Anna KUCZUK
Opole University of Technology, Department of Thermal Engineering and Industrial Facilities
ul. S. Mikołajczyka 5, 45-271 Opole, Poland
e-mail: a.kuczuk@po.opole.pl

THE WORTH OF SOIL ORGANIC MATTER – ENERGY-NUTRITIONAL APPROACH

Summary

Organic soil content is considered to be the basic attribute of the soil quality and health as well as of the quality of the environment, and organic matter content determines a number of important soil characteristics. Various agricultural activities lead to the accelerated mineralization of the organic matter, which results in its loss by 2-4% every year. The economic value of the organic soil matter can be evaluated by taking into account the environmental, as well as productivity and social aspects. The foundation for the study was provided by the results of the laboratory research (provided by the District Chemical and Agricultural Station in Opole) regarding humus content in selected farms located in the Opole Province. In this manner, the stock volume of humus in soil was determined along with the volume of energy in it expressed in MJ·ha^{-1}. The details of the results were supplemented by determining the theoretical energy potential of the examined soils. In addition, the content of nutrients released from the soil organic matter could be estimated. As a consequence, the economic value was assessed by comparison of this value to the prices of the pure component of mineral fertilizers.
***Key words**: soil, soil organic matter, energy, economic value*

WARTOŚĆ GLEBOWEJ MATERII ORGANICZNEJ – PODEJŚCIE ENERGETYCZNO-POKARMOWE

Streszczenie

Organiczna część gleby uważana jest za podstawowy atrybut jakości i zdrowia gleby i zarazem jakości środowiska, a sama zawartość materii organicznej decyduje o wielu istotnych właściwościach gleb. Liczne praktyki rolnicze powodują przyspieszoną mineralizację materii organicznej, a co roku ma miejsce jej ubytek o 2-4%. Wartość materii organicznej gleby można wycenić biorąc pod uwagę kryteria środowiskowe, produkcyjne czy społeczne. W artykule, zaprezentowano wycenę wartości materii organicznej uwzględniając podejście energetyczno-pokarmowe. Bazę dla oceny stanowiły wyniki badań laboratoryjnych (udostępnione przez Okręgową Stację Chemiczno-Rolniczą w Opolu) zawartości próchnicy w przykładowych gospodarstwach rolnych zlokalizowanych na terenie województwa opolskiego. Określono zasobność gleb w próchnicę, zgromadzoną w niej energii wyrażoną w MJ·ha^{-1} oraz określono teoretyczny potencjał energetyczny gleb. Ponadto oszacowano zawartość składników pokarmowych uwalnianych z materii organicznej gleby oraz wyceniono ich wartość ekonomiczną odnosząc ją do cen czystego składnika nawozów mineralnych.
***Słowa kluczowe**: gleba, glebowa materia organiczna, energia, wartość ekonomiczna*

1. Introduction – soil organic matter: notion, content in soil and its role

Soil organic matter is considered to be the basic attribute of soil quality and its health as well as of the quality of the environment. The content of the organic matter also determines a variety of important soil properties. By application of a criterion based on the soil organic matter content, soils are classified as organic (e.g. peat, mucks soils) or mineral. The first category is naturally rich in the organic parts and can contain more than 30% of its content, which is basically determined by the climate. Its volume in the mineral soils varies from trace levels to 20% (according to Systematics of Soils in Poland [27], other sources say that even more than 30% [3].

The term soil organic matter (SOM) is often ambiguous, and the organic parts in soil can take a variety of forms (Fig. 1), and have different degree of decomposition. An important part of SOM is formed by living organisms, whose role cannot be overestimated. According to Dziadowiec [10], SOM comprises all animal and plant remains both freshly dead and in various stages of decomposition as well as non-specific compounds present in the soil. A similar approach is represented in a work by Buhan [6], which contains a statement that SOM consists of the matter at various stages of decomposition, from fresh remains to almost completely decomposed humus. Such a notion of organic matter in soil does not comprise nor plant roots, despite the fact that it is difficult to identify them in the soil mass. In particular this is true with regard to the soil organisms with a small size. Other approaches account for the presence of living organisms as the component of SOM, with a note that they can form 10-15% (and even as much as 10-40%) of the total soil content [3, 13, 14, 36]. If such an approach is taken, SOM is understood as the total of all organic compounds present in the soil that comprise carbon ($C_{org.}$), regardless of their origin and the stage of decomposition. Due to the fact that humus can account for as much as 70-90% of the total organic matter in the soil, it is often equated with it [9, 41]. This approach promotes the analysis concerned with the determination of the resources of the fresh matter in the soil. In this paper, the estimates adopt an assumption that the organic matter in the soil is equated with the humus content in soil.

