INTERNATIONAL SCIENTIFIC CONFERENCE

"100TH ANNIVERSARY OF AGRICULTURAL EXPERIMENTATION AT THE WARSAW UNIVERSITY OF LIFE SCIENCES – SGGW"

BOOK OF ABSTRACTS

12–13 June 2026, WARSAW, POLAND

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Conference program

12 June 2026 – Scientific session in the Crystal Hall of the Warsaw University of Life Sciences (WULS-SGGW)

8:00-10:00 – Crystal Hall of the WULS: registration, poster placement
10:00 – 10:30 – The opening of the conference and the plenary session
10:30 – 11:00 – *A century of research and future challenges at the Experimental Station in Skierniewice* – Jan Łabętowicz, Tomasz Niedziński, Beata Rutkowska, Tomasz Sosulski, Wojciech Stępień, Ewa Szara, Wiesław Szulc, Magdalena Szymańska, Wiktoria Wierzchowska (Warsaw University of Life Sciences – SGGW, Poland)
11:00 – 11:30 – *The Rothamsted long-term experiments: past achievements and future opportunities* – Andrew Gregory, Paul Poulton, David Powlson, Margaret Glendining, Sarah Perryman, Richard Ostler, Steve McGrath, Jonathan Storkey, Laura Cárdenas, Ian Clark, Stephan Haefele, Vanessa Kavamura, Timothy Mauchline (Rothamsted Research, United Kingdom)
11:30 – 12:00 – *An open-access (meta) data platform for long-term field experiments to support soil monitoring and assessment* – Cenk Dönmez, Carsten Hoffmann, Nikolai Svoboda, Xenia Specka, Igo Silva de Almeida, Valeh Khaledi, Katharina Helming (Leibniz Centre for Agricultural Landscape Research (ZALF); Eberswalde University for Sustainable Development; Germany)

12:00 – 12:10 – Group photo
12:10 – 12:45 – Coffee break / Poster session

Session 1
Chairs: *Assoc. Prof. Stanisław Samborski, Dr. Ing. Pavel Čermák*
12:45 – 13:00 – *Knorr Holden Plot – the longest running irrigated continuous maize fertility experiment* – Bijesh Maharjan
13:00 – 13:15 – *Insights from Lithuanian long-term soil management experiments: soil organic matter stability and carbon sequestration* – Vaclovas Bogužas, Zita Kriaučiūnienė, Aušra Marcinkevičienė, Rimantas Vaisvalavičius, Vaida Steponavičienė, Lina Skinulienė, Edyta Hewelke, Lilla Mielnik, Riccardo Spaccini, Dariusz Gozdowski, Marek Podlasiński, Irmina Ćwieląg-Piasecka, Elżbieta Jamroz, Maria Jerzykiewicz, Aneta Perzanowska, Magdalena Dębicka, Agata Gryta, Jacek Panek, Dominika Siegieda, Karolina Oszust, Giorgia Pertile, Yakov Kuzyakov, Magdalena Frąc, Jerzy Weber
13:15 – 13:30 – *Past, present and future of the Hungarian long-term experiments, and main conclusions from acidic sandy soil* – Marianna Makádi, Márton Jolánkai, Csilla Almási, Viktória Orosz, Ibolya Demeter, Zsolt Bogdányi, Tamás Szegi, Khalid Suleiman Ibrahim, Katalin M. Kassai, István Henzsel
13:30 – 13:45 – *69 years of fertilization experiment in Brody with cultivation of plants in crop rotation and monoculture* – Zuzanna Sawinska, Andrzej Blecharczyk, Tomasz Piechota, Dominika Radzikowska-Kujawska, Stanisław Świtek, Wojciech Waniorek
13:45 – 14:00 – *Organic carbon and nutrient distribution in long-term field experiment with different soil tillage practices* – Gabriela Mühlbachová, Helena Kusá, Pavel Růžek, Radek Vavera

14:00 – 15:30 – Lunch (Crystal Hall of the WULS)

Session 2

Chairs: *Assoc. Prof. Zuzanna Sawinska, Prof. Bijesh Maharjan*

15:30 – 15:45 – *Soil management effects on soil organic matter quality and -storage: evidence from long-term experiments in Poland and Lithuania and sophisticated analytical methods* – Peter K. Leinweber, Aneta Perzanowska, Vaclovas Boguzas

15:45 – 16:00 – *Selected properties of black earths and winter wheat yield after 70 years of different fertilization and crop rotation* – Irena Suwara, Dariusz Gozdowski, Aneta Perzanowska, Szymon Młynek

16:00 – 16:15 – *Seasonal variation of basal soil respiration under long-term sewage sludge compost application in acidic sandy soil* – Khalid Suleiman Ibrahim, Tamás Szegi, András Sebők, Réka Döbröntey, Viktória Labancz, Csilla Almási, Viktória Orosz, Ibolya Demeter, István Henzsel, Yuri Andrei Gelsleichter, Péter Molnár, Boglárka Szála, Bence Paulisz, Janka Szabó, Marianna Makádi

16:15 – 16:30 – *Long-term field experiments in response to new challenges in agriculture: a multi-indicator assessment of carbon farming practices* – Beata Jurga, Ryszard Winiarski, Tamara Jadczyszyn, Piotr Jurga, Anna Gałązka

16:30 – 17:00 – Coffee break / Poster session

Session 3

Chairs: *Prof. Józef Chojnicki, Prof. Rimantas Vaisvalavičius*

17:00 – 17:15 – *Kernza in Wyoming, USA: perennial grains for vulnerable lands* – Urszula Norton, Hannah R. Rodgers

17:15 – 17:30 – *Cereal crop productivity under different management intensity in long term field experiment* – Virmantas Povilaitis, Renaldas Žydelis

17:30 – 17:45 – *Soil management effects on soil chemistry and water infiltration in different tillage* – Elizaveta Watzlová, Pavel Čermák

17:45 – 18:00 – *Effects of soil tillage, catch crops and soil conditioners on epigeic arthropods in a 60-year winter rye monoculture* – Olena Niszczak, Jacek Twardowski, Roman Wacławowicz, Iwona Gruss, Kamila Twardowska, Joanna Magiera-Dulewicz

18:00 – 21:00 – Banquet (Crystal Hall of the WULS)

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13 June 2026 – Conference and field session at the Experimental Station in Skierniewice

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8:00 – Coach departure from Warsaw to Skierniewice (meeting place: Crystal Hall of the WULS)

8:00 – 10:00 – Transfer from Warsaw to Skierniewice

10:00 – 10:30 – Coffee buffet / Welcome to the Experimental Station in Skierniewice

Session: field experiments at the Experimental Station in Skierniewice

10:30 – 11:00 – Long-term field experiments in Skierniewice – Dr. Tomasz Niedziński et al.

11:00 – 11:30 – Long-term field experiments in Chylice – Dr. Aneta Perzanowska et al.

11:30 – 12:00 – Field experiments in Miedniewice – Dr. Beata Michalska Klimczak et al.

12:00 – 12:30 – Summary of the conference

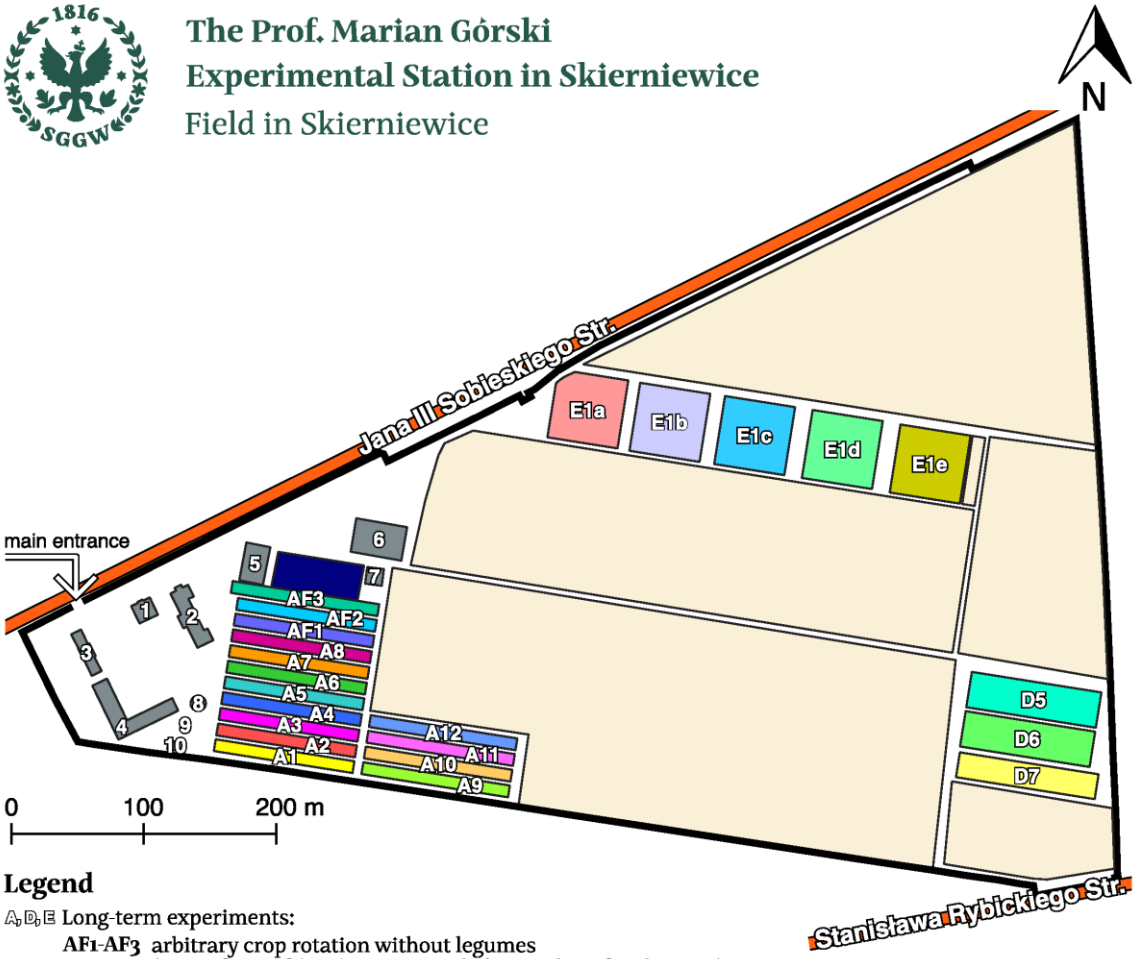
12:30 – 14:00 – Lunch

14:00 – 16:30 – Visit to long-term agricultural experiments in Skierniewice, Agricultural Experimentation History Room, soils in the area of long-term experiments, company demonstrations

16:30 – 17:00 – Coffee buffet

17:00 – 19:00 – Transfer from Skierniewice to Warsaw

A trip in the Experimental Station in Skierniewice



Legend

Long-term experiments:

- **AF1-AF3** arbitrary crop rotation without legumes (N in a form of $(NH_4)_2SO_4$, control plots with no fertilization) - since 1921-1923
- **A1-A4** arbitrary crop rotation without legumes (N in a form of NH_4NO_3, control plots with no fertilization) - since 1921-1923
- **A5-A8** arbitrary crop rotation without legumes (N in a form of NH_4NO_3, control plots with Ca) - since 1921-1923
- **A9-A12** arbitrary crop rotation with legumes (N in a form of NH_4NO_3, control plots with Ca) - since 1924-1925
- **D5** potato monoculture (N in a form of NH_4NO_3, control plots with Ca) - since 1924-1925
- **D6** rye monoculture (N in a form of NH_4NO_3, control plots with Ca) - since 1924-1925
- **D7** triticale monoculture (N in a form of NH_4NO_3, control plots with Ca) - since 1989
- **E1a-E1e** 5-field crop rotation with legumes and FYM (N in a form of NH_4NO_3, control plots with Ca) - since 1924-1925

Commercial blueberry field

Reserved area for setting up experiments, currently cropped with cereals or potato

Buildings:

1 - administration and laboratory building
2 - teaching and staff building with a conference room
3 - former granary - Agricultural Experimentation Exhibition Hall, soil archive, workshops
4 - garage and workshop facilities
5 - vegetation hall no. 1
6 - vegetation hall no. 2 with ground vases
7 - IMGW-PIB meteorological station
8 - barbecue hut
9 - station for filling and washing sprayers (Biobed)
10 - machine washing station

Prepared by: Damian Murach, MSc Eng.

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PLENARY SESSION

A century of research and future challenges at the Experimental Station in Skierniewice

Jan Łabętowicz, Tomasz Niedziński, Beata Rutkowska, Tomasz Sosulski, Wojciech Stępień, Ewa Szara, Wiesław Szulc, Magdalena Szymańska, Wiktoria Wierzchowska

Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail: tomasz_niedzinski@sggw.edu.pl

The Experimental Station of the Prof. Marian Górski Institute of Agriculture at the Warsaw University of Life Sciences (SGGW) in Skierniewice is one of the most important centers for long-term agricultural research in Poland and Europe, combining historical continuity, a unique layout of field experiments, and a focus on current environmental and production issues. The long-term fertilizer experiments in Skierniewice were initiated in 1921–1924 by Prof. Józef Mikułowski-Pomorski and expanded in 1923–1925 by Prof. Marian Górski. Their primary scientific value lies in the uninterrupted conduct of experiments for over a century within the same research framework, maintaining consistent fertilization schemes, replicates, and long-term recording of data on soil, plants, and meteorological conditions. As a result, the Station serves not only as an experimental base for agricultural chemistry, soil science, and agronomy, but also as a research infrastructure of strategic importance for assessing the sustainability of agrosystems.

The uniqueness of the facility stems from the combination of scale, duration, and diversity of experimental factors. In Skierniewice, long-term experiments on fertilization, crop rotation, and monocultures are conducted, covering a total of 660 plots across an area of approximately 4 hectares. The experiments are conducted on Luvic Stagnosols, which are representative of a significant part of central Poland, under climatic conditions characterized by, among other things, an average annual temperature of approximately 8°C, an average annual precipitation of approximately 540 mm, and a growing season of approximately 213 days. A particular strength of the Station is the conduct of experiments in four rotation systems (non-fixed rotation, balanced five-field rotation, monocultures), making them the only such experiments in Europe. Potato and rye monocultures have been conducted since 1921, and triticale monocultures since 1989. An important part of the infrastructure is also a meteorological station operating since 1921, soil columns preserving the natural soil profile, a growth chamber, and a pilot line for the production of granular fertilizers from organic waste products. This system is complemented by experiments in Chylicach and Miedniewice, including cultivation experiments (plow, simplified, and strip tillage systems), crop rotation experiments, and a certified organic field.

The published works based on the experimental fields in Skierniewice, documented in a list of publications from 1925 to 2025, show the evolution of research topics from classical studies on plant fertilizer requirements, soil pH, mineral fertilizers, manure, liming, potassium, phosphorus, and nitrogen, through soil and plant diagnostics, element balances, the regeneration of degraded soils, carbon and nitrogen cycles, and the assessment of risks associated with heavy metals and waste, all the way to contemporary research on N2O emissions, nitrogen and phosphorus leaching, soil carbon sequestration, soil microbiota, soil health, biochar, localized fertilization, UAV remote sensing, hyperspectral data, and the use of neural networks to assess plant nutrition. These achievements were both theoretical and applied in nature: they contributed to refining fertilization recommendations, assessing the long-term effects of mineral and organic fertilization, identifying the mechanisms of soil acidification and regeneration, determining C, N, P, K, and Mg balances, and evaluating the environmental consequences of agricultural intensification. The Station's achievements also include work carried out in international collaboration, including with centers such as Rothamsted Research, Bad Lauchstädt, Prague, and the University of Bonn, which confirms its importance as a partner in comparative and model-based research.

The Station's legacy, spanning over a century, highlights the vital role that decades of agricultural research in Skierniewice have played in establishing the Polish school of agricultural chemistry. It presents the Station as a unique field laboratory where researchers can analyze the relationships between fertilization, crop rotation, soil properties, crop yield, plant quality, and the impact of agriculture on the environment. The Station is a place with enormous potential. In the future, it will serve as a platform for

scientific and implementation cooperation in the areas of yield modeling under climate change conditions, soil health monitoring, reducing nutrient losses, assessing greenhouse gas emissions from soils, developing fertilizers from waste materials, validating remote sensing tools, and applying artificial intelligence methods to the analysis of long-term data series. The Station's greatest asset is the continuity of data collection and its long-term datasets. Data gathered over decades allow for the study of processes that cannot be reliably assessed in short-term experiments. The Experimental Station in Skierniewice is an open, scientifically credible center with a forward-looking collaborative infrastructure for research institutions, government agencies, the fertilizer sector, technology companies, and partners interested in sustainable agricultural development and the protection of soil resources.

The Rothamsted long-term experiments: past achievements and future opportunities

Andrew Gregory[1], Paul Poulton[1], David Powlson[1], Margaret Glendining[1], Sarah Perryman[1], Richard Ostler[1], Steve McGrath[1], Jonathan Storkey[1], Laura Cárdenas[2], Ian Clark[1], Stephan Haefele[1], Vanessa Kavamura[1], Timothy Mauchline[1]

[1]Rothamsted Research, Harpenden, Hertfordshire, AL5 2JQ, United Kingdom, andy.gregory@rothamsted.ac.uk
[2]Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, United Kingdom

The Rothamsted Long-Term Experiments (LTEs) in the UK comprise the "Classical" experiments established by Lawes and Gilbert at Rothamsted in 1843-1856, later experiments established in the 20th Century, and more recent modifications of existing experiments. They are the oldest continuous agronomic experiments in the world. Together with the Rothamsted Sample Archive (RSA) of crop, soil, fertiliser and manure samples, and the Electronic Rothamsted Archive (e-RA) of crop, soil, and meteorological datasets and associated metadata, they form a globally-unique strategic research platform recognised as a national and international resource. We present a summary of the past achievements from scientific research conducted on the Rothamsted LTEs and what the future opportunities may be in supporting new science to tackle the interrelated societal challenges of sustainable agriculture, food security, and climate change. We also discuss some of the challenges involved in managing and maintaining the Rothamsted LTEs as a research platform.

The long-term treatments on the Rothamsted LTEs have resulted in gradients of soil fertility (from nutrient inputs), soil organic carbon (from organic inputs and management change), and soil pH (from chalk, fertilizer and atmospheric inputs). These gradients control subsequent effects on functions and services in agricultural systems. We show that crop yields can be sustained in the long-term through nutrient inputs, but that injudicious fertilisation can lead to undesirable effects. We explore the links between soil fertility, crop yields and crop nutritional quality in arable systems, and examine the trade-offs between productivity and biodiversity in grassland systems. We summarise current research in soil health, including management effects on soil organic carbon and microbiology, and the subsequent control on soil physical properties and, hence, the storage and transmission of water and air. The role of agricultural soils to mitigate climate change by offsetting emissions through carbon sequestration is evaluated with reference to what we have learned from the Rothamsted LTEs.

Future opportunities for the Rothamsted LTEs are plentiful. The detailed history of long-term management and long datasets in e-RA provide a platform to test new technologies, methodologies and theories that cannot be supported by short-term experimentation. The RSA provides a physical resource capturing nearly two centuries of environmental and management change that can be characterised through new analysis and investigation.

Despite the opportunities, there are significant challenges in managing and maintaining resources like the Rothamsted LTEs. There is a constant need to find the right balance between protecting the integrity of LTEs and maintaining their relevance through careful adaption. Other challenges include securing funding, having good governance structures, increasing external collaborative use of the resources, making data freely available, and, not least, succession-planning to ensure a smooth transition to the next generation tasked with the upkeep of these most unique resources. Nevertheless, these challenges provide opportunities.

The Rothamsted LTEs are just one member of a family of global agricultural LTEs. It is this network of irreplaceable resources around the globe, under different climates, soil types, and agricultural systems, that will provide the opportunities for new research in tackling the challenges of sustainable agriculture, food security, and climate change.

Acknowledgements
The Rothamsted Long-Term Experiments - National Bioscience Research Infrastructure (RLTE-NBRI) is funded by the UK Research and Innovation – Biotechnology and Biological Sciences Research Council (UKRI-BBSRC) under award BBS/E/RH/23NB0007 (2023-2028). The RLTE-NBRI is also supported by the Lawes Agricultural Trust.

An open-access (meta) data platform for long-term field experiments to support soil monitoring and assessment

Cenk Dönmez[1], Carsten Hoffmann1[1], Nikolai Svoboda[1], Xenia Specka[1], Igo Silva de Almeida[1], Valeh Khaledi[1], Katharina Helming[1, 2]

[1] Leibniz center for agricultural landscape research, Eberswalde str. 84 15374 Müncheberg, Germany, cenk.doenmez@zalf.de

[2] Eberswalde university for sustainable development (HNEE), Schicklerstraße 5, 16225 Eberswalde Eberswalde, Germany

Long-Term Field Experiments (LTEs) are permanently operated agricultural research infrastructures designed to study the long-term effects of management practices under changing climate conditions. These trials are essential for assessing the impacts of practices on crop production and soil across different textures and types, and for understanding soil health trajectories. LTEs therefore represent a high-value legacy data; however, their information is typically dispersed across various institutions and difficult to access.

To address this challenge, we developed an open-access (meta)data and knowledge platform centred on the LTE-Map (https://lte.bonares.de), providing a free and open access service to compile, harmonize, and reuse information on LTEs across Europe (Dönmez et al., 2026). The LTE-Map provides a spatial representation of LTEs and their key attributes by exchanging and harmonizing information from EU- and nationally funded initiatives (BonaRes, SoilWise, EJP SOIL). LTEs are clustered into categories directly relevant for soil monitoring (management operations, land use, duration, experimental status, etc.) (Grosse et al., 2020; Dönmez et al., 2022; Dönmez et al., 2023; Blanchy et al., 2024). Applying minimum duration thresholds of 5 years for mid-term trials and 20 years for LTEs, the (meta)database currently includes approximately 700 LTE records in a well structured and harmonized form across Europe and in a global context.

Our platform indicates that fertilization experiments represent the dominant research theme, followed by crop rotation and tillage, highlighting both strengths and gaps in long-term soil research coverage. By enabling the reuse of LTE data through geospatial approaches, including GIS-based climate impact analysis (Dönmez et al., 2023), spatial representation (Grosse et al., 2020), GeoAI, and modelling (Dönmez et al., 2024), the platform supports cross-country comparability and methodological innovation. It facilitates the scaling up of soil and agricultural knowledge from field to landscape level and supports strategies for resilient agricultural production, soil management, and food security in Europe, contributing to EU soil monitoring objectives. In our contribution, we demonstrate the potential that the LTE map has as a platform for collaboration in general and identify possible scientific evaluation methods for published LTE data and metadata.

