Enclosure No 2 b

Presentation

Description of achievements and scientific achievements

(in English language)

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Pulawy 2019

1. PERSONAL DATA:

Name and surname: Dorota Pikuła
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2. PROFESSIONAL TITLES AND ACADEMIC DEGREES

Master's degree in engineering, Warsaw University of Life Sciences, Faculty of Agriculture and Biology, Specialisation in Environmental Protection, 2000. Master's thesis: ,,Heavy metal fractions in soils fertilized with sewage sludge".
Promoter: prof. dr. hab. Barbara Gworek.

Doctor of agricultural sciences in agronomy, Warsaw University of Life Sciences, Department of Agriculture and Biology, Department of Agricultural Chemistry, 2006) thesis entitled: "Influence of the selected physicochemical properties of the soil on the content of heavy metals in fodder plants".
Promoter: prof. dr hab. Jan Łabętowicz
Reviewers: prof. dr hab. Jerzy Pracz
prof. dr hab. Florian Gambuś

3. INFORMATION ON THE CURRENT EMPLOYMENT IN SCIENTIFIC/ARTISTIC INSTITUTIONS

- 2002-2003 – **editor, agrotechnical advisor;** internship: Editorial staff of the weekly magazine Agro- Spółdzielca "Plon"; Spółdzielnia Pracy Dziennikarzy,
- 2003-2006 – **editor;** Editorial Staff of „Poradnik Rolniczy" (Agricultural Guidebook); Promark Ltd., Pszczelarz Polski, Polish Beekeeping Association Warsaw,
- 2006 -2016 – **senior research and technical specialist**; Institute of Soil Science and Plant Cultivation; State Research Institute in Puławy; Department of Plant Nutrition and Fertilization
- 2016- currently – **adjunct;** Institute of Soil Science and Plant Cultivation; State Research Institute in Puławy; Department of Plant Nutrition and Fertilization

4. AN INDICATION OF THE SCIENTIFIC ACHIEVEMENT IN CONSISTENCE WITH ART. 16 PARAGRAPH 2 OF THE ACT OF LAW OF 14TH MARCH, 2003 ON ACADEMIC DEGREES AND TITLES AND DEGREES AND TITLE IN THE ARTS (JOURNAL OF LAWS NO. 65, ENTRY 595 WITH MODIFICATIONS)

The achievement, which is the basis for applying for habilitation degree, is a cycle of **5** scientific publications related to the subject matter and gathered under a common title:

4A. Title of scientific achievement

Environmental and production effects of crop cultivation in rotations differing in the amount of inflowing organic matter

4B. List of publications constituting scientific achievements

1. **Pikuła D.**, Rutkowska A. Effect of leguminous crop and fertilization on soil organic carbon in 30-years field experiment. Plant Soil Environ. Vol. 60, (2014), No. 11: 507–511.
5-year IF = 1.53, IF2014 = 1.226; MNiSW points =30; share:95%

2. Ten Berge H.F.M., **Pikuła D**., Goedhart P.W., Schröder J.J. Apparent nitrogen fertilizer replacement value of grass–clover leys and of farmyard manure in an arable rotation. Part I: grass–clover leys. Soil Use and Management 32 S1. ISSN 0266-0032, (2016), 9 - 19.
5-year IF = 2.143; IF2016 = 2.1; MNiSW points =30; share 50%

3. **Pikuła D**., Berge, Ten H.F.M.; Goedhart, P.W.; Schröder, J.J. Apparent nitrogen fertilizer replacement value of grass– clover leys and of farmyard manure in an arable rotation. Part II: farmyard manure. Soil Use and Management, 32 S1. ISSN 0266-0032, (2016), 20-31.
5-year IF = 2.143; IF2016 = 2.117; MNiSW points =30; share 55%

4. Martyniuk S., **Pikuła D.**, Kozieł M. Soil properties and productivity in two long-term crop rotations differing with respect to organic matter management on an Albic Luvisol. Scientific Reports, DOI:10.1038/s41598-018-37087-4, (2019), 9:1878:1-9.
5-year IF = 4.609; IF2018 = 4.122; MNiSW points =40; share 50%

5. **Pikuła D**. Variability of the fractional composition of soil organic matter by means of soil quality index, The monograph entitled Agriculture of the XXI century - problems and challenges"); edited D. Łuczyckiej, ISBN 978-83-945311-9-5, (2018), 251-260.
5-year IF = 0; IF2018 = 0; MNiSW points=5; share100%

The coauthors' declarations are set out in Annex 4.

Summary Impact Factor (IF) of the most important achievements of the scientific data as listed in the Journal Citation Reports (JCR), according to the year of publication is: 9.582, points of the Ministry of Science and Higher Education = 135

4C. DISCUSSION OF THE SCIENTIFIC OBJECTIVE AND RESULTS ACHIEVED

Introduction

Production capacity of soils in Poland is limited due to the predominance of light soils (35%) and very light soils (30%), thus, poorly humus soils characterised by a very acidic and acidic pH, which adversely affects their fertility (Ochal and Kopiński 2017). In the case of light soils, fertility and yield can be maintained, restored and even increased through the use of natural, organic and mineral fertilizers (Mercik et al. 2000; Maćkowiak 2000). The most important role in maintaining soil fertility and ensuring long-term stability of crop yield is, undoubtedly, played by organic matter. To a large extent, it determines the biological, chemical and physical properties of soils. The organic matter content is an integrative and, most frequently mentioned, soil quality index (Reeves, 1997, Liu et al., 2006). Due to the low content of organic matter in soils and the progressive loss of organic matter, in most European countries, it is proposed to monitor soil organic matter resources and to introduce practices aimed at protecting the humus soil (Terelak et al. 2008).

Soil organic matter is constantly being mineralized and humified at the same time, but the effects on soil properties differ. Humification is a process that results in the creation of new products that supplement the resources of organic compounds formed during the process of mineralization (Gonet 2007; Bieńkowski and Janowiak 2006). As a result of humification, fractions of specific humus compounds, very important for the quality and stability of organic matter, are formed: humic acids, fuvic acids and humins (Gonet 1989; Rutkowska and Pikuła 2013). In addition to measures to increase organic matter content, especially in light soils, it is important to study the quality and stability of organic matter. The humification index is one of the basic indicators of soil quality assessment. It is expressed as the ratio of carbon content of humic acid fractions to fulvic acid carbon (C_{KH}:C_{KF}). This parameter indicates the direction of organic matter transformation in soil, allows to assess the stability of humus and to estimate the changes occurring in the soil, caused, among others, by long-term cultivation of various plants in crop rotations, monoculture, regular use or lack of natural and mineral fertilizers. It is commonly assumed that humus with values of humification index higher than 1 is characteristic for fertile soils. The C_{KH}:C_{KF} index with values <1 is typical for soils with a predominant process of mineralization.

The transformation of soil organic matter into humus compounds takes place with the participation of soil microorganisms and is a result of their enzymatic activity (Diacono and Montemurro 2010; Blanchet et al. 2016; Scottti et al. 2015).

In addition to increasing the organic matter content of the soil, it is important to reduce the loss of nutrient from the soil in order to maintain the fertility of light soils. Nitrogen brought into the soil in the form of natural and organic fertilizers is generally less available for cultivation than nitrogen brought in the form of mineral fertilizers (Flavel and Murphy 2006). Despite significantly lower availability of nitrogen from organic (green) and natural fertilisers (manure, liquid manure), the most efficient use is ensured by balanced doses of organic and mineral N fertilisers (Schröder 2014). However, their determination requires accurate information on the recoverable value of organic nitrogen resources expressed in a common unit. Although nitrogen is important for crop yield and the effects of using it are quickly visible in the form of increased yields, this element is vulnerable to leaching from the soil into groundwater. It may, therefore, pose a risk to the environment. For this reason, nitrogen injected into organic and natural fertilisers must be precisely matched to the dosage of mineral nitrogen fertilisers in order to avoid losses. Natural and organic fertilisers, in addition to influencing plant yields, also cause significant changes in the physical, chemical and biological properties of soils, and their effects are most evident in permanent fertiliser experiments.

Many years of static fertilization, crop rotation and monoculture experiments are valuable because of the ability to track changes in soil properties. In Poland, the fertilizer and crop rotation experiments is the oldest experiments, which is still being practised today and had continued even during World War II. It was established in 1923 at the Experimental Station in Skierniewice, belonging to the Warsaw Agricultural University (Marks et al. 2018). A similar experiment was established in 1979, in Grabowo, in order to investigate the impact of manure and mineral nitrogen application on crop productivity. This experiment was my basic research subject.

Description of the field experiment

The results of the research presented in 5 scientific publications come from the above mentioned static long term experiment, led by me for 12 years, and conducted in the Experimental Department of IUNG-PIB in Grabowo-upon-Wistula (52° 7′ 36″ N, 19° 0′ 9″ E). The experiment is located on the Albic Luvisol soil (FAO, 1998) with light clay sand grain size distribution, very good rye complex, IVa quality class. The climate in this part of the country is temperate, with average annual rainfall of around 560 mm and an average annual temperature of 7,8^{o}C. Therefore, the results of the study can be generalized for similar soil and climatic conditions in central Poland.