The content of the organic matter (humus) in the soil can be varied, in the same manner as the pace of its transformations. This is relative to the volume of the organic residue that is reversed into the soil (through accumulation) and its pace of decomposition (through mineralization and migration of $C_{org.}$ in the form of CO_2 as a result of microbiological decomposition). Besides, the types of soils (Table 1), climate conditions, type and size and quality of the vegetation covering the soil as well as intensity of soil management exert an impact on the level of the SOM balance. The last of these elements plays a crucial role due to the fact that the agricultural land is most susceptible to the loss of the organic matter from soil. The estimates conducted for Poland by the Institute of Soil Science and Plant Cultivation (IUNG-PIB) [35] indicate that on the average, soil organic matter content in the agricultural areas in Poland is equal to 2.20% (1.28% $C_{org.}$), with the maximum of 3.04% (1.76% $C_{org.}$) in the Dolnośląskie Province and the lowest – 1.83% (1.06% $C_{org.}$), for the Świętokrzyskie Province. The forecast regarding the loss of soil organic matter indicates that in the perspective up to 2020, the mean losses of this soil component will exceed its deposition and we may have to do with a phenomenon associated with the loss of 10.5 tons of organic matter from each 1 ha of the agricultural land. We can note that in accordance with the criteria set by the European Soil Information System, the soils characterized by a low content of $C_{org.}$, are the ones that contain 1-2% $C_{org.}$, whereas according to the IUNG PIB data, this ratio is <1% [11, 35].

As it is commonly known, organic matter plays an important role in the soil, as it affects the biological, chemical and physical soil properties. Soil is an environmental resource and the presence of the organic matter in it indicates its life and health since it forms a source of nutrients for the soil fauna and contributes to the existence of biological diversity. In addition, the organic soil content determines soil fertility [33]. The biological role of the organic material is inseparably linked to the existence and functioning of the soil organisms, and it is estimated that over a quarter of all earth species inhabit the soil [12]. As they are responsible for the decomposition process, such organisms participate directly in a number of biogeochemical cycles involving nutrients that are indispensable for the development and growth of plants. Concurrently, the deficiency of the organic soil matter can lead to the reduced ability of the soil to transfer nutrients to the plants [3]. In general, the decomposition of the organic matter supplies energy and carbon necessary for the development of microorganisms and growth of their cells [23].

Organic matter plays a relevant role as a resource in terms of the content of nutrient and energy in it, although its function in this area is not as important as the benefits to the formation of the physical and chemical properties of soils. With the exception of the soils applied in intensive cultivation, which are usually supplemented by nutrients coming from mineral fertilizers, organic matter forms the major source of the macrocomponents in soils. In particular, nitrogen and phosphorus form the most important macrocomponent forming the SOM. As given by Baldock and Nelson [1], nitrogen originating from SOM is responsible for the existence of the total resource of nitrogen that is contained in soils. In the soils with the considerable potassium ion content, containing clay minerals capable of binding NH_4^+ - of around 90% of nitrogen that is present in the soil, 8% occurs in the form of NH_4^+, and 1-3% of the volume is formed by nitrogen present in inorganic compounds (NO_3^- NH_4^+).

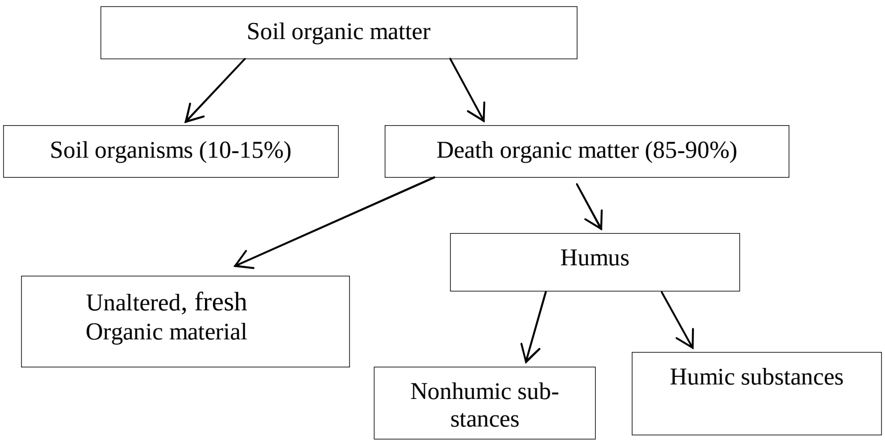

Fig. 1. Composition of soil organic matter - *Source: [3, 36] modified*
Rys. 1. Składniki materii organicznej gleby - Źródło: [3, 36] zmienione