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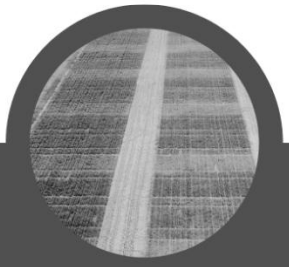
Grosse, M. et al., (2020): Long-term field experiments in Germany: classification and spatial representation. https://doi.org/10.5194/soil-6-579-2020. Soil.



SESSION 1

Knorr Holden Plot – the longest running irrigated continuous maize fertility experiment

Bijesh Maharjan

University of Nebraska-Lincoln, 4502 Avenue I, Scottsbluff, Nebraska 69361, United State, bmaharjan@unl.edu

Soil health lies at the core of a sustainable food production system. A comprehensive evaluation of different agronomic practices and their effect on soil health is essential to determine the best practices that support soil ecosystem services. However, it may take years or decades to observe measurable changes in soil health under varying management practices. The objective of this experiment was to evaluate the effects of long-term (>77 years) manure and inorganic nitrogen (N) fertilizer on soil health and determine the interrelationship among the measured soil bio-physicochemical indicators. The study also aims to understand the sustainability of the monocropping maize production system under long-term manure and inorganic N fertilizer management. The experiment site is the historic Knorr–Holden Plot, established in 1910 and continued till today. Over the years, the treatments were constant, with manure as the main factor and N rates as the sub-plot factor. Aligning with advancements in agronomic management, the rates of fertilizer and manure have been revised from time to time. Analysis of soil health indicators showed a significant effect of manure on different labile C & N fractions, soil enzymes, and soil organic matter (SOM). Manure treatment improved C stabilization and reached a C equilibrium for management. Water holding capacity was significantly improved at the wilting point and field capacity for manure treatment. Nitrogen treatments only affected soil pH, cationic exchange capacity (CEC), and P. SOM was determinative for C & N fractions and CEC. SOC can be used as a proxy for soil total N ($R2 = 0.98$). Water extractable fractions of C and N were interrelated and can be used as determinative factors for each other. Although a monocropping system can be maintained using long-term manure application, other conservation practices, such as crop rotation and minimal tillage, would enhance sustainability efforts.

Insights from Lithuanian long-term soil management experiments: soil organic matter stability and carbon sequestration

Vaclovas Bogužas[1], Zita Kriaučiūnienė[1], Aušra Marcinkevičienė[1], Rimantas Vaisvalavičius[1], Vaida Steponavičienė[1], Lina Skinulienė[1], Edyta Hewelke[2], Lilla Mielnik[3], Riccardo Spaccini[4], Dariusz Gozdowski[2], Marek Podlasiński[5], Irmina Ćwieląg-Piasecka[6], Elżbieta Jamroz[6], Maria Jerzykiewicz[7], Aneta Perzanowska[2], Magdalena Dębicka[6], Agata Gryta[8], Jacek Panek[8], Dominika Siegieda[8], Karolina Oszust[8], Giorgia Pertile[8], Yakov Kuzyakov[9], Magdalena Frąc[8], Jerzy Weber[6]

[1]Vytautas Magnus University, Agriculture Academy, LT-53361, Kaunas, Lithuania, vaclovas.boguzas@vdu.lt
[2]Warsaw University of Life Sciences, Warsaw 02-787, Poland
[3]West Pomeranian University of Technology in Szczecin, Szczecin 70-310, Poland
[4]Universit`a di Napoli Federico II, Piazza Carlo di Borbone 1, Portici 80055, Italy
[5]West Pomeranian University of Technology in Szczecin, Szczecin 70-310, Poland
[6]Wrocław University of Environmental and Life Sciences, Wrocław 50-375, Poland
[7]University of Wroclaw, Joliot-Curie 14 St., Wroclaw 50-383, Poland
[8]Institute of Agrophysics, Polish Academy of Sciences, Lublin, Poland
[9]Department of Soil Science of Temperate Ecosystems, University of Göttingen, 37077 Göttingen, Germany

The study presents the findings of long-term soil management experiments established in Lithuania since 1967 and 2000. These experiments provide valuable insights into soil organic matter (SOM) transformation, stability, and carbon (C) sequestration under contrasting agrotechnological systems. The research evaluated the long-term effects of deep ploughing; no-till systems combined with cover crops and straw incorporation; and mineral and organic fertilisation, monoculture, and diversified crop rotations on soil physicochemical, biological, and spectroscopic properties.

Deep ploughing significantly increased CO_2 emissions from the soil surface for 1.5–2 months after fulfilment due to enhanced soil aeration. It accelerated SOM mineralisation compared to no-till with or without cover crops. In contrast, no-till systems promoted greater accumulation of total organic carbon and stable humin fractions in the topsoil. The integration of cover crops and residue retention further strengthened these effects by sustaining continuous organic matter inputs and improving soil structural stability.

Intensive crop rotations enriched with legumes, perennial grasses, and organic fertilisation significantly enhanced soil biological activity and enzyme functioning compared with continuous bare fallow and unfertilised monoculture systems. Saccharase activity increased up to 6.2-fold and urease activity up to 110-fold relative to fallow soils, indicating intensified C and N cycling processes. Monoculture and permanent fallow were associated with reduced microbial diversity, lower biochemical activity, and less favourable soil health indicators.

Spectroscopic analyses revealed distinct humification pathways under different soil management. Intensive rotations produced humin with a relatively more aliphatic character, reflecting ongoing incorporation of fresh organic residues, whereas soils under long-term fallow exhibited more aromatic, highly humified structures. Although organic fertilization increased total C stocks, the structural stabilization of humin depended on crop type and rotation complexity. Specifically, continuous wheat monocropping resulted in lower humin stability than rotations that included legumes. This suggests that the quality of organic inputs, rather than just the quantity, plays a crucial role in long-term C sequestration within humin fractions.

Yield assessments confirmed that, after transitional periods, no-till achieved equal or higher productivity compared with conventional deep ploughing. Winter oilseed rape and winter wheat yields increased significantly under no-till with cover crops and straw retention. Maize biomass production responded strongly to integrated organic and mineral fertilization within diversified rotation.

Overall, Lithuanian long-term soil management experiments demonstrate that reduced soil disturbance, diversified crop rotations, and continuous organic matter inputs are key drivers to stabilising SOM, carbon sequestration, improving microbial functioning, and increasing the resilience of agroecosystems.

Past, present and future of the Hungarian long-term experiments, and main conclusions from acidic sandy soil

Marianna Makádi [1], Márton Jolánkai[2], Csilla Almási [1], Viktória Orosz [1], Ibolya Demeter [1], Zsolt Bogdányi [1], Tamás Szegi [3], Khalid Suleiman Ibrahim [3], Katalin M. Kassai[2], István Henzsel[1]

[1]Research Institute of Nyíregyháza, IAREF, University of Debrecen, Westsik Vilmos u. 4-6., 4400 Nyíregyháza,Hungary, makadim@agr.unideb.hu
[2] Department of Agronomy, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary
[3] Department of Soil Science, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary

The story of the Hungarian long-term experiments started with a winter school for farmers in Nyíregyháza in 1929, when Vilmos Westsik started with his crop rotation experiment for teaching the farmers working on acidic sandy soil. Some of his suggestions, like using organic matter as a farmyard or green manure, application of crop rotation, covering soil all the year remain relevant theories even in the 21th century.

The valuable and fertile soils of Hungary resulted in effective and diverse agriculture. To improve the agricultural productivity, long-term experiments were started all around the country studying the effects of chemical fertilizers, organic manuring, liming, some wastes and by-products application, crop rotation, irrigation, the productivity of different plant varieties. In this way, field experiments function as living laboratories, enabling reliable studies of the physical, chemical and biological parameters of the agricultural environment, providing scientists and policymakers with essential information to monitor changes in mechanisms.

There were 55 LTEs in Hungary in 2018. After 1929, the new LTEs were found continuously from 1955 starting the first one in Martonvásár. Nowadays, the number of LTEs decreased seriously, and some of them are maintained without examinations. In the last 5 years, 13 LTEs were added to the GLTEN database (www.glten.org) of Rothamsted Research, but some of them have already ended.

Causes of discontinuation of the Hungarian LTEs were the closure of the research institutes responsible for the maintenance of the experiments, changes the land use of the experiments, or financial problems of experimentation. The possible solutions to maintain the existing LTEs could be the cooperation with companies, new scientific projects, intensifying their role in education with the help of state aids.

Nyírség region is the North-Eastern part of Hungary where soils are heterogeneous but the area is covered mainly by acidic sand (Arenosol). The Research Institute of Nyíregyháza maintains two LTEs: the 97 years old Westsik's crop rotation experiment and the 23 years old sewage sludge compost experiment. Both experiments proved that complex amendments (organic and inorganic matter together) have the best effects on acidic sandy soil.

The Westsik's crop rotation experiment revealed, that

1. chemical fertilizers strengthen the favourable effects of farmyard manure to improve the soil chemical properties,
2. lupine green manure with NPK fertilizer in the crop rotation has great effect on the yield of rye,
3. farmyard manure could increase the microbiological activity of ploughed acidic sandy soil,
4. the preceding crop is an important determining factor of the yield of the next crop.

The regular, long-term application of sewage sludge compost proved, that this complex soil improving material with bentonite and rhyolite

1. improves the physical and chemical properties of the soil,
2. is a very good source of phosphorous,
3. increases the activity of soil microbes,
4. changes the soil microbial community.

Long-term experiments are valuable sites, representing the agricultural potential of different countries. LTEs can serve as the base of knowledge for agricultural practice.

69 years of fertilization experiment in Brody with cultivation of plants in crop rotation and monoculture

Zuzanna Sawinska, Andrzej Blecharczyk, Tomasz Piechota, Dominika Radzikowska-Kujawska, Stanisław Świtek, Wojciech Waniorek

Poznań University of Life Sciences, Department of Agronomy, ul. Dojazd 11, 60-632 Poznań

Long-term field experiments are invaluable sources of information. They are extremely important in monitoring and explaining changes resulting from the impact of agrotechnical factors. One of the most important tasks of long-term experiments today is assessing the sustainability of a given management system. Furthermore, these experiments are a valuable source of practical information. They provide objective information on the impact of anthropogenic factors on soil fertility and productivity, as well as on the condition of the agricultural environment. The experiment at the Brody Experimental Station was founded in 1957 and authored the original research concept by Professor Jan Bender. The field experiment was established using a two-factor randomized block design, with four replications, at the Brody Experimental Station (16°18' E, 52°26' N, 90 m above sea level), belonging to the Poznań University of Life Sciences. This locality is administratively part of the Lwówek commune, Nowy Tomyśl County, Greater Poland Voivodeship.

The experiment combines aspects of the classic fertilization model with crop rotation and monoculture. During the experiment, the original research design was partially modified in terms of plant selection and fertilization rates. Currently, it includes a seven-field crop rotation (potato, spring barley, winter triticale, peas, winter wheat, winter wheat, winter rye) and a continuous monoculture of five species (potato, spring barley, winter rye, winter wheat, winter triticale). Additionally, the experiment includes permanent fallow (crop-cut) and black fallow plots as control elements for studying soil changes. The fertilization aspect of the experiment includes 11 variants of organic and mineral fertilization. The recorded observations and 69 years of accumulated research results serve to further explore the relationships between land use systems and the environment and support the comprehensive development of various models for yield and assessment of the impact of climate change on plants and soil.

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Organic carbon and nutrient distribution in long-term field experiment with different soil tillage practices

Gabriela Mühlbachová, Helena Kusá, Pavel Růžek, Radek Vavera

Czech Agrifood Research Center, Drnovská 507/73, CZ161 00 Prague 6 – Ruzyně, Czech Republic
Conservation tillage practices are increasingly used in agricultural systems. These practices require a complex approach regarding distribution of organic carbon (SOC) and soil nutrition in the soil profile.

The organic carbon content of soil (SOC) is considered a key factor for soil health and plays an important role in climate change. Reduced and no-tillage systems promote carbon sequestration and reduce greenhouse gas emissions. Reduced and no-tillage practices change also the distribution of nutrient contents (P, K, Mg, and Ca) in the soil profile. Little is known about the time changes in carbon content and nutrient distribution in the soil profile under conservation tillage practices.

A long-term field experiment with different soil tillage practices (conventional tillage — ploughing to 20–22 cm: CT; reduced tillage — chiseling to 8–10 cm: RT; and no tillage: NT) has been conducted in Prague-Ruzyně (Czech Republic) since 1995. The soil's organic carbon content, microbial biomass (C_{mic}), enzymatic characteristics and nutrient contents were evaluated in four-year crop rotation periods from 2005 to 2024. The soil nutrient contents have been determined since 2009 using the Mehlich 3 method and through extraction in 0.5 M ammonium acetate. The crop rotation was as follows: winter oil seed rape, winter wheat, pea, and winter wheat. The following soil layers were studied: 0–10, 10–20, and 20–30 cm. Crop residues remained in the field and were incorporated into the soil according to the used tillage—completely under CT, partly under RT, and the remaining mulch under NT.

Under RT and NT, the SOC, C_{mic}, and enzymatic activity were concentrated in the top soil layer and decreased in deeper layers, whereas all these characteristics were evenly distributed across the soil layers under the CT practice. The SOC content increased gradually in the whole soil profile (0–30 cm) from 51.0 t ha^{-1} on average in 2005–2008 to 56.0 t ha^{-1} in 2021–2024 under CT. An SOC increase from 57.4 to 63.1 t ha^{-1} under RT and from 61.1 to 65.7 t ha^{-1} under NT was noted in 2017–2020, after which the stagnation in SOC content was observed in the years of 2021–2024. Similarly, a lower C_{mic} and enzymatic activity were found in the same period. The highest C sequestration was found under NT; an increase of 571 kg C ha^{-1} $year^{-1}$ was recorded from the establishment of the experiment in 1995 to 2024. This was followed by the RT and CT practices (462 and 221 kg C ha^{-1} $year^{-1}$, respectively).

The P, K, and, to a lesser extent, Mg contents increased in the soil surface layer (0–10 cm) under the reduced and no-tillage practices, whereas Ca and pH values showed an opposite trend. We found an unbalanced ratio of nutrients in the upper soil layer in RT and NT caused by a high concentration of the monovalent cation K^+ and the leaching of the divalent cations Ca_2^+ and Mg_2^+ into the deeper soil layers. In conventional practices, the ion contents are equalized throughout the topsoil due to the soil inverting during plowing. The determination of nutrient contents in deeper soil layers revealed that, over time, calcium, magnesium, and potassium were transported to deeper parts of the soil profile under RT and especially NT. Low nutrient ratios were found in the surface layer under RT and NT, negatively affecting the quality of the soil surface layer, including its structure. Fertilizer management and nutrient ratios in soils under RT and NT should be considered to maintain and possibly improve sustainable agricultural practices in fields with reduced or no-tillage practices. Furthermore, nutrient contents and their mutual ratios should be evaluated in more soil layers under these systems, enabling the detection of eventual problems in the upper layer that must be addressed by changing fertilization.

Conservation tillage practices increase the organic carbon and microbial activity and change also the nutrient distribution in soils. However, the ongoing climate change associated with higher average temperatures and irregular precipitation will affect all these processes. Therefore new approaches in crop nutrition will be necesary to be adopted by agronomists.

SESSION 2

Soil management effects on soil organic matter quality and -storage: evidence from long-term experiments in Poland and Lithuania and sophisticated analytical methods

Peter K. Leinweber[1,2], Aneta Perzanowska[3], Vaclovas Boguzas[2]

[1] Soil Science, University of Rostock, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany, peter.leinweber@uni-rostock.de

[2] Bioeconomy Research Institute, Academy of Agriculture, Vytautas Magnus University, K. Donelaiˇcio g. 58, Kaunas 44248, Lithuania

[3] Department of Agronomy, Institute of Agriculture, Warsaw University of Life Sciences, Nowoursynowska St. 166, 02-787, 02-776 Warsaw, Poland

The effects of soil management on the composition of soil organic matter (SOM) are insufficiently understood, making it challenging to propose agronomic measures that enrich soils with organic carbon compounds and mitigate CO2-driven climate change. Long-term field experiments are essential tools for studying how management practices—such as fertilization, amendments, crop rotations, and tillage—alter SOM composition and storage. In recent years, sophisticated analytical techniques have increasingly been utilized to reveal the composition of SOM and its changes. Mass spectrometry and synchrotron-based X-ray absorption near-edge spectroscopy (XANES) are among the suitable analytical techniques; however, they have not yet been applied to samples from long-term experiments in Eastern Europe. We studied samples from three field experiments in Poland (Skierniewice, 100 years; Chylice, 46 years; and Swojec, 30 years) and two field experiments in Lithuania (Noreikiškės 1 and 2) to compare a wide range of agronomic practices. The SOM composition was investigated using C- and N-XANES, as well as thermochemolysis-gas chromatography/mass spectrometry (TC-GC/MS).

The calculation of the average C enrichment rate revealed that no-tillage treatments appeared to be more efficient in storing organic C compounds in soil over the medium term than fertilization, manuring, or diverse crop rotations. Surprisingly, the overall chemical composition of SOM in the long-term experiments conducted in Poland (PL) and Lithuania (LT) was quite similar, despite obvious differences in soil texture: sandy loam (PL) and loam to silty loam (LT). The order of compound classes derived from TC-GC/MS was lipids (46.8%/47.1%) >carbohydrates (25.1%/31.6%) >lignin compounds (16.8%/16.8%), representing the means across all studied treatments in PL and LT.

In three Polish experiments, the no-tillage treatments at the Chylice site exhibited the largest proportions of carbohydrates in the upper topsoil (37%) and of lipids in the lower topsoil (61%). In the Lithuanian experiment 2NO, carbohydrates (32%) and lignin compounds (22%) were relatively enriched in the no till-upper topsoil, with less pronounced effects observed in the lower topsoil. Growing catch crops in addition to straw leftovers resulted in a larger proportion of alkanes at both sampling depths, at the expense of fatty acids, consequently increasing lipid proportions in the lower topsoil only (49%).No-tillage in the 2NO experiment led to the enrichment of –COOH-C compounds, which were subordinate in the Polish experiments. However, both the Polish and Lithuanian tillage experiments showed similar enrichments of 6- and 5-membered heterocyclic N compounds under no-tillage conditions. As these compounds are less decomposable than peptides, it can be concluded, that stabilized N compounds in complex organic molecules contribute to a pool of SOM that is particularly promoted under minimal soil disturbance. More generally, these studies provide additional evidence for the close links between the soil C- and N-cycles at the molecular level and under the influence of management practices.

Selected properties of black earths and winter wheat yield after 70 years of different fertilization and crop rotation

Irena Suwara[1] , Dariusz Gozdowski[2], Aneta Perzanowska[1], Szymon Młynek[1]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland
[2]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Biometry, Nowoursynowska 159 St., 02–776 Warsaw, Poland e-mail: irena_suwara@sggw.edu.pl

The aim of the research is to assess the impact of the fertilization system (mineral, farmyard manure and mixed mineral and farmyard manure) used in two rotations on the selected chemical properties of the soil and yield of winter wheat grown in one experiment after red clover and in the other after winter rapeseed. To achieve this goal, two long-term static experiments were used, in which varied mineral and organic fertilization was applied in two crop rotations: a rotation without red clover (sugar beet – spring barley – winter rapeseed – winter wheat) and a rotation with red clover (sugar beet – spring barley with undersown red clover – red clover – winter wheat). The experiments were established in Chylice (52°06'N, 20°33'E) in 1955 on leached black earth (according to the World Reference Base for Soil Resources WRB – Endogleyic Phaeozems), which developed from light boulder clay. The experiments were conducted using the randomized block method with four replications. A plow tillage system was used in the experiments (plowing depth 20 cm). Since 1955, no liming or fertilization with microelements has been used. Before the experiments were carried out in 1955, the arable layer was slightly acidic (pH 6.2–6.5) and contained 1.15% organic carbon, 44 mg kg^{-1} of available phosphorus (P), and 83 mg kg^{-1} of available potassium (K) - low content of available phosphorus and potassium.

The paper presents the results of winter wheat yields and soil chemical properties, such as soil reaction (pH) and the content of total nitrogen (N), organic carbon, available forms of phosphorus (P), potassium (K) and magnesium (Mg), and microelements: manganese (Mn), copper (Cu), zinc (Zn), boron (B) and iron (Fe) obtained in 2025 after 70 years of using differentiated fertilization. After 70 years, the soil in the red clover rotation became significantly acidic and the pH decreased to 5.3, while in the rotation without legumes, a higher pH of 5.9 was observed. Organic carbon and total nitrogen content were significantly higher in the soil from the legume rotation compared to the non-legume rotation. Crop rotation with red clover also provided higher soil micronutrient content (Cu, Zn, Fe) but significantly reduced soil available phosphorus (P 59.6 mg kg^{-1}) and potassium (K 95.1 mg kg^{-1}) compared to crop rotation without legumes (P 95.3 mg kg^{-1}; K 180.4 mg kg^{-1}). The content of available magnesium (Mg), manganese (Mn) and boron (B) was not varied by crop rotation.

Mineral fertilization (NPK) led to a slight deterioration of the studied properties compared to those observed in organically fertilized plots (FYM, ½NPK + ½FYM). This is indicated by slightly lower values for total nitrogen and organic carbon content but also available phosphorus, magnesium and potassium. Organic and mineral-organic fertilization counteracted the decrease in soil pH, while mineral fertilization led to its reduction. A beneficial effect of manure application on soil pH was observed, as well as increased total nitrogen, available phosphorus (P), potassium (K), magnesium (Mg), manganese (Mn), and zinc (Zn) content.

The fertilization systems used created favorable conditions for plant growth and yield. This is evidenced by the highest plant yields obtained compared to the unfertilized plot. The highest yields of winter wheat grain were recorded in the objects with exclusive mineral fertilization (9.1 t ha^{-1}) (NPK), significantly lower yields in the objects where mineral fertilizers were used in combination with manure (8.4 t ha^{-1}) (½NPK + ½FYM) and only manure (7.9 t ha^{-1}) (FYM), and the lowest in the absence of fertilization since 1955. The use of red clover as a forecrop for winter wheat created favorable conditions for plant growth. This is evidenced by significantly higher grain yields of winter wheat grown after red clover (8.2 t ha^{-1}) compared to the yields of this plant obtained after winter rapeseed (7.1 t ha^{-1}).