The experiment with the area of over 2 ha covers two four-field rotation and is carried out with the fields of two plants in each vegetation season. In crop rotation A, defined as "soil impoverished" in organic matter, the following crops are cultivated: grain maize, (potato until 2007), winter wheat, spring barley and silage maize. In crop rotation B, referred to as „enriched" soil in organic matter, the following crops are cultivated: grain maize (potato until 2007), winter wheat + mustard for ploughing as catch crop, barley with clover undersown and a mixture of clover and grass. For the first two four-year crop rotations, manure fertilization levels were the second experimental factor besides rotations. This fertilizer was applied to potatoes in doses of 0, 20, 40, 60 and 80 t·ha^{-1} every 4 years. From the third rotation - another factor was introduced in the experiment, and that is a differentiated level of fertilization with mineral nitrogen (N0, N1, N2, N3), adjusted to the nutritional requirements of cultivated plants. Doses N2 and N3 are multiples of dose N1, which, since 2007, in A rotation is respectively: 50 kg for grain maize, 50 kg for winter wheat, 30 kg for spring barley and in the crop rotation B: 50 kg for grain maize, 50 kg for winter wheat, 30 kg for spring barley with catch crop, and 50 kg for each swath of clover-grass mixture. The doses of phosphorus fertilizers for all plants are the same in both crop rotation and amount to 54 kg P2O5·ha^{-1}.

Potassium fertilisers comes in appropriate doses: 85 kg K_2O·ha^{-1} for spring barley, 100 kg P_2O_5·ha^{-1} for winter wheat, 115 kg K_2O·ha^{-1} for clover-grass mixture, 120 kg K_2O·ha^{-1} for silo maize and 160 kg K_2O·ha^{-1} for grain maize.

<u>The scheme of the experiment:</u>

- I factor: crop rotation A (defined as "soil impoverished" in organic matter) i crop rotation B (referred to as „enriched" soil in organic matter)

- II factor: varied doses of manure in both crop rotation t·ha^{-1}):

1.0. 0

2.0. 20

3.0. 40

4.0. 60

5.0. 80

- III factor: 4 levels of mineral nitrogen fertilization in kg N·ha^{-1} (used in appropriate doses for all crops in both crop rotation)

0.1. No

0.2. N_1

0.3. N_2

0.4. N_3

In both rotations, plant by-products were harvested from the field and no liming of soil was applied. Each year, the yields of the main crops were determined and samples were taken to determine the content of total mineral component forms. At 4-year intervals (after each crop rotation) soil samples were taken from the arable layer (0-30 cm) and the content of available forms of mineral component, organic carbon and pH were determined. In 2013, detailed microbiological tests were also carried out on the soil: Corg. and N content integral in extracts of cold and hot water, biomass of microorganisms by fumigation-extraction method, dehydrogenase activity (total activity of soil microorganisms), acid phosphatase and alkaline phosphatase activity and physical properties of the soil - granulometric composition. In order to assess the soil structure (aggregation), dry soil samples were sieved through a set of sieves. Two fractions of macroaggregates (> 0.5 mm and 0.5-0.25 mm) and one fraction of microaggregates (<0.25 mm) were separated. The fractionation of organic matter by the Schnitzer method was also performed.

Scientific objectives of the study:

Having at my disposal an experiment in the form of long-term experience, I have gathered an extensive database and carried out research that allowed me to set and implement the following scientific objectives:

1. To determine crop yields depending on the level of fertilization with manure and mineral nitrogen in crop rotations differing in the amount of inflowing organic matter (**4B.2, 4B.3, 4B.4).**

2. To study the influence of experimental factors under study based on the quantity and quality of soil organic matter and selected physicochemical and biological properties of soil (**4B.1, 4B.4 and 4B.5).**

3. To determine the fertiliser equivalents for manure nitrogen and nitrogen biologically bound by a mixture of clover and grass (**4B.3 and 4B.2).**

Discussion of the obtained research results

- **Research objectives 1 and 2**

Crop yield depending on the level of fertilization with manure and mineral nitrogen in crop rotation differing in the amount of inflowing organic matter.

The complex of factors included in the experiment allowed for the evaluation of the influence of different doses of mineral nitrogen and manure on plant yields in two crop rotations A and B. Comparable rotations differed in the inflow of fresh organic matter. In B crop rotation the inflow was higher - after winter wheat harvest, mustard was cultivated for ploughing and a mixture of clover and grass. The average yield of mustard on objects not fertilized with manure and mineral nitrogen was 3,1 $t \cdot ha^{-1}$, on objects with the highest dose of manure and mineral fertilizer even 20 $t \cdot ha^{-1}$ (**4B.4**). It is worth noting that although the biomass of mustard roots was not determined in the studies, the literature data show that at a yield of about 20 $t \cdot ha^{-1}$ mustard leaves about 2,5 $t \cdot ha^{-1}$ of roots in the soil (Nowakowski and Franke 2013). Taking this into account in the crop rotation B, depending on the level of fertilization with manure and mineral nitrogen in the soil, from 6 to 23 $t \cdot ha^{-1}$ 1 more fresh organic matter was provided than in the crop rotation A. In addition, it was estimated that the mixture of clover and grass, which is grown in the 4th year of rotation, provides up to 10 $t \cdot ha^{-1}$ 1 dry matter of organic matter residues (Jarchow and Liebman 2012).

The weather conditions in the years analysed for research was the factor that most differentiated the yield. It also affected the interactions of years with experimental factors. Nevertheless, the influence of the studied factors and their interactions on crop yields was similar. The yields of all plants increased after the application of mineral nitrogen and manure. Yields obtained in crop rotation A were, however, lower in comparison with yields in crop rotation B. For example, at the same dose of manure, the yields of potato tubers in crop rotation B without any addition of mineral nitrogen amounted to 103-107% of the yields obtained in crop rotation A at maximum dose of mineral nitrogen 150 kg $N \cdot ha^{-1}$. These values were 70-91% for wheat and 73-88% for barley (A rotation) and 92-104% for barley (B rotation) respectively. The yields of potato tubers, winter wheat and spring barley grain depended on crop rotation and were significantly higher in B rotation (with clover) than in A rotation. The effect of manure and mineral fertilizers was higher in A rotation than in B rotation, and nitrogen supplied in mineral fertilizers always worked significantly better than nitrogen from manure (**4B.2 and 4B.3**). In order to determine the effect of the inflow of more organic matter on the productivity of rotation, winter wheat yields at work were analysed in detail (**4B.4**).

In crop rotation without fabaceous plant and catch crop, the natural fertility of the soil not fertilized with manure and mineral nitrogen provided a yield of 2,5 $t \cdot ha^{-1}$ of this plant in crop rotation A. The introduction of manure fertilization at the dose of 40 t·ha^{-1} increased its productivity by 72,5%, and the simultaneous application of manure and mineral nitrogen by 163%. In B rotation, with Fabaceae and mustard catch crop, without fertilization with manure and mineral nitrogen, the productivity of the soil yielded upto 3,7 t·ha^{-1} of grain. Moreover, in this crop rotation, in order to obtain the same yields of wheat grain as in the compared crop rotation A, it was possible to reduce both the doses of manure and mineral nitrogen. However, the maximum productivity of wheat at the level of ca. 8,1 t·ha^{-1} of grain was ensured by crop rotation in which the faba bean crop was cultivated and mustard seed was ploughed in after wheat, as well as manure at the dose of 40 t·ha^{-1} and 150 kg N of nitrogen t·ha^{-1}. was applied.

The obtained results showed that on plots without the use of manure and mineral nitrogen, comparable B rotation facilities, the winter wheat yields were higher by more than 1 t·ha^{-1} than in rotation A. Grain yields on plots without mineral nitrogen fertilization were 4,4 t·ha^{-1} and 4,9 t·ha^{-1} in A and B rotation respectively. A favourable effect of manure fertilization on winter wheat yields was also clearly visible at both 100 and 150 kg·ha^{-1} levels of mineral nitrogen fertilization. In both rotations, maximum grain yields were obtained at the highest mineral nitrogen dose of - 150 kg·ha^{-1} and manure application. However in B rotation, yields were almost 10% higher than in A rotation. A significantly lower (acidic) soil reaction in B rotation than in A, was an interesting effect obtained in the study.

Regular use of manure alleviated the negative effects of acidification in both rotations; however, it did not eliminate them. In facilities without manure fertilization, the mean pH was 4.5, and after the application of 40 t·ha^{-1} of manure the pH increased to 4.7. For comparison, in the A rotation, the pH was 5.0 and 5.3 respectively. A large decrease in pH in the B rotation was caused by the incorporation of a large amount of fresh mustard mass, which had an acidifying effect on the soil, and a greater Ca and Mg removal (greater yield) from the soil of this rotation (**4B.4**). However, despite the less favourable soil reaction, compared to A rotation, the introduction of more fresh organic matter into the soil in B rotation had a positive effect. This allowed the accumulation of more organic carbon in the soil and was probably responsible for the better yield of winter wheat and other cultivated B-rotation crops than A-rotation crops, with lower input of fresh organic matter.

My yield analysis confirmed that the productivity of light soils can be increased by up to about 50% with the introduction of clover into the rotation with grass as well as mustard seeded as a catch crop and then ploughed in. A significant increase in soil

productivity, by about 73% in A rotation and about 30% in B rotation, can be achieved with regular, every 4 years, application of manure. The interactions between mineral nitrogen (fertilizer nitrogen) and nitrogen bound by faba bean plant and manure nitrogen were significant.

Application of nitrogen fertilizer dose (150 $kg \cdot ha^{-1}$ even in the most favourable conditions (B rotation with manure) ensured an increase in wheat grain yield by almost 70% (**4B.4**). Similar results were obtained in many other field experiments and therefore my attention was focused mainly on the environmental effects of plant cultivation in the compared crop rotations. As mentioned earlier, liming was not used in this experiment in order to assess its buffering properties following the application of manure. The mechanisms occurring in the soil after ploughing mustard seeds - leading to a change in the pH of the soil – have not been fully explained. It is generally assumed that the most important processes of proton (H^+) and hydroxyl ions (OH^-) generation are related to C and N transformations in soils (Butterly et al. 2013). Another factor leading to the acidification of soil in this rotation may have been higher CO_2 production during the microbiological decomposition of fresh organic matter. Higher crop yields obtained in B rotation (**4B.2**) indicate also that higher uptake of nutrients from soil by plants (including alkaline cations K^+, Ca^{2+}, Mg^{2+}) in comparison with A rotation, which was probably caused by higher soil acidity in B rotation. However, a very interesting and little known phenomenon observed in the literature was the lack of negative reaction of plant yield to soil acidification in this rotation. Schröder et al. (2011), who studied soil acidification as a result of more than 30 years of application of increasing doses (up to 272 $kg \cdot ha^{-1}$) of various nitrogen fertilizers, found that although the pH value of soil decreased to <5.0 after 10 years of nitrogen fertilization, only a slight decrease in winter wheat grain yield was observed during 25 consecutive growing seasons. It is worth mentioning that in the experiment of the above authors, winter wheat was cultivated in monoculture and no organic fertilizers were added to the soil.

