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Whether the addition of preparations with microorganism affects the organic carbon and humic substances in soil? A 3-year field study in cereal monoculture

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Abstract

This paper presents an assessment of humic substances and organic carbon content in soil after application of two microorganism preparations (EmFarma Plus and UGmax) in cereal monocultures. A three-year field study was carried out at the Agricultural Experimental Station in Grabow, belonging to the Institute of Soil Science and Plant Cultivation (IUNG) – State Research Institute. The first factor was tested products with microorganisms and a control without microbiological preparations. The second factor was the 2 methods of application of the above products: on stubble, on stubble + straw. The third factor was the 2 levels of N fertilisation: 0 and 180 kg N·ha^{-1}. The preparations with microorganisms together with mineral nitrogen without were applied annually directly to stubble or stubble + straw left in the field after cereal harvest and compared with a control treatment without the above preparations. The fractional composition of soil organic matter was more sensitive indicator of changes than the analyses the quantity of total organic carbon (TOC). EmFarma Plus applied on stubble and straw stubble, resulted in the organic carbon content increasing by an average of about 3.7% compared to the control plot. The second product tested had the opposite effect. The content of TOC decreased by an average of 2.5% under Ugmax applied to straw and stubble, remaining at a similar level to the control. This product, applied at a rate of 0.9 litres per hectare may have a stimulating effect on the mineralisation processes of soil organic matter (reducing the C_{HA}: C_{FA} ratio), hence the lower organic carbon content after application. Furthermore, it the applied on stubble and straw, without mineral nitrogen fertilisation, it reduced the C_{HA}, and increased of C_{FA} in the organic carbon pool and reduced of index of humification. EmFarma Plus acted in reverse.

1. Introduction

The decline in the organic matter content of Polish arable soils is a serious problem and requires increased agrotechnical inputs for its restoration. The average organic carbon content in the country is 1.12% (Siebielec et al., 2020; Kaczyński et al., 2017). Low SOM (soil organic matter) content can lead to a large decrease in soil fertility and, consequently, lower yields (Diacono and Montemurro, 2010). In Poland, as traditional methods of increasing soil organic matter, such as ploughing manure, have been exhausted, there are high hopes that ploughing straw will increase soil organic matter (Smagacz and Martyniuk, 2023). However, there is a high probability that the straw will not decompose due to frequent droughts (Smagacz and Martyniuk, 2023). For this reason, preparations containing micro-organisms have been used in agricultural practice to speed up decomposition. Researchers have shown that soil microorganisms have an important role in the transformation of plant residues and natural and organic fertilisers applied (Jurys and Feiziene, 2021; Gałązka et., 2017) resulted in an increase in the organic carbon content in the soil (Khalafalla, 2019; Shenck and Müller, 2009). Soil microorganisms are responsible for carrying out the biochemical processes and transformations that occur in soils, 75–80% of crop residues with the participation of microorganisms are mineralised into plant-available nutrients, while the remaining 20–25% are humified to form soil humus (Czyż and Reszkowska, 2007; Koyama et al., 2017; Pranagal et al., 2020). Adequate application of organic fertilisers is one of the measures that increase the amount of soil organic matter in agricultural soils, which can, in turn, increase microbial activity (Li et al., 2022; Tian et al., 2017). Their abundance and activity directly affects the mineralisation and humification processes of organic matter in the soil and, consequently, the fertility and quality of the soil and the growth and quality of the crop (Valarnini et al., 2003; Tołoczko et al., 2009).

In the literature, we can find studies on the effect of microbial preparations on soil organic carbon content (Khalafalla, 2019; Kong et al., 2024; Bongiorno et al., 2018; Stevenson, 1994). There is, however, a lack of studies on their effect on organic matter quality. Some researchers confirm that the application of microbial amendments could increase soil organic carbon content and improve soil organic matter quality, thereby reducing negative impacts on the environment (Khalafalla, 2019; Kong et al., 2024; Bongiorno et al., 2018; Stevenson, 1994). In our study, we also wanted to find out whether preparations applied to straw improve the quality of soil organic matter. Soil organic matter includes both living organisms and soil organic matter. Besides being a good source of energy for beneficial soil organisms, humic substances (HS) constitute also major fractions of soil organic matter (Jurys and Feiziene, 2021). HS are formed by the decomposition of plant and animal residues by microorganisms. Humic substances can be divided into three main fractions: humins – (C_H), humic acid (C_{HA}) and fulvic acid (C_{FA}) (Guimiaraes et al., 2013). In the literature, a special role in the mineralisation and humification process is attributed to the activity of microorganisms. Humic substances are formed through the process of humification, i.e. humus formation, which consists of the chemical and microbiological processes of decomposition of plant and animal residues in the soil and the remodelling and synthesis of organic compounds (Siebielec et al., 2020; Guimaraes et al., 2013; Dziadowiec and Gonet, 1999). Humification leads to the restoration or increase of humic substances in the soil. However, this process is limited by the mineralisation of soil organic matter, which results in the formation of simple mineral compounds. Both processes occur simultaneously and are closely linked − the products of the humification process are incorporated into the mineralisation process and vice versa (Khalafalla, 2019).