Seasonal variation of basal soil respiration under long-term sewage sludge compost application in acidic sandy soil

Khalid Suleiman Ibrahim[1,3], Tamás Szegi[1], András Sebők[1], Réka Döbröntey[1], Viktória Labancz[1], Csilla Almási[2], Viktória Orosz[2], Ibolya Demeter[2], István Henzsel[2], Yuri Andrei Gelsleichter[1], Péter Molnár[1], Boglárka Szála[1], Bence Paulisz[1], Janka Szabó[1], Marianna Makádi[2]

[1]Department of Soil Science, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, 2100 Gödöllő, Hungary, Ibrahim.Khalid.Suleiman@phd.uni-mate.hu
[2]Research Institute of Nyíregyháza, IAREF, University of Debrecen, 4400 Nyíregyháza, Hungary
[3]Department of Forestry and Wildlife Management, Federal University Dutse, PMB 7156, Dutse 720101, Jigawa State, Nigeria

Soil respiration is an important way to measure microbial activities and carbon turnover in soil, giving insight into soil functioning and its role in limiting the effect of climate change. The acidic, sandy soils in the Nyírség region of Hungary have little clay, low organic matter, weak structure, and poor water holding, which makes them very suitable for adding organic material. Basal soil respiration (BSR) varies with the seasons and is influenced by nutrients, organic matter, and soil depth. This study examined BSR seasonal variation in a long-term sewage sludge compost (SSC) experiment and assessed how different compost amounts influenced soil at different depths.

Soil samples were collected during four campaigns from April to September 2024 from a long-term field experiment started in 2003 on Dystric Arenosol soils. Four SSC treatments (0, 9, 18, and 27 t ha^{-1}) and four soil depth intervals (0–10, 10–20, 20–30, 30–40 cm) were analyzed. Basal soil respiration was measured according to ISO 16072:2002, along with other physicochemical parameters, including pH, moisture content, organic carbon, and nitrogen.

Preliminary findings demonstrate a positive correlation between basal soil respiration (BSR) and increasing sewage sludge compost (SSC) rates, with mean values ranging from 0.87 in control plots to 1.31 in the highest treatment (27 t ha^{-1}), representing a 20% increase. The most pronounced responses occurred at 10–30 cm, the compost incorporation zone, whereas control plots exhibited consistently low respiration rates. These results suggest that long-term SSC application enhances microbial activity and may improve carbon cycling and soil function in degraded sandy soils. This study clarifies seasonal microbial dynamics in response to organic amendments and provides evidence supporting the use of SSC as a sustainable strategy to improve soil quality and ecological balance.

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Long-term field experiments in response to new challenges in agriculture: a multi-indicator assessment of carbon farming practices

Beata Jurga[1], Ryszard Winiarski[1], Tamara Jadczyszyn[1],Piotr Jurga [2], Anna Gałązka[3]

[1] Department of Plant Nutrition and Nutrient Management, email:bjurga@iung.pulawy.pl
[2]Department of Geomatics, [3] Department of Microbiology
The Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, Czartoryskich 8, 24-100 Puławy, Poland

Long-term field experiments are becoming increasingly important in the context of new challenges faced by agriculture, including climate change, soil organic matter decline, circular use of biomass and the need to verify carbon farming practices under real production conditions. Agricultural soils are recognised as an important component of climate change mitigation and food security strategies, but the real effects of management practices depend strongly on soil, climate, cropping system and the duration of their application (Lal, 2004). The aim of this study was to demonstrate the usefulness of a long-term field experimental approach for the multi-indicator assessment of organic amendments used in maize cultivation, with particular attention to their potential role in supporting soil carbon sequestration and soil biological activity.

The study was based on long term field experiments carried out at the Agricultural Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Grabów nad Wisłą, Poland, on Luvisol soil. Earlier static experiments conducted in 2014–2022 and 2015–2022 assessed the fertilising value of agricultural biogas digestate and compared its effects with natural fertilizers in maize grown for green biomass. In the Carbon Farming CE demonstration experiment, the following treatments were compared: control without organic amendments, cattle slurry, solid cattle manure and digestate, applied at 30 m^3 or t ha^{-1}. The experiment was conducted in a split-plot design with four replications. The assessment included yield of fresh and dry aboveground biomass, root mass, soil organic carbon, nutrient content and selected indicators of soil biological activity. This approach is consistent with the growing need to assess soil carbon sequestration not only through single measurements, but also through long-term monitoring of management effects, as shown in global analyses of tillage and crop rotation impacts on soil organic carbon (West and Post, 2002).

The results confirmed that organic amendments significantly increased maize yield compared with the control. In 2024, total organic carbon ranged from 0.56% in the control treatment to 1.35% after digestate application. Digestate and solid cattle manure also stimulated microbial processes, including dehydrogenase activity, microbial biomass and phosphatase activity, indicating their positive influence on soil biological functioning. At the same time, differences in root biomass and microbial substrate utilisation showed that the assessment of carbon farming practices should not be limited to yield response alone. A broader assessment is particularly important because carbon farming practices should contribute simultaneously to mitigation, soil health and agricultural resilience, which is consistent with the concept of climate-smart soils (Paustian et al., 2016).

The findings indicate that long-term and well-documented field experiments provide a valuable basis for evaluating the agronomic, environmental and biological effects of carbon farming practices. Such experiments make it possible to combine classical productivity indicators with soil health parameters and thus support evidence-based recommendations for more resilient, resource-efficient and climate-smart agriculture. They also provide an important reference point for evaluating different carbon farming options, including organic amendments and biomass-based practices, whose effectiveness depends on additional carbon inputs, nutrient cycling and the stability of soil organic matter over time (Poeplau and Don, 2015).

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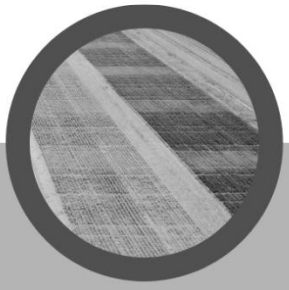

SESSION 3

Kernza in Wyoming, USA: perennial grains for vulnerable lands

Urszula Norton[1], Hannah R. Rodgers[2]

[1]University of Wyoming, Department of Plant Sciences, 1000 East University Avenue, Laramie, WY 82071-2000, email: unorton@uwyo.edu
[2]University of Wyoming, Department of Ecosystem Sciences and Management, 1000 East University Avenue, Laramie, WY 82071-2000

Kernza® is a perennial grain harvested from varieties of intermediate wheatgrass (*Thinopyrum intermedium,* Barkworth & D.R. Dewey). Its versatility for being harvested for grain and/ or hay and its perennial nature has the potential to improve soil health. Importantly, Kernza may become a crucial player in semiarid dryland agriculture, such as in the U.S. Northern High Plains. From 2021 to 2023, Kernza was compared at the field scale to winter wheat (*Triticum aestivum*, L.)/fallow and perennial grassland (Conservation Reserve Program,CRP) on a working farm in southeastern Wyoming. Indices analyzed included grain and forage yields, root biomass, soil health, and soil microbiology in rhizosphere-associated and bulk soils.

The first growing season experienced drought, yet still, Kernza produced substantial forage (3 t ha^{-1}) but insufficient grain to harvest. In the second year, Kernza produced 0.3 t ha^{-1} of grain, compared to two tons ha^{-1} produced by winter wheat. Despite low grain yields, after two years, rhizosphere soil beneath Kernza has shown significant soil health improvements compared to rhizosphere soil beneath winter wheat. And specifically, enzyme activities, and microbial communities were more like the rhizosphere of intermediate wheatgrass from CRP than of winter wheat. Kernza produced three times more root biomass and soil organic matter than winter wheat. Although Kernza remains a low-yielding crop in development, potential soil health benefits, a high market value, and the flexibility to harvest grain or forage may make it a viable option for semiarid dryland agriculture (Rodgers et a., 2026).

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Cereal crop productivity under different management intensity in long term field experiment

Virmantas Povilaitis[1], Renaldas Žydelis[1]

[1]Lithuanian research center for agriculture and forestry, Instituto al. 1, LT 58344 Akademija, Kėdainiai distr. Lithuania, e-mail: virmantas.povilaitis@lammc.lt

The Valinava long-term field experiment was established in 1991 at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry (55.22° N, 23.51° E). The experiment is located on a terrace of the Dotnuvėlė River and covers 4.4 ha. The soil is sandy loam to light loam Endocalcari–Endohypogleyic Cambisol with a pH (KCl) of 7.2, total nitrogen content of 0.18%, available phosphorus of 120 – 155 mg kg^{-1}, and available potassium of 125 – 132 mg kg^{-1} (Mašauskas et.al. 2010; Povilaitis et al., 2018). From 2002 crops are grown under different intensity management in a four-course rotation including spring barley, red clover, winter wheat, and spring rape (spring wheat since 2015).

Three management systems—conventional, integrated, and low-input are applied, each replicated twice in space and occupies approximately 786 m^2 (32.2 m long, and 24.4 m wide) and contains 6 sub-plots. Experimental area includes plots with perennial grasses thus providing possibility to observe the changes in plant species. There are performed measuring of crop yield and biomass production in this experiment.

The growing period of crops during the experimental years was warmer than the climate normal, with contrasting rainfall. The grain yields average of winter wheat in conventional system ranged from 4.43 t ha^{-1} in 2011 by 8.47 t ha^{-1} in 2025. Under integrated management grown winter wheat grain yield average highest was 8.04 t ha^{-1} in 2015, while drought limited yield by 4.2 t ha^{-1} in 2006. The lowest yields were in low-input system – from 1.99 t ha^{-1} in 2019 by 5.1 t ha^{-1} in 2025.

The spring barley grain yield average ranged from 3,37 t ha^{-1} in 2023 by 6,2 t ha^{-1} in 2021 under conventional management. In low-input systems the spring barley grain yield ranged between 1.98 t ha^{-1} in 2014 by 4.4 t ha^{-1} in 2008 and 2021. The yield of red clover biomass was higher in low-input system comparing with conventional or integrated systems.

Soil moisture measurements indicated water stress in late spring or early summer in all experimental years, significant yield losses occurred only in a few cases. On average, the grain yield of winter wheats grown under low-input system was 58%, spring barley 67% and red clover 113% of that grown under conventional management.

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Soil management effects on soil chemistry and water infiltration in different tillage

Elizaveta Watzlová[1], Pavel Čermák[2]

[1]Czech University of Life Sciences Prague (CZU), Kamýcká 129, 165 00 Praha - Suchdol, Prague, elizaveta.watzlova@seznam.cz
[2]Institute of Animal Science Prague, Přátelství 815, 104 00 Praha - Uhříněves, Prague, Czech Republic

Due to ongoing climate change and limited sources of quality farm and organic fertilizers, conservation tillage technologies with higher water, carbon and nutrient sequestration in the soil will be increasingly used. One of these technologies is no-till, in which the soil is not tilled, thereby reducing the number of passes of equipment, mineralization of organic matter in the soil, which has a positive effect on soil structure, water infiltration from precipitation, diversity of soil organisms, etc. As a result of lower soil mineralization, the process of making nutrients available to plants is slower, which can have a negative effect on yield and quality of production. With long-term use of no-till tillage technologies, carbon and nutrients are sequestered in the surface layer of the soil. After the application of mineral fertilizers, the concentration of poorly mobile nutrients in the surface layer of the soil may increase, which can have a negative effect on its quality, including its retention capacity.

According to previous experiments, the effect of nitrogen fertilization (fertilizers with various forms of N, urease and nitrification inhibitors) and potassium during various soil treatments on changes in the properties of the surface layer of the soil, including its ability to retain water from precipitation, was determined.

The results ultimately confirm that soil management practices significantly influence the physical and chemical properties of the topsoil. These results provide a necessary basis for the development of site-specific soil management plans.

Effects of soil tillage, catch crops and soil conditioners on epigeic arthropods in a 60-year winter rye monoculture

Olena Niszczak, Jacek Twardowski, Roman Wacławowicz, Iwona Gruss, Kamila Twardowska, Joanna Magiera-Dulewicz

Department of Plant Protection, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24a, 50-36 Wrocław, Poland, e-mail: olena.niszczak@upwr.edu.pl

Regenerative agricultural practices are considered crucial for enhancing soil biodiversity and improving soil quality. The soil ecosystem is a highly dynamic environment that provides habitat for both saprophagous and predatory arthropods. Some of these organisms are particularly sensitive to changes in soil conditions and can therefore serve as reliable bioindicators of soil health and ecosystem functioning. The aim of this study was to assess the effects of different soil regeneration treatments on epigeic fauna in a long-term winter rye monoculture. The field study was conducted in 2025 at the Research and Education Station in Swojczyce, Wrocław University of Environmental and Life Sciences, within a sixty-year winter rye monoculture established on light sandy soil. Experimental treatments included conventional or reduced (non-inversion) tillage systems, catch crops (buckwheat, white mustard, fodder radish, and common vetch), and application of soil conditioners: Groundfix Extreme (a microbial product produced by BTU-CENTER Europe GmbH) or MultiGeo (mineral fertilizer produced by Agresta). Each experimental plot had an area of 6 × 10 m. The experiment was arranged in a randomized block design with three replicates. Epigeic fauna was sampled using Barber pitfall traps during seven sampling periods from mid-spring to early summer. Collected organisms were identified under a microscope and classified into: ground beetles (Carabidae), rove beetles (Staphylinidae), arachnids (Arachnida), springtails (Collembola), and predatory larvae.

In total, the highest abundance of epigeic fauna was recorded under reduced tillage with Groundfix application. The greatest number of predatory ground beetles (Carabidae) was observed in reduced tillage combined with MultiGeo application, whereas the lowest abundance occurred under conventional ploughing with Groundfix. In contrast, Carabidae species richness was highest under the ploughing system (42 species) and lowest under the reduced tillage (33 species), with *Bembidion lampros* being the dominant species across all treatments. Rove beetle (Staphylinidae) abundance was significantly higher in conventional tillage with soil conditioners and in reduced tillage with Groundfix. Springtails (Collembola) were classified into four main taxa (Isotomidae, Entomobryidae, Hypogastruridae, and Symphypleona) and were most abundant under reduced tillage when combined with catch crops and soil conditioner applications. Overall, these results indicate that reduced tillage, particularly when combined with catch crops or soil conditioners, most effectively promotes the abundance of epigeic arthropods in long-term monoculture systems.

POSTER SESSION

1. Sugar beet yields in the 6th rotation of sugar beet – winter wheat – winter rapeseed

Arkadiusz Artyszak[1], Dariusz Gozdowski[2]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail: arkadiusz_artyszak@sggw.edu.pl
[2]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Biometry, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail: dariusz_gozdowski@sggw.edu.pl

Since 2006, in Sahryń, in south-eastern Poland (50°41′ N, 23°46′ E), sugar beet has been grown after winter oilseed rape in a crop rotation of sugar beet – winter wheat – winter oilseed rape. In the years 2021-2023, the sixth rotation of this cropping system was conducted.

The mean sugar beet root yield amounted to 89.87 t ha-¹ (85.16–97.94 t ha-¹) and was 5.4% higher than the average yields obtained in the Post-registration Variety Testing (PDO) supervised by COBORU (2021, 2022, 2023), which were 85.27 t ha-¹ (82.50-87.40 t ha-¹). At the same time, the yields were 42.1% higher than those obtained in commercial production in Poland according to FAO (2026), i.e. 63.25 t ha-¹ (60.96–64.97 t ha-¹).

In the authors' own study conducted in 2021–2023, sugar beet roots contained on average 15.3% sugar (14.5-16.4%), which was 2.3 percentage points lower than the average reported in the PDO trials (17.6%; 16.9-17.9%). The content of the most important molasses-forming component, α-amino nitrogen, was 18.9 mmol kg-¹, whereas in the PDO trials it was 13.3 mmol kg-¹. Roots from the present study were characterised by a slightly lower content of K^+ ions (36.5 mmol kg-¹) than in the PDO trials (39.9 mmol kg-¹) and a higher content of Na^+ ions (5.1 and 4.1 mmol kg-¹, respectively).

The biological sugar yield in the present study was 13.79 t ha-¹ and was 7.6% lower than in the PDO trials. The technological sugar yield amounted to 11.95 t ha-¹, which was 10.2% lower than in the PDO trials.

The results of the present study demonstrate that, under specific soil and climatic conditions, long-term cultivation of sugar beet in the crop rotation sugar beet – winter wheat – winter oilseed rape can result in good production performance.

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2. The influence of different soil tillage systems on weed flora and soil seed bank

Ona Auškalnienė [1], Gražina Kadžienė[1], Skaidrė Supronienė, Ieva Banytė[1]

[1]Institute of Agriculture, LAMMC, Instituto alėja 1, 58341, Akademija, Kėdainiai district, Lithuania
ona.auskalniene@lammc.lt

A main reason to till soil is to reduce the competition of weeds and to favour early crop growth, because the success of weed control is generally manifested in crop yield. Increasing environmental risks and economic considerations have led worldwide to use more extensive soil tillage. In recent years, there has been an increasing interest around agricultural science and practice in conservation tillage systems that are compatible with sustainable agriculture. (Feledyn-Szewczyk, 2020).

Non-inversion tillage also reduces energy usage, enable faster land preparation and improves soil aggregation (Bottinelli et al., 2017). New weed communities have emerged which are adapted to specific tillage conditions. It has been observed, that grasses are a major problem in no-till (Melander et al., 2013).

The research has been performed in a long-term experiment in Dotnuva, Lithuania, Kedainiai District (55°23′20.7″ N 23°52′06.5″ E) in Central Lithuania's lowland. The soil of the trial was named as an *Endocalcari–Epihypogleyic Cambisol* of a loam texture (19% clay, 34% silt, and 47% sand). Crop sequence: winter wheat, winter oilseed, spring wheat, spring barley, and field pea. Soil was prepared according to trial design: 1. Stubble cultivation to 10-12 cm depth; plough to 22-24 cm depth - conventional tillage (CT). 2. Stubble cultivation to 10-12 cm depth, non-selective herbicide (glyphosate) spray applied after harvesting - minimal tillage (MT); 3. No tillage (NT) direct sowing with sowing aggregate with rotary cultivator, non-selective herbicide (glyphosate) spray applied after harvesting.

Soil weed seed bank varies in density according to tillage system. The number of seeds in the soil was significantly higher in less disturbed systems particularly in reduced – tillage system. No significant differences in size of weed seed bank were obtained between treatments with reduced and no tillage systems. Significant differences recorded in weed species composition in different tillage systems: NT promotes infestations by some broadleaf weed species rapidly increasing the total weed biomass - *Capsella bursa pastoris* and *Tripleurospermum inodorum* particularly and annual monocotyledonous – *Poa annua*. In plots with conventional tillage weed mass was lower, compare it to lower intensity soil tillage systems: reduced tillage or, especially, no-till system.

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3. Spent mushroom substrate – properties and effect on agricultural soils

Marcin Becher[1], Adam Matyszczak[2], Ewa Trzcińska[1], Dawid Jaremko[1]

[1]University of Siedlce, Faculty of Agricultural Science, 14 B. Prusa St., 08-110 Siedlce, Poland
marcin.becher@uws.edu.pl
[2]Mazovian Agricultural Advisory Centre, 98 Czereśniowa St., 02-456 Warszawa, Poland

Poland is a leading mushroom producer in Europe. Mushroom cultivation generates large amounts of spent mushroom substrate (SMS). The primary method of disposing of SMS is its use as fertilizer, to recover organic matter and nutrients essential for crop production. Comprehensive studies of the properties of SMS were conducted and the impact of long-term fertilization of this material on soil properties was assessed, particularly soil organic matter (SOM) resources and the speciation of nutrients (Becher et al., 2021; Trzcińska, 2022; Matysczak, 2025). The research was conducted in central-eastern Poland (a region known for the centralization of mushroom production).

The following properties were determined in SMS samples: dry matter content; salinity; carbonate content; C, N, P, K, Ca, Mg, S, trace elements, and heavy metals content. The following tests were performed: organic matter fractionation; humic acid properties; nitrogen compound fractionation (using acid hydrolysis); metals fractionation. The dynamics of SMS decomposition in soil was studied (for 1 year) under controlled conditions of an incubation experiment.

Soil science studies were conducted on arable lands of the South Podlasie Lowland. The study material consisted of humus horizons from five Luvisols and five Rusty Soils fertilized with SOM (15-20 years). The same soil types, unfertilized with SOM, served as a reference point. Basic soil properties were measured: bulk density, pH, salinity, nutrient kontent (including plant-available forms); carbonate kontent; sorption properties; heavy metals content. SOM resources were determined and its quality was assessed. Nitrogen compounds were fractionated. Phosphorus compounds were fractionated.

Studies have shown the beneficial properties of SMS in the context of providing plants with nutrients and SOM reproduction.

A comprehensive, favorable change in the properties of soil humus horizons was observed in the soils fertilized with SOM, regardless of soil type. Long-term use of SMS as a fertilizer resulted in effective soil deacidification, significantly greater accumulation of nutrients – including in plant-available forms – carbonate accumulation, and improved sorption properties. Long-term use of SMS as a fertilizer did not lead to the accumulation of excessive amounts of heavy metals that could threaten food safety.

Significantly higher (two to three times) SOM resources were found in the humus horizons of soils fertilized with SMS compared to unfertilized soils. SOM accumulation in soils fertilized with SMS occurs primarily in the form of the most stable residual fraction. Humus horizons of soils fertilized with SMS contained higher amounts of labile forms of organic matter compared to unfertilized soils. The studies have shown that the quality of SOM in soils fertilized with SMS is mainly determined by the properties and transformation of SMS in the soil, and to a lesser extent depends on the soil type.

Research has proven that the use of SMS in fertilization ensures their proper utilization, contributing to the improvement of soil properties and carbon sequestration.

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4. Optimization of fertilization processes under environmental stress conditions: results of work on the innovative POLIST® biomineral formula

Magdalena Białomazur[1], Krzysztof Czachór[1], Dariusz Dojss[1], Beata Furmańczyk[1], Izabella Jasińska[1], Piotr Jaworski[1], Anna Kaleta[1], Jadwiga Kaniecka[1], Monika Karsznia[2], Kornelia Malarczyk-Matusiak[1], Piotr Masztalerz[1], Krzysztof Sokołowski[1], Aleksandra Wasilewska[1], Edyta Zielińska[1], Monika Zienkiewicz[1]

[1]Grupa Azoty Zakłady Chemiczne "Police" S.A., ul. Kuźnicka 1, 72-010 Police, Poland
izabella.jasinska@grupaazoty.com
[2]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland

In the face of new challenges caused by climate change, progressive soil degradation, and the legislative regulations, the fertilizer sector is seeking innovative solutions for evolving plant nutrition strategies. The response to these challenges is the advanced work carried out by Grupa Azoty Zakłady Chemiczne "Police" S.A. on a new generation of products, which go beyond traditional schemes of macronutrient delivery. The aim of this research was to develop the liquid fertilizer called POLIST®, constituting a highly specialized supplement to standard soil fertilization. This product is a unique multi-component composition, combining traditional nitrogen nutrition with the synergistic action of silicon, precisely selected micronutrients and carefully selected microbiological components. This project addresses identified technological gaps in the area of preparations which simultaneously stimulate productivity and strengthen the natural defense mechanisms of plants.