Table 1. Examples of composition and organic matter resources in soils of arable land [22*, 14]
Tab. 1. Przykładowe zawartości i zasoby materii organicznej w glebach gruntów ornych [22, 14]*

Soil type	Level	Content of $C_{org.}$ [%]	Resources [tons·ha^{-1}]
Chernozem	A	1.5-2.3	200-270
Black soil	A	1.0-3.2	310-590
Brown soil	A	0.9-1.5	40-100
Luvisols	A	0.5-1.3	30-90
Fluvial muds	A	0.6-2.4	40-120
Chernozem from Kamienny Step area*	0-20/20-25	4.79/4.82	data not available
Protokaukazian carbonate chernozem *	0-10/40-50	3.20/1.78	data not available
Podsol turf in the area of the South-Taiga Subprovince*	0-10/10-23	1.16/1.21	data not available
Standard greysoil, Uzbek SRR*	0-20	0.78	data not available
Light greysoil, Kazakh SRR*	0-15	0.72	data not available
Light semipodsol of the South-Taiga Subprovince*	0-10/10-23	1.16/1.21	data not available

The impact exerted SOM on the physical soil properties refers primarily to the stabilization of its structure. The presence of the organic matter results in a better soil resilience to a variety of external stress factors, such as crop cultivation, kneading as well as irrigation secures the improvement of an optimum water content**.** There is a linear dependence between the stabilization of the soil aggregates and the increase of the SOM content, which was demonstrated by the results of a study of a cropland by Chaney and Swift [7]. In turn, Kay and Angers [21] remark that the indispensable minimum $C_{org.}$ content in soil amounting to 2% is necessary to sustain soil stability. The decrease of this value results in an abrupt decrease of the soil stability. Similar dependencies were found to apply in the aspect of the increase of the waste content in soil depending on the increase of the volume of the soil organic matter. It was observed that the increase of the SOM content by 1% is reflected by the increase of the soil moisture content by 1.5% [40].

The formation of the chemical soil properties also refers to the impact of SOM on the ability of cation exchange by the soil particles, soils buffering abilities as well as the adsorption phenomenon. The soil organic matter has a considerably greater sorption ability compared to the mineral coloids, and the high cation exchange capacity demonstrates the ability of soils to gather nutrients available for plants, which is highly desirable. There is a direct relation between the cation exchange capacity, pH value of soil and its buffering abilities, and the ability to exchange cations is often correlated with the increase of the soil buffering abilities [23]. The high organic matter content in soil also secures soil functionality by stabilization of the metal compounds, which was observed by Thomas [37] among others. This study demonstrated that the greater SOM content affects considerably the reduction of the content of aluminum in the soil.

The above characteristic does not cover all aspects that relate to the role of the organic matter in soils. We are still aware that a number of mechanisms occurring in the soils and related to the presence or deficiency of the organic matter are still unknown.

The further part of this paper is concerned with the potential application of the ways to evaluate the organic matter and discussing the value of soil organic matter.

2. The valuation of the soil organic matter – variety of approaches

The ways of assessing the economic value of SOM most commonly account for the direct relation between the SOM content and the economic value of agricultural production. As humus affects the physical and chemical soil properties, it determines the fertility of soil and hence decides on the volume of agricultural production. However, in this context we tend not to pay due attention to the fact that the SOM content determines the condition of the soil along with its health and quality. Therefore, we focus little on the environmental functions of SOM, although it is known that it determines the physicochemical soil properties. The richness of the biological soil diversity is relative to the input of the organic residue as it contributes to the formation of soils and improves its quality for the purposes of agricultural production. The contents of the organic mass are involved in the pool of a variety of biogeochemical cycles during the process of residue decomposition, which occurs as a result of the activity known as biological life. As a result of such processes, nutrients are passed to the soil, as they are needed for the plant growth and CO_2 sequestration is implemented resulting in the reduction of the content of this gas in the atmosphere [29]. As demonstrated by the results of a complex experiment [8], crop diversity and skillful management of organic carbon in soil can contribute to the forecast revenues from agricultural production and reduce the potential hazard in the future.