The quality of organic matter is assessed by separating organic carbon into humic acid, fulvic acid and humins fractions. The quality of organic matter can be calculated from the value ratio of humic acids to fulvic acids (Guimaraes et al., 2013; Dziadowiec and Gonet, 1999; Franzluebbers, 2002). An C_{HA}:C_{FA} ratio below 1 indicates that fulvic acids predominate in the composition of organic matter, while humus stabilising fractions, i.e. humic acids and humins, are scarce. These changes should be compensated for by introducing organic fertilization or straw. Excessive mineralisation of organic compounds can reduce soil fertility and consequently crop yields (Li et al., 2017).

Long-term experiments on the quantity and quality of organic matter indicate, irrespective of the fractionation methods adopted, that the fractions separated are a good indicator for assessing the impact of different agrotechnical treatments on soil physico-chemical properties (Diacono and Montemurro, 2010; Jurys and Feiziene, 2021; Khalafalla, 2019; Valarnini et al., 2003; Guimiaraes et al., 2013; Franzluebbers, 2002). Various fractionation methods can be used to assess the quality of organic matter (Dziadowiec and Gonet, 1999). It should be mentioned that these methods are costly and laborintensive. Several years ago, humic acids, fulvic acids and humins were determined using the complicated and time-consuming methods of Turin, Boratynsky and Wilk and Kononova and Belchikova (Dziadowiec and Gonet, 1999). Nowadays, in studies of light textured soils, the division of humic substances into humic acids (C_{HA}), fulvic acids (C_{FA}) and humins (C_H) is made according to the much simpler Schnitzers method, which uses the solubility of these compounds in selective solvents. This is a classic method, but is excellent for Polish, light textured and acidic soils (Dziadowiec and Gonet, 1999; Pikuła and Ciotucha, 2022; Schnitzer, 1982).

The study aimed to analyze the changes of organic carbon and the fractional composition of organic matter after the application of preparations with microorganism applied to straw and straw + stubble with mineral nitrogen, differing in dosage and composition. Our hypothesis is that application of the products will increase soil organic carbon content and will improve the quality of soil organic matter. It will be tested whether the application preparations with microorganisms in agricultural practice can bring additional significant benefits on sandy soils improving soil fertility.-

The aim of the study was to compare the soil organic carbon content and humic substances after application of the preparations with microorganism in a 3-year field study in cereal monoculture.

2. Materials and Methods

2.1. Study area

Three years of field studies were conducted in field experiment at the Agricultural Experimental Station (AES) of Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB) in Grabow, the Mazowieckie province, Poland (52°13'N, 19°37'E) in 2012–2014. The research in Grabow was conducted on lessive soil formed from sandy loam and was classified as Retisol as for use of World Reference Base for Soil Resources (IUSS Working Group WRB, 2022). The climate at the site is temperate with a the mean annual precipitation on the level of 577.7 mm (Fig. 1) and the mean annual air temperature 9.0°C. (Fig. 2) (2011–2014). This climate is considered as Dfb i.e., warm humid continental climate, according to the Köppen-Geiger climate classification. The basic properties of soil was characterized by a neutral soil reaction (pH_{KCl} –6.8) and TOC was 7 g·kg^{-1} content (Kocoń, 2014).

The experiment was conducted using the method of equivalent sub-blocks: split-block-split-plot, as a 3 factorial, where the first factor research (I) were the tested preparations with microorganisms: EmFarma Plus and UGmax (Table 1), and a control facility − without microbial preparations. The second factor (II) was the different ways of application of the above preparations: on stubble, on stubble with straw. The third factor (III) was the fertilisation levels with nitrogen: N0 – 0 kg N·ha^{-1}, NII – 140 kg N·ha^{-1}. In all 3 years of the study, different cereal species were used as trial crops. UGmax is Soil Conditioner -an extract from slurry and manure and is used to improve soil fertility. It contains, among others, microorganisms: lactic acid

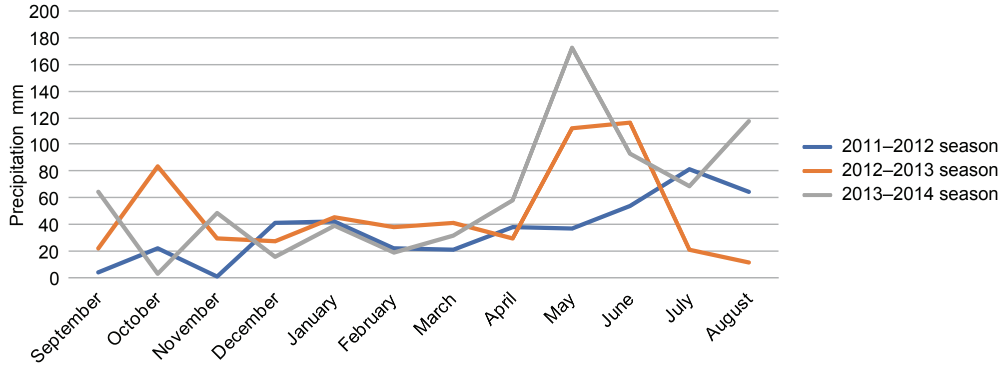

Fig. 1. Precipitation (in mm) in individual growing seasons (September–August) in research years