It seems reasonable to assume, however, that my studies will show a decrease in plant yields in the future and that the delay in the occurrence of the negative effects of stronger soil acidification in B rotation may result from the beneficial effects (as discussed above) of the introduction of fresh organic mustard mass and residues of clover-grass mixture into the soil.

Quantity and quality of soil organic matter and selected physicochemical and biological properties of soil

The quantity and quality of soil organic matter depends on many environmental factors and, in arable land, to a high degree on management (Blanchet et al. 2016; Pranagal 2004; West and Post 2002). My long-term experience includes basic agrotechnical factors that may influence the content of organic matter in the soil, i.e. crop rotation, cultivation in the rotation of faba bean plant and mustard catch crop, fertilization with manure and mineral nitrogen (Gonet, 2007; Maćkowiak 2000; Mazzoncini 2011; Rutkowska and Pikuła 2013). This allowed the study of their influence on the quantity and quality of organic matter (Corg.). The biggest influence on the accumulation of organic matter in the soil was caused by crop rotation, followed by manure fertilization. A relatively benifical effect of mineral nitrogen fertilization was found (**4B.1 and 4B.4**). The effect of regular use of manure (once every four years) on the content of organic carbon was closely related to the selection of plant species for cultivation. In extreme experimental facilities (without manure and mineral nitrogen fertilization) the content of organic carbon after 33 years of the experiment ranged from 6.1 g C kg^{-1} soil (crop rotation A) to 8.5 g C kg^{-1} soil (crop rotation B) with manure fertilization and the highest dose of mineral nitrogen (**4B.4**). The favourable effect of B rotation was mainly due to the cultivation of clover-grass mixtures and the cultivation of catch crops on ploughing.

The influence of rotation was systematically increased within the year of conducting the experiment (**4B.1**). The long-term trend analysis of Corg. content changes in soil presented in the paper (**4B.1**) showed that manure fertilization increased Corg content more in B rotation (by 17.4 %) than in A rotation (by 14.5 %), while this effect increased with manure dose. After 33 years of manure application at a dose of 20 $t \cdot ha^{-1}$ in A rotation, no increase in Corg. content in soil was observed. This increase of 8.1% occurred only after the application of the dose of 40 $t \cdot ha^{-1}$. The highest increase of 19.3% of this component content was obtained after the application of 60 $t \cdot ha^{-1}$ of manure. In B rotation with faba bean plant, the application of the dose of 20 $t \cdot ha^{-1}$ of manure caused an increase of 7.2% in the content of organic carbon in the soil, as compared to the facility without this fertilizer. However, in crop rotation without this plant, even the highest doses of manure (60 and 80 $t \cdot ha^{-1}$) were not sufficient to maintain the organic carbon content at the initial level**. This confirms the beneficial effect of manure interaction with appropriate selection of plant species on the accumulation of organic carbon in the soil. In my research, I confirmed an increase in the content of this**

component in the soil with increase in the dose of manure. Thus, it was significantly higher in the soil under B rotation than in the A.

In my research, the significant effect of mineral nitrogen fertilization was proven effect on organic carbon content in soil (**4B.1**). In crop rotation without legumes mineral fertilization increased Corg content by 3% as compared to the control treatment, and in crop rotation with clover by 4.6%, respectively. Data on this subject appear in the literature are not conclusive (Gregorach et al 1994, Liebig 2002, Janowiak 1995). It is interesting, also as the next research challenge.

The mere storage of organic carbon in the soil does not guarantee stability and good quality of organic matter. Soil organic matter consists of a light fraction not associated with mineral colloids (labile fraction), a fraction associated with soil aggregates as well as a fraction strongly associated with mineral particles that determine its quality and stability (Józefowska 2009; Sollins et al. 1996). From the chemical point of view, the quality of organic matter is determined by the composition of humus substances, i.e. the share of fractions of humic acids (C_{KH}), fulvic acids (C_{KF}) and humine (C_H) in the pool of total organic carbon and the ratio of their content of C_{KH}:C_{KF}. In the studies presented in this paper (**4B.5**), I confirmed a significant, although small effect of manure fertilization and plant selection in crop rotation on the fractional composition of humus substances. As a result of the application of increasing doses of manure, the content of fulvic acid carbon fraction (C_{KF}) decreased and the content of humus fraction (C_H) increased in relation to the facilities without manure fertilization. The percentage share of humic acid fractions (C_{KH}) in the total organic carbon pool was higher in the "impoverished" A rotation than in the "enriched" B rotation. The soil in B rotation was characterized by a significantly higher share of fulvic acid carbon fraction (C_{KF}). Changes in the humification index of the C_{KH}:C_{KF} were the consequence of changes in the content of carbon humic and fulvic acids under the influence of plant selection in crop rotation and manure fertilization. According to the value of this index, the soil in crop rotation A and the soil fertilized with manure were characterized by more stable humus (higher value of this ratio). A lower value of the index in B rotation was, most probably, caused by the cultivation of a faba bean plant in this rotation, which left higher amounts of nitrogen in the soil and an acidifying effect of the ploughed mustard on the soil, which could have caused an intensification of the mineralization process. n addition, the process of humification of plant residues containing a lot of nitrogen may be characterized by a lower value of the humification index. Explanation of this issue will be the next stage of my research.

Fertilization with mineral nitrogen had practically no effect on the composition of humic acid fractions.

All soil organic matter metabolism is carried out with the participation of soil microorganisms and their enzymes (Allison 2006; Bastyda et al. 2006; Gałązka et al. 2017; Scherer et al. 2011). In my own research, I also analyzed the microbiological properties of the soil. The above research issue required explanation that since the cultivation of fabaceous plants has a positive effect on the accumulation of organic carbon and the quality of organic matter, it can also have a positive effect on the physical and biological properties of the soil and have other environmental effects depending on the inflow or absence of fresh organic matter. I decided to check whether the sowing of green plants on ploughed land has a similar effect to the liming of the soil, i.e. if it has a so-called 'liming effect'. This is very important for the agricultural use of acidic soils and for mitigating the acidifying side effects of nitrogen fertilization (Xu and Coventry 2003; Naramabuye and Haynes 2007; Mazzoncini et al. 2011; Tejada et al. 2008). I presented the results of the research in my paper (**4B.4**). Jarchow and Liebman (2012) indicate that maize grown in crop rotation can produce from 4 to 6 times less root biomass than C3 grasses or grass mixtures. Taking into account these results, as well as the results of my own research on the roots of cultivated plants, I assumed that the mixture of clover and grasses enriches the soil with much higher amounts of organic matter than maize green (roots and lower parts of stems).

In my research, I proved that the increased long-term supply of organic matter in B rotation caused both positive and negative changes in selected soil properties. After 33 years of plant cultivation in two crop rotations, the soil in B rotation contained more organic carbon than the soil in A rotation, regardless of the dose of mineral fertilizers and manure, on average, by almost 12%. The carbon content of soil microorganisms (SMBC) and the activity of soil enzymes (dehydrogenase, acid phosphatase) were significantly affected by all the factors studied in this experiment. In general, these parameters had much higher values in A rotation than in B rotation and in manure fertilized facilities, in comparison with facilities without this fertilizer. SMBC content was higher in B rotation than in A rotation and significantly increased under the influence of manure fertilization. The influence of mineral nitrogen on this soil parameter is interesting. As the N doses increased, the SMBC content, generally, decreased. This negative effect was the greatest in A rotation and in facilities without manure and was mitigated both by the selection of plant species in B rotation and by the application of manure. The activity of acidic and alkaline phosphatase and

dehydrogenase were similar to the SMBC content and can be used as an indirect indicator of this content. There is also a general opinion that appropriate agricultural soil management practices, especially with respect to nitrogen fertilization, increase soil organic carbon sequestration and are beneficial for soil microorganisms and their activity, mainly due to the higher amount of crop residues entering the soil (Blanchet et al. 2016; Mazzoncini et al. Acosta-Martinez et al. 2011; Acosta-Martinez et al. 2007; Halvorson et al. 1999). However, there are also reports that N mineral fertilizers, especially their high doses, can reduce SMBC content as well as soil enzyme activity, and the results of my studies on SMBC and dehydrogenase activity are compatible with them (Ghimire 2017; Liebig 2002). The high biochemical activity of microorganisms makes them a decisive factor in shaping the ecological stability and productivity of ecosystems, therefore SMBC is considered a good soil quality indicator.

In the publication (**4B.4**), the influence of the studied experimental factors on the pH and content of exchangeable forms of calcium and magnesium in soil was discussed and interpreted. As mentioned in the introduction, liming and magnesium fertilizers were not used in the experiment. Slightly acidic initial pH of the soil was significantly reduced to acid in all experimental facilities. In the absence of liming increasing fertilizer N rates caused stronger soil acidification, particularly in the unmanured plots of both rotations. The application of nitrogen fertilizers and the ploughing of a large amount of mustard mass in B rotation had a negative effect on the soil pH value. This effect was "mitigated" but was not eliminated as a result of manure fertilization. It is interesting that the content of exchangeable calcium decreased more strongly than the soil pH. The initial magnesium content was significantly reduced, regardless of experimental factors, especially in objects without manure and with higher doses of nitrogen fertilizers.

