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MANAGING SOIL CAPITAL ON A FARM

Summary

The purpose of study was to report on the undertaken assessment with regard to selected activities undertaken in experimental farms that operate according to various cultivation systems, including a variety of activities related to the management of soil resources and its capital. The assessment and analysis was performed on the basis of preliminary results of a study involving a period of three years. The analysis applied the following indicators to assess the quality of soil management: the variety of plants production, the ratio of plants applied to improve soil fertility, the ratio of cereals in sown area and the ratio of green fields, soil organic matter balance, the C:N ratio and intensity of plant production organization. The obtained results allow to state that both farms (traditional soil cultivation and conservative soil cultivation), strive to protect soil quality and its capital. However, on a farm employing conservation tillage it was noted slightly better results in the case of in some indicators.

Keywords: *soil, soil organic matter, soil conservation tillage, green fields*

ZARZĄDZANIE KAPITAŁEM GLEBY W GOSPODARSTWIE ROLNYM

Streszczenie

Celem badań była ocena wybranych działań podejmowanych w przykładowych gospodarstwach rolnych prowadzących odmienne systemy uprawy roli - działań związanych z zarządzaniem zasobem gleby i jej kapitałem. Ocenę i analizę dokonano w oparciu o wstępne wyniki badań obejmujące okres trzech lat. Do oceny poprawności gospodarowania glebą wykorzystano następujące wskaźniki: różnorodność uprawianych roślin, udział roślin zwiększających żyzność gleby, udział zbóż w zasiewach i udział zielonych pól, bilans glebowej materii organicznej, stosunek C:N, intensywność organizacji produkcji roślinnej. Uzyskane wyniki, pozwalają stwierdzić, że w obu gospodarstwach (tradycyjna uprawa gleby oraz konserwująca uprawa gleby), dąży się do ochrony jakości i kapitału gleby. Jednak w gospodarstwie stosującym uprawę konserwującą odnotowano nieco lepsze wyniki niektórych wskaźników.

Słowa kluczowe: *gleba, materia organiczna gleby, uprawa gleby konserwująca, zielone pola*

1. Introduction

Soil is undoubtedly one of the most important and most valuable of all environmental resources, and it is subjected to permanent dynamic changes. This resource is significant both in the context of agricultural production as well for reasons associated with the environment (the circulation of elements in nature) [1]. The course of the changes taking place in the soil, their pace, and as a result, the changes in the well-being of the soil ecosystem depend to a large extent on the way of dealing with this exceptionally sensitive element of the environment. This sensitivity results directly from the fact that soil is probably the most complex form of biological diversity in which the existing variety of organisms contributes to the development of numerous ecosystem services. These, in turn, play a significant role in maintaining the balance between many other natural as well as man-managed ecosystems [2]. As demonstrated by various works, application of inadequate procedures while handling soil resources may lead to disturbing erosion phenomena that reduce the production potential of soil [3-5], and the additional production costs caused by these phenomena actually affect the consumers by increasing the prices of final products [1].

The study by Blaikie and Brookfield [6] contains a statement regarding the outcomes of oil degradation in terms of the social problem. The human involvement in its structure may prevent it, as well as lead to an increase of such problems. The authors describe the degradation of the soil in terms of the reduction of its potential defined in terms of current and future potential use. The so-called net soil degradation is associated with the disparity between the processes of natural degradation and human interference, and the processes of its natural renewal and the operations aimed at its recovery executed by humans.

Despite the fact that the natural causes of soil degradation play a significant role on its function, human activity associated with the use of various tools and practices applied for environmentally sustainable farming can reduce the outcomes of the human interference on natural soil capital, affect its security and support natural soil regeneration processes [7-9]. There are many possibilities including the use of an ecological production system. In addition, the use of crops planted with the purpose of soil conservation is becoming increasingly popular. The interest in the implementation of protective techniques for the soil environment, based on limiting soil movement, permanent covering of post-harvest residues, plants and the use of extensive crop rotation, has increased in recent decades, for example, the Americas and Australia. Numerous studies have demonstrated that the use of direct sowing technique has resulted in a greater degree of water infiltration than in the case of conventional cultivation system [10]. However, as reported in [11], the use of the first cultivation system in Europe is increasing more to reduce production costs. This is obviously significant due to lower energy consumption or gas emissions. The efforts concerned with conservation of soils against erosion and preservation of soil moisture and its well-being also start to play increasing and significant roles.