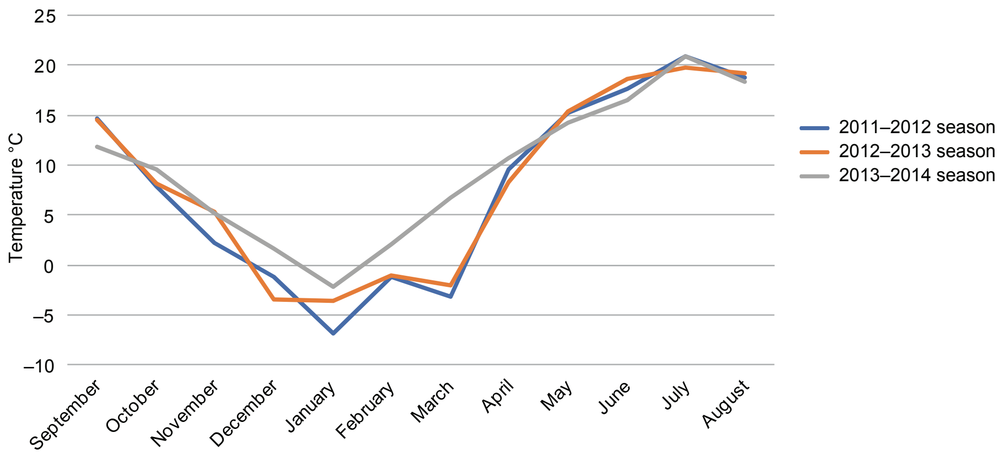

Fig. 2. Temperature (in °C) in individual growing seasons (September–August) inresearch years

Table 1
The abundance of each microbial group in the tested preparations

Trait examined	**UGmax** [cfu /ml preparation]	**EmFarma Plus** [cfu/ml preparation]
Total bacterial and actinobacterial abundance	56 x 10^3	14 x 10^5
Overall yeast count	15 x 10^2	23 x 10^3
Total abundance of lactic bacteria *Lactobacilli*	42 x 10^2	34 x 10^4
Total abundance of phototropic bacteria of the family *Thiorhodaceae*	–	10 x 10^2

bacteria, photosynthetic bacteria, *Pseudomonas ssp.*, *Penicillinum, Azotobacter*, yeasts, Actinomycetes and the following macro- and micronutrients: N, P, K, Mg, S, Na and Mn (Gałązka et al., 2014; Kocoń, 2014). EmFarma includes lactic acid bacteria (*Lactobacillus* and *Bifidobacterium*), actinomycetes and yeasts (*Saccharomyces*), which produce substances of phytohormonal compounds, enzymes and others, as well as compounds that are usually the nutrient for lactic acid bacteria and beneficial (*Actinomycetes*). They also include photosynthetic bacteria, which play a leading role in biochemical processes (Gałązka et al., 2017; Kocoń, 2014).

In all 3 years of the study, different cereal species were used as trial crops. In the first year, winter triticale cv. Leontino was used, which unfortunately froze in February 2012 and was replaced in the spring with spring triticale cv. Nagano. In the second year, winter wheat of the variety Figura was sown and in the third year spring barley of the variety Kucyk was sown. The cereals were sown at the optimum time for each species. The experiment was static and was carried out using the equivalent sub-block method: split-block-split-plot, in 3 replicates (Kocoń, 2014). This paper presents the results after harvest of spring barley- the last crop grown in a cereals monoculture.

2.2. Analytical methods

Soil samples were collected before ploughing (September–October) of 2012–2014 from the plough layer (0–30 cm) in three replicates. This paper presents the results of a post-harvest study of spring barley. The moist soil samples were sieved through a 2 mm sieve until analysis. Selected properties of the soil: soil pH_{KCl} (pH in the suspension 1 M KCl (N-ISO 10390:199, the content of total organic carbon (TOC) by the Tyurin method (PB 021-wyd.IV.28.08.2020) were performed by the certified chemical laboratory of the Institute of Soil Science and Plant Cultivation in Puławy, Poland and also detailed soil organic quality tests: the group and fraction composition of humic substances (HS) were determined using by the Schnitzer method (Dziadowiec and Gonet, 1999; Schnitzer, 1982). Humic acids were extracted from the soil under study according to the method of Schnitzer to obtain humins (C_H), humic acid (C_{HA}), and fulvic acid (C_{FA}) fractions. The separation of the differing properties of three categories of substances humic substances: humic acids, fulvic acids and humins, is the result of the analytical procedure for their fractionation, based on the criterion of their solubility in selective solvents: in acids and alkali. The carbon contents in soil extracts (individual fractions) was determined using the automated N/C analyzer (Multi N/C 3100, Analytik Jena, Jena, Germany). Based on the results obtained, the percentage share of individual fractions in the total poll of organic carbon was calculated. The carbon of the humins fraction was calculated from the difference between organic carbon and the sum of marked factions. The content of organic carbon of separated fraction was calculated as follows: carbon in solution (C_S), **s**um of humic and fulvic acids in extracts obtained with 0,5 M NaOH (C_{HA}+ C_{FA}) carbon of fulvic acids in solutions, following humic acids precipitation (C_{FA}), carbon of humic acids (C_{HA}) calculated from the difference: (C_{HA} + C_{FA}) – C_{FA} and humins: 100 – (C_{HA}+ C_{FA}+ C_d). The fractional composition was expressed as the percentage share of respective fraction in the total pool of organic carbon (TOC). The relationships C_{HA}: C_{FA} and DH = (C_{HA}+ C_{FA}) were also calculated. The Schnitzer method (Dziadowiec and Gonet, 1999) was used to determine the effect of the application of preparations with beneficial microorganisms on the quality of organic matter. According to this method, the following carbon fractions of soil organic matter were isolated from the soil after harvesting spring triticale. Based on the fractional composition of organic matter, the humification, which determines the amount of stable humus compounds (resistant to microorganisms), was determined.