In the presented studies published in the paper **4B.4,** I also assessed the soil structure in A and B rotations in the context of the favourable or negative influence of the factors of this experiment. Some authors point out (Liebig 2002, Butterly 2013) that mineral fertilisation does not have a positive effect on the aggregated soil structure and destroys the biological life of the soil. The soil in the A rotation contained significantly more fractions of macroaggregates > 0.5 mm than the soil in the B rotation, contrary to the smaller macroaggregates (0.5-0.25 mm) and the fraction of microaggregates (**4B.4**). These results indicate that the formation of large aggregates in B rotation was reduced. Although Zhang et al. (2016), Whalen and Chang (2002), report that in soils treated annually and for a long time with manure, the dispersion of large aggregates may be increased, but in the case of my studies a reduced share of macroaggregate fractions > 0.5 mm in soil in B rotation was obtained. This may result mainly from lower content of bivalent cations, Ca^{2+} i Mg^{2+} in this soil in comparison with the soil in A rotation. Ions, especially Ca^{2+}, are important because of their important role in soil aggregation through the formation of bridges between clay minerals and organic carbon molecules (Six et al. 2004). Similarly, in the studies of other authors (Zhang et al. 2016; Wang et al. 2017), ploughed manure at a dose of 40 $t \cdot ha^{-1}$ increased the content of macroaggregate fractions > 0.5 mm and decreased the fraction of microaggregates in comparison with unfertilized soil, but this effect was significant only in A rotation.

The 3 studies discussed so far show **that maximum productivity of plants cultivated on light soils can only be achieved if proper rotation, manure fertilization and mineral nitrogen dose are applied simultaneously. On the example of a detailed analysis of winter wheat cultivation, the pure effect of rotation allowed to increase soil productivity by 45%. In crop rotation B, in order to obtain the same yields of wheat grain as in, the compared, crop rotation A, it was possible to reduce both the doses of manure and the doses of mineral nitrogen. Regular application of manure mitigated the negative effects of acidification in both rotations, but did not eliminate it. The soil in the B rotation, contrary to the A rotation, was more acidic, had lower Ca and Mg content and contained a reduced part of aggregate fractions > 0.5 mm. Taking into account that the ploughing of the faba bean plant and catch crop in crop rotation has a positive effect on all soil characteristics that make up its fertility. These agrotechnical factors allow to stabilize the productivity of light soil at the level of average yields. However, obtaining high yields of plants is only possible if appropriate doses of nitrogen fertilizers are applied.**

- **The purpose of the study 3.**

Nitrogen fertiliser equivalents for manure and nitrogen biologically fixed by a mixture of clover and grass

The most important interactions between mineral nitrogen (fertilizer nitrogen) and nitrogen bound by fabaceous plants and manure nitrogen are the most interesting in the static field experiment. I measured these interactions on the basis of calculated nitrogen fertilizer replacement value (NFRV), which was the next goal for the study and is my key scientific achievement.

I prepared the concept and method of calculating nitrogen equivalents during my scientific internship in Wageningen (Netherlands), realized within the Catch-C project, which I was a contractor of. The aim of this project was to develop and assess best practices for on-farm nutrient management (increasing crop yields, mitigating climate change and improving soil quality), based inter alia on the results of many years of EU fertiliser experience. Both in EU and Poland, for many years the issue of safe use of nitrogen in agriculture has been examined in the context of reducing its negative impact on the environment. The intensification of agriculture based on mineral nitrogen fertilizers and the development of livestock farms focused on animal production, which has been progressing for many years, is connected with the dispersion of nitrogen to the environment. This requires the development of a proper management of nutrients on the farm. In order to reduce the pressure of nitrogen on the environment, methods for more efficient uptake by plants and reducing the use of mineral nitrogen fertilisers by replacing them with organic or natural fertilisers are still being sought. The literature shows that 100 kg of nitrogen bound by fabaceous plants may be equivalent to 200 kg of nitrogen applied in the form of mineral fertilizer (Prusiński and Kotecki 2006). Therefore, a proper assessment of the replacement value of nitrogen from these crops, as well as from fertilisers, is particularly important on large scale farms in view of possible high nitrogen losses to the environment. In order to do so, I have analysed data covering 24 years of experiments, from six four-year shifts of A and B rotations and have presented the results in two studies (**4B.2 and 4B.3**).

Nitrogen in natural fertilisers (manure) is, generally, less available for plants than nitrogen in mineral fertilisers (Flavel and Murphy 2006). Differences in nitrogen availability from both sources are valued using the so-called *Mineral Fertilizer Equivalent*, also known as *Mineral Fertilizer Replacement Value* (NFRV) (Jensen 2013). This value is expressed as the ratio of the amount of kg N in mineral fertilizer to kg N in manure (Schröder 2005a) needed to obtain the same crop yield. To determine the NFRV value, it is necessary to conduct field experiments with increasing doses of nitrogen fertilizers applied without organic fertilizers and against the background of a specific dose of these fertilizers. Due to the follow-up effect of organic fertilisers, such experiments should be carried out for a number of years in the same field (Gutser in. 2005, Schröder 2005b). The experiment in Grabowo is one of the relevant sites (few in Europe). The publication (**4B.3**) presents the methodology for calculating the NFRV for manure and the appropriate calculations in relation to the sum of dry matter yields or the sum of nitrogen uptake by three or four consecutive crops grown in A and B rotations, for 4 levels of manure fertilisation. The mean NFRV values calculated in relation to the yields of dry matter of plants and the sum of nitrogen uptake by plants were 0.37 and 0.50 kg N of nitrogen fertilizers per kg N in manure, respectively. These values can be directly submitted for fertilizer recommendations. However, it should be taken into account that these values refer to a long period of time and not to one year's fertiliser application. It should be stressed that the fertiliser effect of manure may be greater than the values of manure nitrogen equivalents presented above (the fertiliser values of manure account for about half of the mineral fertiliser values), as the nonfertiliser effects of manure fertilisation become more and more important over the years.

The publication (**4B.2**) presents the methodology and calculations of the fertilizer equivalent of nitrogen bound biologically by the Fabaceae plant - clover cultivated with grasses in B rotation. Clover cultivated in monoculture or mixed with grass is an important component of crop rotation due to soil supply of biologically bound nitrogen and productivity (Van der Meer and Baan Hofman 1989). The nitrogen biologically bound by clover is partly accumulated in the roots remaining in the field after harvest. The post-harvest residues of this plant that have undergone the process provide significant amounts of nitrogen for subsequent crops. (Grootenhuis 1977; Fotyma i Filipiak 2006; Pikuła i Rutkowska 2014).

The assessment of NFRV for faba bean is complicated by the fact that the non-fertilizer faba bean value, including the beneficial phytosanitary impact on the soil environment, is used for the assessment of yield or nitrogen uptake by succeeding plants. Therefore, the difficulty in determining the NFRV of fabaceous plants lies in the separation of the "pure" effect of nitrogen accumulated in the soil, biologically bound, to the total effect of cultivation of these plants (Giller 2002; Schröder 2005a, b). Likewise, the determination of "pure" nitrogenous manure effect is complicated by its side effects, but the challenge is much greater for the faba bean plant. It should also be taken into account that in organic and natural fertilisers, there are other nutrients, in addition to nitrogen, such as phosphorus (P), potassium (K) or sulphur (S), which also affect yields. It is therefore necessary to exclude these additional effects when estimating NFRV on the basis of yields or nitrogen uptake.

The NRFV I determined also differed in the analysed three, four-year shift of rotations due to the fact that the yields of clover with grasses varied in the years of the study and the different share of clover in this mixture. The calculations also showed that the NRFV was affected by the level of fertilization with nitrogen squeezed under the succeeding plant and it was necessary to estimate this value separately for low (L) and high doses of nitrogen fertilizers (H), always comparing A and B rotattions at manure doses (0, 20, 40, 60 and 80 $t \cdot ha^{-1}$). All these elements were taken into account in the determination of NFRV for the faba bean plant. In the case of determining the fertilizer equivalent of biologically bound nitrogen, a simplified concept of nitrogen substitution, applied in mineral fertilizers with biologically bound nitrogen due to the cultivation of clover in a grass mixture, was used. The nitrogen replacement value is the amount of nitrogen saved with respect to mineral fertilizer by cultivating a grass-clover mixture. In relation to my experience, this is the amount of nitrogen in the mineral fertilizer necessary in A rotation in order to obtain the same crop yield or the same nitrogen uptake by the plants as in the B rotation in the facility without mineral nitrogen fertilization. The values were calculated separately for each dose of manure. The total nitrogen savings calculated for three crops cultivated in the B rotation (excluding clover with grasses) were equal to: 188, 246, 270, 295 and 312 kg N/ha, which in percentage terms represents 50, 65, 72, 79 and 83% of manure doses (0, 20, 40, 60 and 80 $t{\cdot}ha^{-1}$) These values refer to the B rotation in relation to the A rotation.

Such high values of mineral nitrogen savings obtained after the introduction of clover-grass mixture to the crop rotation are probably the result of nonfertilizer cultivation effect in faba bean crop rotation and leaving large amounts of residues in the soil after harvesting. This means that the fertilizer value of mineral nitrogen applied in rotation with clover is 50-83% of the value of nitrogen applied in rotation without faba bean plant. Replacement values of N fertilizer for harvest residues of clover-grass mixture in this experiment indicate that mixtures in arable rotation may significantly reduce nitrogen demand. I have proved that using organic nitrogen sources can bring other benefits, in addition to providing nitrogen, for the next crop grown in rotation. The most obvious of these is the supply of other nutrients, such as P and K, as well as organic matter, which have influence on the physical and chemical properties of soils. This has already been widely introduced.

Summary and conclusions

From many years of field and laboratory research, already discussed in 5 publications, I have drawn the following conclusions, both of scientific and practical nature.