All procedures and activities performed with the aim of improving the structure of the soil, its well-being, fertility and productivity are very desirable nowadays. This is particularly important in the context of the recent reports, which state that according to new data [12], 35% of soils in the Eurasian area have low levels of organic carbon (1–2 %) and in 15% of soils this level is very low (<1%). Only 6% of soils in this continent have high (> 6%) organic carbon content. According to this criterion, about 90% of Polish soils used for agriculture is susceptible to conditions associated with drought [13].

Natural soil capital can be defined in terms of various characteristics, both through fertility, productivity or its well-being. These characteristics are closely related to the of soil organic matter content, which in mineral soils, forms only a small ratio but plays a significant role. This natural capital is generally represented by organic matter content in a soil [14], and this ratio is determined by the condition of the composition of the soil system (its resources), which affects the functions performed by the soil to the benefit of the entire ecosystem (ecosystem services) [14, 15]. In the literature there are a number of studies in which attempts have been made to assess whether various agricultural risks can be avoided by managing the natural capital of the soil, and even how this capital can affect farm revenues [14, 16].

The purpose of this study was to report on the undertaken assessment with regard to selected activities undertaken in experimental farms that operate according to various cultivation systems, including a variety of activities related to the management of soil resources and its capital. The assessment and analysis was performed on the basis of preliminary results of a study involving a period of three years. Research conducted on farms is part of a broader study covering the impact of farms on the natural environment.

2. Materials and methods

The material applied in the present calculations and analysis was derived on the basis of data from two conventional farms located in the Opolskie Voivodeship. One of the farms applies traditional farming (TF) and the other simplified-conservative farming (CF). Three fields in each farm were examined and analyzed for this purpose. The presented results and analysis include the years 2015/2016, 2016/2017 and 2017/2018 and form a part of a more extensive research conducted into the problem of assessing the impact of agriculture on the natural environment in example farms. In order to implement the analysis of the problem, the following bulk of data was collected from the farms:

a) type and surface of the sown area (including catch crops in a given year),
b) scope of agricultural activities: from the end of the from forecrop in the field to the harvest of the main crops;
c) nitrogen fertilization rates,
d) crop production per unit area of land.

In addition, laboratory tests were performed for each field with the aim of establishing the following: soil texture, pH, total nitrogen content ($N_{tot.}$) as well as humus content. Soil samples were collected annually at the turn of February/March, before field works began. Depth of sampling was from 0 to 30 cm. The tests were carried out in the laboratory of the District Chemical-Agricultural Station in Opole.

Additionally, in 2016, soil samples were taken (depth of sampling: 0-10 cm) to determine the soil density profiles.

On the basis of the insight from works [17, 18], this analysis applied the following indicators to assess the quality of soil management:

a) the variety of plants production, including the ratio of plants applied to improve soil fertility,
b) the ratio of cereals in sown area and the ratio of green fields,
c) soil organic matter balance using reproduction and degradation coefficients developed by to Eich and Kundler [based on 19],
d) the C:N ratio,
e) intensity of plant production organization.

3. Results and discussion

3.1. Summary of basic information regarding the fields

The analyzed fields are located in the Opolskie Voivodeship, county of Krapkowice:

a) fields A, B, C (TF farm) – Strzeleczki commune, Komorniki village,
b) fields D, E, F (CF farm) – Walce commune, Rozkochów village.

Due to the relatively close location of both farms, as well as similar soil and climate conditions, an objective assessment of production and the impact of both systems on the soil ecosystem was feasible. On the fields applying TF system, traditional soil cultivation techniques were used, with ploughing to a depth of about 20 cm coupled with other procedures (grubbing, disking), which to a lesser extent interfere with the soil environment. With regard to the CF farm, simplified cultivation is applied in all fields – there is no traditional ploughing, as harvest residue, straw, beet leaves, mass of crops are ground and mixed with the soil to a depth of about 5 cm. This exemplary procedure repeated in the fields of farms TF and CF is summarized in Table 1.

In the TF farm, apart from the frequent process of grinding and mixing soil residues and the green mass of beet leaves, an important element of soil protection and its enrichment into organic matter was associated with grinding catch crops in the spring and mixing them with the soil.