Hence, how can we valuate SOM? Should we consider the strictly production-related aspects or the environmental ones as well? If we decide for the latter, should we also valuate the effort exerted by the soil organisms forming the organic matter? On the basis of the estimates presented by Pimentel et al. [30], the cumulative value of the economic benefits for the agriculture that result from the activity of the biological diversity in soil (such as: utilization of pollutants, soil formation, nitrogen fixation, bioremediation of chemical compounds or pest control) on the global scale is estimated to be worth $1.542 \cdot 10^9$ $\$ \cdot year^{-1}$, whereas the soil organisms represent the worth of topsoil equal to $25 \cdot 10^9$ $\$ \cdot year^{-1}$.

In general, it is quite difficult to directly determine the economic value of the soil properties which result from the SOM content in it. For certain, it is considerably higher from the value of the carbon content in the soil [26]. Often such valuation applies an indirect approach accounting for the impact of SOM on the growth or fall of the agricultural production. In an experiment reported by Bauer and Black [2], which lasted for four years, the study aimed to experimentally determine how one ton of SOM impacts the productivity of one soil hectare. This utility was estimated to be equal to an equivalent of 35.2 $kg \cdot ha^{-1}$ of the total dry mass of the spring wheat and 15.6 $kg \cdot ha^{-1}$ of grain crops. Concurrently, the drop in the productivity resulting from the decrease of the soil organic matter content is associated with the decrease of the soil fertility. Other works [32], also contain a remark that the addition of manure (depending on the crop rotation and applied technique of cultivation) can reduce the pace of the decrease in soil organic matter and nitrogen and result in increase of the yield (Table 2).

The analysis of such a problem was also undertaken by Bock et al. [4], who observed that the level of crops of non-leguminous plants is positively correlated with the content of soil organic matter, for the case of the application of an ecological cultivation system (however, it was not so in the case of conventional system). An interesting approach is represented in the study by Sparling et al. [34], who attempted to evaluate the monetary worth of the SOM function, represented by the equivalent value of the dry mass of cow milk. By developing a simulation of the relation between dry mass obtained from pastures and accumulation of SOM, they noted that the crops from the pasture decrease in the conditions when lower SOM content was recorded in the soils. The estimates provided in this work conclude that the lower SOM content results in the decrease of the dry mass of cow milk in the range from od 8.5 to 47.7 kg, which corresponded to the monetary value in the range from NZ\$27 to NZ\$150$\cdot ha^{-1} \cdot year^{-1}$.

The value of the organic matter can also be determined by assessing the economic value of the nutrients present in it since they are responsible for the plant growth and development [15, 18], or by the application of an approach based on energy use [20].

Table 2. Soil organic matter content vs obtained yields [2]
Tab. 2. Zawartość glebowej materii organicznej w glebie i wysokość osiąganych plonów [2]

Crop-rotation	Organic matter content [%]*				Yields [$kg \cdot ha^{-1}$]**			
	Control	Monoammonium phosphate	Manure	Monoammonium phosphate + manure	Control	Monoammonium phosphate	Manure	Monoammonium phosphate + manure
Fallow-wheat	3.7	5.0	4.1	4.6	1.23	1.37	1.17	1.28
Fallow-wheat-wheat	4.9	4.6	5.5	6.0	1.45	**1.56**	**1.63**	**1.70**
Fallow-wheat-wheat-wheat-wheat	4.7	6.3	5.5	5.8	1.46	**1.61**	**1.79**	**1.81**
Wheat-continuously	7.2	5.0	7.6	7.4	1.81	**2.00**	**2.06**	**2.08**

*after 37 y. of cropping; **mean for 23 y.

Such approaches do not apply direct valuation, which could account for all benefits and functions performed by the organic matter in soil. This assessment is most commonly applied taking into consideration its individual aspects by application of indirect methods and price substitutes. The value of the soil organic matter can also be considered in terms of its social worth, as a monetary equivalent of the ecosystem services provided by the specific unit of the soil carbon. As a consequence, this involves a number of utilities, such as: increase of the primary production and yields in the context of the food security, reduction of the effects of soil erosion and mitigation of the consequences of human activities [25].

This paper contains an attempt to assess SOM by application of an approach that uses its energy and nutrition value. The objective of this analysis is to focus on the function of SOM as a resource containing nutrients along with the consideration of its energy potential. The issue associated with the valuation of SOM is relevant in the aspect of the drop of its content in the soil, which can lead to a number of losses in terms of productivity and environmental aspects for the conditions when rational soil management is not involved in the process.