The data were subjected to the 3 way analysis of variance (ANOVA) with significance of differences assessed at $p \leq 0.05$, using the FR-ANALWAR software based on Microsoft Excel.

3. Results and Discussion

3.1. Total organic carbon ontent

The results obtained indicate that the type of preparation with microorganism influenced soil organic carbon content (Fig. 3). Applying EmFarma Plus on stubble and straw stubble caused the organic carbon content to increase by an average of about 3.7–2.4% compared to the control plot. This preparation, containing lactic acid bacteria, actinomycetes and yeasts, applied at a rate of 30 L per hectare, resulted in an increase in soil organic carbon content, due to its beneficial effect on the conversion of straw into stable forms of organic matter and the predominant humification process.

The second product tested had the opposite effect. The organic carbon content decreased by an average of 2.5% under Ugmax, applied to stubble. When it was applied to stubble and straw, it resulted in a similar level of organic carbon to that of the control object. Preparation based on slurry and manure extract applied at a rate of 0.9 L per hectare may have a stimulating effect on organic matter mineralization processes, hence the lower organic carbon content after application. A similar trend was observed when the dose of mineral nitrogen was increased. Mineral nitrogen at a dose of 140 kg·ha^{-1} in combinations with the tested preparations did not increase of total organic carbon (TOC) content, but had a stabilizing effect on its content in the soil. The effect of the preparations containing microorganism depending on weather conditions (Gałązka et al., 2016). The most favorable weather conditions were recorded in 2014 (Fig. 1 and 2). This year, rainfall and temperature were higher and well distributed throughout the growing season. Many researchers have confirmed that increased precipitation and optimum soil temperatures favour soil microorganisms and more efficient transformation of fresh soil organic matter in the mineralization process by regulating nutrient availability (Gałązka et al., 2016; Czyż and Reszkowska, 2007; Koyama et al., 2017; Li et al., 2022). In contrast, drought reduces the diversity and amount of soil bacteria and fungi by reducing plant cover and, consequently, the supply of organic carbon into the soil (Koyama et al., 2017; Li et al., 2017).

Some authors find an increase in organic carbon content after the application of microbiopreparations, while others find

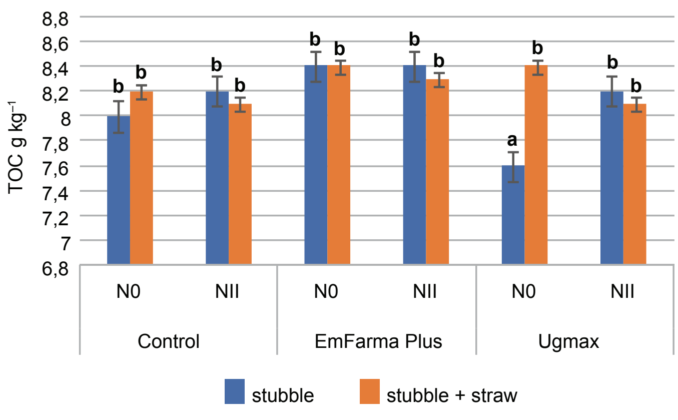

Fig. 3. Total organic carbon (TOC) content in the top layer of soil (0–30 cm) as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III) in the long-term field experiment at Grabow, Poland. Error bars indicate standard deviations (n = 3). LSD ($p \leq 0.05$): for I = 104, II = n.s., III = n.s. II/I = 0.196, I/II = 0.190, III/I = n.s., I/III =n.s., III/II = 0.092, II/III = 0.113. Treatments with the same letter are not significantly different ($p \leq 0.05$)

the opposite. Piotrowska et al. (2012) concluded that, compared to the control, the application of UGmax increased soil reaction and TOC concentrations throughout the study period, although the changes for the latter property were not statistically significant in 2007. According to research conducted by Kong et al., (2004), conventional application rates and excessive use of compound fertilisers have reduced both the diversity of the soil bacterial community and the organic carbon content of the soil.