Laboratory tests into the texture of soils in the analyzed fields and the analysis of the bulk density are presented in Table 2. We can note that in the CF farm the field soils demonstrate a slightly lower bulk density, which may indicate thorough breaking up of soil leading to more favorable water and air conditions in the topsoil layer (0-10 cm). The studies into bulk density applied only a single season, however, due to the use of regular activities and sowing on both farms, in this study for the purpose of preliminary analysis, its results were assumed to apply for the whole research period. In accordance with the data from literature [20, 21], the bulk density of mineral soils ranges from 1.1-1.8 $g \cdot cm^{-3}$, and for humid soils it could assume a value below 1. Due to the fact that conservation tillage is applied in CF farm, probably the accumulation of organic matter over many years and its better distribution contributes to lower values of bulk density of the soil. This is also confirmed by the results of the study by Tebrügge and Düring [22], according to which after about 8 years

Table 1. Examples of procedures applied based on fields in farms TF and CF
Tab. 1. Przykładowe zabiegi na polach gospodarstw TF i CF

2015/2016			2015/2016		
A	B	C	D	E	F
Mixtures of cereals and pulses	Winter wheat	Potatoes	Winter wheat	Sugar beetroot	Peas
grubbing, disking, winter ploughing, mineral fertilization (x2), grain sowing plant protection, harvesting + straw grinding and ploughing, grain transport	grubbing, disking, ploughing, mineral fertilization, sowing, mineral fertilization, plant protection measures (x2), fertilization, plant protection measures, mineral fertilization, harvesting+ straw grinding and ploughing, grain transport	grubbing, disking, manure fertilization, ploughing, fertilization (x2), potato planting, plant protection (x2), harvesting, transport	stubble cultivation, sowing, mineral fertilization (x2), plant protection measures (x3), mineral fertilization., plant protection, straw harvesting	stubble cultivation manure fertilization, catch crop sowing mineral fertilization, soil cultivation, point sowing plant protection measures (x3), mineral fertilization, plant protection measures, harvesting, grinding leaves and mixing with soil	stubble cultivation, catch crop sowing mineral fertilization, soil cultivation, plant protection measures (x2), grain harvesting, mixing residue with soil

Source: own study / Źródło: opracowanie własne

Table 2. Soil textural classes and their bulk density
Tab. 2. Gatunki gleb oraz ich gęstość objętościowa

Field	Textural classes	Bulk density[g·cm^{-3}] (0–10 cm profile)
A	silty loam soil	0.94
B	sandy loam soil	1.05
C	sandy loam soil	1.10
D	sandy loam soil	0.89
E	silty loam soil	0.97
F	silty loam soil	0.93

Source: own study / Źródło: opracowanie własne

with no tillage applied in the field, the upper and lower layers of the soil profile assume a lower density than in the case of conventional tillage. The results of other research [23-25], however, indicate higher soil bulk density in the conditions of conservation tillage

One of the factors that affected the yield of crops is the volume of mineral as well as organic fertilization. Both farms were dominated by the use of mineral fertilization. Only for growing potatoes (field C year 2015/2016) and for growing sugar beet (field E year 2015/2016 and field F year 2017/2018) additional fertilization with pig manure was applied.

In the following years, the following input of pure nitrogen was used on average per 1 ha of the analyzed fields:
a) fields A, B, C: 102, 147 and 89 kg·ha^{-1}
b) fields D, E, F: 133, 148 and 117 kg·ha^{-1}.

Higher rates of nitrogen use in the CF farm in 2015/2016 and 2017/2018 resulted from both the mineral fertilization applied as well as the manure for growing sugar beet. On average, nitrogen fertilization at the CF farm in 2015/2016 and 2017/2018 was higher by 23%. The use of natural fertilization in both farms did not exceed the admissible level of 170 kg·ha^{-1}·year^{-1}. As a result of referring to the data regarding nitrogen fertilization in Table 3 and comparing them with the standards set out in the Regulation of June 5, 2018 on the adoption of the "Program of measures envisaged to prevent and mitigate adverse effects of pollution with nitrates from agricultural sources and prevention of further pollution" (Journal of Laws of 12 July 2018, item 1339 [26]), it we can note that in particular from the season 2017/2018, nitrogen consumption has reduced. This contributes to protection of the soil and water environment, as well as leads to the decrease of the cost of fertilization, while maintaining similar yields in the analyzed years. Table 3 presents data regarding the areas of sowing land, yields, catch crops and nitrogen fertilization. Winter wheat was the most commonly cultivated plant in both farms in the analyzed period. The yields recorded in both farms were at comparable levels.