The basis for the innovative nature of POLIST® is its unique hybrid composition, integrating mineral nutrients with microbiological components. During the work, substances acting as carries of trace elements were precisely selected, ensuring their optimal bioavailability. The process of optimizing the composition of the fertilizer was based on strict physicochemical analyses, which verified rheological profiles, turbidity change depending on the concentration of individual functional additives and the chemical stability of solutions as a function of time and variable storage conditions, including exposure to different temperatures and solar radiation. Logistic guidelines were formulated to ensure the maintenance of the declared product quality throughout the entire distribution chain.

A key aspect of product design was the addition of beneficial microorganisms into the fertilizer matrix, which required a detailed analysis of their survival in a concentrated mineral solution environment. Systems with the highest biological stability were selected. It was assessed that after application, the preparations have a beneficial effect on the processes taking place in the root zone and improve the overall condition of the plants. In the context of environmental protection, the integration of modern urease inhibitors has been a breakthrough solution. Research conducted under controlled incubation conditions and on a field scale confirmed that the resulting modification of the fertilizer composition significantly reduces nitrogen losses and limits the emission of gaseous nitrogen derivatives into the atmosphere, which directly translates into increased efficiency of nutrient use while minimizing the environmental footprint of agricultural production.

The agrotechnical effectiveness of the new formula was verified in research cycles, including both pot experiments and field trials on cereals and selected horticultural crops. The fertilizer's high effectiveness in stimulating natural plant resistance mechanisms to abiotic and biotic stresses, such as water deficits, extreme rainfall events and pathogen pressure, has been confirmed. Plants treated with POLIST® fertilizer showed improved physiological parameters and greater yield stability compared to standard agricultural practices.

Technological guidelines for the pilot scale have been formulated, which is an important step towards the implementation of a new generation of safe and effective plant production support products, fully adapted to the requirements of modern precision agriculture.

The work was carried out as part of project POIR.01.01.01-00-1313/20 co-financed by the European Union from the European Regional Development Fund under the Intelligent Development Operational Program for 2014-2020. The project was implemented as part of the National Center for Research and Development's "Fast Path" competition.

5. Changes in yield, species composition and utility value of meadow sward in long-term use in conventional and organic systems under conditions of silicon application

Barbara Borawska-Jarmułowicz, Grażyna Mastalerczuk

Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail:barbara_borawska_jarmulowicz@sggw.edu.pl

The aim of the study was to assess changes in the yield, botanical composition and fodder-value score (FVS) of the meadow sward under silicon application over the long-term period of utilization. The research was conducted in experiments in conventional and organic systems at the Experimental Field in Miedniewice (central Poland). In 2014 on arable land (Luvisol soils) mixtures of grasses and legumes containing three species of: *Festulolium braunii*, *Dactylis glomerata*, *Lolium perenne*, *Trifolium pratense* or *Medicago x varia* were sown in conventional system while in organic system *Trifolium pratense*, *Trifolium repens* and *Lolium perenne* were components of a legume-grass mixture.

During the next three following years, the sward was fertilized (only in conventional system) and cut three times per year. Then, for five years, on both experiments the sward was mown twice, without fertilization. In the last years (2023-25), three cuts per year, the silicon application (Optysil, Si or without Si) were used. In conventional system mineral fertilization was applied. The yield of dry matter, botanical composition, utilization value score of the meadows sward (in regrowths and annual) as well as dry mass of roots (after the 3-rd cut) in each year of utilization were estimated.

In the initial period of utilization (2015-2017) the yields in both systems were relatively high, and slightly higher in the conventional system (9-10 Mg/ha) than in the organic system (6.5-8.5 Mg/ha), with low weed infestation (and the number of other species). As a result, the FVS of evaluated swards was very good (8-9.9). The beneficial effect of silicon application on dry matter yields was found under organic management.

In the next period (2023-2025), the yields were initially high (significant share of sown species in the sward), but gradually decreased, which was caused by the large share of other unsown species, especially in the organic system (up to 40-50% of monocotyledons and dicotyledons). Changes in the botanical composition showed a decrease or disappearance of sown species and an increase in the share of rosette plants in the sward (especially herbs – *Taraxacum officinale* and *Plantago lanceolata*). It was also found that the botanical composition of the sward in both systems was very diverse due to the occurrence of 33-35 plant species during the 3-year period of utilization. Simultaneously changes in botanical composition resulted in lower FVS of sward to good (6.5-7.4) and a reduction in yields, especially in the organic system. The research also showed a beneficial effect of silicon application on the root mass, especially in the 0-10 cm layer, and the r/s index value in both systems.

During many years of mowing the sward, initially composed of several species of legumes and grasses, underwent significant changes in yield, species composition, and utility value, resulting in the development of a multi-species community in a conventional and organic system.

6. The calculation of GHG emissions - crop & animal production

Pavel Čermák[1], Magdalena Štolcová[1], Martin Dědina[2], Petr Jevič[2], Tomáš Lošák[3]

[1]Institute of Animal Science, Přátelství 815, 104 00, Praha, the Czech Republic, pavel.cermak@vuzv.cz
[2]Czech Agrifood Research Center, Drnovská 507/73, 161 00 Praha 6 – Ruzyně, the Czech Republic
[3]Mendel University, Faculty of Regional Development and International Studies, Zemědělská 1665/1, 613 00 Brno, the Czech Republic

In accordance with EU directives, there is a need to update the typical values of the carbon footprint of selected cultivated crops and livestock products and to develop and verify the so-called "carbon calculator" for calculating the quantification of the carbon footprint according to the local conditions of agricultural farms in connection with the calculation methods applied in the EU and the development of innovative procedures for reducing the carbon footprint for the conditions of the Czech Republic.

This is understood to mean the greenhouse gas (GHG) emission factor expressed in CO2eq per unit of product weight when growing field crops related to various local soil, climate and production conditions of the Czech Republic.

The calculation of the carbon footprint in the area of the main livestock products (meat, milk, eggs) was focused on identifying the key points of its reduction.

The emission factors for the main crops and main livestock products reflect the entire production technology (cultivation or breeding) with all phases and are expressed by a mathematical formula.

For specific mathematical concepts, GHG emission values were used for: 1) plant production from:

a) production, storage and transport of seeds (seedlings); b) production and transport of fertilizers (organic, organomineral, mineral), sludge from wastewater treatment plants and soil additives; c) production and transport of pesticides; d) fuels for field operations, especially the used tillage systems; e) field emissions (i.e. GHG emissions from evaporation and leaching - especially from applied fertilizers).

2) animal production from: a) data on milk production (meat, eggs); b) breeding data; c) feed rations; d) calculation of the carbon footprint of feed crops; e) manure management; f) energy and fuel consumption in milk (meat, eggs) production.

The influence of different conditions and different agricultural systems (e.g. tillage systems, fertilization, etc.) on the final value of emissions (emission coefficients) from cultivated crops is monitored, which are further used to produce feed mixtures for animal nutrition and are reflected in the emission limits of livestock products.

These emission coefficients (values) will be used in agricultural practice in real local farm conditions and at the same time these values will be used to reduce greenhouse gas and ammonia emissions in animal nutrition, respectively in breeding.

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7. Typology and agricultural suitability of soils at the Miedniewice field in the Experimental Station of the Institute of Agriculture, Warsaw University of Life Sciences – SGGW

Józef Chojnicki, Wojciech Stępień, Wojciech Kwasowski, Łukasz Uzarowicz

Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Soil Science, Nowoursynowska 159 St., 02–776 Warsaw, Poland; jozef_chojnicki@sggw.edu.pl

The soils at the experimental field in Miedniewice, belonging to the Prof. Marian Górski Experimental Station of the Institute of Agriculture in Skierniewice, central Poland, were studied. The field covers about 31 ha and has relatively low soil diversity. It contains (1) stagnogleyic brown soils (according to WRB: Stagnic Cambisols) developed from light loam, (2) leached, stagnogleyic brown soils (according to WRB: Eutric/Epidystric, Stagnic Cambisols), and (3) stagnogleyic lessive soils (according to WRB: Stagnic Luvisols or Luvic Stagnosols) developed from loamy sands on light loam. A small area is covered with gleyic brown soils (according to WRB: Gleyic Cambisols) developed from loamy sand. The properties of loam, as a parent rock, mainly determine the soil-forming processes of brownification, lessive and overlapping stagnogleyic processes occurring in these soils. The soils have beneficial chemical and physical properties and a high agricultural value. The commonly occurring, differentiated stagnogleyic process in brown and lessive soils does not significantly reduce their agricultural value. The lightest loam does not create conditions for strong, periodic or excessive accumulation of rainwater, and the flat location of these soils ensures uniform rainwater retention across their entire surface, while at the same time greatly limiting surface runoff and erosion.

According to the Polish agricultural soil evaluation system, the most common soil type is class IIIb, which includes lessive and leached, stagnogleyic brown soils, developed from light and heavy loamy sands on loam. Class IIIa soils, which mainly include stagnogleyic brown soils developed from light loam, occupy smaller areas. Classes IVa and IVb, on the other hand, comprise gleyic brown soils developed from loamy sand and weakly loamy sand. Due to their agricultural suitability, the soils of class IIIa were classified as 2 good wheat complex, class IIIb as 4 very good rye complex, and class IVa and IVb as 5 good rye complex. Thanks to many years of proper use, these soils have developed a high degree of agricultural culture. Hence, their humus horizon is well developed (about 30 cm thick), with a well-developed soil structure and a slightly acidic pH. They show adequate levels of available macro- and micronutrients, except for phosphorus, which is low. These soils contain naturally occurring levels of soluble (mobile) trace elements, such as lead and cadmium.

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8. Impact of different botanical compositions of cover crop mixtures for managing soil quality

Auksė Daukšytė[1], Aušra Marcinkevičienė[1], Rimantas Vaisvalavičius[1], Rimantas Velička[1], Robertas Kosteckas[1]

[1]Vytautas Magnus University Agriculture Academy, LT-53361, Kaunas, Lithuania, aukse.dauksyte@vdu.lt

The cultivation of cover crop mixtures with different botanical compositions is an important agronomic measure for maintaining good soil quality. Cover crops improve the physical, chemical, and biological properties of the soil. A field experiment was conducted in 2024 at the Vytautas Magnus University Agriculture Academy Experimental Station. The aim of this study was to evaluate the effect of cover crop mixtures of different botanical composition, consisting of 2–13 plant species, on above-ground biomass accumulation, the activity of soil enzymes sucrase and urease, the number and biomass of earthworms in the soil, the organic carbon content of the soil, and the soil structure. The above-ground biomass of cover crops ranged from 1.35 to 2.93 t ha^{-1}. The highest above-ground biomass was formed by cover crop mixtures consisting of 8 and 9 short-lived plant species. With increasing plant species diversity in cover crop mixtures, a tendency towards an increase in earthworm numbers and biomass in the soil was observed. The highest soil urease enzyme activity, ranging from 1.5 to 2.1 times higher, was found in soil where 9–13 short-season plant species were grown as cover crops. The activity of the enzyme sucrase increased most significantly in soil where a mixture of 12 short-term plant species was grown as cover crops. The mixtures of cover crops did not have a significant effect on soil structure and organic carbon. A strong, positive, and statistically significant correlation ($r = 0.80$, $P < 0.05$) was found between the number of earthworms and the activity of the enzyme sucrase in the soil.

9. The influence of different intensities of tillage and crop rotations on soil CO_2 exchange rate

Irena Deveikytė[1], Virginijus Feiza[1], Vytautas Seibutis[1]

[1]Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344, Kėdainiai dist., Lithuania, irena.deveikyte@lammc.lt

The amount of CO_2 emitted from the soil is determined by soil properties, location, climate, and farming practices (Mohammed et al., 2022; Nissan et al., 2023). Greenhouse gas emissions can be reduced by applying appropriate tillage methods, diversifying crop rotations, growing catch crops, incorporating plant residues and organic fertilizers (King and Blesh, 2018; Kraamwinkel et al., 2021).

To study different tillage and cropping strategies effect on variation on soil CO_2 emission, the field experiment was executed during the four-year period in 2021–2024. The experiment was laid out in a complete two-factor randomised split-plot block design with four replicates. The experiment included two tillage treatments - direct drilling (DD) and conventional tillage (CT); and five cropping systems: winter wheat – spring wheat - winter wheat - spring wheat (WW-SW-WW-SW), winter wheat + catch crop - spring wheat - winter wheat + catch crop - spring wheat (WW+CC-SW-WW+CC-SW), spring wheat + catch crop - peas + catch crop - spring wheat - winter wheat + catch crop (SW+CC-P+CC-SW-WW+CC), spring wheat + catch crop - peas - winter rape - winter wheat + catch crop (SW+CC-P-WR-WW+CC), winter rape + catch crop - spring wheat + catch crop – peas + catch crop - winter wheat (WR+CC-SW+CC-P+CC-WW). A closed chamber method used to measure soil CO_2 emission from soil (heterotrophic and autotrophic soil respiration). Using a portable analyser Li-Cor 6400-09 (ADC Bioscientific Ltd., Hoddesdon, UK), the soil CO_2 emission (μmol m^2 s^{-1}) measured within the topsoil (0–5 cm) layer (Cueva et al., 2017). CC composition consisted of 20 % *Trifolium alexandrinum*, 20 % *Vicia sativa*, 10 % *Helianthus annuus*, 10 % *Pisum arvense*, 10 % *Phacelia tanacetifolia*, 10 % *Avena strigosa*, 5 % *Lolium multiflorum*, 5 % *Fagopyrum esculentum*, 5 % *Lupinus angustifolius* and 5 % *Linum usitatissimum*.

It can be stated that the intensity of CO_2 emission is highly dependent on the vegetative stage of the plants. Regardless of cropping strategies, cultivation year and type of tillage used the highest emissions were determined in the initial stages of vegetative development and then decreased until the end of vegetation. Tillage methods significantly affected soil CO_2 emissions, and crop rotation also had an impact on emissions, although no significant differences were registered between study years or combinations of factors. DD had increased CO_2 emissions by 23 % compared to CT. Crop rotation was another crucial factor affecting soil CO_2 emissions. By including cover crops in the cropping systems had increased emissions by 25 %, with the highest levels observed in SW+CC-P+CC-SW-WW+CC crop rotation, which included legumes and cover crops. The frequency of cover crops in rotations also influenced emissions. SW+CC-P-WR-WW+CC rotation, with annual cover crops, had the lowest CO_2 emissions while the cover crops can initially increase the easily degradable soil organic carbon fraction, promoting a short-term CO_2 release. The highest CO_2 emissions were recorded under WW+CC-SW-WW+CC-SW crop rotation, especially under DD. Overall, the study confirmed that the combined influence of tillage and crop rotation affects soil carbon dynamics.

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10. Organic matter properties of Luvisol of 40-year fertilizer experiment

Bożena Dębska, Magdalena Banach-Szott, Wojciech Kozera, Tomasz Knapowski

Department of Biogeochemistry, Soil Science and Irrigation and Drainage, Bydgoszcz University of Science and Technology, 6 Bernardynska St., 85-029 Bydgoszcz, Poland, kozera@pbs.edu.pl

Soil performs essential ecosystem services like: agricultural production, water and nutrient storage and regulation, C sequestration, the degradation and immobilization of pollutants and the reduction in greenhouse gases emissions. One of the basic soil components that determines the properties is organic matter (OM) (Cao et al., 2016, Chen et al., 2009, Zhao et al., 2023, Vogel et al. 2019).

The aim of this research was to determine the impact that long-term use of manure and mineral fertilisers has on the quantity and quality of organic matter and propertirs of humic acids.

The soil samples were sampled from a long-time field experiment that was established in 1979 at the experimental field WRiB PBS (Wierzchucinek, Kujawsko-Pomorskie province). The experiment was established on *Luvisol* with a grain size of sandy loam, carbon (TOC) content of 6.90 g kg^{-1} and nitrogen 0.78 g kg^{-1}. Factors of the experiment was: dose of manure: 0 and 30 t ha^{-1} (factor I) and dose of nitrogen: 0, 40, 60, 120 kg ha^{-1} (factor II). The samples were taken from a depth of 0‑30 cm, were combined and carefully mixed then dried at room temperature and sieved (2 mm) and the following parameters were determined: total organic carbon and total nitrogen content, dissolved organic matter, fractional composition of organic matter. From the soil samples humic acids (HAs) were extracted and the following were determined: elemental composition, hydrophilic and hydrophobic properties and spectrometric properties in the UV–VIS and IR range.

A higher content of total organic carbon (8.42 g kg^{-1}) and humic acid fraction (1761 mg kg^{-1}) and higher values of the CHA/CFA ratio (0.79; parameters that are indicators of soil quality) were found in the soil fertilised with manure compared to the soil without manure added (TOC—7.00 g kg^{-1}; CHAs—1285 mg kg^{-1}; CHAs/CFAs 0.66). The value of the TOC/TN ratio, which was highest for the soil samples of the variant with manure without addition of N.

The long-term application of manure and mineral fertilizers determined the properties of soil HAs. The HAs molecules of the soil fertilized with manure and N (40, 60, 120 kg ha^{-1}) compared to the HAs of the soil fertilized with N alone were characterized by a higher degree of aliphaticity (higher H/C values and higher band intensities: 2960‑2920 and 2850 cm^{-1}) and consequently a higher share of hydrophilic fractions and a lower degree of internal oxidation. Spectrometric parameters indicate a higher proportion of undecomposed lignin fragments and, at the same time, a higher susceptibility to oxidation of the HAs molecules of the manure-fertilized soil compared to only the N-fertilized soil. The obtained relationships also indicate that the aromaticity and hydrophobicity of the HAs particles of manure-fertilized soil can be increased at higher N doses (60 and 120 kg ha^{-1}), which is particularly important in terms of the role humic substances play in carbon sequestration. An increase in organic matter content and increase in the stability of humic acid molecules will affect soil quality (including structure, sorption and buffering capacity). Soil quality, in turn, will shape the yield and its health parameters (“healthy soil” is “healthy food”).

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11. Soybean yield response to spatial arrangement

Ewelina Flis-Olszewska[1], Dominika Skiba[2]

[1]University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland, ewelina.flis-olszewska@up.edu.pl
[2]University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland

Soybean is one of the most important legume crops cultivated worldwide, valued for its high protein and oil content as well as its wide range of applications in the food and feed industries. In recent years, increasing interest in soybean cultivation has also been observed in Poland, which is partly associated with ongoing climate change favouring the cultivation of thermophilic species (Kaliska et al., 2026).

Plant growth, development, and yield performance are influenced not only by cultivar selection but also by sowing parameters, including row spacing, which in Poland typically ranges from 15 cm to 45 cm (Bubniewicz et al., 2017; Kozak et al., 2008). In 2023–2025, a field experiment was conducted at the Felin Experimental Farm of the University of Life Sciences in Lublin involving three soybean cultivars representing different maturity groups: Erica (early), Abelina (medium-early), and Viola (late). Each cultivar was sown at three row spacings: 15 cm, 30 cm, and 45 cm, while maintaining a constant plant density of 70 seeds·m^{-2}.

Among the tested cultivars, Abelina showed the greatest yield stability and produced relatively high yields in most years, with the highest yield recorded in 2025. This cultivar was also characterised by the greatest plant height, although considerable variation in this trait was observed between years.

The Erica cultivar was distinguished by the highest thousand seed weight (TSW), but at the same time produced the lowest seed yields among the analysed cultivars. It also exhibited the lowest variability between years, indicating a relatively stable response to environmental conditions. In contrast, Viola proved to be the least stable in terms of yield performance; however, in 2024 and 2025 it produced the highest yields among all cultivars included in the study.

The obtained results also demonstrated a clear effect of row spacing on soybean morphological traits. Increasing row spacing resulted in a greater number of lateral branches. Plants grown at 45 cm row spacing were shorter, more branched, and developed a higher number of branches, whereas plants cultivated at 15 cm spacing were taller, more slender, and produced fewer branches. At the same time, greater plant height did not necessarily correspond to higher seed yield.

In most cases, the lowest yields were obtained at 45 cm row spacing, whereas 15 cm and 30 cm spacing promoted higher seed yields. In 2024, the highest yields were recorded at 15 cm spacing, while in 2025 the most favourable results were obtained at 30 cm spacing.

Weather conditions significantly affected soybean growth and yield formation during the study period. It was observed that moderate water stress, particularly during the initial stages of plant growth, contributed to increased seed yield. At the same time, 2025 was characterised by the lowest plant height and the lowest yield level despite the highest TSW values.

The conducted study demonstrated a significant influence of both weather conditions and row spacing on the development of soybean morphological traits and seed yield performance. The obtained results indicate the need for further studies on the interaction between cultivar characteristics, sowing parameters, and environmental conditions in soybean cultivation

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12. Assessment of changes in biological activity and genetic diversity of microorganisms after biochar application in cereal cultivation

Anna Gałązka[1], Karolina Gawryjołek[1], Jarosław Ciepiel[1], Anna Marzec-Grządziel[1], Krzysztof Jończyk[2]

[1]Department of Microbiology, [2]Department of Agroecology and Economics Institute of Soil Science and Plant Cultivation- State Research Institute, Pulawy, Poland; Czartoryskich 8, 24-100 Pulawy, tel. (0-81) 4786950,

Biochar and production thereof have been one of the leading research trends in Europe in the recent years. Biochar is a solid renewable fuel extracted from various types of biomass in the pyrolysis process, in which liquid and gas fuels are generated. Material used for production of biochar varies greatly and comprises e.g. energy plants, forest waste, rapeseed and sunflower biomass, corncobs, sewage sludge, and organic waste.

Despite the benefits of using biochar in agriculture, scientific research reveals a fragmentary and insufficient character of current knowledge in this field. An additional problem in investigations of biochar and determination of e.g. doses that are best suited for production and environmental effects is the large variety of biochar forms that can be applied in practice (diversity of fractions, sources, and origins of biochar). There are no literature reports on the assessment of the effects of biochar doses on changes in the soil and, especially, in the structure and function of soil microorganisms. The choice of an appropriate dose of biochar has economic importance; additionally, it should focus on maintenance of soil biological activity and prevention of loss of biodiversity in the soil environment. Although some research has been conducted to assess the properties and possibilities of using biochar in agriculture, the problem of its impact on the biological activity of soil has still not been elucidated worldwide. This is evidenced by the limited number of literature reports on biochar doses and their impact on the comprehensive assessment of soil microbiology. The control of microbial processes occurring in soil supplemented with biochar is essential.

The aim of the study was to assess the impact of biochar addition on soil quality and microbial functional diversity. The biochar doses were determined based on the initial carbon content in the soil, and they were increased to 2.5%, 5%, 10%, 20%, 50%, and 100% in the experimental objects. The experiment design also included a control object, which was not treated with biochar. The basic biological activities in the soil, i.e. enzymatic activity and the content of carbon and nitrogen in the microbial biomass, were determined. Additionally, the functional biodiversity of soil microorganisms was assessed. It was demonstrated that biochar added to the soil at the dose of 10-20% significantly increased soil biological activity and functional diversity. The biochar dose of 20% turned out to be an optimal dose for enhancement of soil biological activity. This dose induced a significant increase in the total carbon content in the microbial biomass, enzymatic activity, and the overall content of total and easily extractable glomalins. The highest values of the Shannon and AWCD indices were determined in soil supplemented with 5-20% of biochar.