1. Maximum productivity of plants cultivated on light soils can sonly be achieved, if appropriate crop rotation, manure fertilisation and application of appropriate dose of mineral nitrogen are applied.
2. In B rotation with grass-clover mixture and catch crop (mustard), the yield of all the plants in this rotation was significantly higher than in the rotation without mixture and catch crop (A rotation). For example, after six rotations, the average yields (for all N

and manure levels) of potato tubers, winter wheat and spring barley were higher in B rotation by 27.5%, 12.5%, 17.0 %, respectively. In the case of winter wheat, the pure effect of rotation allowed for an increase in soil productivity by 45%. Moreover, in the B crop rotation, in order to obtain the same yields of wheat grain as in the compared crop rotation A, it was possible to have both the doses of manure and that of mineral nitrogen reduced.

3. Many years of manure application every 4 years and the cultivation of faba bean crop and mustard catch crop resulted in a significant increase in the content of organic matter in the soil and an improvement in its quality. Manure fertilization in this crop rotation (so-called "enriching") increased the content of organic matter to a much greater extent than in the A rotation (so-called "impoverishing"). After 33 years of manure application in the dose of 20 $t \cdot ha^{-1}$ in A rotation, no increase in the content of organic matter in the soil was obtained. In B rotation, the application of the dose of 20 $t \cdot ha^{-1}$ of manure resulted in an increase of Corg. content by 7.2%. Despite this, a decreasing rate of organic matter accumulation in the soil has been observed in recent years. This indicates the progressive saturation of light organic matter in the soil, which is particularly visible in the facilities with the highest inflow, in the form of the remains of fabaceous plant and ploughed mustard (B rotation).
4. Crop rotation and manure fertilization affected not only the amount of accumulated organic matter, but also its quality, assessed on the basis of chemical separation into fractions of humic acids, fulic acids and humins and on the basis of carbon characteristics of soil microorganisms. These parameters were higher in B rotation than in A rotation and increased under the influence of manure dose, which indicates better and more stable quality of organic matter in this rotation.
5. The inflow of large quantities of fresh organic matter to the soil has had many beneficial effects and has improved the properties of light soil and its productivity, but under certain conditions, e.g. in the absence of liming of the soil, such rotations may also have an adverse effect on certain properties (soil pH and aggregation) of loamy-sandy soils (Luvisols).
6. The nitrogen fertilizer equivalent of manure determined in own research in relation to the sum of plant yields in A rotation was 0.37 kg N mineral per 1 kg N in manure. The value determined in relation to the sum of nitrogen uptake by all plants grown in A rotation was 0.50 kg mineral N per 1 kg N in manure.

7. The substitution of mineral nitrogen in B rotation, in relation to A rotation, amounted from 50 to 83%. These values indicate the possible high savings in the use of mineral nitrogen fertilizers, which has an environmental dimension (lower nitrogen losses) and an economic dimension, i.e. lower expenditures on the purchase of mineral nitrogen fertilizers.

The most important findings from the research carried out are of practical importance:

Studies on the environmental and production effects of crop production in rotation with different amounts of incoming organic matter under light acidic soil conditions are primarily of practical relevance. The problem of preserving soil fertility is currently reflected in European and global legislation (Gonet 2007). The depletion of soil organic matter reserves can lead, on the one hand, to a disturbance of basic soil functions and, on the other hand, to a significant decline in soil fertility and, consequently, to a reduction in yields (Pranagal 1994, Wiater 2000). This is a particularly important and current problem in the case of Polish soils, which are mostly light and acidified. It is confirmed in my research that agricultural practices influence the growth of soil organic matter resources including, among others, the application of green fertilizers and manure. The experience with two rotations has clearly shown that the cultivation of faba bean plants in mixtures with grasses and the use of green fertilizers in the form of mustard, grown as a catch crop after winter wheat harvest, allow to store large amounts of organic carbon within the soil. In addition, they improve the structure of light soil and increase the biological life of the soil. The determination of nitrogen equivalents for manure and for the mixture of clover and grass is a valuable research achievement. The obtained substitute N values of 0.37 and 0.50 kg of fertilizer N per kg of nitrogen, respectively from manure, are also important outside of local experimental conditions. The obtained high substitute values of nitrogen from clover grass mixture indicate the possibility of saving mineral fertilizers, which in the crop rotation experiment for manure doses: 0, 20, 40.60 and 80 $t \cdot ha^{-1}$ amounted to 50, 65, 72, 79 and 83 percent.

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5C. MAIN DIRECTIONS OF RESEARCH AND OTHER SCIENTIFIC-RESEARCH ACHIEVEMENTS

- **Before obtaining the degree of doctor (2000-2006)**

Research topics, which I dealt with during my doctoral studies at the Department of Agricultural Chemistry, Warsaw University of Life Sciences in Warsaw, included issues related to the protection of soil environment. At that time, contamination of soils with heavy metals, resulting from the progressive development of civilization, was one of the most important environmental problems. At the same time, the aim was to obtain high quality agricultural products for consumption, fodder and processing. On the other hand, it was not possible to discontinue activities aimed at reducing soil contamination in our agro-climatic conditions, as this would affect the uptake, by plants, of increased amounts of heavy metals and, in the case of soils, would result in their degradation. Failure to cultivate plants on soils with increased heavy metal content could result in the soil becoming unused and pose a threat to groundwater and watercourses. Therefore, at the Department of Agricultural Chemistry at that time, a search for practical solutions for the management of soils with increased heavy metals content was undertaken. Such soils are usually located along expressways. Reducing the level of heavy metal contamination of soils can be achieved through the use of proper agrotechnology and balanced mineral and organic fertilization and liming of soil. In my research, I used my micro-polylette experience on soils artificially contaminated with oxides of copper, zinc, lead and cadmium. The soils were differentiated in terms of pH, organic matter content (by adding brown coal) and granulometric composition (strong clay sand and light dusty clay). As test plants, I cultivated green plants for ruminants' feed: serradella, winter rye and barley. I took soil samples for analysis from different levels of soil profile. I came up with a research hypothesis that on soils contaminated with heavy metals, fodder crops can be grown safely, if the soils are calcified and enriched with organic matter. This hypothesis has been partially confirmed. The results are presented in my doctoral dissertation and in my publications. The following research issues have been clarified within the scope of this topic:

- **Resistance of cultivated crops to heavy metal contamination**

The determination of plant tolerance to the presence of heavy metals in soil was an important element of my research (**II.B1,V.B2**). The reaction of all feed plants to the excess of heavy metals was similar - they reacted by reduced yields, proportional to the level of contamination. The mean values of the tolerance index (determining the degree of inhibition of plant growth under cultivation conditions on soil contaminated with heavy metals) were higher on medium soil than on light soil. This means that under cultivation conditions on soils contaminated with heavy metals, the inhibition of plant growth is higher on light soil than on medium soil. The value of this indicator also depended on the plant species. Among the plants studied, the most sensitive to contamination was serradella - harvested for green fodder - with the lowest value of tolerance index. On the other hand, rye for green fodder and barley for grain cultivation were characterized by a higher value of tolerance index. An increase in soil pH from 4 to 6 and an increase in organic carbon content from 6 to 12 $\cdot kg^{-1}$ increased the value of the tolerance index. I found that the tolerance index of plants was useful for the evaluation of their sensitivity to soil contamination with heavy metals. The sensitivity of plants to exceeding the permissible level of heavy metals in soils was lower in the case of cultivation on soils with a higher fraction content below 0.02 mm compared to light soils with a small capacity of a sorption complex. The plant tolerance to heavy metals in soil is negatively correlated with the level of heavy metal contamination and acidification of the soil. I showed that the values of the tolerance index were differentiated for the heavy metals studied and depended on both the plant species and soil properties.

The collected results also allowed me to determine the bioaccumulation index of heavy metals. The bioaccumulation index is the ratio of metal content in a plant to its content in soil. I showed that the values of the bioaccumulation index depended mainly on the plant species, but also on the soil properties (**II.B2**). In my research, I confirmed that cadmium has a higher bioaccumulation index than lead. As far as plants are concerned, I found the highest value of this index in serradella fodder and the lowest value in barley grain. The uptake of cadmium by plants in the conditions of soil contamination with heavy metals is more intensive than the uptake of lead, which should be combined with different mobility in soil and other chemical properties of both elements. One of the ways to limit the absorption of heavy metals from the soil is to increase the content of organic matter in it **(V.B3).** In the studies, I showed that the value of bioaccumulation index was also dependent on the Corg. content in the soil. On soils with higher content of Corg. I obtained lower values of bioaccumulation index Pb and Cd. The values of bioaccumulation index Cd and Pb indicate that the accumulation of heavy metals in plants may be higher than their content in soil and depends on the type of metal. The increase of cadmium content in soils by one unit may cause the increase of cadmium content in barley straw by as much as 1.2 units. The literature indicates that the ratio of Cd content in a plant to its content in soil ranges from 1 to 10. However, the value of bioaccumulation index Pb does not exceed 0.1. (**II.B2**).

In the conditions of simulated contamination of soil with heavy metals, the biomass of feed plants contained more Cd and Pb in the facilities with the lowest Corg. content in the soil. Cd and Pb content in plants depended on plant species and metal type. The highest amount of Cd was accumulated by serradella green fodder and the lowest by barley grain (**V.B3**). Cadmium was characterized by a higher value of bioaccumulation index in comparison to lead. One of the ways of reducing the bioavailability of heavy metals for plants is soil pH regulation (**V.B1**). As it is known, a decrease in soil pH (acidity) leads to an increase in the assimilability of heavy metals. The content of heavy metals in feed plants depended on the type of soil and plant species. For all studied, plants the lowest effect of pH growth on the reduction of accumulation was obtained for copper, then for zinc, on both light and medium soils. The decrease of heavy metal content in soil, under the influence of increased pH (alkalinity), was greater on light soils than on medium soils, and the decrease of heavy metal accumulation was differentiated depending on the type of metal. For the majority of plants, an increase in pH was the most restrictive of cadmium assimilability; only in the case of serradella on light soil, did the increase in pH decrease lead content more. On the basis of the mean value of bioaccumulation index, it can be stated that plants in the conditions of soil contamination with heavy metals more easily accumulate Zn and Cd (high bioaccumulation value), and to a lesser extent Pb and Cu (lower value of the index). In the study, I showed that the highest bioaccumulation rates of Zn, Cd and Pb have serradella, and rye had Cu. The mean bioaccumulation index decreased with increasing soil pH.