The remaining information regarding the analyzed fields that is needed for the purposes of assessing the quality of managing soil capital is summarized in Table 4.

3.2. Environmental assessment of activities aimed at protecting natural soil capital

a) Diversity of crops, ratio of plants applied to improve soil fertility

As reported in [14], crop diversification forms one of the basic methods of reducing agricultural hazard in production. However, we can note that the diversity of crops on the farm aims to protect the soil, whose consequent condition and well-being is better, provides higher yields.

The application of simplified sowing patterns coupled with the dominance of cereal cultivation now provide the traditional approach to agricultural production in many modern farms. To increase the diversity of species on agricultural land, a multispecies crop rotation is recommended, including the application of diversity of sowing catch crops. According to recommendations [27], such crop rotation should include from 3 to 5 species depending on the agronomic class of the soil. We can also note that rich crop diversity contributes to the improvement of soil fertility and its protective function against erosion or water loss, leading to the protection of valuable resources of humus in soil [17]. The diversity of cultivated species in the sowing structure in a given year is also important. Although the time window applied for this analysis of fields included only 3 years, it was already noted in this period that in each field the species diversity of cultivated plants has been preserved, and in the farm 2 mainly this was due to the catch crops cultivated almost annually (Table 5).

Table 3. Summary of basic information ono analyzed fields in years: 2015/2016, 2016/2017, 2017/2018
Tab. 3. Podstawowe informacje dotyczące analizowanych pól w latach 2015/2016, 2016/2017, 2017/2018

	Crop area [ha]	Plant cultivated as main crop	Yield [dt·ha $^{-1}$]	Catch crop	Fertilization rates of N expressed in pure component [kg·ha^{-1}]
Farm TF					
2015/2016					
Field A	1.20	mixture of cereals and legumes	42	n/a	60
Field B	1.40	winter wheat	**60**	n/a	155
Field C	0.62	potatoes	220	n/a	**92***
2016/2017					
Field A	1.20	winter rape	33	n/a	134
Field B	1.40	winter barley	65	n/a	140
Field C	0.62	winter wheat	**67**	n/a	166
2017/2018					
Field A	1.20	winter wheat	**62**	n/a	96
Field B	1.40	peas	32	oats + beans	14
Field C	0.62	winter rape	30	n/a	158
CF farm					
2015/2016					
Field D	2.14	winter wheat	**60**	n/a	176
Field E	3.20	sugar beetroot	600	mustard (*Sinapis alba* L.)	**163.5***
Field F	2.57	peas	37	n/a	60
2016/2017					
Field D	2.14	peas	40	mustard (*Sinapis alba* L.)	73,5
Field E	3.20	winter wheat	**62.5**	n/a	202
Field F	2.57	winter barley	70	mustard (*Sinapis alba* L.)	168
2017/2018					
Field D	2.14	winter wheat + spring barley (0.53 ha)	**60** 42	mustard (*Sinapis alba* L.)	140
Field E	3.20	peas	30	n/a	35
Field F	2.57	sugar beetroot	500	mustard (*Sinapis alba* L.)	**175***

*including manure – pig manure applied in the production of potatoes and sugar beet root equal to 25 ton·ha^{-1}.

Source: own study / Źródło: opracowanie własne

Table 4. Humus content [%], $C_{org.}$ [%] and pH of examined soils
Tab. 4. Zawartość próchnicy [%], $C_{org.}$ [%] oraz pH badanych gleb

Field	Spring of 2016			Spring of 2017			Spring of 2018		
	Humus content/ $C_{org.}$ [%]	$N_{og.}$ [%]	pH	Humus content / $C_{org.}$ [%]	$N_{og.}$ [%]	pH	Humus content / $C_{org.}$ [%]	$N_{og.}$ [%]	pH
A	1.06/0.62	0.101	6.3	2.57/1.49	0.092	5.9	1.91/1.11	0.09	5.7
B	2.81/1.63	0.048	6.4	1.59/0.92	0,064	6.5	1.55/0.9	0.09	6.7
C	2.66/1.55	0.134	5.6	1.45/0.84	0,039	6.4	1.41/0.82	0.069	6.3
D	2.16/1.25	0.174	6.2	1.69/0.98	0,056	6.0	1.69/0.98	0.099	5.9
E	2.22/1.29	0.134	6.9	1.78/1.03	0,067	6.1	2.00/1.16	0.11	6.8
F	2.59/1.50	0.190	7.2	1.64/0.95	0,081	7.0	2.16/1.25	0.132	7.1