13. The use of waste for fertilization in accordance with regulations – possibilities and limitations

Tamara Jadczyszyn

Institute of Soil Science and Plant Cultivation – State Research Institute, ul. Czartoryskich 8, 24-100 Puławy, Poland, tj@iung.pulawy.pl

Municipal and post-production waste is a source of nutrients for plants and organic matter. In the context of a growing shortage of manure, the rational management of organic waste plays an important role in maintaining soil humus resources, which is particularly important for soil fertility. Waste can also substitute mineral fertilizers produced from non-renewable raw materials. The supply of recyclable materials is increasing thanks to the implementation of waste segregation regulations.

The legal basis for the use of waste in agriculture is the Regulation of the Minister of the Environment on the R10 recovery process (Dz.U.2015.132), defined as "treatment on the ground surface that benefits agriculture or improves the environment." The Regulation contains a list of waste that can be managed in this way and detailed conditions that must be met. In the case of all waste, it is mandatory to carry out tests confirming its quality and the quality of the soil on which it is to be used. The tests must be carried out in accredited laboratories. Waste must be used in such a way that it does not cause soil degradation or influence surface and underground water quality. However, the regulation does not specify what parameters should be considered as indicators of good soil quality. This provision is quite general and it can be assumed that it was implemented from the regulation on municipal sewage sludge, which pays particular attention to potential heavy metal contamination. Therefore, in practice, it is assumed that it is necessary to determine the concentration of heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) in both the waste and the soil. These analyses are quite expensive and increase in proportion to the area of land needed to manage a given batch of waste (the results of testing one soil sample refer to an area of no more than 4 ha). Waste doses should be determined taking into account soil fertility, land use, waste quality, and plant nutrient requirements. In order to meet the above condition, it is necessary to determine at least the following in soil samples: pH and the content of available phosphorus and potassium (the cost of analysis is also proportional to the area of land). In addition, the waste producer should be familiar with the species and yield of crops grown on fields designated for waste management in order to determine their nutrient requirements. In practice, it is unlikely that the waste producer - an entrepreneur – has the knowledge and skills to elaborate crop fertilization plans. An additional difficulty for agricultural waste management is the need to obtain an R10 recovery permit, which the landowner is required to do in accordance with Article 41.1 of the Waste Act (Dz.U.2013.21) .

A number of requirements resulting from environmental regulations and the high costs of potential analyses limit the direct use of waste in agriculture. In this situation, producers most often decide to convert waste into fertilizers or soil improvers on the basis of the provisions on fertilizers and fertilization (Dz.U. 2024.1261). Products made from waste can obtain a permit from the Minister of Agriculture and Rural Development to be placed on the market, thereby losing their status as waste. Most often, such fertilizers or soil improvers are made from biodegradable green waste, sewage sludge, digestate, etc. The chemical composition of the products is not stable. It depends mainly on the proportion of various substances available to biogas plants or composting plants. This creates problems with appropriate declaration of nutrient content in the product. The marketing authorization specifies the chemical composition of the product and the manufacturer is obliged to meet the quality requirements. The fertilizer market is controlled by the State Inspection for Plant Protection and Seed production. If any non-compliance is found, the marketing authorization for the product is revoked.

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14. Reaction of common winter wheat to foliar fertilization with micronutrients

Wacław Jarecki

University of Rzeszów, St. Zelwerowicza 4, 35-601, Rzeszów, Poland, wjarecki@ur.edu.pl

Individual cereal species reaction to foliar fertilization is highly varied and depends on many factors (Vasundhara and Chhabra 2021). These especially include habitat conditions, but also genetic determinants or applied agrotechnical treatments (Stepien 2019). It should be emphasized that soil fertilization is a common and effective treatment, while foliar spraying is justified in high-yielding varieties and when other agrotechnical treatments have already been properly performed.

Foliar fertilization enables quick and easy penetration of nutrients through the leaves, which usually results in an increase in the size and quality of the obtained yield (Sobolewska et al. 2020). Jaskulska and Jaskulski (2019) showed that foliar application of nutrients increased yield components, yield size and grain protein content in wheat. Khan et al. (2009) also obtained an increase in grain yield after foliar spraying, however, excessively high concentration of urea was toxic to plants. Sultonov et al. (2025) conclude that moderate soil fertilization with additional foliar fertilization is the best solution as it reduces environmental risks. Additionally, foliar fertilizers can be used together with pesticides, which reduces the number of spraying runs. In studies by Matras et al. (2022) such combined agrochemical treatments resulted in improved chlorophyll content in leaves (SPAD) and a reduction in fungal diseases.

Foliar fertilization is a treatment applied by spraying in order to provide plants with the necessary macronutrients and micronutrients. Nutrient application is carried out at different developmental stages and in appropriate doses. A field experiment with winter wheat of the RGT Kilimanjaro variety was carried out in the seasons 2021/2022 – 2023/2024 at the University of Rzeszów Experimental Station in Krasne, near Rzeszów. The examined factor was foliar fertilization with selected micronutrients, i.e. zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo) and boron (B), as compared to the control treatment. The one-factor experiment was established on a brown soil, quality class IIIa, good wheat complex. The levels of absorbable macronutrients (P, K, Mg) in the soil were high, while medium levels of micronutrients (Fe, Zn, Mn, Cu, B) were found. Weather conditions during the plant vegetation period varied over the years of research, which modified the obtained effects of foliar fertilization. The difference in grain yield between 2022 and 2023 was 1.4 t ha^{-1}. The SPAD (Soil Plant Analysis Development) measurement showed that foliar fertilization with Cu and Mn was the most effective, increasing the grain yield by 0.19 t ha^{-1} and 0.15 t ha^{-1}, respectively, compared to the control treatment. This was the result of an increase in the Grains Number per Spike (GNS) and the Thousand Grain Weight (TGW) after spraying with these microelements. Grain Protein Content (GPC) increased significantly after the application of Cu, Mo, Mn and Zn. Foliar fertilization differentiated the grain macronutrient and micronutrient values, but not always favorably, which resulted from synergism or antagonism between individual elements.

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15. The influence of mineral nitrogen fertilization in the form of YaraBela Sulfan, Ammonium nitrate and Saletrosan®26 fertilizers on the grain yield and yield components of winter rye

Anna Jaroszewska[1], Magdalena Sobolewska[1], Marek Bury[1]

[1]West Pomeranian University of Technology in Szczecin, Faculty of Environmental Management and Agriculture, Department of Agroengineering, ul. Pawła VI nr 3, 71-459 Szczecin, Poland, marek.bury@zut.edu.pl

Winter rye is a low-demanding and low-yielding crop. So its cultivated area has decreased several-times in the last 50 years and now takes up only 581,000 hectares (2025). Rye is grown in poor soil conditions, where other species are unreliable. Rye is often cultivated extensively, with low levels of fertilization and protection against the pests. The potential of new winter rye varieties is high and can be fully utilized with proper agrotechnics and fertilization. The effect of three nitrogen fertilizers applied as top dressing at three rates on the yield structure and grain yield of winter rye was investigated

The field experiment at the Agricultural Experimental Station in Lipnik (53°20′25″N; 14°58′03″E), belonging to the West Pomeranian University of Technology in Szczecin, was established in 2021 on brown-rusty soil composed of light sand with an underlay of loamy sand, good rye complex, class IVb. After harvesting the previous crop, disking, sowing plowing and fertilization with Polifoska 6 (6-20-30) were performed in the amount of 250 kg per 1 ha. Rye, cv. Dańkowskie Diament was sown with a density of 300 grains per 1 m^2 (1.10.2021). In spring, mineral nitrogen fertilization was applied in the amount of 50, 100 and 150 kg $N \cdot ha^{-1}$ in the form of YaraBela Sulfan (N - 24%, SO_3 - 16.25%), ammonium nitrate (N - 34%) and Salterosan®26 (N - 26%, SO_3 - 32.5%) fertilizers per 1 ha on three dates: March 8 (50 kg N), March 29 (50 kg N) and May 4 (50 kg N) in accordance with the experimental scheme. Rye shortening (Orius Extra 250 EW) and protection against diseases and pests (Azoksar 250 SC, Inazuma) were applied.

During the kernel development stage (BBCH 71) chlorophyll content as leaf greenness index (SPAD) and the leaf area index (LAI) were determined. The average leaf greenness of rye increased with increasing nitrogen application, from approximately 40 SPAD at the 50 kg N treatment to ca. 55 SPAD at the 150 kg N treatment, regardless of the fertilizer type used. A similar trend was observed when analyzing the results for the leaf area index (LAI) – from ca. 1.70 at the 50 kg N treatment to approximately 2.69 at the 150 kg N treatment. The number of ears per 1 m² ranged from ca. 330 to 370, increasing after the application of 100 kg N and then decreasing after the application of 150 kg N, regardless of the fertilizer type used. The grain weight per ear ranged from 1.08 to 1.68 g and depended on the type of fertilizer and nitrogen dose used. The highest grain weight per ear was observed after the application of YaraBela Sulfan (1.63 g), and lower - after the application of ammonium nitrate and Saletrosan®26 (ca. 1.30 g). As nitrogen fertilization levels increased, grain weight per ear increased, regardless of the fertilizer type tested. The number of grains per ear ranged from 35 to 48, and the highest number of seeds was observed after the application of YaraBela Sulfan (average 46.9). After the application of ammonium nitrate and Saletrosan®26, the number of grains per ear was approximately 38.6 to 38.7. Thousand grain weight (TGW) ranged from 33.1 to 35.4 g. As the level of mineral nitrogen fertilization increased, TGW increased. The highest TGW was observed after the application of YaraBela Sulfan – an average of 34.8 g, regardless of the N fertilization level. Grain yield was determined primarily by the number of ears per unit area and grain weight per ear. Grain yield increased with increasing mineral nitrogen fertilization levels, regardless of the type of fertilizer tested, but the highest yield was obtained after application of YaraBela Sulfan, at 4.87 t ha^{-1}. A 7% lower yield was obtained after application of Saletrosan®26 (4.55 t ha^{-1}), and the lowest yield (11% lower compared to the yield after application of YaraBela Sulfan) was obtained after application of ammonium nitrate (4.33 t ha^{-1}), regardless of the level of mineral nitrogen applied.

Based on the obtained results, it can be concluded that fertilization with fertilizers containing sulfur (YaraBela Sulfan and Saletrosan®26) brings significant benefits to winter rye cultivation. The study showed grain yields increased by 12.5% and 5%, respectively, compared to those from plots fertilized with traditional ammonium nitrate. Nitrogen fertilization levels ranging from 50 to 150 kg N ha^{-1} increased the number and weight of grain per ear, as well as the TGW, regardless of the fertilizer type used.

16. The response of winter rapeseed to varied fertilisation in a long-term static experiment

Iwona Jaskulska[1], Dariusz Jaskulski[1],

[1]Bydgoszcz University of Science and Technology, Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland, darekjas@pbs.edu.pl

Winter rapeseed (*Brassica napus* L. ssp. *oleifera* Metzg.) is a crop with high requirements regarding site conditions habitat and agrotechnical practices. Its cultivation should be preceded by a thorough site assessment, especially of soil conditions (Vilček et al., 2025). Soil fertility can be increased by organic and mineral fertilisation. However, unsustainable fertiliser types, doses and ingredients may degrade the soil environment and reduce plant productivity, as evidenced by the results of many years of agricultural experiments (Bhatt et al., 2019; Kirchmann et al., 2020).

The research objective was to evaluate winter rapeseed yields on research plots of a fertiliser experiment established in 1948 in Mochełek (53°12'24"N, 17°51'40"E, 98.5 m a.s.l.) near Bydgoszcz, Poland (Jaskulska, 2020). Currently, the experiment comprises 14 fertilisation treatments: ½ NPK (nitrogen, phosphorus, potassium); wheat straw (ST) once per crop rotation + annual mineral fertilisation (NPK); NPK + liming once per rotation (Ca); NPK; manure (M) once per rotation – for rapeseed; and also M PK; M NK; M NKMg (magnesium); M NP; M NPMg; M NPK; M NPKMg; M NPK + Ca; M NPKMg + Ca. Rapeseed is grown as the first crop in a 4–5-year rotation on a site after winter wheat, and the results presented are the average of the last two rotations. Full organic and mineral fertilisation for winter rapeseed is: M – 25 t ha^{-1}, N – 135 kg ha^{-1}, P_2O_5 – 75 kg ha^{-1}, K_2O – 120 kg ha^{-1}, MgO – 40 kg ha^{-1}.

In both crop rotations, the best winter rapeseed yields were obtained on soil that was regularly limed and fertilised with manure and NPKMg mineral fertilisers. The average seed yields under these conditions were 3.83 t ha^{-1} and even (in the second rotation) 4.78 t ha^{-1}. The absence of manure fertilisation resulted in a yield reduction of 11.4%, and the absence of regular liming reduced yield by 3.5%. Long-term omissions of phosphorus and of potassium, despite fertilisation with manure, resulted in respective seed yield reductions of 11.2% and 6.2%. Under NPK mineral fertilisation, the yield-improving effect of straw did not constitute a replacement for manure. Application of straw was associated with a 0.07 t ha^{-1} decrease in rapeseed yield (insignificant difference), whereas applying manure increased yield by 0.47 t ha^{-1}. Much the lowest yield of winter rapeseed seeds in the long-term static fertilisation experiment was recorded on the plot fertilised with ½ dose of NPK mineral fertilisers. It amounted to 3.16 t ha^{-1}. Doubling the dose of this mineral fertiliser mix (NPK) increased the seed yield to 3.38 t ha^{-1}, and, in combination with additional liming (NPKCa), to 3.50 t ha^{-1}, i.e. by 7.0% and 10.8%, respectively.

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17. Organic carbon and water management in soil in a long-term soil tillage experiment

Dariusz Jaskulski[1], Iwona Jaskulska[1], Emilian Różniak[2]

[1]Bydgoszcz University of Science and Technology, Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland, darekjas@pbs.edu.pl
[2]Research & Development Centre Agro-Land Marek Różniak Śmielin, Kościelna 1, 89-110 Sadki, Poland

The two basic sets of goals of modern agriculture are production-oriented and environmental (Devlet, 2021). The latter often necessitate lower intensity mechanical soil tillage. Therefore, many cultivation methods currently in use involve fewer operations, shallower soil intervention, zonal tilling, mulching, or limiting cultivation only to direct sowing (Šarauskis et al., 2018; Tsyliuryk et al., 2025).

One objective of the multi-year field experiment established in 2012/13 in Śmielin (53°09′04.0″ N, 17°29′10.7″ E, 93.8 m a.s.l.), Kuyavian-Pomeranian Voivodeship, Poland, is to compare the impact that three soil tillage methods and the associated plant cultivation technology had on organic carbon management and soil water management. The experimental treatments are: plough tillage, full-surface reduced (non-inversion) tillage, and strip-till. The main operations for each cultivation method, in order, are: ploughing to a depth of 20–25 cm using a mouldboard plough; equally deep soil loosening without inversion – cultivator, also known as a grubber; and cultivation of 12-cm-wide soil strips (separated by 24-cm untilled strips) to a depth of 20–25 cm with simultaneous fertiliser application and seed sowing using MZURI machines. Since 2023, strip-till has been implemented using the MZURI PRO-TIL* machine, which, based on actual working conditions, automatically adjusts loosening-tine and seed-coulter working depths, the pressure force of copying wheels, and fertiliser dosing. In the conventional ploughing and reduced tillage methods, deep tillage is followed by fertiliser application, seedbed preparation, and sowing. The experiment examined, among others, CO_2 emissions from diesel combustion for tillage and sowing of winter wheat, CO_2 emissions from the soil during the cereal crop growing season, organic carbon sequestration in the 0–20 cm soil layer over the 12 years since the establishment of the experiment, and soil water reserves at the time of sowing of winter crops and maize.

We conclude that average soil emission of CO_2 during the vegetation period of strip-till-cultivated winter wheat is a little over half that of conventional tillage (plough tillage). However, replacing plough tillage with non-inversion tillage reduced CO_2 emissions from soil from 284 to 220 mg CO_2 m^{-2} h^{-1}. Fuel combustion CO_2 emissions were 137.3, 95.6 and 37.2 kg ha^{-1} for plough, non-inversion and strip-till cultivation, respectively. Soil tillage method and plant cultivation technology also strongly differentiated carbon sequestration in the soil and amount of water in the soil. In the 0–20-cm layer of conventionally ploughed soil, organic carbon decreased by 363 kg ha^{-1} per year. However, in the soil under non-inversion tillage and strip-till, it increased by 42 and 385 kg ha^{-1}, respectively. In turn, replacing plough tillage with non-inversion tillage and strip-till increased soil water reserves at the time of sowing winter crops by 52.2 and 103.6 t ha^{-1}, respectively, and at the time of sowing maize by 16.9 and 88.4 t ha^{-1}.

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18. Carbon and nitrogen responses to sowing methods, tillage intensity, and cover crops in winter oilseed rape

Birute Jomantaite[1], Jurgita Ceseviciene[1], Marlo Jimenez[2], Gražina Kadziene[1]

[1] Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Instituto av. 1, Akademija, Kedainiai distr., LT-58344, Lithuania, birute.jomantaite@lammc.lt
[2] Institut Agro Dijon, 26 Boulevard Docteur Petitjean, 21079 Dijon Cedex, France

Soil organic carbon (SOC) is the key constituent of soil organic matter (SOM). High SOM content supplies nutrients to plants, improves water availability, and enhances soil structural stability through aggregate formation and porosity, thereby supporting adequate aeration, water infiltration, and overall soil fertility (Topa et al., 2025). The carbon (C) cycle within agroecosystems plays a fundamental role in regulating climate processes, maintaining soil fertility, and ensuring the sustainability of agricultural systems (O'Neill et al., 2021). Plants are the primary pathway for the incorporation of atmospheric CO_2 into soils via photosynthetic activity, root-derived carbon inputs, and crop residues, thereby contributing to the accumulation of SOC (Raza et al., 2024).

The magnitude and stabilization of these carbon inputs are strongly influenced by tillage intensity, sowing techniques (Jaskulska et al., 2020), and crop selection. This study examines how varying tillage and sowing practices affect the distribution of carbon and nitrogen in winter oilseed rape (*Brassica napus* L.) cropping systems and the associated soil under temperate climatic conditions. In this context, it is essential to assess how different tillage and sowing systems influence carbon and nitrogen dynamics in plants and soil.

A two-factorial field experiment evaluating different tillage and cover crop management practices was established in 2021 at the Lithuanian Research Centre for Agriculture and Forestry, Institute of Agriculture, in Central Lithuania. The soil at the experimental site is classified as an Endocalcari–Epihypogleyic Cambisol with a loam texture. A four-course crop rotation was applied: winter oilseed rape (*Brassica napus* L.), pea (*Pisum sativum*), winter wheat (*Triticum aestivum* L.), spring wheat (*Triticum aestivum* L.). From 2024, the experiment included three factors: Factor A – sowing methods (strip sowing without soil surface preparation with 50 cm row spacing, and sowing with pre-sowing soil cultivation); Factor B – tillage methods (conventional tillage, CT – ploughing to 22–24 cm; reduced tillage, RT – harrowing to 8–10 cm; and no-tillage, NT – direct drilling); and Factor C – cover crop application (with and without cover crop). The experiment was arranged as a randomized complete block design with four replications. Crop management followed standard agricultural practices, including pesticide application. The data are presented from the 2024/2025 growing season.

The results indicated that the highest accumulations of SOC, N, and water-extractable C were observed in soils where winter oilseed rape was established using strip sowing. A similar trend was recorded under no-tillage management and with the application of cover crops, both of which promoted greater accumulation of these components. Lower accumulation levels were likely associated with enhanced organic matter decomposition in disturbed soils and reduced inputs of plant residues in treatments without cover crops. The highest SOC concentrations were recorded in the 0–10 and 10–20 cm soil layers (2.15 and 2.09%, respectively), whereas the 20–30 cm layer contained nearly half of these values.

In plant tissues, carbon accumulation was lower in treatments without cover crops, whereas nitrogen concentrations were significantly higher under no-tillage compared with the other tillage systems, as well as under strip sowing.

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19. The production and environmental impacts of organic and conventional farming systems

Krzysztof Jończyk, Adam Berbeć

Institute of Soil Science and Plant Cultivation - State Research Institute in Puławy, Department of Agroecology and Economics, Czartoryskich 8 St. 24-100 Puławy, Poland, kjonczyk@iung.pulawy.pl

This paper presents the results of research conducted at the IUNG-PIB Experimental Station in Osiny between 1995 and 2025. The research was conducted in an experimental facility which compared various production systems under consistent environmental conditions. The design of the experimental facility is based on the principles of research on agricutltural production systems employed at other research centres (Vereijken 1992, 1994): Nagele (the Netherlands), Lautenbach, Reinshof and Mariensteien (Germany), Long Aston (England), Folum (Denmark), and Burgrain (Switzerland).

The results of the research enable a comprehensive assessment of the long-term application of management systems to be made, covering crop yields and the productivity of entire systems. They also allowed an analysis of factors limiting yields and their impact on soil fertility and biological activity to be performed (Dąbek-Szreniawska et al., 2004, Doltra et al., 2019, Feledyn-Szewczyk, 2013, Król et al., 2012, Kuś and Jończyk, 2010).

The study analysed the magnitude and variability of cereal yields and total crop rotations in organic and conventional production systems (the conventional system includes intensive, integrated and monoculture variants). The environmental impact assessment was based on an analysis of key soil fertility parameters: organic matter content, pH, and P and K levels.

The integrated system achieved the highest productivity, as measured by winter wheat yield and the total yield of all crops in grain units. The greatest variability in yields and other anylsed parameters was observed in the organic production system and in the monoculture. Yields obtained in the organic system were lower than in the conventional intensive system, by 15% to 35% depending on the year. The factor most strongly influencing wheat yield in organic production system was infection by fungal pathogens. Organic farming led to a periodic declines in soil potassium levels. In the conventional and integrated systems, a slight increase in organic carbon accumulation in soil was observed, although it was lower than in the organic system. A downward trend in organic matter content was observed in the monoculture.