Moreover, the examined heavy metals differed in the indicators of the degree of contamination of plants and, in this respect, I ranked them in the following order: Cd>Pb>Zn>Cu. I confirmed that the value of this indicator also depended on the species of plants examined. The most important results presented in this work allowed me to draw the following conclusions:

The increase in soil pH in the range from 4 to 6 caused a decrease in heavy metals content in fodder plants, on light and medium soils. At the same time, it limited the mobility of Cd. The index of the degree of plant contamination confirms that Cd content in plants increases the most and the least Cu content. The exceeding of permissible standards of Cd and Zn content in fodder was found in serradella, green rye and barley straw. Only barley grain may be used for fodder without reservation. The tolerance factor (**II.B1**) is an important information on the resistance of crops to soil contamination. According to the Decree of the

Ministry of Agriculture and Rural Development of 28 June 2004 on the permissible content of undesirable substances in fodder, the Cd content in fodder ought not to exceed 1 mg·kg^{-} and the Pb-10 mg·kg^{-1} s.m. The high Cd content in green rye and green saradella, according to the above criteria, particularly in light soils, disqualified these plants from being used for fodder. Barley grain, on the other hand, could have been used for fodder without any reservations. The results obtained by me confirmed plant species predisposition to accumulation of heavy metals.

- **Heavy metal mobility in soil profile**

After entering the soil, heavy metals undergo various transformations depending on their physical and chemical properties. The solubility of heavy metals in the soil solution, on the one hand, and the accumulation in the soil, on the other hand, are most affected by soil properties such as pH, granulometric composition, capacity of the sorption complex, content and type of organic matter. After 4 years following the application of different doses of heavy metals added to light soils, containing 17% of clay parts, a relatively large displacement of the elements studied in the soil profile was observed (**V.A2**). The amount of metals leached depended on the dose of a given element. As the dose increased, the amount of the element displaced deep into the soil profile increased. The highest contents of heavy metals were detected in the humus level and in the EET layer of soil, but significant amounts, especially at high contamination, were also found in the Bt level at a depth below 50 cm. Using the highest dose of heavy metals, their content in this soil level was seven times higher than in uncontaminated soils. The addition of brown carbon caused an increase in soil sorption capacity, an increase in pH value, limiting the mobility of heavy metals added to the soil. The increase in organic carbon content limited the leaching of lead the most and cadmium the least.

After obtaining a PhD in agricultural sciences (from 2006 until now)

Apart from the subject matter presented in the main research achievement in my area of research, including methodological research, I have identified the following directions:

1. Methodological achievements

For more than 12 years I have been directing my long-standing field experiment, established in the mid-seventies, which, right after the famous Skierniewice experience, is one of the longest carried out in Poland and, apart from being a field experiment, it is part of the cultural heritage of Polish science. Based on this experience, I collected results of archival analysis and conducted my own research that allowed me to create a huge database, which I used for publishing articles in JCR journals, preparing scientific publications from outside the JCR list, popular-scientific publications, trainings, lectures and poster presentations in Poland and abroad. In addition to constant supervision, experiments require constant, thoughtful modifications, but without breaking the established field pattern.

In 2007, instead of the potato, cultivation of which is already less important, I introduced grain maize in both crop rotation. Grain maize, on the other hand, has become one of the dominant crops in Poland. It is therefore important to study the impact of its cultivation on soil and its yield potential, as a consequence of cereal crops, on light, acidified soil, i.e. soil representing the predominant soil type in Poland. Moreover, as it results from the data presented in the paper (**4B.4**), it is necessary to eliminate the factors limiting plant productivity and soil fertility - significant decrease in soil pH and depletion of calcium and magnesium - by liming and the modification of fertilization with these components. As part of this experiment, I am conducting a research into the amount of root biomass left in the soil after harvesting the crops, determining their Corg. and N content. These results will be used to determine the current coefficients of reproduction and degradation of soil organic matter within the statutory subject, of which I am the main contractor.

To verify the hypotheses concerning the accumulation and transformation of organic matter in soil, it was necessary to master new methods of determination of soil granulometric composition, total carbon forms and carbon fractions, nitrogen and physicochemical methods of humus fractionation. In 2012, after a scientific internship in Nitra (Slovakia), I implemented a method of testing the quality of organic matter, using chemical fractionation according to the Schnitzer method in the Plant Nutrition and IUNG Fertilization Department. For this purpose, we purchased modern equipment (Magafuge 40 centrifuges and TOC/TN Multi 3100 analyzer) and created a laboratory for humus quality testing. This made it possible to conduct research into the quality of organic matter and to characterise the changes in the proportion of individual soil organic matter fractions in relation to the total Corg. pool in the soil. Moreover, it was possible to determine an important soil fertility and organic matter quality index - humification index calculated from the ratio of humic acids carbon to fulic acids (C_{KH}:C_{KF}). I tested this method in research on the influence of various plant cultivation technologies, management systems, rotations and microbiological preparations on the fractional composition of organic matter. Based on the conducted research, I confirmed the influence of different cultivation technologies, application of fertilizers, applied preparations with useful microorganisms on the changes in the fractional composition of humus and evaluated its quality. This method was used in five completed statutory topics (**XIX.B3, XIX.B5, XIX.B6, XIX.B7, XIX.B9**).

The quality of organic matter is currently being studied in the statutory theme (**XIX.B11**) and the project (**XVII.B1**) in which I am a contractor. The results of the current research will allow for the development of the best agrotechnical solutions leading to the maintenance of optimal soil fertility, and even to determine humus quality classes for different soil species in the future.

In addition to its scientific activities, the organic matter quality laboratory fits perfectly into the current market demand for the study of humus substances. Currently, in the organic matter fractionation laboratory, analyses of preparations containing humus substances are performed. **The creation of new research facilities, which are used, not only for scientific purposes, but also for agricultural practices, is a significant scientific achievement and an important contribution to the development and modernization of IUNG-PIB research activities.**

Assessing soil fertility is complicated and requires many analyses, which are costly and time-consuming. In literature, there are reports of attempts to directly measure soil quality and fertility using VIS-NIR spectroscopy. Visible and near infrared spectroscopy (VIS-NIR) is a tool that enables the analysis of multiple chemical and physical components of soil at the same time. It is cheap, uncomplicated and does not require the use of large quantities of chemical reagents, except for calibration samples. Furthermore, VIS-NIR is a practical precision farming tool that can support fertilization decisions leading to improved nutrient availability for plants. Within the framework of the statutory subject, of which I was the head, I decided to test together with a team of soil experts the advisability of using the spectroscopy method to characterise the spatial variability of soil properties in the area of static experience in Grabowo. Corg. analyses confirmed that VIS-NIR spectroscopy can be used to predict many properties related to soil fertility, including organic carbon content (**II.B4; IV.B5**). On a farm scale, the VIS-NIR method gives results comparable to those obtained with classical methods. On a regional scale or more, this method is not as precise as the laboratory methods. However, given that the costs of its application are up to 90% lower and the duration of analysis can also be reduced several times, it can be used on a larger scale, as it is probably the best alternative to classical methods of mapping these properties, requiring hundreds or thousands of samples to be taken. The VIS-NIR method is a fast, accurate and more economical technique than the conventional soil analysis methods, which do not require large amounts of soil material, it is also non-destructive and, in combination with the multidimensional calibration of the soil spectrum, can be used to estimate the organic carbon content (**4B.11**). The high sensitivity to organic and inorganic soil components makes it, potentially, a very useful tool for assessing and monitoring soil properties, quality and functionality.

2. Current trends in the protection of organic matter and the reduction of nitrogen dispersion into the environment

- **Improvement of the reproduction and degradation rates of soil organic matter within the soil**

The assessment of the richness of our soils in humus is important not only from the point of view of production potential, but also of environmental effects. Currently, the most important and current issue is to pay special attention to expanding the scope of organic matter research in order to develop standards that may be necessary in the development of programs to prevent the organic matter from decreasing in soils, in the light of the growing area of crops in monocultures and reducing the use of natural fertilizers agriculture **(V.B12**). In preliminary studies on model profiles carried out in selected regions of Poland, significant losses of soil organic matter have been reported over the last 30 years. In addition, there is a significant lack of consistency between the results of the analyses carried out using different analytical methods - comparative studies in reference profiles, models of changes in soil carbon content, and carbon balance based on reproduction/degradation coefficients. One of the reasons for this differentiation in assessment results may be the lack of soil organic matter balancing coefficients for specific crops, production and tillage systems, types of rotation, which have been updated and adapted to national conditions.