3.2. Characterisation of the fractions of organic matter

In our studies, C_{HA}, C_{FA} and C_H were particularly influenced by the method of application and the dose of nitrogen fertiliser. This is confirmed by the results of the statistical analysis. On average, the content of C_{HA} represented slightly more than 20% of the total organic carbon pool, C_{FA} –16% and C_H – 60% (Fig. 4, 5, 6). After application of EmFarma Plus to stubble and straw stubble, the average content of the C_{HA} fraction was 6.32% and 2.65% higher, respectively, than in the control plot. Mineral nitrogen fertilisation maintained the content of this fraction at a similar or slightly higher level compared to the control plot (Fig. 4).

In the case of the Ugmax, the opposite tendency was observed. C_{HA} dropped by 10.6% in the object with stubble. In the object stubble + straw was at a similar level as at the control treatments respectively after the application of this preparation on both stubble and stubble + straw. The obtained results confirm the findings of other researchers that mineral nitrogen can stimulate the process of mineralisation of the permanent humus fraction. Similar conclusions were reached by the authors of Li et al., (2017) and Pikuła and Ciotucha (2022). After putting in this preparation to the stubble and applying mineral nitrogen, an increase of 11.98% was observed in this part compared to the control object. The content of C_{FA} in the control plot without application of the tested formulations, but fertilised with mineral nitrogen, was 17% higher in the combination with stubble than without mineral nitrogen and 25% higher in the plot with stubble and straw. A similar trend was observed after the application of EmFarma and Ugmax. The highest content of the fulvic acid

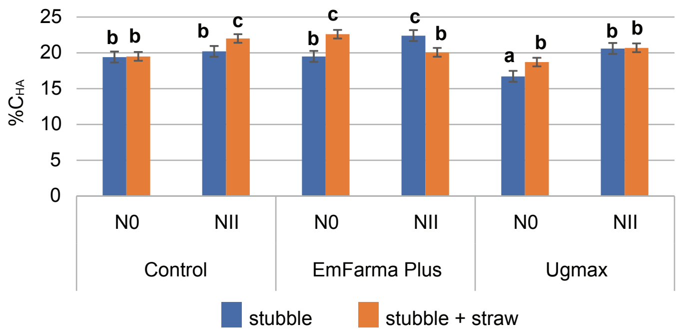

Fig. 4. The C_{HA} contents in the top layer of soil (0–30 cm) as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III). Error bars denote standard deviations (n = 3). LSD ($p \le 0.05$): for I = 0.170, II = 0,169, III 0.146, II/I = 0.173, I/II = 0.257, III/I = 0.252, I/III = 0.263, III/II = 0.181, II/III = 0.116. Treatments with the same letter are not significantly different ($p \le 0.05$)

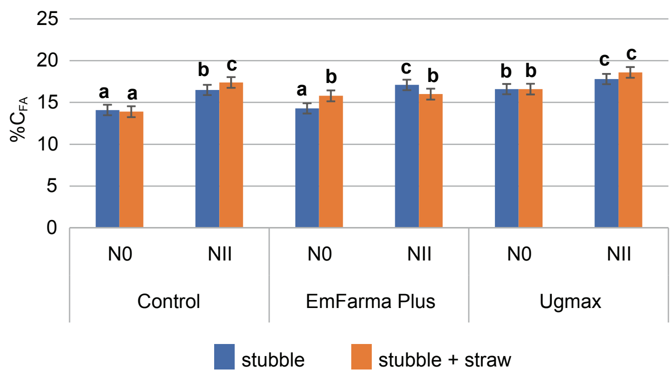

Fig. 5. The C_{FA} contents in the top layer of soil (0–30 cm) as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III). Error bars denote standard deviations (n = 3). LSD ($p \le 0.05$): for I = 0.159, II = 0.448, III = 0.318, II/I = 0.139, I/II = 1.190, III/I = 0.046, I/III = 0.121, III/II = 0.038, II/III = 0.084. Treatments with the same letter are not significantly different ($p \le 0.05$)

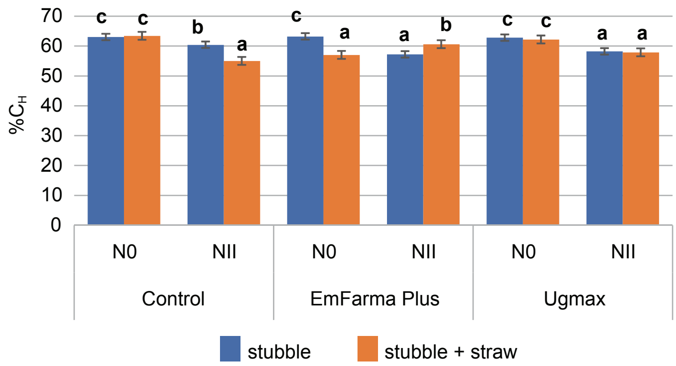

Fig. 6. The C_H contents in the top layer of soil (0–30 cm) as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III). Error bars denote standard deviations (n = 3). LSD ($p \le 0.05$): for I = 0.753, II = n.s., III = 0.313, II/I = 0.923, I/II = 0.984, III/I = 0.553, I/III = 0.741, III/II = 0.455, II/III = 0.644. Treatments with the same letter are not significantly different ($p \le 0.05$)