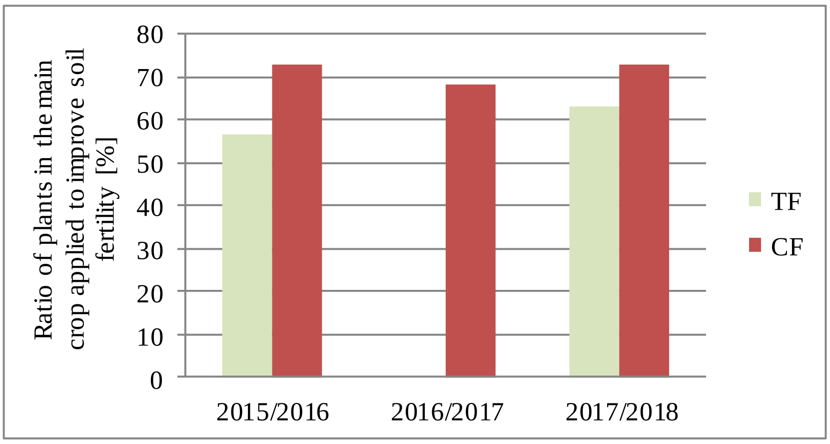
Source: own study / Źródło: opracowanie własne

Table 5. Diversity of crop structure
Tab. 5. Różnorodność uprawianych roślin

Field	Area	Forecrop	2015/2016	2016/2017	2017/2018
A	1.20	winter triticale	mixture of cereals and legumes	winter rape	winter wheat + *catch crop (oats+peas)*
B	1.40	winter rape	winter wheat	winter barley	peas
C	0.62	mixture of cereals and legumes + *catch crops* *(mustard - Sinapis alba* L.*)*	potatoes	winter wheat	winter rape
species		5	4	3	5
D	2.14	sugar beetroot + *catch crops (mustard Sinapis alba* L.*)*	winter wheat	peas + catch crops *(mustard Sinapis alba* L.*)*	Cereal mixture
E	3.20	winter wheat	sugar beetroot + catch crop *(mustard (Sinapis alba* L.*)*	winter wheat	peas + catch crop *(mustard - Sinapis alba* L.*)*
F	2.57	winter wheat	peas + catch crop *(mustard - Sinapis alba* L.*)*	winter barley	sugar beetroot + *catch crops (mustard - Sinapis alba* L.*)*
species		4	4	4	5

Catch crops listed in a given column refer to the period from the autumn to spring in a given season.

Source: own study / Źródło: opracowanie własne



Source: own study / Źródło: opracowanie własne

Fig. 1. Ratio of plants in the main crop applied to improve soil fertility
Rys. 1. Udział roślin w plonie głównym poprawiających żyzność gleby

A preliminary comparative analysis of the activities of both production systems provide grounds for a positive assessment of both farms in terms of the diversity of cultivated plant species. The proportional use of 3-5 species is preserved in them. At the CF farm, catch crops are often cultivated, which certainly offers an example of better crop rotation. In the applied conservation tillage, the aim is to leave large amounts of organic matter on the fields (e.g. sugar beet leaves, that is ground and mixed with soil) or enriching the soil with nitrogen (as a result of cultivation of peas). This may affect both the more favorable result of the density of the topsoil profile and, over the long term, the accumulated volume of organic matter increases as well.

In terms of the structure of the sowing area, as well as in the crop rotation, whose aim is to protect the soil and ensure the demand of organic matter, it is important to provide high ratio of the main crops cultivated with the purpose of improving soil fertility (e.g. hard seeded as well as small-seeded legumes, growing grass on fields, ploughing intercrops). Their minimum ratio should be around 20% [18]. In this work, the following plants were included in the main crop: leguminous, cereal-leguminous and root crop mixtures (due to fertilization with manure from the farm and leaving the green mass of beet leaves on the field). For the analyzed fields, a more favorable ratio of plants applied with the purpose of improving fertility was established in the fields of the CF farm. In addition to the ratio of these plants in the main crop, as shown in Fig. 1, the crops, whose presence on the CF farm fields also play an important role. The analysis of the changes based on Table 4 also indicates respect for the soil quality and its capital in the CF farm.