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20. Impact of long-term tillage and inter-cropping systems on soil organic carbon content and stratification of humified fractions

Gražina Kadžienė, Alvyra Šlepetienė, Aida Skersienė, Arman Shamshitov, Ona Auškalnienė, Simona Pranaitienė, Skaidrė Supronienė

Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Instituto av. 1, Akademija, Kedainiai distr., LT-58344, Lithuania, birute.jomantaite@lammc.lt

Sustainable agricultural management increasingly emphasizes preventive strategies that maintain soil functionality and long-term productivity. Central to this approach is soil organic matter (SOM), a fundamental component governing soil structure, nutrient cycling, water retention, and biological activity. SOM is commonly defined as the organic fraction of soil excluding undecomposed plant and animal residues, although broader interpretations may also include living microorganisms and fresh organic remains (Shamshitov et al., 2023). As SOM decomposes, soil organic carbon (SOC) is formed and released, serving as a key indicator of soil quality and ecosystem sustainability in agricultural landscapes (Chevallier et al., 2016). SOC stocks are controlled by interactions between natural conditions and human management practices (Tayebi et al., 2021), while soil properties and climatic factors strongly regulate SOC dynamics (Wiesmeier et al., 2019).

A long-term experiment was conducted on a loam-textured Cambisol to assess the influence of five tillage systems: conventional ploughing at 22–24 cm (CT), shallow ploughing at 16–18 cm (ShT), harrowing at 8–10 cm (MT1), harrowing at 14–16 cm (MT2), and no-till (NT). The study aimed to determine how varying tillage intensities and inter-cropping practices affect SOC accumulation, vertical distribution, and the formation of its humified fractions within different soil layers. SOC content responded significantly to both tillage treatment and the inclusion of inter-crops. Stratification ratios (SR) were calculated to compare SOC concentrations in the 0–10 cm layer with those at 10–20 cm (SR1) and 20–30 cm (SR2). SR1 values ranged from 0.97 to 1.35, whereas SR2 ranged from 1.02 to 1.99, indicating variable carbon distribution depending on management practice.

Inter-cropping consistently promoted greater SOC accumulation in the surface layer (0–10 cm) across all tillage systems. The results demonstrate that tillage intensity combined with inter-cropping influences soil carbon turnover and organic matter humification processes. The enhancement of stable, humified carbon compounds supports soil productivity and resilience while contributing to environmental sustainability through improved carbon sequestration and reduced atmospheric carbon dioxide emissions. These findings suggest that integrating sustainable tillage systems with inter-cropping practices can play a meaningful role in climate change mitigation by increasing SOC storage in agricultural soils.

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21. Development of technologies for recovering nutrients from secondary raw materials: barriers and challenges

Monika Karsznia[1], Piotr Skowron[1], Damian Wach[1], Aleksandra Bibow[1], Agata Witorożec-Piechnik[1], Elina Tampio[2], Johanna Laakso[2]

[1]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland, mkarsznia@iung.pulawy.pl
[2]Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790 Helsinki, Finland

Sustainable recycling of nutrients from secondary raw materials is becoming a key element in the transition to a circular economy. Growing pressure to reduce mineral fertiliser use, reduce waste and improve resource efficiency means that alternative sources of nutrients are becoming strategically important. Despite growing interest and technological progress, the sector still faces significant technological, regulatory, economic and social barriers that slow down its development and large-scale implementation. Early identification of these barriers is essential to effectively support the further development of recycling technologies and increase their share in sustainable agriculture.

The FERTITEC project, carried out under the EU Horizon grant CSA 101181513, used a four-element, complementary methodology that enabled a consistent assessment of the state of development of technologies for the recovery and recycling of nutrients from secondary raw materials, the identification of key barriers and the indication of possible directions for further development. The study used secondary data analysis based on desk research and interview questionnaires. It included a review of scientific literature available in public databases and an analysis of reports from 15 thematically related EU projects (including B-Ferst, bio-SOLUTIONS, CiNURGi, FER-PLAY, FERTIMANURE, Lex4Bio, MainstreamBIO, Novafert, NUTRI-KNOW, NUTRIMAN, P2GreeN, SEA2LAND, SuMaNu, SYSTEMIC and WalNUT), as well as an assessment of the results of the FERTITEC project to date in terms of technological, environmental, economic, market and regulatory aspects. This was supplemented by an analysis of the opinions of 43 experts collected through interview questionnaires.

The results of the study confirm that the sector of nutrient recovery and recycling from waste in the EU faces serious regulatory, technical, economic and social challenges. Differences in national interpretations of regulations on fertilisers, environmental permits and product classification under EU law create formal barriers to their introduction on the market. High investment and operating costs, as well as variability in raw material quality and product composition, further limit the potential for larger-scale implementation of the technology. At the same time, demand for sustainable and bio-based fertilisers is growing, supported by the development of organic farming and EU policies promoting the circular economy. Nutrient recovery technologies have great potential, and their wider use could reduce nutrient losses, decrease dependence on synthetic fertilisers and strengthen raw material security.

Key conclusions point to the need to harmonise legal regulations, increase financial support, improve technological readiness, and build awareness and trust among users. Combining these measures is a prerequisite for fully exploiting the potential of the alternative fertiliser market and will accelerate the development of nutrient recovery technologies within and outside the EU.

The work was carried out as part of the FERTITEC project „FERTIliser product recovery from secondary raw materials using best available TEChniques", funded by the European Union Horizon CSA under GA no. 101181513EU, under the HORIZON-CL6-2024-ZEROPOLLUTION-01-02

22. Strategic assessment of nutrient recovery technologies: results of the SWOT analysis of the FERTITEC project

Monika Karsznia[1], Damian Wach[1], Piotr Skowron[1], Agata Witorożec-Piechnik[1], Aleksandra Bibow[1]

[1]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland, mkarsznia@iung.pulawy.pl

Despite growing interest in nutrient recycling in agriculture and increasing EU policy support in this area, the sector still faces numerous challenges that hinder the widespread implementation of alternative fertilisers (AF). As part of the FERTITEC project, funded by the EU Horizon CSA 101181513 programme, a SWOT analysis was conducted to assess the current and future potential of nutrient recovery technologies from secondary raw materials and the development of the AF market.

SWOT analysis was selected as an appropriate tool for strategic assessment in a context of complex systemic changes. It is a method that enables comprehensive identification and assessment of strengths and weaknesses as well as existing and potential opportunities and threats arising from the external environment, which allows for a better understanding of the project's potential and assessment of its development prospects.

Based on a review of scientific literature, the results of previous related EU projects, surveys and market and legal analyses conducted as part of the FERTITEC project, key barriers, gaps, challenges and factors conducive to the implementation of nutrient recovery technologies were identified. This information was used to develop a consolidated SWOT analysis, in which the five most important strengths, weaknesses, opportunities and threats were selected. Next, a panel of experts – a 29-member international group of specialists in the field of circular economy technologies – assigned weights and impact assessments to these factors, which made it possible to calculate weighted results for each category. The values obtained made it possible to identify the dominant trends in the project environment and the internal potential of AF technology, providing a basis for selecting the most appropriate strategy for the development of the market and nutrient recovery technology.

The analysis results indicate that the project has strengths that outweigh its weaknesses, but it operates in an environment filled with threats. As a result, the project falls into the maxi-mini strategy category, which involves a conservative approach that focuses on leveraging internal strengths to mitigate the effects of negative external factors.

The most important strengths include the high availability of raw materials for the production of AF fertilisers and the existence of regulations enabling their market introduction and ensuring their safe use. The main weaknesses include the variable composition of raw materials, the presence of new contaminants, high investment and production costs, and logistical difficulties that require long-term corrective measures. Key opportunities include EU initiatives supporting the circular economy, rising mineral fertiliser prices, and educational and certification activities that increase confidence in AF. The most serious threats are complex regulations on AF production and registration, and low levels of knowledge and confidence among farmers and the general public.

The SWOT analysis shows that the project has strong resources and competencies to address threats, but external challenges limit its growth potential. In the current situation, it is crucial to strengthen the market position and stabilise the situation, while waiting for the regulatory and market environment to improve. At the same time, it is necessary to minimise threats by optimising costs, developing products, segmenting the market and taking measures to build trust and support the development of circular technologies.

The work was carried out as part of the FERTITEC project „FERTIliser product recovery from secondary raw materials using best available TEChniques", funded by the European Union Horizon CSA under GA no. 101181513EU, under the HORIZON-CL6-2024-ZEROPOLLUTION-01-02

23. Selected soil properties after the 11th crop rotation in a long-term fertilizer experiment

Tomasz Knapowski, Wojciech Kozera, Magdalena Banach-Szott, Bożena Dębska

Department of Biogeochemistry, Soil Science and Irrigation and Drainage, Faculty of Agriculture and Biotechnology, Bydgoszcz University of Science and Technology, 6 Bernardyńska Street, 85-029 Bydgoszcz, Poland; knap@pbs.edu.pl

Long-term static fertilizer experiments constitute a valuable source of agricultural knowledge and provide a basis for drawing conclusions about changes occurring in the soil–plant system. They make it possible to determine long-term changes in the physicochemical properties of soil that affect its fertility under the influence of natural and anthropogenic factors. These changes may verify soil fertility and agricultural productivity, which are, in turn, determined by diverse weather, soil, and cropping conditions (Jaskulska & Urbanowski, 2018; Poulton & Johnston, 2018; Stępień et al., 2018; Laamrani, 2020).

One of such long-term fertilizer experiments was established in 1973 at the Research Station of the Faculty of Rural and Agricultural Engineering of the Bydgoszcz University of Technology in Wierzchucinek (53°15′12″N, 17°46′46″E). The experiment was conducted on typical Luvisol (lessive soil), quality class IIIa, developed from boulder clay of undulating ground moraine, classified as a very good rye complex (strong loamy sand overlying light silty clay). The experimental factor was the type of fertilization. The crop rotation included table potato, spring barley, winter rapeseed, and winter wheat. The following fertilization treatments were applied: i) natural fertilization in the form of manure at a rate of 40 t·ha^{-1} (424 kg NPK·ha^{-1}); ii) mineral fertilization with NPK (1339 kg NPK·ha^{-1}); and iii) combined organic–mineral fertilization consisting of manure at 40 t·ha^{-1} and NPK (1763 kg NPK·ha^{-1}). When determining mineral fertilizer rates, in accordance with the recommendations valid in the 1970s, an assumed yield equivalent to 45 cereal units per hectare was adopted.

For chemical analyses, soil samples were collected from the topsoil layer (0–20 cm) after the 11th crop rotation, and the results were compared with those obtained in 1973 and after the completion of the 6th and 10th crop rotations. The following parameters were determined in the soil material: hydrolytic acidity, pH in 1 M KCl, total nitrogen (N_og.), organic carbon ($C_o$rg.), and available forms of P, K, Mg, Ca, and Na.

The obtained results were subjected to analysis of variance (ANOVA) in a completely randomized design, appropriate for the field experiment layout. Tukey's multiple range test was used to assess differences between treatment means. Statistical calculations were performed using the STATISTICA software package and MS Excel. Based on the conducted research, it was found that in the 11th crop rotation, hydrolytic acidity values were significantly highest in the soil after the combined application of manure and mineral fertilization (NPK). However, such a trend was not observed for soil pH, as the highest pH values were recorded after the application of manure alone. It is noteworthy that after the 11th rotation, regardless of the fertilization treatment, soil reaction changed from neutral (1974) to acidic or very acidic. The contents of total nitrogen and organic carbon were significantly higher in soils treated with manure compared to the other treatments. A predominance of mineralization processes over immobilization processes was also observed in the studied soils. The contents of available phosphorus, potassium, and magnesium were significantly highest in soils fertilized exclusively with manure compared to the other fertilization treatments.

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24. Long-term field experiments as a tool for assessing the impact of fertilization and plant selection on the content of polycyclic aromatic hydrocarbons (PAHs) in the soil

Sławomir Józef Krzebietke[1], Ewa Mackiewicz[2], Piotr Jarosław Żarczyński[1], Stanisław Sienkiewicz[1]

[1]Department of Agricultural and Environmental Chemistry, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland, e-mail: slawomir.krzebietke@uwm.edu.pl
[2]Department of Agrotechnology and Agribusiness, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland

Multi-year field experiments allow for the assessment of the cumulative impact of agricultural practices and changing environmental conditions on soil quality. The aim of the study was to assess the impact of long-term mineral fertilization, manure fertilization, and their combined application, crop selection (sugar beet, spring wheat, corn, and spring barley), as well as weather conditions and soil sampling dates throughout the year on the content of polycyclic aromatic hydrocarbons (PAHs) in soil.

The study was conducted on archived soil samples from 1998-2009 and in 2015 as part of a static multi-year field experiment located in northeastern Poland at ZPD sp. z o.o. in Bałcyny. The field experiment was established in 1986. Soil samples were collected from two depths: 0-30 cm and 30-60 cm of the soil profile. In the case of spring barley, soil samples were collected at key stages of the growing season, including pre-sowing, the intensive plant growth phase, and post-harvest, which enabled the assessment of seasonal variation in PAH content. In 2015, selected biological soil parameters were analyzed, including the number of soil microorganisms and enzymatic activity, along with the PAH content in the spring barley soil. The content of the sum of 16 PAHs and the light and heavy fractions was determined by gas chromatography using an FID detector.

The results indicate that the type of fertilization significantly determined the accumulation of PAHs in the soil. The highest total PAH content was observed in the manure-fertilized plots, while mineral fertilization helped maintain lower concentrations of these compounds. The combined use of manure and mineral fertilization led to an increase in the share of heavy PAHs, which are characterized by greater environmental persistence. The highest PAH concentrations were found in the topsoil, confirming the limited migration of these compounds into the soil profile.

Weather conditions, particularly the distribution of precipitation and temperature during the growing season, modified the seasonal dynamics of PAH content in the soil during spring barley cultivation. The higher rainfall observed in 2015 resulted in greater variability in PAH content between sampling dates, indicating the significant role of biological and physicochemical processes occurring in the soil.

A significant factor modifying PAH content was crop selection. Corn and sugar beet promoted higher PAH accumulation in the soil compared to spring wheat and spring barley, which was attributed to the greater amount and different nature of crop residues and the intensity of root system impacts. In the case of spring barley, a more favorable relationship between PAH content and soil biological activity was observed.

The content of the sum of 16 PAHs in the soil ranged from several dozen to several hundred $\mu g \cdot kg^{-1}$, with higher values in the objects fertilized with manure and the lowest in the variants with mineral fertilization. In accordance with applicable regulations regarding soil contamination assessment, no exceedances of permissible PAH concentrations were observed in any of the fertilization and plant selection options. The research results confirm the usefulness of long-term field experiments in assessing the cumulative impact of agricultural practices on soil quality and indicate the need to take into account the type of fertilization and crop structure in the long-term management of agroecosystems.

25. The productivity of maize cultivated in multi-year monoculture depending on soil presowing methods

Jerzy Księżak*, Jolanta Bojarszczuk

Institute of Soil Science and Plant Cultivation - State Research Institute Puławy
*Department of Crops and Yield Quality *e-mail: jerzy.ksiezak.@iung.pulawy.pl*

Maize is a species, whose economic importance has significantly increased in recent years. It is used for feed, food purposes, or as an energy and industrial raw material. Grain, silage from whole plants or cobs, and green fodder constitute an energy feed for all types of animals, mainly cattle and pigs.

The aim of the study was to determined the maize yielding and determine changes in the soil environment caused by the cultivation of this species in monoculture using three methods of soil pre-sowing, and to compare them with crop rotation cultivation.

The study was conducted in the multi-year stationary field experiment established in 2004, which involved maize cropped continuously and rotated with other crops. The field experiment was carried out since 2004 to 2025 at the Agricultural Experimental Station (AES) of the Institute of Soil Science and Plant Cultivation in Grabow, the Mazowieckie voivodeship (51°23'N; 21°38'E), Poland.

The experimental scheme involved four treatments: maize monoculture – direct sowing; maize monoculture – full tillage; cultivation in crop rotation (spring barley winter wheat-maize) – full ploughing tillage and crop rotation and reduced tillage (grubbers). The research was conducted on a grey brown podsolic soil formed from light loam.

The experiment was established with the method of long strips with the mirror image of treatments.

The grain yield and its structure were demonstrated.

The assessment of the production effects of growing maize in monoculture and crop rotation was made based on the obtained grain yields. Maize yields was significantly influenced by the course of weather conditions during the growing season and the methods used to prepare the soil before sowing. On average, over the whole period covered by the studies, the best yields (grain and straw) were obtained grown maize in monoculture using a reduced cultivation method. Yields of maize grown in this method were about 27% higher than maize grown in monoculture with direct sowing. Moreover, during this period, the average grain yields of maize grown in monoculture using plow cultivation and in crop rotation were about 18% higher than maize cultivated in direct sowing.

Maize yielded the lowest regardless of the method of soil preparing for sowing in years with unfavorable weather conditions during the growing season (2006, 2015), while the highest yields were recorded in years with greater sum of precipitation and its even distribution (2016, 2018, 2021, and 2023). Average yields in those years exceeded 12 tons per hectare. In years with low sum of precipitation, maize cultivated in monoculture using direct sowing yielded significantly better, while in years with favorable sum of precipitation, it performed better both in monoculture with full cultivation and in crop rotation. Relatively low grain yields, especially of spring barley, resulted in lower cereal unit yields under crop rotation compared to maize cultivated in monoculture, both with full plowing and reduced soil tillage, including direct sowing.

The lowest yields of cereal units, regardless of the method of soil preparing for sowing, were recorded in 2006 and 2015, during periods of significant sum of precipitation deficite in the growing season.

Dzienia and Sosnowski (1991) reported that in warm years, maize yielded better after using no-till sowing, whereas in cold and wet years, yields were higher where maize cultivated in monoculture used full tillage. According to Pabin et al. (2003), the grain yields of maize cultivated in monoculture compared to maize cultivated in crop rotation decrease only in the first three years. Dubas and Szulc (2006) found that regardless of the method of soil preparation, maize yields in monoculture decreased in the following years, with more pronounced reductions in the case of zero-tillage and direct sowing than in ploughing cultivation. Torbert et al. (2001) obtained higher maize biomass and grain yields in a zero-tillage method.

26. The influence of long-term crop rotation on selected physical properties of light soil

Anna Lehmann-Skoczylas, Wiesław Wojciechowski, Roman Wacławowicz

Wrocław University of Environmental and Life Sciences, Institute of Agroecology and Plant Production, pl. Grunwadzki 24A, 50-363, Wrocław, Poland, anna.lehmann-skoczylas@upwr.edu.pl

Conventional crop production often promotes improperly designed crop rotations and even long-term monocultures. This leads to soil degradation, including depletion of organic matter content and loss of its production potential. The use of these agrotechnical practices also results in increased pest pressure, which consequently translates into reduced yields.

The unfavorable condition of the soil environment necessitates regenerative measures, including the use of thoughtful crop rotations and the inclusion of catch crops. These measures, aimed at protecting the natural environment and improving the natural fertility of agricultural soils, are fully aligned with the principles of sustainable agriculture. Proper crop rotation also helps reduce pest pressure, thus improving the overall condition of the agroecosystem. To improve the position in the crop rotation, catch crops are increasingly being incorporated into agricultural practices. They play a significant role in protecting soil from degradation – they improve soil structure, reduce compaction, and protect against erosion, while also exhibiting phytosanitary benefits by limiting pest development (Dopka et al., 2013). By enriching the soil with organic matter and nutrients, they can also provide an alternative to manure deficiencies on farms specializing solely in crop production (Lehmann-Skoczylas, 2020).

In a long-term field experiment conducted on light soil in 2012-2015 and 2023-2025, the effects of crop rotations with different shares of cereals in the cropping structure (from 50 to 100%) and with the inclusion of catch crops, white mustard or a mixture of yellow lupine and field pea, were examined with respect to selected physical soil properties, including moisture, porosity, compaction and soil structure parameters. Thirteen crop rotations were evaluated: 1) potato^{++}-oat-field pea-rye, 2) potato-oat-rye, 3) potato-oat-rye + mustard catch crop, 4) potato-oat-rye + legume catch crop, 5) potato-rye, 6) potato-rye + mustard catch crop, 7) potato-rye + legume catch crop, 8) oat-rye, 9) oat-rye + mustard catch crop, 10) oat-rye + legume catch crop, 11) rye monoculture, 12) rye monoculture + mustard catch crop, and 13) rye monoculture + legume catch crop. In each of the analyzed crop rotations, soil samples were collected after the harvest of winter rye.

It was shown that deviating from the correct crop rotation usually had a negative impact on the studied soil properties, although the observed differences were not always statistically significant. In the first period of the study, the highest soil compaction was observed in the oat-rye two-field rotation, while in 2023–2025, it was observed in the three-field rotation. Regardless of the analyzed time period, the highest soil moisture content in both layers was observed in the oat-rye rotation. The highest capillary porosity was observed in the three-field rotation in the initial years of the study, while in the final years, it was observed in the Norfolk-type crop rotation and in the rye monoculture. Catch crops generally had a positive effect on the analyzed parameters, often equaling the results obtained in a corect crop rotation, in which the full dose of manure was applied.

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27. Precision agriculture technologies for supporting crop management decisions: a case study based on UAV imagery and autonomous field robots

Renata Leszczyńska[1], Danuta Leszczyńska[2]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland; e-mail: renata_leszczynska@sggw.edu.pl
[2] Institute of Soil Science and Plant Cultivation, Czartoryskich 8, 24-100 Puławy, Poland

Precision agriculture technologies are increasingly used to improve the efficiency of crop production and to support decision-making under variable soil and weather conditions. Among these technologies, unmanned aerial vehicles (UAVs) and autonomous field robots provide new opportunities for monitoring crop status, identifying spatial variability within fields and optimizing selected agronomic practices (Velusamy et al., 2022; Käthner et al., 2023)**.** The aim of this study was to present a case study of the potential application of UAV imagery and autonomous field robots in crop monitoring and management.

The case study focuses on the use of UAV-based remote sensing and an autonomous field robot as complementary tools in precision agriculture. UAV imagery, including RGB and multispectral data, can be used to assess crop canopy development, calculate vegetation indices and identify areas with reduced plant vigour (Li et al., 2020**)**. Such information may support decisions related to fertilization, irrigation, plant protection and yield prediction. Autonomous field robots, such as robotic platforms used for seeding, mechanical weed control or site-specific field operations, may contribute to reducing labour requirements, improving the precision of treatments and limiting soil compaction caused by repeated machinery traffic.

The presented case study indicates that the integration of UAV data and robotic technologies may improve the spatial understanding of crop variability and support more sustainable crop management. However, the practical implementation of these tools depends on data quality, the availability of technical expertise, investment costs and the possibility of linking remote sensing information with field operations. Therefore, precision agriculture technologies should be considered not only as separate tools, but as elements of an integrated decision-support system adapted to specific field and farm conditions.