fraction FA was observed after the application of Ugmax, averaging 17.2% in the stubble field and 17.6% in the stubble and straw field. In the combination with stubble and mineral nitrogen, the content of this fraction was 17.8% and with stubble and straw 18.6%. Straw left on the stubble is a source of a large amount of fresh organic matter, providing a source of energy for soil microorganisms, promoting a transformation process with a predominance of mineralization (Czyż and Reszkowska, 2007; Li et al., 2017). Averaged over all treatments, the C_{FA} fraction in the combination with stubble and Ugmax application was almost 12.4% higher than in the combination without these preparation. In the combination with stubble + crop with Ugmax C_{FA} was 12.8% higher (Fig. 5). UGmax-Soil Conditioner is an extract of slurry and manure (Gałązka et al., 2017; Kocoń 2014). Numerous long-term experiments have confirmed that such a composition has a similar effect on the fulvic fractions as manure or slurry (Pikuła and Ciotucha, 2022; Yagüe et al., 2012). Soil microorganisms that influence the mineralisation of organic carbon, humification of organic matter, making nutrients more readily available to plants (Czopek et al., 2013), but also promote the conversion of fresh organic matter into permanent humus. Preparations with microorganisms can reduce the intensity of the mineralisation process and have a positive effect on the humification process (Zydlik and Zydlik, 2008). This results in the formation of humus fractions, i.e. humic and humic acid fractions, which are beneficial to the quality of soil organic matter.

Humins, which constitute a major part of organic carbon, are closely related to the mineral fraction of the soil. Both preparations used did not largely alter the content of the H and the average content of this fraction in comparison with the control objects was at a similar level: 60.2% after using the EmFarma preparation and 60.5% after applying Ugmax to the stubble. In the stubble + straw combinations, the average content of this fraction slightly increased by 1.5% compared to the control object. In addition, the process of humification of plant residues with high levels of nitrogen and bacteria, is characterised by a lower humification index. Undoubtedly, the efficacy of both formulations was strongly influenced by favourable weather conditions, increased and well-spaced rainfall and higher air temperatures and higher air temperatures in 2013–2014 season period. The increase in soil moisture and temperature improved the conditions for the development of micro-organisms and biological life in the soil (Koyama et al., 2017), which had a beneficial effect on the mineralisation and humification processes (Pranagal et al., 2020; Tołoczko et al.,2009). Our research (Fig. 2) has confirmed that preparations containing microorganisms, such as bacteria, can slow down the mineralisation process. Similar results were obtained by Pranagal et al. (2020), Tołoczko et al. (2009), and Kong et al. (2004).

3.3. The C_{HA}:C_{FA} ratio

The ratio of humic to fulvic acids (C_{HA}: C_{FA}) is described in literature as reflecting the mobility of soil organic carbon (Franzluebbers, 2002; Schnitzer, 1982). It also indicates the abundance and rate of humus accumulation (Guimaraes et al., 2013; Ukalska-Jaruga et al., 2007). Stevenson (1994) points to this relationship as an indicator of soil organic matter humification. With the decrease of C_{HA}: C_{FA} ratio, the organic matter humification rate decreases as well, which may result from soil management or recent introduction of fresh organic matter. The value of ratio C_{HA}: C_{FA} ratio about 1 is characteristic for good quality organic material that may enhance soil physical properties and plant growth. The C_{HA}: C_{FA} ratio <1 indicates a loss of the more labile C_{FA} fraction, which commonly occurs in sandy soils (Pikuła and Ciotucha, 2020). The changes in the C_{HA}: C_{FA} ratio in consequence of changes in the humic and fulvic acid carbon content in the total organic carbon pool due to the type of application of the amendments affecting humus quality, have been observed. The results of the statistical analysis in our study showed that the factors that significantly affected the C_{HA}: C_{FA} ratio included the type of application of the preparation and the rate of nitrogen (Fig. 7).

The quality of humus measured by this ratio was higher in plots with straw and stubble after using of the preparation EmFarma. Compared to the control plots, mineral N fertilisation resulted in a lower C_{HA}: C_{FA} ratio with the Ugmax plots. Data on the effect of mineral N fertilisation on organic matter quality remain unclear (Pikuła and Ciotucha, 2022; Kopecky et al., 2022). Mineral fertilisation in combination with Ugmax resulted in a reduction of the C_{HA}: C_{FA} ratio compared to the control object by 5% after application on stubble and by 11.9% after application on stubble + straw. The effect of EmFrama resulted in an increase in this ratio compared to the control subject, by 7% in the case of spruce and by 3% in the case of stubble + straw. According to several studies, applying high doses of mineral fertilizers can accelerate mineralization process, and consequently, lower organic carbon (Czyż and Reszkowska, 2007; Tian et al, 2017). The long-term ap-