3. Energy and nutritional value of organic matter

3.1. Materials and methods

For the purposes of the valuation, the results of laboratory studies were taken with regard to the content of humus in soil. These results were obtained from District Chemical and Agricultural Station in Opole. The content of soil humus was determined according to the Tiurin's method, and $C_{org.}$ - according to the formula: humus content [%] = $C_{org.}$ [%] · 1,724. The laboratory results and information about total area of surveyed fields concerned 30 farms located in the Opole Province. Due to their participation in the agri-environmental and climate program, the farms were obliged to perform tests of the humus content. The results of the measurements concerned 2015. Besides, the following assumptions were adopted during the calculations:

a) The soil samples were extracted from a soil depth profile of 30 cm.

b) The mean bulk density of mineral soils was adopted to be equal to 1.40 $g \cdot cm^{-3}$ [5, 28, 39], and the weight of one cubic meter of soil – 1.4 ton.

c) The calorific value of SOM was taken to be equal to 4.7 $kcal \cdot g^{-1}$ (19.7 $MJ \cdot kg^{-1}$) [19].

d) The prices of pure component (N, P, K) for 2015 was adopted on the basis of data derived from Opole Agricultural Advisory Centre in Łosiów [38]. As for the price of pure Sulphur, it is calculated at market prices [17].

e) Accounting for the low SOM content and under the assumption of the use of traditional tillage technique in the analyzed farms, the annual rate of SOM decomposition and release of nutrients was adopted at the level of 1%. [15].

f) Carbon forms 58% of the soil organic matter by content, and the ratio of C:N:P:K:S is equal to 10:1:0.1:0.1:0.1 [15].

4. Results and discussion

The overall surface of the agricultural land taken for the analysis was equal to 1192.20 ha, and the number of samples subject to the study was 474. On the basis of laboratory analysis we can conclude that the mean humus content in soil was equal to 1.85% (1.07% - $C_{org.}$). 13 farms have a low humus content in the soils, 16 – average (with a remark that the recorded values are close to the low boundary), and only one demonstrates a high humus content.

By comparing above value to the minimum carbon content that is necessary to sustain soil health and quality, we can conclude that it is on average level according to the IUNG-PIB criteria. By adopting the criteria put forward by the European Soil Information System, this level is assessed as low (Table 3).

Table 3. Soil organic matter and $C_{org.}$ content and organic matter resources in the analyzed farms
Tab. 3. Zawartość SOM, $C_{org.}$ oraz zasoby materii organicznej w analizowanych gospodarstwach

No. of samples	Agricultural land [ha]	SOM [%]		$C_{org.}$ [%]		SOM resources [$t \cdot ha^{-1}$]	
474	1192.20	min.	0.96	min.	0.56	min.	40.32
		max.	4.10	max.	2.38	max.	172.20
		mean	1.85	mean	1.07	mean	77.56

Source: own work / Źródło: opracowanie własne

Such results are in conformity with the data presented by Stuczyński et al. [35] for the conditions in Poland, as well as the results of other research, e.g. Howard and Howard [16]. The determined mean content of the organic matter resource derived from a soil depth profile of 30 cm was equal to around 77 tons per 1 ha and this value is adequate for the majority of soils cultivated in Poland.

The organic matter contains considerable amounts of energy, which can be potentially applied by the soil organisms in their biological processes. A portion of this energy is accumulated in the stable forms of humus, which is subject to gradual decomposition and some is released in the form of heat. The calorific value of the organic matter which is accumulated in the plough layer over a surface of 1 ha can be equivalent to tens of tons of heat generated from the anthracite-colored carbon [5].

Under the assumption that the calorific value of SOM contained in the surface layer of soil is equal to 4.7 $kcal \cdot g^{-1}$ (19.7 $MJ \cdot kg^{-1}$), in the analyzed farms the mean energy value of SOM was equal to $1.53 \cdot 10^6$ $MJ \cdot ha^{-1}$. Concurrently, this value corresponds to the volume of heat that can be gained from the combustion of 47 tons of anthracite-colored carbon. The energy value of SOM can also be compared with the energy value of the means of production applied on a farm. Apparently, the energy expenditure associated with production of various crops can differ considerably depending on the production system and soil and weather conditions. We can remark at this point that organic matter can constitute the equivalent of both anthracite-colored carbon, as well as other means of agricultural production (such as labor, machines and fuel). We can undertake a comparison by adopting the energy-based criteria, however, it is difficult to convert it into practical application. Hence, the considerations regarding the substitution of the energy value of the industrial means of production with a measure of energy value of SOM (including the impact of solar energy and assuming that there are no losses of SOM resulting from erosion and oxidization), lead to the conclusion that the soil organic matter has a potential to replace the input of energy to industry for many years to come [20]. Table 4 contains the examples of data regarding cumulative energy efficiency of production of maize and winter wheat (organic and conventional). The energy value of SOM that is derived clearly demonstrates that on average, its theoretical potential could last for 45 years of the maize cultivation, 64 years of winter wheat production and as much as 136 years with regard to winter wheat production in an organic cultivation system.