Due to the often changing results of field experiments on soil organic matter balance (due to the high influence of climatic and weather factors, soil and level of plant protection) and high cost of perennial experiments, individual countries very rarely decide to define or verify soil organic matter accumulation coefficients. In Germany, the reproduction and degradation coefficients developed in the 1980s were updated in 2004 on the initiative of the VDLUFA (German Association of Agricultural Institutes). In Poland, a number of studies on the dynamics of changes and the quality of organic matter have been conducted and conducted, but in majority they are analytical (descriptive) and have not been summarized in the form of norms (**IV.B1).** In Poland, the balance of dental caries is determined based on the already valid in Germany, and still used in Poland, the values of reproduction and degradation rates of organic matter. Their disadvantage is also the fact that the concept of coefficients refers to 1 ha of a given crop, irrespective of the size of the crop and the amount of crop residues introduced into the soil, and does not take into account the pool of organic carbon brought into the soil with root crops of crops. For example, crop rotations containing faba beans favoured soil carbon accumulation, but it was not possible to demonstrate statistically significant differences compared to monoculture or crop rotation with cereals. In addition, the analyses of long-term experiments in EU projects (CATCH-C) justify the necessity to establish reliable, empirically and experimentally confirmed soil carbon balance coefficients, indicating significant differences in soil organic matter management depending on the system of tillage or organic fertilization, and ambiguous results of comparisons of different rotations. In Poland, a number of studies on the dynamics of changes and the quality of organic matter have been conducted and conducted, but in majority they are analytical (descriptive) and have not been summarized in the form of norms (**IV.B1).** Their disadvantage is also the fact that the concept of coefficients refers to 1 ha of a given crop, regardless of the size of the crop and the amount of crop residues introduced into the soil, and does not take into account the pool of coal brought to the soil with root crops of crops. These indicators would be extremely useful for modelling the perennial impact of different agricultural production systems and farming practices on soil organic matter management and for assessing the impact of agricultural policy tools supporting soil protection. It is also necessary to pay attention to the wider perception of soil fertility in terms of the environment, especially to increase the content of humus in it through various agrotechnical measures does not deteriorate water quality, feed quality and food.

Nitrogen introduced into the soil does not accumulate in the soil, but is directly or indirectly dispersed into the environment. Modern methods of mechanical soil tillage encourage the mineralisation of soil organic matter and the nitrogen associated with it. On the other hand, it is noted that in recent years the carbon content has increased by a dozen or so tonnes per hectare as a result of the deepening of the topsoil to 35 cm and this has also been accompanied by an accumulation of nitrogen (Nieder and Richter 2000). On the other hand, Polish farms, which are exclusively dedicated to livestock production have seen an increase in the dispersion of nitrogen into the environment. Therefore, sustainable fertilization is sought, which, as a supplement to mineral fertilisation, takes into account all the sources of nitrogen - from natural and organic fertilisers and nitrogen biologically bound by faba bean plants.

The above reasons prompted me to clarify the reproduction and degradation coefficients of soil organic matter and to estimate the amount of biologically fixed nitrogen. The aim of the research conducted in 2008-2011 was to clarify the reproduction and degradation coefficients of soil organic matter (WRD), officially accepted in Poland and borrowed from Germany. Reproduction coefficient (+)/degradation(-) is the amount of organic matter remaining in the soil after cultivation of a specific plant or application of a specific dose of organic fertilizer. The research was conducted on the basis of the experiment described in the introduction. The results are presented in the works (**IV.B7, XV.B1**). The content of organic matter in the soil was determined at 4 year intervals always following wheat harvest as the last crop in the 4-field segment rotation. It was also a crop coming in the fourth year after the application of manure. For these reasons, the verification of the carbon accumulation coefficients for organic fertilization was possible only for the whole 4-year crop rotation. As you would expect, manure fertilized objects had a higher content of organic carbon than the reference soils not fertilized with this fertilizer, however, these differences, even in long-term practices, were not greater than 20% of the reference soils.

On average, 12.1% of the total amount of carbon carried over in manure in the soil under crop rotation A (without Fabaceae plant and catch crop) was humifiable, and 31.4% in the soil under crop rotation B (with Fabaceae plant and catch crop). The size of humification coefficients depended on the size of manure doses and the length of regular period (every 4 years) of application of this fertilizer. The effect of the crop rotation type on the increase of organic matter content in the soil was very clear and was greater than the effect of manure. In B rotattion, a dose of 20 $t \cdot ha^{-1}$ in a four-year rotation ensured only a slightly negative or balanced organic matter balance in the soil. On the other hand, in the A rotation the loss of organic matter in the soil progressed regardless of the size of manure doses. The values of the reproduction and organic matter degradation coefficients (WRD) for manure calculated by me differed from the German values of the coefficients used in agricultural practice. Even in B rotation, they reached only 50% of the German coefficients (**IV.B7**).

Currently, this research is being continued on the statutory subject, on which I am a contractor. The main objective of the research is to develop coefficients of organic carbon balance in soil depending on the method of soil tillage and plant rotation for different soil conditions. The coefficients are determined on the basis of the database of long-term experiments of IUNG-PIB. These coefficients will be used to assess the sustainability of different combinations of agricultural practices (rotation and agrotechnology) and to forecast the effects of the use of agricultural policy tools on the preservation of soil organic carbon.

Reliable and detailed organic matter balancing coefficients will be an extremely useful tool for assessing the sustainability of agricultural production and the effectiveness of Common Agricultural Policy tools. In the short term, it is difficult to assess changes in soil carbon levels based on direct measurements - the effect of particular plant production methods may be measurable only after many years.

- **Estimation of the amount of nitrogen bound biologically by clover grown in a mixture with grasses**

Growing Fabaceae mixed with grasses or mixtures of Fabaceae with cereals is the most common practice in agriculture. Determination of the amount of nitrogen bound biologically by faba bean plants under field conditions is a difficult task. Its amount can only be estimated precisely by isotopic methods (**V.B4**). Therefore, the best indirect methods of valuation of this component have been sought for years. The most frequently used coefficients of symbiotic nitrogen fixation from the 1990s are used on the assumption that 1% of clover and grass share in meadow sward is balanced by 2 to 3 kg of nitrate nitrogen is used. The use of isotopic methods in field conditions is rarely used in agricultural research due to high costs. Thanks to the experimental system in Grabowo, I have used the method of estimating the amount of nitrogen biologically bound by a Fabaceae plant in my paper - based on the balance difference resulting from the comparison of the amount of component taken up by a mixture of clover-grass mixture and a test plant grown equally - maize intended for green fooder (**4.B2**). The difference in nitrogen uptake by green maize and clover-grass mixture corresponds to the amount of nitrogen bound biologically. To estimate the amount of nitrogen bound biologically by clover grown in a grassland mixture, I used the results of three four-year shifts of rotations A and B during the research years (1992-1996; 1997-2000; 2001-2004).

Both plants benefited from the follow-up action of the same doses of nitrogen in manure and were compared in the facilities with almost the same dose of mineral fertilizers 120 kg $N \cdot ha^{-1}$ for clover with grass and 135 kg $N \cdot ha^{-1}$ for maize for green manure. A great advantage of such an approach is the combination of the introduction of nitrogen bound biologically with the yield of Fabaceae plants. In the facility without mineral nitrogen fertilization the intake difference was 180 kg $N \cdot ha^{-1}$, in the facility with the dose of 135 kg $N \cdot ha^{-1}$ it decreased to 139 kg $N \cdot ha^{-1}$. On average, clover grown in a mixture with grasses bound 155 kg $N \cdot ha^{-1}$. Results of a 24-year study on the estimation of nitrogen biologically bound by the clover mixture indicate that, except for cycle VIII, this amount ranged from 150 to 400 kg·ha^{-1}. It was calculated based on the difference in nitrogen uptake from all sources, with slightly higher values in the absence of N fertilizer or manure (**4B.2**). Given the fact that 100 kg of nitrogen bound by Fabaceae plant is equivalent to 200 kg N applied as mineral fertiliser, it is possible to save between 300 and even 800 kg of nitrogen in mineral fertilisers. In my calculations, the savings can be even greater and it is possible to suggest a complete abandonment of mineral nitrogen fertilization.

The results I have obtained are more reliable than those obtained using the so-called Köpke's symbiotic nitrogen fixation factor for clover-grass mixtures used in field experiments, as they refer directly to the harvest of the ingredient with the crop yields. The amount of nitrogen bound by clover grown in the mixture with grasses estimated in own studies were almost twice higher than the quantity determined with this coefficient. These values indicate large potential savings in the use of mineral nitrogen fertilizers.

3. The influence of selected agrotechnical factors, technologies, preparations with useful microorganisms on the quantity and quality of soil organic matter.

I conducted studies on the influence of selected agrotechnical factors, technologies, preparations with useful microorganisms for the quantity and quality of soil organic matter within the statutory activity in the years 2012 - 2016. Based on the conducted research, I confirmed the influence of various technologies of soil cultivation, system of production: (ecological, integrated and conventional) and the aftermath of plants: (classic and monoculture crop rotation) and type of fertilization; on changes in the fractional composition of soil organic matter and I estimated its quality. The scope of the study included: share of cereals in the structure of sowings (50%, 75%, 100%), method of tillage (ploughed, ploughless), production technologies (integrated, intensive), cultivar. The study included winter and spring wheat and spring barley (**XV.B10**). In the next statutory topic, I assessed the quantity facility and quality of soil organic matter, depending on the system of production (ecological, conventional and monoculture) and manure fertilization (**XV.B7**). For this purpose, a research of about 16 ha was used, in which various management systems are compared: ecological (5-field crop rotation: potato - spring wheat + undersown crop - red clover with grass (1st year) - red clover with grass (2nd year) - winter wheat + catch crop), integrated and conventional in two variants: simplified rotation and winter wheat monoculture. In the ecological system, the nutritional needs of plants in relation to nitrogen were satisfied by biological binding of this component by fabaceous plants, as well as by manure used only once in rotation at the dose of 30 t·ha^{-1}. The conventional system included two variants: A - 3 field crop rotation (rape - winter wheat - spring wheat). Intensive production technologies were implemented in this system. Nitrogen fertilization was applied based on doses determined in terms of maximizing yields; B - monoculture of winter wheat.