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28. Influence of diversified seed material on canopy characteristics and yielding of sugar beet

Joanna Leśniewska-Mućko[1], Zdzisław Wyszyński[1], Kinga Noras[2], Beata Michalska-Klimczak[1]

[1] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland
[2] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Biometry, Nowoursynowska 159 St., 02–776 Warsaw, Poland

The aim of the study was to assess the influence of diversified seed material on the formation of canopy spatial characteristics, plant development, yielding and technological quality of sugar beet roots. The research was conducted in 2016–2018 as a series of strict field experiments at the experimental fields in Miedniewice, belonging to the Experimental Station of the Institute of Agriculture of Warsaw University of Life Sciences. The experiment was established in a randomized block design with three replications. The experimental factor consisted of eight types of seed material differing in cultivar, seed preparation technology, seed size and breeding origin. The study included commercial seeds of the cultivars Hunor, Jagusia and Janosik, Janosik seeds primed using the Quick Beet technology, Janosik seeds of high calibration, 4.0–4.2 mm, and low calibration, 2.5–3.0 mm, as well as two F6 breeding lines, Flog141 and Flog142. Seeds were precision-sown at a depth of 3 cm, with 45 cm row spacing and 18 cm spacing between seeds in the row. During the growing season, detailed observations were carried out on plants from the fourth row of each plot, excluding 1-metre border strips. The assessment included field emergence capacity, emergence rate and uniformity calculated using the Pieper coefficient, number of leaves per plant 40 days after sowing, living area of individual plants and the centrality coefficient of plant position within the occupied area. At harvest, the final plant density, root yield, leaf yield and mean root mass were determined. In addition, root quality parameters were analysed, including sucrose content and the content of molasses-forming compounds, i.e. α-amino nitrogen, sodium and potassium. Biological and technological sugar yields were calculated on the basis of yield and quality parameters. The obtained data were subjected to analysis of variance, and the significance of differences between means was verified using Fisher's LSD test at the significance level of $\alpha = 0.05$. The results showed that the type and quality of seed material significantly affected the development of the sugar beet canopy and the final production effects. The highest technological sugar yield, amounting to 13.5 $t \cdot ha^{-1}$, was obtained for the cultivar Hunor, which indicates its high production potential under the conditions of the experiment. Within the Janosik cultivar, seed calibration had a clear effect on plant performance. The use of high-calibrated seeds resulted in a technological sugar yield higher by 2.0 $t \cdot ha^{-1}$ compared with low-calibrated seeds. This confirms that larger, well-developed seeds may ensure better initial plant growth, more favourable canopy structure and higher final productivity. The application of Quick Beet seed priming technology also had a positive effect, increasing technological sugar yield by 4.5% in relation to standard commercial seeds of the same cultivar. The obtained results indicate that rapid and uniform emergence, balanced early leaf development and more favourable spatial distribution of plants in the row are important determinants of yield formation in sugar beet. The study confirmed that cultivar choice, seed size and pre-sowing seed preparation are key factors affecting canopy architecture, root yield and technological sugar yield. The use of high-quality seed material may therefore contribute to improved crop uniformity and greater efficiency of sugar beet production.

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29. Cation exchange capacity under long-term application of pig slurry and mineral fertilizers

Remigiusz Łukowiak[1], Lukáš Hlisnikovský[2], Przemysław Barłóg[1]

[1]Institution, Department of Agricultural Chemistry and Environmental Biogeochemistry, Poznan University of Life Sciences, Wojska Polskiego 71F, 60-625 Poznan, Poland; remigiusz.lukowiak@up.poznan.pl.
[2]Institution, Department of Nutrition Management, Crop Research Institute, Drnovská 507, CZ-161 01 Prague 6, Ruzyně, Czechia

Cation Exchange Capacity (CEC) is a key indicator of soil fertility, reflecting the soil's ability to retain and supply essential nutrient cations to crops (Ćirić et al., 2023). Although long-term slurry application generally increases SOM and may enhance CEC, the durability of this effect, its impact on soil acidification, and its dependence on soil type remain unclear (Yost et al., 2022; Barłóg et al., 2025). Uncertainty is even greater when slurry is applied cyclically only to root crops in long-term rotations, as this "pulsed" input of organic matter and base cations introduces temporal variability. It is still unknown whether such a system leads to a sustained reduction in Al^{3+} activity or only a temporary effect. This study hypothesized that the regular application of pig slurry (PS) only to root crops within a nine-year rotation including cereals and alfalfa, combined with mineral NPK fertilization, would enhance soil fertility to a greater extent than the exclusive use of mineral NPK fertilizers. The objective of the study was to evaluate the effects of PS application and different NPK rates on: (i) soil organic carbon content; (ii) soil reaction (pH); and (iii) exchangeable cation content. The hypothesis was tested using data from a 65-year long-term field experiment established in 1955 in Prague-Ruzyně, Czechia. Field Strip III was selected for analysis. This strip represents the so-called "Classical Crop Rotation," comprising 45% cereals, 33% root crops, and 22% legumes. For the purpose of the study, we evaluated 10 selected fertilization treatments: $N_0P_0K_0$; $N_1P_1K_1$; $N_3P_2K_2$; $N_4P_2K_2$; PS+$N_0P_0K_0$; PS+$N_1P_1K_1$; PS+$N_3P_2K_2$ and PS+$N_4P_2K_2$; where PS denotes for pig slurry application, and numbers 1–4 indicate different nutrient rates. PS was only applied during the sugar beet and potato growing seasons. The experiment was conducted on soil classified as Orthic Luvisol, according to World Reference Base for Soil Resources (WRB). Soil samples were collected in early spring, before the start of vegetation (in February), and over two years: 2020 and 2021. Soil samples were taken at two depths: 0-30 cm (topsoil) and 31-60 cm (subsoil). Basic cations and CEC were determined in 1 M NH_4OAc, and the acidic cations in a 1 M KCl solution. The total soil carbon (TSC) content was determined using an ELTRA CS-2000 analyzer. The studied traits were significantly affected by fertilization, particularly in the 0–30 cm soil layer. The regular application of PS resulted in a significant reduction in pH compared to plots without manure, regardless of soil depth. The application of NPK fertilizers also had a negative effect on pH, especially in plots treated with PS. The lowest pH value was recorded in the PS+$N_4P_2K_2$ treatment. Simultaneous application of PS and NPK fertilizers increased TSC. The greatest difference in TSC was found between the control – $N_0P_0K_0$ (13.35 g kg^{-1}) and the PS+$N_3P_2K_2$ treatment (14.88 g kg^{-1}). Changes in soil reaction (pH) and TSC were associated with changes in CEC and in the composition of exchangeable cations. As soil pH decreased, the proportion of exchangeable calcium in the CEC decreased, while the proportion of exchangeable aluminum (Al^{3+}) increased. The content of exchangeable potassium (K) was positively related to the rates of this nutrient applied to the soil with fertilizers.

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30. The efficiency of organic waste utilization in the production of biomass from selected C4 grass species

Elżbieta Malinowska[1], Milena Truba[1]

[1] *Institute of Agriculture and Horticulture, University of Siedlce, Bolesława Prusa 14, 08-114 Siedlce, Poland, e-mail elzbieta.malinowska@uws.edu.pl*

The dynamic development of the bioenergy sector makes biomass a key renewable energy source (Lewandowski et al. 2003). Perennial grasses with C4 photosynthesis, such as giant miscanthus (*Miscanthus x giganteus*), Chinese miscanthus (*Miscanthus sinensis*), prairie spartina (*Spartina pectinata*) and switchgrass (*Panicum virgatum*), are a valuable source of lignocellulosic biomass. Their yield and chemical composition are closely dependent on the availability of nitrogen in the soil.

The aim of the study was to assess the impact of organic waste with fertilising properties in the form of municipal sewage sludge and mushroom substrate on the N, K, S, Cl, C and H content in the biomass of *Spartina pectinata* and *Panicum virgatum* L. var. Northwind.

The field experiment was established in 2018 at the research facility of the University of Siedlce (52°17'N, 22°28'E). The experiment was conducted in a randomised block design with four replicates on anthropogenic soil of the cultivated soil type (hortisol subtype), produced from heavy clay sand. The test plants were: switchgrass (Northwind variety) and prairie cordgrass. Three grass rhizomes were planted per m² (approx. 30,000 per ha). The study used different variants of organic waste, balanced in terms of nitrogen dose (170 kg N · ha^{-1}):

- Control (no fertilizer treatment);
- Municipal sewage sludge, introducing 170 kg N · ha^{-1} (0.907 kg of sludge per plot, i.e., 4.54 Mg · ha^{-1}), (SS);
- Municipal sewage sludge + mushroom substrate, introducing 170 kg N · ha^{-1}, 75% was sewage sludge and 25% mushroom substrate (0.683 kg + 1.40 kg per plot, i.e., 3.38 Mg · ha^{-1} + 7 Mg · ha^{-1}), (SS75 + SMS25);
- Municipal sewage sludge + mushroom substrate, introducing 170 kg · N ha^{-1}, 50% was sewage sludge and 50% mushroom substrate (0.454 kg + 2.80 kg per plot, i.e., 2.25 Mg · ha^{-1} + 14 Mg · ha^{-1}), (SS50 + SMS50);
- Municipal sewage sludge + mushroom substrate, introducing 170 kg N · ha^{-1}, 25% was sewage sludge and 75% mushroom substrate (0.227 kg + 4.20 kg per plot, i.e., 1.13 Mg · ha^{-1} + 21 Mg · ha^{-1}), (SS25 + SMS75);
- Mushroom substrate, introducing 170 kg N · ha^{-1} (5.60 kg per plot, i.e., 28 Mg · ha^{-1}), (SMS).

Organic waste materials (municipal sewage sludge and mushroom substrate) were introduced once in 2018 in the spring, before the grass was planted.

Test plants were collected annually in December 2018 (year I), 2019 (year II) and 2020 (year III). Then, a representative sample of plants consisting of 5 leafy shoots was taken from each plot and the dry weight was determined using the oven-weighing method after drying at 105oC until a constant weight was obtained. The total (overall) content of selected elements: N, K, S, Cl, C and H was determined in the appropriately prepared plant material using various analytical methods.

The chlorine content in the above-ground parts of the test plants was highest in the first year of the study. Chlorine is an element that has a very strong effect on the corrosion of heating equipment, hence its excessive content in biomass is undesirable. It can also cause a decrease in the melting point of ash and deposits on the surface, hindering heat exchange. The highest average Cl content over the three years of research was found in the biomass of both grasses treated with municipal sewage sludge, and the lowest after treatment with mushroom substrate. The content of sulphur, hydrogen, nitrogen and potassium in the biomass was highest in the first year of cultivation and lowest in the third year.

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31. Assessment of the durability of selected grass species in anthropogenically modified soil conditions depending on silicon application

Grażyna Mastalerczuk, Barbara Borawska-Jarmułowicz, Ewa Szara, Aneta Perzanowska

Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail:grazyna_mastalerczuk@sggw.edu.pl

The study aimed to determine the effect of foliar application of silicon nanoparticles on plant viability, above-ground mass, and weed infestation of forage grass sward. The durability of plants was assessed in single-species sowings in the years 2018-2023 on soil anthropogenically transformed as a result of mixing the top layer with construction waste (fragments of bricks and concrete). The soil was alkaline (pH_{KCl} 7.3)and was characterized by a low content of available forms of phosphorus, medium potassium, and high magnesium. Three aggregate fractions dominated the soil structure: 3-1 mm, <0.25 mm, and >10 mm.

The study included four species of forage grasses: *Festuca arundinacea* (cv. Odys), *Dactylis glomerata* (cv. Bepro), *Festulolium braunii* (cv. Sulino), and *Lolium perenne* (cv. Gagat). Depending on weather conditions, single-species sowings were mown two or three times during the growing season. A plant growth enhancer containing silicon nanoparticles (NanoFyt Si) was foliar applied at two levels: no Si and Si application (twice before each cut: 14 and 7 days). The soil water properties, degree of soil cover with plants, relative chlorophyll content, leaf area index (LAI), aboveground biomass, and the share of unsown species in the sward were determined.

The research showed that after six years of utilization, *D. glomerata* and *F. arundinacea*, due to the greater durability of plant cover and stable share in the sward, were more suitable for cultivation on anthropogenically transformed soil than *F. braunii* and *L. perenne*. They were characterized by similar aboveground mass and good soil cover with plants. The use of a preparation containing silicon nanoparticles in grass sowing increased the values of LAI index and plant mass. It also had a positive impact on the degree of soil cover with plants.

32. Effect of different tillage and mustard cover crops on soil health: microbial diversity and pathogen suppression

Neringa Matelionienė[1], Gražina Kadžienė[1], Arman Shamshitov[1], Inga Tamošiūnė[1], Danas Baniulis[1], Skaidrė Supronienė[1]

[1]Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344 Kedainiai, Lithuania

Tillage intensity and cover cropping are key agronomic practices shaping soil microbial diversity and community composition. Brassica cover crops, including white mustard, are widely recognized for their biofumigation potential, which can suppress soil-borne pathogens and alter microbial community structure. This study evaluated the combined effects of tillage systems and mustard cover cropping on soil bacterial and fungal diversity, with particular emphasis on pathogenic fungi in a wheat-based cropping system. Soil samples were collected during spring, summer, and autumn in 2024 and 2025. Microbial DNA was extracted from lyophilized soil samples, and microbial diversity was analyzed using 16S rRNA and ITS metabarcoding with Illumina NovaSeq sequencing. Fungal alpha diversity did not differ in 2024. While at genus-level Shannon diversity was significantly higher under no-tillage compared with conventional tillage in 2025. PERMANOVA analysis revealed that tillage and combination with cover cropping influenced soil fungal β-diversity in 2025. In contrast, bacterial alpha diversity was significantly affected by tillage intensity and combination with white mustard cover cropping in both years. However, bacterial beta diversity did not differ among treatments. Among the twenty most abundant fungal genera, we identified potential plant pathogens: Gibellulopsis, Fusarium, Didymella, Plectosphaerella and others. Seasonal changes in the DNA abundance of pathogens were quantified using qPCR. The DNA amount of Fusarium culmorum during summer was significantly influenced by tillage system in both years, with an increase observed in 2025, particularly under conventional tillage. The DNA content of Didymella pinodes was lowest in spring and increased markedly during summer in both years. Similarly, Plectosphaerella cucumerina abundance was significantly lower in both no-till treatments compared with reduced tillage combined with cover cropping. Overall, these findings demonstrate that tillage practices and white mustard cover cropping influence soil microbial diversity and pathogenic fungal abundance, but the effects depend on year, seasonal conditions and pathogen species.

33. Reduced nitrogen fertilization and diversified crop rotations with legumes: effects on winter wheat yield and grain quality under different tillage intensities

Klaudija Meižienė[1], Gražina Kadžienė[2], Agnė Veršulienė[3]

[1,2,3] Lithuanian Research Centre for Agriculture and Forestry (LAMMC), Instituto al. 1, Akademija, LT-58344 Kėdainiai dist., Lithuania, e-mail – klaudijameiziene@lammc.lt

Conservation tillage and the use of legume-based cover crops or undersowing systems are increasingly promoted as sustainable strategies to maintain soil fertility, improve nitrogen supply, and stabilize crop productivity while reducing external inputs. Legume intercropping and perennial forage legumes can enhance soil nitrate nitrogen availability, suppress weeds, and contribute to cereal yield formation, particularly in low-input systems (Arlauskienė et al., 2021a; Arlauskienė et al., 2021b). Nitrogen fertilization remains one of the key factors determining wheat productivity and grain protein accumulation, although its effectiveness strongly depends on environmental conditions and management practices (Jarecki, 2024; Gaile et al., 2023). However, the effectiveness of these practices depends strongly on tillage intensity, residue management, and fertilization level. Therefore, long-term field experiments are essential to evaluate the combined effects of reduced tillage, legume integration, and nitrogen management on agroecosystem productivity and grain quality.

Field experiments are being conducted at the experimental field of the Lithuanian Research Centre for Agriculture and Forestry (LAMMC), Institute of Agriculture, Akademija, Kėdainiai district municipality. The study aims to evaluate the effects of different tillage intensities, inclusion of cover crops and legumes in crop rotation, and reduced nitrogen fertilization on soil fertility, carbon and nitrogen balance. The experiment is arranged as a split-split-plot design with four replications. Winter wheat cultivar 'Lakaja' was grown under conventional tillage, reduced tillage, and no-tillage systems within integrated and traditional cropping technologies, with or without spring nitrogen fertilization reduced by 30 %.

In 2025, fertilized plots produced higher winter wheat grain yields compared to non-fertilized treatments across both cropping systems and tillage methods. Under fertilization, yields generally ranged from about 7.0 to 7.5 t ha^{-1}, whereas non-fertilized treatments produced approximately 6.1– 6.8 t ha^{-1}. In the integrated system, reduced tillage and conventional tillage showed similar or slightly higher yields compared with no-till, particularly in non-fertilized conditions. In the traditional system, the highest yields were observed in fertilized no-till plots. In the integrated crop management system, the difference between fertilized and unfertilized treatments was smaller, indicating that legumes and catch crops helped maintain relatively high yields even with reduced nitrogen input. In contrast, under the traditional system fertilization had a stronger effect on yield, especially under no-tillage, where the gap between fertilized and non-fertilized treatments was the largest.

Grain protein content, wet gluten content and sedimentation values were higher in fertilized treatments, with the highest values observed under conventional tillage, while no-till treatments tended to show lower protein-related quality parameters. Starch content showed an opposite tendency, being higher in non-fertilized treatments and particularly under reduced tillage and no-till systems.

These results summarize the first-year (2025) response of winter wheat yield and selected grain quality parameters to tillage intensity, cropping system and reduced nitrogen fertilization.

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34. Field evaluation of waste-based liquid organic fertilizers for blueberry cultivation

Edvinas Meižys[1], Donata Drapanauskaitė[2]

[1-2] Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344 Kėdainiai distr., Lithuania, email: edvinas.meizys@lammc.lt

Highbush blueberry cultivation requires acidic substrates and precise nutrient management to ensure optimal plant growth and productivity. Conventional fertilization practices rely heavily on synthetic mineral fertilizers, which may contribute to environmental concerns and increased production costs (Yang et al., 2021). The use of waste-derived liquid fertilizers represents a sustainable alternative, enabling nutrient recycling while supporting plant nutrition and reducing environmental impact (Zhang et al., 2021). However, their effects on nutrient availability and substrate chemical properties in acidic peat systems under field conditions remain insufficiently investigated. The aim of this study was to assess the effectiveness of acidified waste-derived liquid fertilizers in improving nutrient availability and influencing substrate chemical properties in highbush blueberry cultivation under field conditions in Lithuania.

A field experiment was conducted in 2025 in Daumantai Gardens community, Kėdainiai district, Lithuania, where a highbush blueberry plantation has been established. Laboratory analyses were carried out at the Agrobiology Laboratory of the Lithuanian Research Centre for Agriculture and Forestry (LAMMC). The experiment was established using the cultivar 'Bluecrop', a mid-early, high-yielding variety widely cultivated in Lithuania due to its winter hardiness, tolerance to drought and diseases, and suitability for commercial plantations.

Four fertilization treatments were applied in acidic peat trenches: (1) unfertilized control; (2) nitric acid–acidified compost extract; (3) sulfuric acid-acidified compost extract; (4) combined nitrogen and sulfur acids acidified compost extract. Fertilizers were applied once per month from April to July, after which fertilization was discontinued to allow plants to prepare for winter dormancy.

Substrate pH, as well as nitrogen (N), phosphorus (P), and potassium (K) concentrations in peat, were monitored monthly. Preliminary results showed that fertilization increased nutrient availability during the active growing season, with nitrogen- and nitrogen+sulfur-based treatments enhancing N levels, while sulfur-containing treatments influenced P and K dynamics. Fertilization also temporarily decreased substrate pH, particularly in sulfur-containing treatments, with gradual stabilization after the fertilization period.

These findings indicate that waste-based liquid fertilizers can effectively influence nutrient dynamics in acidic peat soils and may serve as sustainable alternatives to conventional fertilization for highbush blueberry cultivation, supporting plant nutrition while reducing dependency on synthetic inputs.

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35. Effects of cropping systems and tillage on yield and grain quality of winter wheat in central Poland

Beata Michalska-Klimczak[1], Aneta Perzanowska[1], Paweł Szacki[2], Patrycja Ojdowska[3], Marcin Studnicki[3]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland, beata_michalska-klimczak@sggw.edu.pl
[2]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, The Prof. Marian Górski Experimental Station in Skierniewice, Nowoursynowska 159 St., 02–776 Warsaw, Poland
[3]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Biometry, Nowoursynowska 159 St., 02–776 Warsaw, Poland

Cropping systems and tillage practices play a key role in determining both yield and grain quality of winter wheat under temperate climatic conditions. Conservation-oriented management practices are increasingly recognized as important components of sustainable crop production (Lal, 2015). The aim of this study was to evaluate the effects of cropping systems and tillage on yield components and grain quality based on a three-year field experiment (2021-2023) conducted in central Poland. Two cropping systems were compared: an intensive 3-field rotation including spring barley and winter oilseed rape, and an integrated 4-field rotation including sugar beet, spring wheat and legumes. Within each system, three tillage practices were applied: conventional ploughing, strip-till and reduced tillage.

The results showed that the intensive cropping system significantly increased grain yield compared to the integrated system. Among tillage practices, reduced tillage resulted in the highest yield, while conventional and strip-till systems showed similar performance. Yield differences were mainly associated with variation in the number of grains per spike and per unit area, whereas thousand grain weight remained relatively stable across treatments.

Grain quality traits were less affected by cropping systems but were significantly influenced by tillage practices. Strip-till and reduced tillage increased grain protein content, wet gluten content and sedimentation value compared to conventional ploughing. Similar responses of quality parameters to reduced tillage have been reported in previous studies (Dolijanović et al., 2025). In contrast, starch content and test weight were not significantly affected. Weak relationships between yield and grain quality traits indicate that both can be optimized simultaneously under appropriate management.

The results suggest that intensive cropping systems combined with reduced tillage can improve winter wheat productivity without compromising grain quality. These findings support the use of conservation tillage practices in sustainable cropping systems in Central Europe.

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36. Effects of sensor-based and NDVI-supported nitrogen management on soil nitrogen dynamics and use efficiency in winter wheat

Romutė Mikučionienė

Lietuvos Inžinerijos Kolegija | Higher Education Institution, Faculty of Environmental Engineering, Liepų g.1, Girionys, Kaunas dirst., LT- 53101, Lithuania, romute.mikucioniene@lik.tech

To mitigate nitrogen leaching, non-contact methods for determining crop nitrogen demand are increasingly employed, enhancing the efficiency of farm resource utilization and providing additional agronomic benefits, including increased and improved yield quality as well as reduced fertilizer inputs. This study evaluated innovative nitrogen management technologies in winter wheat, including real-time optical nitrogen sensors equipped with target rate and two-point calibration algorithms, as well as a satellite-based NDVI digital platform. Field experiments conducted in 2022–2023 under contrasting weather conditions demonstrated that sensor-based variable-rate fertilization ensured precise nitrogen allocation aligned with plant demand, particularly during the critical stem elongation stage (BBCH 33–34).