The analysis of the nutritional value involved the determination of the overall content of nutrients in the applied resources of organic matter and their available quantities for plant were calculated throughout a period of year, under the assumption of decomposition equal to 1%. In addition, their monetary value was assessed as well (Table 5). Under the assumption that C:N = 10:1, nitrogen accounts for 5.8% of the total SOM. The content of the remaining components: P, K and S was taken to be equal to 0.58% each. [15, 18].

These calculations imply that for the SOM content equal to 1,85%, the following amounts of nutrients are released: N – 44.98 $kg \cdot ha^{-1}$, and for the case of, K and S, 4,50 $kg \cdot ha^{-1}$ each. Accounting for he market prices, the value of pure nutrients derived from SOM and available for plant from one hectare is equal to 223.93 $PLN \cdot ha^{-1}$ on average over the period of one year. An increase in the organic matter content to the boundary level equal to $C_{org.} \geq 2\%$ (which would mean an increase by two times in the analyzed farms) would result in a concurrent increase of the potentially available nutrients as well.

3. Conclusions

1. Organic matter constitutes an important component of soils applied for agricultural purposes, and its level determines the physical, chemical and biological soil functions.
2. In the case of a majorly of soil types, organic matter content is at a low level (i.e. below 2% $C_{org.}$). This was established both on the basis of the insight from the literature and analysis performed on the examined farms.

Table 4. Energy value of organic matter [$MJ \cdot ha^{-1}$] in the analyzed farms and its theoretical potential *[31], **[24]
*Tab. 4. Wartość energetyczna materii organicznej [$MJ \cdot ha^{-1}$] analizowanych gospodarstw oraz jej teoretyczny potencjał *[31], **[24]*

Energy value of SOM [$MJ \cdot ha^{-1}$]		Energy needed for maize production * [$MJ \cdot ha^{-1} \cdot y^{-1}$]	Energy potential of SOM [years]	Energy needed for winter wheat production (conventional)* [$MJ \cdot ha^{-1} \cdot y^{-1}$]	Energy potential of SOM [years]	Energy needed for winter wheat production (organic)** [$MJ \cdot ha^{-1} \cdot y^{-1}$]	Energy potential of SOM [years]
min.	794021.76	34001.85	23	23934.54	34	11247.46	71
max.	3391134.60		100		142		302
mean	1527389.08		45		64		136

Table 5. Annual value of nutrients provided by the resources of soil organic matter (1% decomposition)
Tab. 5. Roczna wartość składników pokarmowych dostarczanych przez zasoby glebowej materii organicznej (1% dekompozycji)

Value	SOM [$kg \cdot ha^{-1}$]	Total level of N [$kg \cdot ha^{-1}$]	Value of N available for plants [$PLN \cdot ha^{-1}$]	Total content [$kg \cdot ha^{-1}$]			Values of components available for plants [$PLN \cdot ha^{-1}$]		
				P	K	S	P	K	S
min.	40320	2338.56	84.89	233.86			9.33	6.06	16.14
max.	172200	9987.6	362.55	998.76			39.85	25.87	68.91
mean	77560	4498.48	163.29	449.85			17.95	11.65	31.04

Source: own work / Źródło: opracowanie własne

3. The valuation of organic matter can apply various approaches. One of the most common uses indirect economic valuation, e.g. assessing the impact of soil organic matter on the increase/decrease of plant production, assessment of the economic value of nutrients that are present in soil (accounting for the price of the pure component of mineral fertilizers) or by valuation of the energy that is contained in the organic matter.

4. The analysis of soils from 30 farms located in the Opole Province demonstrates that 13 farms have a low humus content in the soils, 16 – average, and only one demonstrates a high humus content.

5. The low organic matter content is converted into the energy content in the soil and the value of nutrients contained in it. On average, the value of the energy in the organic soil matter was found to be equal to 1,527,389.08 $MJ\cdot ha^{-1}$. This value can be compared to the energy expenditure needed for the production of selected crops in an area of one hectare. Theoretically, this value is equal to e.g. cumulative energy efficiency that is needed to produce winter wheat over a period of 64 years (conventional cultivation) and 136 years (for the case of organic cultivation).