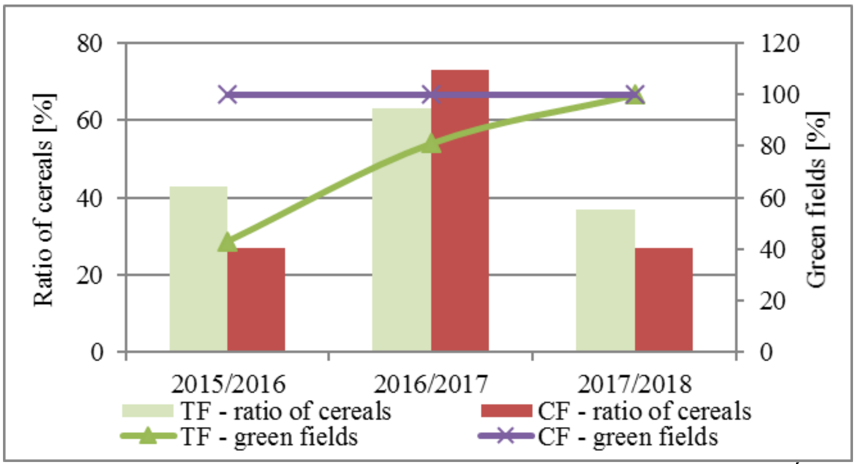
b) Ratio of cereals in sown crops and ratio of green fields in winter

The cultivation of cereals occupies an important place in the national food economy, and cereals are cultivated on almost every farm. Such circumstances can be confirmed using statistical data. In 2017-2018 season, the ratio of cereals in total sown area in Poland was equal to 70.7 to 72.1%, and in the Opolskie Voivodeship this figure was between 73.4 and 71.4%, respectively. At the same time, the ratio of plants that could be used to increase soil fertility (legume, fodder plants) was total to only 12.2-12.1% in Poland and 4.8% in the Opolskie Voivodeship [28, 29].

In accordance with the conclusions stated in a study by Harasim [17], it is necessary to avoid the ratio of cereals in sown land exceeding 66%. It is recommended, in turn, that the share of leguminous crops should not be lower than 20–25% [30], and this figure is not observed in modern farms nowadays. Although the cultivation of cereals plays an important role from the point of view of the food economy, such a large area of cropland, usually in the form of a conventional cultivation system, can seriously affect the quality and well-being of the soil environment. This is particularly important in the context that cereal crops include ones that lead to organic matter degradation in soils. On the other hand, the introduction of leguminous plants to the structure of the sown area and crop rotation may contribute to an increase of the diversity of soil microorganisms [31] In addition, it can also reduce the consumption of nitrogen fertilizers and the emission of nitrous oxide [32]

In the analyzed farms, the ratio of cereals in sown area (based on three analyzed fields in each farm) was higher than in the TF farm (Fig. 2). Only in the second year of research, cereals dominated on both farms the majority of the surface area of the analyzed fields (63% and 73%, respectively). In the CF farm, the system of production generally focuses on the output of large-market crops that generate the largest portion of incomes, but the aspect concerned with the protection of soil ecosystem plays and important role and it is coupled with attempts to reduce degradation of soil organic matter. The potential high ratio of cereals in sown area is counterbalanced by other procedure aimed at soil protection (cultivation of catch crops, leaving crop residues in the field, application of farm manure).

The attempts to protect the fields outside the growing season play a very important role, as they help to retain nutrients in the soil, which can be used for the demand of the main crop in the following year as lower soil erosion is observed in such fields [33]. In general, it is possible and feasible to leave catch crops in the fields during winter in all types of farming systems, but in particular their presence should be widespread in organic and sustainable types of farming. In addition, they can help to minimize the use of pesticides and alleviate the adverse effects of a cereal monoculture [34]. Winter crops should be applied to cover the remaining area of sown fields. Depending on the type of terrain, vegetation should be cultivated on a minimum of 60% of crop field over the entire year, including winter [27].



Source: own study / Źródło: opracowanie własne

Fig. 2. Ratio of cereals in sown field and proportion of green fields

Rys. 2. Udział zbóż w zasiewach i udział zielonych pól

If it is not possible to apply cover crops over arable land in winter, it is permissible to use post-harvest residues, with a note that the protective effect of its use is, however, smaller.