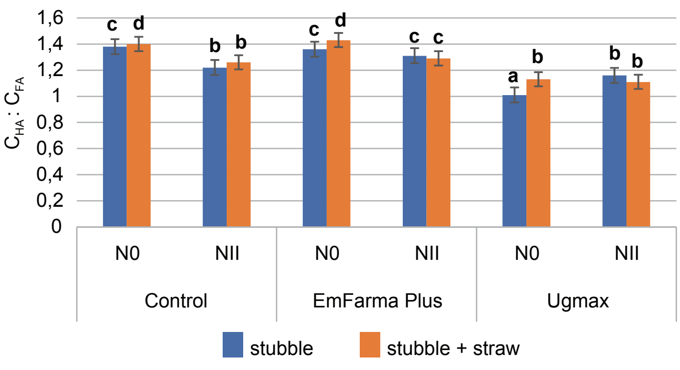

Fig. 7. The C_{HA}:C_{FA} ratio as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III). Error bars denote standard deviations (n = 3). LSD ($p \le 0.05$): for I = 0.053, II = n.s., III = 0.026, II/I = n.s., I/II = n.s., III/I = 0.045, I/III = 0.057, III/II = n.s., II/III = n.s. Treatments with the same letter are not significantly different ($p \le 0.05$)

plication of mineral N fertilisers on brown soils and lessives may decrease carbon content in the soil by about 21% compared to the soils where no mineral fertilizers were applied (Tołoczko et al., 2009; Kong et al., 2024). In contrast, other scientists confirm that mineral nitrogen in optimal doses stabilises humus quality (Pikuła and Ciotucha, 2022; Kopecky et al., 2022). Our studies indicate that mineral nitrogen fertilisation can reduce or increase the C_{HA}: C_{FA} ratio, depending on the dose and type of preparation. This can be explained by the fact that after the application of preparations to the straw with mineral nitrogen, the straw decomposes and undergoes mineralisation processes and more (C_{FA}) than (C_{HA}) indicates low humification rates (Kopecky et al., 2022). The lowest values of this ratio were recorded after the application of Ugmax compared to the control, with an average value of 1.08 for the application on straw and 1.12 for the application on straw + stubble. In the control, the average value of the C_{HA}: C_{FA} ratio was 1.29 and 1.33. The C_{HA}: C_{FA} index with values <1 is typical for soils with a predominant process of mineralization (Guimaraes et al., 2013; Zichun et al., 2019).

It is generally accepted that fertile soils are characterised by a higher humus content and a C_{HA}: C_{FA} ratio >1. The humus properties of the soil depend on mainly of the quantity the crop residues left after harvesting the crops (Guimaraes et al., 2013; Pikuła and Ciotucha, 2022; Zichun et al, 2019). However, the research confirms that the incorporation of straw into the soil leads to an increase in carbon, but this effect lasts for eight years, after which it returns to its previous state (Cui et al., 2024; Khalid et al., 2019). In our study, cereals, which are among the crops that leave few residues after harvest, were grown in succession. Cereal monoculture systems degrade soil quality and fertility by reducing soil organic matter (Smagacz and Martyniuk, 2023). After application of UgMax, the value ratio of humic to fulvic acids decreased compared to the control site. The situation was different after the application of EmFarma, where the ratio improved. Our other studies on the influence of straw on the quality of organic matter (not yet published) show that when straw is incorporated into the soil, it mineralises (C_{HA}: C_{FA} ratio <1), the H content in the fractions decreases and the C_{FA} content increases. Cereal straw contains more lignin, therefore the mineralisation process of cereal residues is slower compared to other crops (Cui et al, 2024). The values of this ratio were 1.31 in the object with stubble and mineral nitrogen, while in the control object C_{HA}: $C_{FA,}$ it was 1.22. This could be due to the different effect of the preparation. Microbial preparations can have a positive effect on the physico-chemical properties of soils, although the nature of their effect depends on the type and dose of the preparation, the soil type, the organic matter content and the meteorological conditions under which they are applied (Gałazka et al., 2017; Canellas et al., 2008; Piotrowska et al., 2012).

3.4. The DH index

The three main factors influencing the value of this index were the type of formulation, the method of application of the above products and the mineral N rate. Significant interactions were found between them (Fig. 8) The lower values of the humification index were found in the plots treated with Ugmax compared to the control plot. Mineral fertilisation influenced the value of the humification index. Mineral nitrogen fertilisation reduced the value of this index in the combinations with Em-Farma and Ugmax. This relationship was observed regardless of the application rate, but the average value of this index was higher after application of the tested products on stubble and straw. The DH values in plots without mineral nitrogen varied between 0.53 to 0.67, respectively in the objects stubble and stubble+straw application. In plots with stubble and straw, the DH value was higher and was 0.57 after the application of Ugmax and 0.67 after the application of Em-Farma (Fig. 8). The DH index in combination with Ugmax points to the potentially bigger mobility of carbon in the soil system under EmFarma application (the stable fraction of soil organic matter), as well as to a higher intensity of organic matter humification process due to a more effective transformation of fresh organic matter into stable soil organic matter forms (Grigatti et al., 2004; Liu, 2016).