6. The nutritional value of organic matter, which is relative to its resources and rate of mineralization, is equal to nearly 45 kg N per 1 ha, and 4.50 $kg\cdot ha^{-1}$ each for the case of P, K and S (under the assumption of 1% decomposition). The economic value that is represented by the released nutritional components over an area of 1 ha is equal to 223.93 $PLN\cdot ha^{-1}$.

7. Each increase of the organic matter content contributes to both the improvement of the soil quality and impacts the economic parameters of agricultural production as well.

4. References

[1] Baldock J.A., Nelson P.N.: Soil organic matter. [In]: Handbook of soil science. (red. Sumner M.E., CRC Press, 1999, B25-B70.

[2] Bauer A., Black A.L.: Quantification of the effect of soil organic matter content on soil productivity. Soil Science Society of America Journal, 1994, 58, 185-193.

[3] Bot. A, Benites J.: The importance of soil organic matter – Key to drought-resistant soil and sustained food and production. FAO Soils Bulltein, Rome, 2005, 80.

[4] Brock Ch., Flieβbach, Oberholzer H-R., Schultz F., Wiesinger K., Reinicke F., Koch W., Pallut B., Dittmann B., Zimmer J., Hülsbergen K-J., Leithold G.: Relation between soil organic matter and yield levels of non-legume crops in organic and conventional farming systems. Journal of Plant Nutrition and Soil Science, 2011, 174, 568-575.

[5] Buckman H.C., Brady N.C.: Gleba i jej właściwości. PWRiL, 1971.

[6] Buhan G.D.: Ode to soil. Journal of Soil and Water Conservation, 2010, Vol.65, 2, 48A-54A.

[7] Chaney K., Swift R.S.: The influence of organic matter on aggregate stability in some British soils. Journal of Soil Science, 1984, 35, 223-230.

[8] Cong R-G., Hedlund K., Anderssson H., Brady M.: Managing soil natural capital: An effective strategy for mitigating future agricultural risk? Agricultural Systems, 2014, 129, 30-39.

[9] Czy można zmienić ilość próchnicy w glebie: www.nawozy.pl/czy-mozna-zmienic-ilosc-prochnicy-w-glebie/.

[10] Dziadowiec H.: Glebowa materia organiczna – pojęcia podstawowe. [W]: Badania ekologiczno-gleboznawcze (red. Bednarek i in.). Warszawa: PWN, 2005.

[11] European Soil Data Base Maps – Primary properties [In]: European Soil Database Centre: www.esdac.jcr.europa.eu/ resource-type/european-soil-database-maps (dostęp on-line: 20.01.2017).

[12] Fabryka życia – dlaczego różnorodność biologiczna gleby jest tak istotna. Urząd Publikacji Unii Europejskiej, 2010.

[13] Gonet S.S.: Materia organiczna gleby w strategii ochrony gleb Unii Europejskiej. Roczniki Gleboznawcze, 2007tom LVIII, 3-4, 15-26.

[14] Gonet S.S., Smal H., Chojnicki J.: Właściwości chemiczne gleb. [W]: Gleboznawstwo – praca zbiorowa pod red. Mocek A., PWN, 2015, 189-231.

[15] Hoorman J.J., Islam R.: Understanding Soil Microbes and Nutrients Recycling. Agriculture and Natural Resources – Fact Sheet, SAG-16-10, The Ohio State University, 2010, 1-5.

[16] Howard P.J.A., Howard D.M.: Use of organic carbon and loss-on-ignition to estimate soil organic matter in different of soil types and horizons. Biology and Fertility of Soils, 1990, 9, 306-310.

[17] http://www.sklep.biomus.eu/pl/ (dostęp on-line 24.04.2017).

[18] Jewett J.G., Lewis H., Baumhardt A.: Farm transitions toolkit. Landstewardship Project, Minnesota Institute for Sustainable Agriculture, National Center for Appropriate Technology, Farmers' Legal Action Group, September 2013.

[19] Jordan C F.: A world pattern in plant energetics. American Scientist, 1971, 59, 425-433.

[20] Jordan C.F.: An ecosystem approach to sustainable agriculture. Energy use efficiency in the American South. Environmental Challenges and Solutions 1. Springer, 2013.