Over three years of the analysis in both farms, the applied field cover in winter was provided by catch crops or winter crops. In the case of the CF farm, where more emphasis is placed on soil protection, it was 100% covered by vegetation all year (Fig. 2). The annual increase in the proportion of green fields in the TF farm resulted also from the accession of this farm to the agri-environmental program (that is, sustainable agriculture).

c) Soil organic matter balance, C:N ratio

The analysis of the soil organic matter balance indicates that a positive result was maintained in both farms over the three years when the production was analyzed (Table 6). The calculations took into account the period from autumn 2015 (straw and mulch of sugar beet leaves seeded into the soil after main crops) to the time of the main crop harvest in 2018. On the CF farm, the changes applied to fields E and F led in total to the introduction of 3 and 3.9 $t{\cdot}ha^{-1}$ of organic matter to the soil. On average, 0.17–0.53 $t{\cdot}ha^{-1}$ of organic matter was introduced to the soils of the analyzed fields – fields A, B, C and 0.05–1.28 $t{\cdot}ha^{-1}$ in the fields D, E and F respectively,

Table 6. Mean soil organic matter balance in the seasons 2015/2016-2017/2018 [$t{\cdot}ha^{-1}$] and C:N ratio

Tab. 6. Bilans glebowej materii organicznej średnio w latach 2015/2016-2017/2018 [$t{\cdot}ha^{-1}$] i stosunek C:N

Field	Soil organic matter balance [$t{\cdot}ha^{-1}$]	Ratio C:N		
		spring 2016	spring 2017	spring 2018
A	+0.6	6	16	12
B	+1.6	34	14	10
C	+0.5	12	22	12
D	+0.2	7	30	17
E	+3.0	10	27	18
F	+3.9	8	14	16

Source: own study / Źródło: opracowanie własne

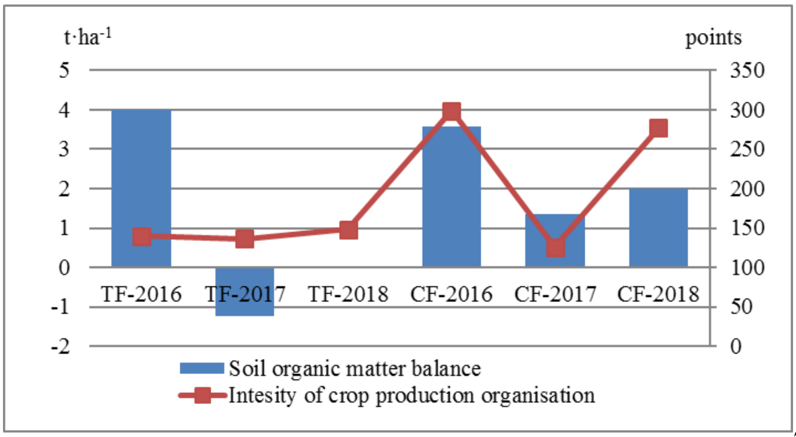
The content of soil organic matter forms a derivative of the input of fresh organic material (residues, roots) and litter in various stages of decay [8] and it is of great importance in shaping soil fertility. In the case of TF farm, catch crops and manure introduced for the purposes of growing of beet root play a large role for the supply of organic material to the soil. In particular, the use of manure and the introduction of green beet leaf weight played an important role in the restoration of organic matter, given that root crop cultivation is most strongly affected by the degradation of soil organic matter.

Although the mean result expressed by the soil organic matter balance in the analyzed period is generally positive, the results of laboratory tests included in Table 3 indicate that in all fields (and in each year), there were no clear differences in terms of the content of both humus and organic carbon between farms. In addition, these values are quite low and characteristic for the content of organic matter that is very common in Poland (i.e., 2.2%). For the Opolskie Voivodeship, the average organic matter content in soil according to [13] is 2.33%. According to the above report, the content of humus (organic matter) below 3.5% (corresponding to around 2% $C_{org.}$) is considered as a sign of desertification. Therefore, in both farms the results of laboratory tests are not satisfactory in this respect.

Quite apparently, the process of restoring organic matter is long-term and complex task, taking into account the ongoing decomposition processes resulting from both physico-chemical and biological soil characteristics as well as the applied cultivation procedures and species of cultivated plants as well as the supply of organic material [8].

