest increase in temperature.

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