[21] Kay B.D., Angrers D.A.: Soil structure [W]: Soil physics companion. Chapter 7. (ed. Warrick), CRC Press 2001, 249-295.

[22] Kononowa M.: Substancje organiczne gleby, ich budowa, właściwości i metody badań. PWRiL, 1968.

[23] Krull E.S., Skejmstad J.O., Baldock J.A.: Functions of Soil Organic Matter and The effects on Soil Properties. GRDC Project No CSO 00029 – Residue Management, Soil Organic Carbon and Crop Performance, 2004.

[24] Kuczuk A.: Cost- Cumulative Energy - and Emergy Aspects of Conventional and organic Winter Wheat (Triticum aestivum L.) Cultivation. Journal of Agricultural Science, 2016, Vol 8, 4:, 140-155.

[25] Lal R.: Societal value of soil carbon. Journal of Soil and Water Conservation, 2014, Vol. 69, 6, 186A-192A.

[26] Lawrence D., Argent S., O'Connor R.: Soil organic matter what is worth to grain production and what practices encourage it DAFF Queensland and Graeme Schwenke. Sally Muir&Malem McLeod, New South Wales DPI, 2013, dostęp on-line: 09.05.2016.

[27] Marcinek J., Komisarek J.: Systematyka gleb Polski. [W]: Gleboznawstwo (red. Mocek A.), Warszawa: PWN, 2005.

[28] Owczarzak, W., Dębicki R., Mocek A.: Właściwości fizyczne gleb. [W]: Gleboznawstwo (Mocek A. red.), PWN 2015.

[29] Pałosz T.: Rolnicze i środowiskowe znaczenie próchnicy glebowej i metodyka jej bilansu, Środkowo-Pomorskie Towarzystwo Naukowe Ochrony Środowiska; www. wbiis.tu.koszalin.pl (dostęp on-line 22.01.2017).

[30] Pimentel D., Wilson Ch., McCullum Ch., Huang R., Dwen P., Flack J., Tran Q., Saltman T., Cliff T.: Economic and Environmental Benefits of Biodiversity. BioScience, 1997, Vol. 47, 11, 747-757.

[31] Pimentel D., Doughty R., Carothers C., Lamberson S., Bora N., Lee K.: Energy inputs in crop production in developing and developed countries. Chapter 12. [In]: Food, Energy and Society Third Edition (red. Pimentel D., Pimentel M. H.), Taylor and Francis, 2008.

[32] Ridley A.O., Hedlin R.A.: Soil organic matter and crop yields as influenced by the frequency of summer following. Canadian Journal of the Soil Science, 1968, Vol., 48, 315-322.

[33] Spadek zawartości materii organicznej - Procesy degradacji gleby. Broszura informacyjna 3. Zrównoważone rolnictwo oraz ochrona gleby. Wspólnoty Europejskie, 2009.

[34] Sparling G.P. Wheeler D., Vesley W-T., Schipper L.A.: What is soil organic matter worth? Journal of Environmental Quality, 2006, 35, 548-557.

[35] Stuczyński T., Kozyra J., Łopatka A., Siebielec G., Jadczyszyn J., Koza P., Doroszewski A., Wawer R., Nowocień E.: Przyrodnicze uwarunkowania produkcji rolniczej w Polsce, Studia i Raporty IUNG-PIB, 2007, 7, 77-115.
[36] Substancje próchniczne gleby: http://karnet.up.wroc.pl/~weber/def1.htm (dostęp on-line: 20.04.2017).(dostęp on-line; 20.04.2017).
[37] Thomas G.W.: The Relationship between Organic Matter Content and Exchangeable Aluminum in Acid Soil. Soil Science Society of America, 1975, Vol. 39, 3, 591.
[38] Ucinek M.: Koszty podstawowych działalności produkcji roślinnej i zwierzęcej (obliczenia w cenach poszczególnych miesięcy roku 2015) bez dotacji krajowych i UE. Dokument do użytku wewnętrznego, OODR Łosiów, 2016.
[39] Uggla H.: Gleboznawstwo rolnicze. Warszawa: PWN, 1976.
[40] Wolf B., Snyder G., H.: The Place of Organic Matter in Sustaining Soils and They Productivity. [W]: Sustainable soils, CRC Press; 1 Edition, July 25, 2003.
[41] Wrzaszcz W.: Bilans nawozowy oraz bilans glebowej substancji organicznej w indywidualnych gospodarstwach rolnych. [W]: Z badań nad rolnictwem społecznie zrównoważonym. Warszawa: IERiGŻ-PIB, 2009, 29.