From these studies, I was able to draw the following conclusions:

1. The long-term maintenance and stabilisation of the content of soil organic matter was mainly influenced by the share of cereals in the planting structure, and to a lesser extent by the type of production technology as well as the system of soil tillage. I found the highest Corg. content in the soil under rotation with 75% share of cereals in the planting structure. The main factor influencing the value of the humification index - C_{KH}:C_{KF} - was tillage technology and soil tillage method. Lower values of this index were obtained in the integrated production technology - 1.13. In the intensive technology, the value of C_{KH}:C_{KF} ratio was higher - 1.26. In the soil, the share of carbon fractions of humic acids C_{KH} increased and the share of carbon fractions of fulvic acids C_{KF} decreased, and thus the C_{KH}:C_{KF} ratio widened, which indicates better quality of the humus. The introduction of simplified soil tillage (ploughless system) and the use of intensive production technology had an influence on the improvement of this ratio in comparison to the integrated technology.

2. The best humus quality (wide ratio C_{KH}:C_{KF}) was characteristic for the soils in the ecological production system. The introduction of simplified system, especially wheat monoculture, caused a significant deterioration of the quality of the humus, which is evidenced by a much lower (<1) ratio of humic acids carbon to fulic acids carbon.

An important research topic that required scientific explanation was the evaluation of the use of microbiological preparations to improve the quality of soil organic matter (**XV.B6**). In agricultural practice, preparations containing so-called "effective" or "useful" microorganisms, abbreviated as EM, have been widely used for several years. EM preparations are mixtures of self-sustaining bacteria, lactic acid bacteria, actinomycetes, yeasts, fungi, often supplemented with macro- and microelements. However, practice, or more precisely commercial practice, has outstripped objective scientific research. Three preparations with useful microorganisms most commonly used in agricultural practice were selected for the study: EM - Effective Microorganisms, EmFarma Plus and UGmax - Soil Fertilizer. The studies on the quantity and quality of organic matter were carried out in field experiments in the years 2012-2014. Three research factors were used in the conducted studies. The first factor was 3 of the studied preparations, the second 3 ways of their application and the third 3 levels of mineral nitrogen fertilization. The second research factor were 3 methods of application: (for stubble, stubble + straw and stubble + straw + 30 kg N). No unambiguous influence of preparations, methods of their application and N fertilization on Corg. content in the soil and fractional composition of organic matter was found. In the second year of the study, a slight increase in the percentage share of humic acid fraction was observed under the influence of microbiological preparations applied directly to the stubble and stubble with straw and mineral nitrogen. The ratio of the carbon content of humic acids to that of carbon content of fulvic acids changed under the influence of microbiological preparations, but no statistically significant change in the quality of organic matter measured by C_{KH}:C_{KF}. was found. No significant effect of the methods of application of the preparations and the level of mineral nitrogen fertilization on the change of Corg content was found.

The study of the influence of microbiological preparations on the quantity and quality of organic matter needs to be continued, as the three-year period is too short to draw clear conclusions, especially under conditions of changing weather. **I believe that under field conditions it is difficult to obtain a positive effect on the accumulation of organic matter, due to the complex interactions between the soil organisms. The supply of a carbon source such as molasses (the carrier of these preparations) to the soil may cause an increase in the number of indigenous microorganisms and their enzymatic activity. Therefore, I assume that as a result of prolonged use of microbiological preparations the Corg. content will decrease, the percentage share of fulvic acid fractions in the total Corg. pool will increase, because microorganisms, after introduction into the soil, stimulate the decomposition of organic matter (mineralization process).**

6. MEASURES TO PROMOTE AGRICULTURAL POLICY, AGRICULTURAL PRACTICES AND SCIENCE

In addition to scientific research, an important achievement of mine that is useful for agricultural practice, was the development of the principles of safe fertilization with mineral and natural fertilizers containing nitrogen and phosphorus. This occurred in 2014, within the framework of the IUNG-PIB Perennial Programme and entitled: "Supporting activities in the field of shaping the agricultural environment and sustainable development of agricultural production in Poland. In order to meet the growing demand for food, many producers implement an intensive production model, in which the production of crops is based on high doses of nitrogen and phosphorus brought by mineral and natural fertilizers. Unfortunately, if used incorrectly (inappropriate times of application, unbalanced doses), these measures can have a significant negative impact on the environment. Sustainable development of agriculture is an ambitious goal, which has been undertaken by most European countries, including Poland. The above premises formed the basis for a nationwide information campaign entitled "The sustainable development of agriculture". The above premises were the basis for the nationwide information campaign entitled "Rational fertilizer management". In the campaign in which I participated, issues concerning the principles of rational management of natural and mineral fertilizers on arable land were raised and sustainable, environmentally friendly fertilization systems for basic crop species were discussed. The campaign was complemented by scientific workshops entitled "Effective and environmentally safe fertilisation of crops", during which I presented, in two separate lectures, the results of research on fertiliser management considered in the aspect of sustainable development, conducted in the Plant Nutrition and Fertilisation Department of the IUNG-PIB in Puławy. Within the framework of the campaign, a monograph entitled "Good Practices in Fertilisation", Studies and Reports of IUNG-PIB, in which I included two chapters: Fertilisation of corn grown for grain" and "Rational management of natural and organic fertilisers". I took part in the development of an information leaflet promoting Good Practices in Fertilization "Stop nitrogen and phosphorus losses" and in the preparation of materials for the website. As part of this task, I developed guidelines for the safe use of natural fertilisers, which were used in the campaign. I also developed training materials entitled: Practices to reduce nitrogen and phosphorus losses from agriculture.

For the above mentioned works I received **the Minister of Agriculture and Rural Development Award** for "Rational fertilizer management" **in 2015**.

Good agricultural practice to protect waters from agricultural nitrate pollution is to optimise nitrogen management from all sources, particularly, fertilizers. The application of fertilizers in optimal quantities, at the right time and in the right way ensures their good uptake by plants, which determines the high efficiency and profitability of fertilization. The high level of component utilization by plants also limits their losses from agriculture. Dispersion of fertilizer components outside the agro-systems of cultivated fields poses a great threat to the natural environment, particularly to the water environment, causing its eutrophication. Total elimination of loss of nutrient from agricultural sources is not possible, but it is possible to significantly reduce them. Within the framework of this issue, I was carrying out another task in the IUNG-PIB Perennial Programme entitled: "Assessment of the impact of agriculture on water quality and support for measures aimed at protection of water resources in Poland". I was the coordinator of the development of new recommendations for the protection of waters against nitrate pollution from agricultural sources – a collection of Good Agricultural Practice Recommendations for voluntary application. The study was prepared in connection with the requirements of Article 103 of the Act of 20 July 2017 Water law. Moreover, it replaced Part H (Abridged set of principles of good agricultural practice for the purposes of implementing the Nitrates Directive) of the Code of Good Agricultural Practice of 2004 and other requirements of the Code relating to the principles of using fertilisers containing nitrogen, liming of soils and storage of natural fertilisers. The document was developed in cooperation with the Institute of Horticulture in Skierniewice, the Institute of Technology and Life Sciences in Falenty, the Ministry of Agriculture and Rural Development, the Ministry of Maritime Economy and Inland Navigation and the Poznań University of Life Sciences.

Since 2006 - (still date) I have conducted and continue to conduct various activities promoting science. I have lectured at the Lublin Science Festival, during the IUNG-PIB Open Door Days, doctoral seminars and postgraduate studies, as well as training for teachers, students and farmers. I am also the author of over 100 popular science articles, the most important of which I have included in the list of scientific achievements. In order to promote a unique experiment in Grabów, I wrote a chapter in my monograph entitled: "Perennial experiments in agricultural research in Poland". I am the author of a chapter in the monograph "Fertilization Lexicon" concerning the rational use of natural and organic fertilizers. I am the author or co-author of 7 training instructions. I am also involved in issuing opinions on the qualification of fertilizers and agents improving soil properties for ecological production and on the evaluation of fertilizers and agents supporting the cultivation of plants intended for use in field crops, in order to introduce them to the Polish market. I also prepare expert opinions for the Ministry of Agriculture and Rural Development. I carry out analyses of the content of humus substances in fertilizers and soil conditioners.

In connection with the EU planned new limits for heavy metals, including cadmium, in phosphate fertilizers I participated as an expert in the debate "Russian fertilizer expansion - a threat to Poland's economic interests" at the Financial and Banking Centre Nowy Świat in Warsaw, presenting solutions for the fertilizer industry in connection with the reduction of the Cd limit in fertilizers.

Planned research work and publications at the preparation stage or in review

The degree of accumulation of organic matter, as mentioned above, depends on a set of agro-ecological factors in the soil. The accumulation of organic matter is particularly important for maintaining the fertility of light soils. It is also important to study the progressive saturation of soil with organic carbon depending on the granulometric composition of the soil. The research on the distribution of organic matter and its quality in particular groups of soil granulometric composition will be of further interest to me. From a scientific point of view, it is also interesting to investigate further the quality of organic matter based on the C_{KH}:C_{KF} humification index and the DH (degree of humification) index, which determines the stability of humus compounds resistant to microorganisms.

Publications dealing with this issue are in the process of print (a chapter in the monograph) and preparation (2 papers), which will be sent to journals in the Journal Citation Reports (JRC) database:

Pikuła D. Kocoń A. Effect of preparations with beneficial microorganisms on the quantity and quality of organic matter. A chapter in the monograph.

Pikuła D., Rutkowska A. The effect of mineral microbiologically enriched fertilizers on the quantity and quality of soil organic matter (JCR).

Pikuła D., Rutkowska A. Effect of leguminous crop and fertilization on the quantity and of soil organic matter in 36-years field experiment (JCR).

Indicators for the assessment of scientific achievements:

Hirsch index according to the Web of Science database:3

Hirsch index according to Scopus database: 3

Total Impact Factor (IF):15,275

Number of citations: 21

Number of citations without self citations: 19 (Web of Science database)

Rating according to MNiSW communication on the list of scientific journals with the number of points awarded for publications in these journals (Orginal Creative Works and Review Articels) according to the publication yaer:401