The proportion of crops leading to degradation of organic matter (potatoes, sugar beets, but also cereals when and rape they are pure sown) may have led to the considerable intensity of decomposition processes of organic matter coupled resulting from the positive attempts to restore and keep soil organic matter content at a high level. We should bear in mind that the years 2015-2018 were exceptionally warm and dry, and 2018 was the warmest in the history of temperature measurements in Poland [35-37], which could have contributed to the decomposition processes, in particular in the light of the results confirming that an increases in temperature leads to greater losses of soil organic matter [38-40].

In the context of the study concerned with the issues related to soil organic matter content in the analyzed fields, we can also note the issues relating to possible dependencies between the soil organic matter balance and the intensity of organization of agricultural production.



Source: own study / Źródło: opracowanie własne

Fig. 3. Soil organic matter balance vs. intensity of crop production
Rys. 3. Bilans glebowej materii organicznej i intensywność organizacji produkcji

This problem was raised by Sawa [41], who, however, remarked that the commonly applied in assessing intensity of production (based on Kopeć) is outdated for the purposes of assessing modern farms. Nevertheless, it is possible to employ the methodology reported in [42] for the needs of such assessment. In the analyzed case of the farms, the use of the referring only to plant production, did not yield definite dependencies. A dependence that occurred in CF farm seems to appeal as a more feasible relation – as the increase in the level of organizational intensity of production was associated with introduction of plants applied with the purpose of forming desired soils structure as well as plants with higher agro-technical demands, among others. Such procedures can promote the increase of organic matter content in soil (Fig. 3). Certainly, research covering a longer period of time can yield a more detailed picture to answer the investigated issues.

Laboratory results of $C_{org.}$ and $N_{tot..}$ also provided the grounds to determine the C:N ratio. This ratio in soils is relatively constant and affects the assimilation of nitrogen, as well as the content of organic matter or the rate of its decomposition. This value in the organic layer of arable soils is usually in the range between 8:1 ad 15:1 [43]. The values above 20:1 result in immobilization of nitrogen. However, according to the results reported by Kononowa [44], the ratio C:N in soils of the same types and subtypes, is subjected to large fluctuations depending on the type of use. All variations in this value may be affected by from climate-related considerations and are in particular subjected to fluctuations in temperature and precipitation levels.

The C:N ratio in the soils of the analyzed fields was most often within the limits specified above. However, in several cases the results of measurements gave increased levels of this ratio even to 30:1. At the CF farm in 2017, this could have been related to bringing a large amount of post-harvest residues to the soil in the autumn of 2016, coupled with abandoned autumn fertilization, which is related to winter period and could have had an effect on the mineralization of organic matter. Field D was additionally fertilized in the spring of 2016 with manure, which could also affect the result of the $C_{org.}$ content in spring of 2017. A similar condition applies to the TF farm, field B, where in 2016, rape straw was ploughed, and the conditions contributed to the insufficient level of its decomposition during the winter season. However, it is difficult to predict for slightly higher individual results of C:N ratio. Nevertheless, adequate measures were applied to determine the optimal C:N ratio in both farms.

4. Conclusions

The analysis and assessment of two soil management systems was performed over a short time span and we cannot clearly determine which of the analyzed soil management systems in the farms has more beneficial effects on the soils.

It can be observed that more beneficial actions and results were employed on the CF farm, e.g. resulting from the use of catch crops, bringing in more plant mass to the soil, coupled with lack of ploughing. This may have an impact on the lower bulk density of soils in the CF farm, as well as on the better balance of soil organic matter.
We can note that the ratio of cereals in sowing area in the analyzed period was also lower in the CF farm. At the same time, cropland was covered with vegetation every year in winter in this farm. These are some of the positive aspects of the adopted method of production. Sowing in the main yield and catch crops were applied, coupled with the activities involving bringing green mass of beet root leaves, shredded straw and manure into the soils, which resulted in a higher overall balance of the soil organic matter.

Unfortunately, laboratory tests concerned with the content of humus and $C_{org.}$ did not demonstrate clear differences between the soils in both farms. These values are quite low and rather representative of the content of organic matter that is considered as mean in Poland. Apparently, the processes of restoring organic matter are long-term, and taking into account the decomposition processes taking place, crops degrading organic matter could be the reason why attempts to restore and maintain the organic matter content at a high level were quite intense. In addition, the result of the balance of soil organic matter was compared with the parameter representing the intensity of plant production. In this case, the relation can be established in favor of the production in the CF farm. The results of the C:N ratio measurements indicate that in both farms the process of determining the optimal C:N ratio was generally correct.

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