4. Conclusions

The use of humus fractions to assess changes in soil carbon dynamics following the use of microbial products was more effective than the determination of total organic carbon.

Preparations containing microorganisms can positively affect the quality of soil organic matter and stabilise soil organic carbon levels. Their effect is dependent on the type and dose of the preparation and the method of application. There were changes in the fractional composition of organic matter following the application of microbial preparations. Ugmax seeded mineralisation processes. On the other hand, EmFarma applied

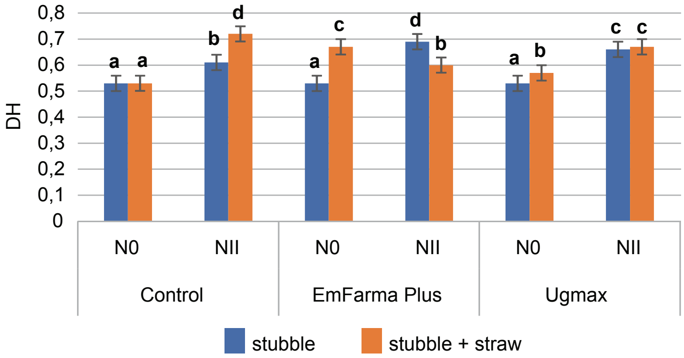

Fig. 8. The degree of humification (DH) index as influenced by type of preparation (I), methods of application of the above products (II) and mineral N rate (III) . Error bars denote standard deviations (n = 3). LSD ($p \leq 0.05$): for I = 0.010, II = 0,011, III = 0,006, II/I = 0,006, I/II = 0.012,III/I = 0.010, I/III = 0.012, III/II = 0.006, II/III = 0.004. Treatments with the same letter are not significantly different ($p \leq 0.05$)

The humification rate (HR) and degree of humification (DH) were calculated as reported by Ciavatta et at one dose increased the organic carbon content and improved the quality of the organic matter. Research has confirmed that both products have a beneficial effect on organic matter quality when applied to straw + stubble together with mineral nitrogen. The resulting higher levels of humic acids and humin in the humic bonds after application of EmFarma demonstrate its beneficial effect on the stability of organic matter. The second formulation shows a stimulating effect on the mineralisation process of organic matter. Using preparations containing microorganisms applied on straw in agricultural practice can bring additional significant benefits on sandy soils. However in the future, it will be essential to monitor the effects of preparations with microorganism over the years following their application to the soil.

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Czy dodatek preparatów z mikroorganizmami wpływa na zawartość węgla organicznego i substancji humusowych w glebie? 3-letnie badanie polowe w monokulturze zbóż

Słowa kluczowe

Mikroorganizmy,
Słoma
Jakość materii organicznej gleby
Substancje humusowe

Streszczenie

W artykule przedstawiono ocenę zawartości substancji humusowych oraz węgla organicznego w glebie po zastosowaniu w uprawie monokultur zbożowych dwóch preparatów zawierających mikroorganizmy: EmFarma Plus i UGmax. Trzyletnie badania polowe przeprowadzono w Rolniczym Zakładzie Doświadczalnym w Grabowie, należącym do Instytutu Uprawy Nawożenia i Gleboznawstwa − Państwowego Instytutu Badawczego w Puławach. Pierwszym czynnikiem były testowane produkty z mikroorganizmami oraz kontrola bez użycia preparatów mikrobiologicznych. Drugim czynnikiem badawczym były 2 sposoby aplikacji ww. produktów: na ściernisko, na ściernisko + słoma. Trzecim czynnikiem były 2 poziomy nawożenia N: 0 i 180 kg $N \cdot ha^{-1}$. Preparaty z mikroorganizmami wraz z azotem mineralnym i bez aplikowano corocznie bezpośrednio na ściernisko lub ściernisko + słomę pozostawioną na polu po zbiorach zbóż i porównywano z zabiegiem kontrolnym bez powyższych preparatów. EmFarma Plus zastosowany na ściernisku i ściernisku + słoma spowodował wzrost zawartości węgla organicznego średnio o około 3,7% w porównaniu z obiektem kontrolnym. Drugi testowany produkt miał odwrotny efekt. Zawartość węgla organicznego zmniejszyła się średnio o 2,5% pod wpływem Ugmax, stosowanego na słomę i ściernisko, pozostając na poziomie podobnym do kontroli. Preparat ten może mieć stymulujący wpływ na procesy mineralizacji materii organicznej (zmniejsza stosunek C_{KH}: C_{KF}), stąd niższa zawartość węgla organicznego po zastosowaniu. Ponadto, zastosowany na ściernisku i słomie, bez mineralnego nawożenia azotem, spowodował zmniejszenie udziału C_{KH} i zwiększenie C_{KF} w puli węgla organicznego oraz spowodował obniżenie wskaźnika humifikacji. EmFarma Plus działał odwrotnie.