The results clearly showed that nitrogen rates calculated using the target rate and two-point algorithms were applied accurately to the required locations and quantities, leading to more uniform plant nutrition. These findings indicate that nitrogen sensors significantly improve nitrogen use efficiency and support the development of a more productive crop structure.

In 2022, nitrogen sensors increased grain yield by 3–6% while reducing nitrogen fertilizer consumption by 2–13%, depending on the applied algorithm. The greatest fertilizer savings (13%) were achieved with the two-point calibration algorithm, while both the target rate algorithm and the four-point measurement range also resulted in 5–6% higher yields with reduced fertilizer inputs. Fertilization based on NDVI satellite data produced yields comparable to those obtained with sensor-based fertilization but reduced fertilizer use by 7%, highlighting the potential of satellite imagery under favourable conditions.

In 2023, a similar pattern was observed: yield increases again reached 5–6%, and nitrogen savings ranged from 6–10%. However, unstable spring weather conditions hindered the acquisition of high-quality satellite NDVI images, resulting in less reliable recommendations. This emphasized the superiority of real-time nitrogen sensors, whose performance remained stable regardless of cloudiness, illumination, or rainfall. Sensors registered a rapid increase in nitrogen demand during the stem elongation and booting stages (BBCH 39–51), particularly at the onset of drought, confirming their sensitivity to real-time physiological changes in the crop.

Overall, nitrogen sensors equipped with algorithm-based calibration, together with satellite-derived NDVI indices, enabled adjustments to fertilization plans and allowed the precise allocation of fertilizers in both location and quantity. Sensor-based systems provided more accurate and resource-efficient outcomes than satellite-based digital tools. The results indicate that excessive nitrogen application and crop lodging were successfully controlled, grain yield increased by 3–6%, and fertilizer use was reduced by up to 13%.

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37. Comparison of the impact of long-term use of tillage systems on some soil chemical properties in integrated farm management

Szymon Młynek[1], Irena Suwara[1]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mail: szymon_mlynek@sggw.edu.pl

Modern agriculture should be based on the principle of sustainable development, and consequently, it should not only provide high and stable yields but also care for the natural environment, including the soil. The method of cultivation directly affects the soil environment and, consequently, its chemical properties.

The aim of this study is to compare the impact of three different tillage systems (conventional plough tillage - CT, ploughless tillage with a cultivator - PT and strip-till - ST) on the most important chemical properties of the soil, from the perspective of proper crop growth and development, as well as soil health. Conventional tillage involved the use of a moldboard plough to a depth of 20 cm. Ploughless tillage was performed with a cultivator to a depth of 20 cm, and strip-till cultivation was carried out with a strip-till Mzuri cultivator.

The research was conducted on an experiment arranged as a Randomized Complete Block Design (RCBD) established in 2011 at the Experimental Station of the Warsaw University of Life Sciences in Miedniewice on Luvisol soil (according to the WRB classification) in a four-field, integrated crop rotation including sugar beet, spring wheat, soybean and winter wheat.

Soil samples were collected from each plot after harvest soya bean in 2024 and after winter wheat in 2025 to a depth of 0-10 cm and 10-20 cm. This paper presents the results of the following soil chemical properties: soil reaction (pH) in 1 M KCl dm^{-3} (determined by the potentiometric method after extraction in 1 M KCl); content of soil organic carbon, total nitrogen and total sulfur (analyses performed using the CNS tool); content of available macro-elements P and K (Mehlich III extraction method and measured using ICP-OES instrument). A two-factor analysis of variance with repeated measurements (two-factor mixed design ANOVA) was used to analyze the effect of tillage treatments on soil chemical properties at different soil depths (0-10 cm and 10-20 cm).

Soil reaction (pH in 1 M KCl) was significantly influenced by tillage system and soil depth. Conventional tillage (CT) consistently resulted in lower acidity than ploughless tillage (PT) and strip-till (ST), with this pattern being evident at both the 0–10 cm depth (pH 4.94 in CT, 4.20 in PT and 4.20 in ST) and the 10–20 cm depth (pH 4.99 in CT, 4.52 in PT and 4.25 in ST), indicating a consistent tillage effect across soil depths. Soil organic carbon content and total nitrogen content were significantly affected by tillage system, soil depth, and their interaction. The use of ST cultivation resulted in significantly higher soil organic carbon content at the 0-10 cm depth (10,23 g kg^{-1}) compared to CT (6,67 g kg^{-1}) and PT (8,62 g kg^{-1}). At the 10-20 cm depth the highest content of organic carbon was found in CT (6,57 g kg^{-1}) and this value was significantly higher than in ST (6,01 g kg^{-1}). In ST (0-10 cm depth) was found significantly higher content of total nitrogen (1,08 mg kg^{-1}) compared to 0,77 g kg^{-1} in CT and 0,95 g kg^{-1} in PT. At the 10-20 cm depth content of total nitrogen in CT (0,77 g kg^{-1}) was significantly higher than in ST (0,71 g kg^{-1}). Total sulfur content was significantly affected by soil depth, and interaction of system and soil depth. The use of CT cultivation resulted in significantly lower total sulfur content at the 0-10 cm depth (132,3 mg kg^{-1}) compared to ST (154,4 mg kg^{-1}) and PT (145,9 mg kg^{-1}). Content of available phosphorus and potassium were significantly affected by tillage system, soil depth, and their interaction. In CT (0-10 cm depth) was found significantly lower available phosphorus content (214,6 mg kg^{-1}) compared to ST (285,3 mg kg^{-1}) and PT (268,5 mg kg^{-1}). In contrast, no significant differences in available phosphorus content were observed among tillage systems at the 10–20 cm depth. Significantly lower available potassium content was found in CT at the 0-10 cm (165,2 mg kg^{-1}) compared to ST (308,6 mg kg^{-1}) and PT (271,8 mg kg^{-1}), as well as at the 10-20 cm depth (153,7 mg kg^{-1}) compared to 213,3 mg kg^{-1} in ST and 189,2 mg kg^{-1} in PT.

38. Influence of recycled organic waste amendments on carbon dioxide (CO_2) and methane (CH_4) fluxes in sandy soil

Tomasz Niedziński[1], Wiesław Szulc[1], Elena Maestri[2], Paolo Pesaresi[3], Stefan Shilev[4], Virmantas Povilaitis[5], Renaldas Žydelis[5], Monica Guarino Amato[6], Valeria Terzi[6], Stefania Tomasiello[7], Evelin Loit[7], Rocio Millán[8], Thomas Schmid[8], Aser Garcia[9], Mustafa Avci[10], Marina Caldara[2], Marta Marmiroli[2], Nelson Marmiroli[2], Beata Rutkowska[1]

[1]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska 159 St., 02–776 Warsaw, Poland, tomasz_niedzinski@sggw.edu.pl
[2]Consorzio Interuniversitario Nazionale per le Scienze Ambientali Unita' Locale Universita' di Parma, Parco Area delle Scienze, 43124, Parma, Italy
[3]University of Milano Bioscinces, Via Celoria, 26, 20133 Milano, Italy
[4]Agricultural University Plovdiv, 12 Mendeleev Str, 4000 Plovdiv Bulgaria
[5]Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344 Lithuania
[6]Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) Centro di ricerca per la zootecnia e l'acquacoltura (CREA-ZA) Via Salaria 31, 00195, 00015, Monterotondo, Italy
[7]University of Tartu, Narva mnt. 18, 51009 Tartu, Estonia
[8]CIEMAT Departamento de Medio Ambiente Avenida Complutense 40 , 28040, 28040 Madrid, Spain
[9]NEIKER, Animal Production, Berreaga 1, 48160 Derio, Spain
[10]Niğde Ömer Halisdemir University, 51240 Merkez, Yerleşke/Niğde, Turkey

Organic amendments derived from agricultural waste biomass can modify greenhouse gas fluxes in sandy soils by stimulating microbial respiration and potentially increasing short-term CO_2 emissions, while often enhancing soil carbon sequestration and reducing CH_4 emissions through improved aeration and stimulation of methanotrophic activity, particularly in the case of biochar (Jeffery et al., 2016; Cayuela et al., 2014; Soria et al., 2021). Therefore, the aim of the study was to determine the impact of different biomass amendments on carbon dioxide (CO_2) and methane (CH_4) fluxes in a field experiment conducted on sandy soil. At the Experimental Station of the Institute of Agriculture in Skierniewice, three composts were produced from agricultural waste. Compost 1 consisted of rye straw (50%), spent mushroom substrate (30%), and chicken manure (20%). Compost 2 comprised oat straw (50%), spent mushroom substrate (10%), chicken manure (30%), and Miscanthus straw (10%). Compost 3 contained rye straw (50%), spent mushroom substrate (10%), chicken manure (30%), and oat biochar (10%). Pellets and biochar were applied at rates corresponding to 5 Mg Corg ha^{-1} and 120 kg N ha^{-1}. Greenhouse gas emissions were measured in spring barley in 2024 at three growth stages according to the BBCH scale: shoot development (BBCH 35), flowering (BBCH 60), and seed development (BBCH 75). The highest mean methane uptake occurred in the treatment receiving biochar at a rate equivalent to 150 kg N ha^{-1} (−0.00514 g CH_4–C ha^{-1} d^{-1}), 26% higher than in the control. Similarly high uptake was observed under mineral fertilization (NPK), reaching −0.00503 g CH_4–C ha^{-1} d^{-1} (23% above the control). The lowest methane uptake was recorded after compost 3 application at 5 Mg Corg ha^{-1} (−0.00288 g CH_4–C ha^{-1} d^{-1}), 29% lower than in the control. Methane uptake increased during the second and third measurement periods, indicating seasonal variation in microbial activity.The mean soil CO_2 emission was 31.02 kg CO_2–C ha^{-1} d^{-1} and increased throughout the growing season, reaching the highest level in the third term (234% of the first), reflecting intensified microbial processes and organic matter mineralization. Overall, both methane uptake and CO_2 emissions depended on fertilization type and measurement timing. The authors acknowledge the financial support through the partners of the Joint Call of the Cofund ERA-Nets SusCrop (Grant N° 771134), FACCE ERA-GAS (Grant N° 696356), ICT-AGRI-FOOD (Grant N° 862665) and SusAn (Grant N° 696231)

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39. Manure stabilization rather than total nitrogen drives soil functioning and maize biomass response

Tomasz Niedziński[1], Martin Brtnicky[2], Jiri Holatko[2], Jiri Kucerik[2]

[1] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland
[2] Mendel University in Brno, Faculty of AgriSciences, Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, 613 00 Brno, Czech Republic

The fertilising value of cattle manure depends less on the total nutrient content of the material and more on how well it is stabilised before soil application. We tested manure from deep-bedding systems amended with wood chips of differing types and doses, and with biochar added either during fermentation or after maturation. The aim was to determine the effect of the stabilisation strategy on nitrogen speciation, soil biochemical functioning and maize biomass response.

After eight weeks of covered storage, all manure treatments were still not fully mature. They were dominated by ammonium, contained high levels of oxidisable carbon and showed limited humification, indicating incomplete stabilisation. The pH of manure was reduced by wood chips, as was the share of labile carbon. The effect of biochar depended strongly on the timing of its application. Biochar introduced during fermentation improved nitrogen stabilisation and carbon humification, whereas addition after maturation promoted ammonium accumulation and early nitrification.

Subsequent to soil application, initial manure pH proved incapable of predicting alterations to soil pH. Instead, microbial turnover of organic acids and cation exchange controlled soil reactions, altering phosphorus availability and shifting nitrogen forms. Although dehydrogenase activity increased, respiration and enzyme stoichiometry revealed microbial limitations in terms of carbon and phosphorus. These constraints likely reduced nutrient transfer efficiency, which explains why maize biomass did not increase despite the high nitrogen input.

Conclusion: Manure performance was driven primarily by stabilization status. It was also driven by microbial stoichiometric balance. Total nutrient concentration alone was not the main driver.

40. Carbon sequestration potential in Luvisols under long-term field experiment conditions – the role of crop rotation and fertilization

Jacek Niedźwiecki[1], Dorota Pikuła[2]

[1]Institute of Soil Science and Plant Cultivation- State Research Institute, Department Soil Science and Environmental Analyses, 24-100, Puławy, Poland, jacekn@iung.pulawy.pl
[2]Institute of Soil Science and Plant Cultivation- State Research Institute, Department of Fertilization and Nutrient Management, 24-100, Puławy, Poland

Enhancing soil organic carbon (SOC) stocks in agricultural soils is widely recognized as an effective strategy for mitigating atmospheric CO_2 concentrations and increasing the climate resilience of agroecosystems. Agricultural soils have considerable potential to function as carbon sinks; however, the magnitude and persistence of carbon sequestration depend strongly on management practices, the quantity and quality of organic inputs, and the stability of soil organic matter. The aim of this study was to evaluate the long-term effects of crop rotation and organic and mineral fertilization on SOC content, carbon stocks, and the stability of soil organic matter, and to identify management practices that promote sustainable carbon accumulation. The study is based on a long-term static field experiment established in 1979 at Grabów (central Poland) on a *Luvisol*. The experiment follows a three-factor design. The first factor comprises two crop rotations differing in their effects on the organic matter balance: a depleting rotation (A) and an enriching rotation (B), which includes a mustard catch crop and a grass–red clover mixture. The second factor consists of farmyard manure (FYM) applied every four years at rates of 0–45 $t \cdot ha^{-1}$, while the third factor includes differentiated levels of mineral nitrogen fertilization adjusted to crop requirements. Straw was not incorporated, and liming was not applied until 2020, allowing the long-term effects of organic matter inputs on SOC dynamics to be evaluated under minimally buffered soil conditions (Martyniuk et. al. 2019). The Grabów experiment has been included in European assessments estimating the carbon input required to achieve the target of increasing SOC stocks by 4‰ annually, highlighting its relevance for climate policy and sustainable agriculture (Bruni et al. 2022). Results from more than four decades of observations demonstrate that sustained inputs of fresh organic matter are the primary driver of SOC accumulation. The enriching crop rotation, particularly when combined with FYM application, significantly increased soil organic matter content and SOC stocks, whereas the depleting rotation resulted in limited accumulation or a decline in carbon levels. Crop rotations including high-biomass species and catch crops enhanced carbon inputs to the soil and improved the overall carbon balance. Management practices affected not only the quantity but also the quality and stability of soil organic matter (Pikuła, Ciotucha 2022). These changes were accompanied by improvements in soil biological activity and water retention. However, under conditions of high organic matter input, the absence of liming resulted in soil acidification and deterioration of selected soil properties, potentially limiting the long-term efficiency of carbon sequestration.

The findings indicate that effective and durable SOC sequestration in arable soils requires an integrated management approach combining carbon-enriching crop rotations, regular application of organic fertilizers, balanced mineral fertilization, and appropriate soil pH management. Long-term field experiments provide essential evidence for quantifying the carbon sequestration potential of agricultural soils and for developing management practices that support climate change mitigation while maintaining soil fertility and productivity.

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41. Stability of grain yield, yield components, and selected grain quality traits of winter wheat based on a 15-year field experiment

Patrycja Ojdowska[1], Adriana Derejko[1], Alicja Sułek[1], Marcin Studnicki[1]

[1] Department of Biometry, Warsaw University of Life Science, Warsaw, Poland
[2] Institute of Soil Science and Plant Cultivation – State Research Institute, Puławy, Poland

Ensuring consistent winter wheat performance under increasingly variable climatic conditions is a key challenge for modern agriculture. Long-term field experiments provide a unique opportunity to investigate how yield formation and grain quality respond to year-to-year environmental fluctuations. This study examined the long-term stability of winter wheat grain yield, major yield components, and selected technological quality traits using data from a field experiment carried out in Osiny (Poland) between 2007 and 2022 by the Institute of Soil Science and Plant Cultivation – State Research Institute.

Analyses focused on grain yield, number of spikes per unit area, number of grains per spike, thousand kernel weight, gluten content, gluten index, falling number, and sedimentation value. The temporal variability of these traits was quantified and their stability was characterized using statistical approaches that account for interannual differences and environmental influences.

Substantial year-to-year variation was observed for all analyzed characteristics; however, the degree of stability differed among traits. Yield components generally showed more consistent performance across years than total grain yield, suggesting a buffering role in yield formation under changing weather conditions. Quality parameters displayed diverse stability patterns, with gluten-related traits being particularly sensitive to environmental variation.

The results demonstrate that long-term datasets are essential for identifying traits with relatively high stability and for improving understanding of wheat responses to climatic variability. Such information can support breeding programs and management strategies aimed at developing more resilient winter wheat production systems.

42. Effect of an integrated cropping system on the stability of winter wheat yield

Patrycja Ojdowska[1], Beata Michalska-Klimczak[2], Adriana Derejko[1], Aneta Perzanowska[2], Marcin Studnicki[1]

[1] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Biometry, Nowoursynowska 159 St., 02–776 Warsaw, Poland
[2] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland

Climate change is increasing the frequency and intensity of weather extremes, posing a major challenge to stable crop production. Therefore, assessment of yield stability has become as important as the evaluation of mean yield levels. The aim of this study was to evaluate the effects of an integrated cropping system and tillage method on the yield stability of winter wheat. A long-term field experiment was conducted from 2012 to 2025 at the experimental station of the Warsaw University of Life Sciences (SGGW) in Miedniewice near Skierniewice, Poland. Two cropping systems, intensive and integrated, were compared in combination with conventional (plough-based) tillage and reduced tillage. Grain yield of winter wheat and its interannual variability were analyzed.

Yield stability was assessed using advanced statistical approaches, including the Shukla stability index, linear mixed-effects models, and Bayesian modeling, allowing for simultaneous consideration of fixed and random effects as well as interactions between experimental factors and environmental conditions.

The results indicated that the integrated cropping system contributed to higher yield stability of winter wheat compared with the intensive system, particularly under conditions of high weather variability. Moreover, significant differences in yield stability were observed between tillage methods, with reduced tillage frequently providing more stable yields than conventional tillage.

These findings demonstrate that combining integrated cropping systems with appropriately selected tillage practices can improve the resilience and yield stability of winter wheat, representing a promising strategy for sustainable crop production under ongoing climate change. In addition, the adoption of such management practices may reduce production risk and enhance the economic stability of farming systems. The long-term (13-year) nature of the experiment strengthens the reliability and robustness of the conclusions and supports their applicability under practical farming conditions.

43. Yield and grain quality characteristics of common wheat, durum wheat and spelt in organic and integrated farming systems

Krzysztof Pągowski[1], Beata Michalska-Klimczak[1], Zdzisław Wyszyński[1], Alicja Ponder[2], Ewa Rembiałkowska[2], Renata Kazimierczak[2], Ewelina Hallmann[2], Klaudia Kopczyńska[2]

[1] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Agronomy, Nowoursynowska 159 St., 02–776 Warsaw, Poland, e-mailkrzysztof_pagowski@sggw.edu.pl
[2] Warsaw University of Life Sciences – SGGW, Institute of Human Nutrition Sciences, Department of Functional and Ecological Foods, Nowoursynowska 159c St., 02-776Warsaw, Poland

Currently, consumers are paying increasing attention to the origin, quality and chemical composition of agricultural products. In assessing crop yields, great importance is attached to agricultural management systems. The significance of organic farming systems, which utilise natural processes occurring in the agroecosystem, is growing. There has been a steady increase in the area under organic cultivation, which in 2023 reached 98.9 million hectares worldwide and 19.5 million hectares in the EU, representing 2.1% and 10.9% of agricultural land, respectively. In Poland, organic farming covers 691,000 ha (4.9% of agricultural land), with cereals accounting for 30% of this area. The choice of a suitable variety has a significant impact on yield and grain quality characteristics within a given farming system. The study aimed to evaluate the yield and grain quality of the common wheat varieties Belissa and Symetria, the spelt varieties SM Orkus and SM Fides, and the durum wheat varieties SM Metis and SM Tetyda, grown under integrated and organic farming systems. In 2022–2023, a two-factor experiment was conducted with two separate blocks, the first located on a field under an integrated farming system and the second on a certified organic field. The varieties under study were randomised within the blocks. The experiment was carried out in three replicates. The fields were close together and had identical soil conditions. Yield, grain density, Zeleny sedimentation index, and the content of starch, protein, gluten and bioactive compounds (phenolic acids, flavonoids and carotenoids) in the grain were assessed. The average wheat grain yield across the study years and varieties in the integrated system was significantly higher by 276.4 $g \cdot m^{-2}$ (81.4%) than that obtained in the organic system. The protein and gluten content, as well as the Zeleny sedimentation index, were also significantly higher in grain from the integrated system, by 3.0 percentage points, 10.1 percentage points, and 17.7 ml, respectively (58.0%). The starch, flavonoid, and carotenoid contents were significantly higher by 3.2 percentage points, 2.5 mg/100 g, and 0.5 mg/100 g, i.e., 14.5% and 4.9%, respectively, in the organic system. Of the varieties studied, regardless of farming system and year, the highest grain yield was obtained for the common wheat varieties Symetria and Belissa, and the spelt variety SM Orkus, at 577.1, 552.3, and 556.9 $g \cdot m^{-2}$, respectively. A significantly lower grain yield was observed for the durum wheat variety SM Tetyda (352.8 $g \cdot m^{-2}$) and the spelt variety SM Fides (376.7 $g \cdot m^{-2}$). The SM Orkus variety was characterised by the highest protein content (13.0%), gluten content (29.5%) and Zeleny index (50.1 ml), regardless of the management system and year. The protein content was significantly lower in the SM Tetyda, Belissa, and Symetria varieties by 1.0, 1.6, and 2.7 pp, respectively, and the gluten content in the Belissa and Symetria varieties by 6.3 and 7.3 pp, respectively. In contrast, the starch content was highest in the Symetria variety (69.2%). It was higher by 2.1, 2.4 and 5.2 pp, respectively, compared to the SM Fides, SM Tetyda and SM Orkus varieties. An assessment of the occurrence of bioactive compounds in the grains of the tested wheat varieties indicates significant differences in flavonoids and carotenoids. The highest flavonoid content was found in the grain of the SM Orkus variety (21.8 mg/100 g). It was significantly higher by 4.8 and 7.0 mg/100 g, respectively, i.e. by 28.2 and 47.3% compared to the SM Fides and SM Tetyda varieties, and carotenoids in the Belissa variety were 12.3 mg/100 g, which was significantly higher by 1.9, 2.8 and 4.3 mg/100 g, i.e. by 18.3, 29.5 and 53.8% compared to the SM Metis, SM Tetyda and SM Orkus varieties.

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44. Some properties of bottom sediments in mid-field reservoirs in the aspect of their agricultural application

Krzysztof Pakuła, Robert Rosa, Jacek Sosnowski, Paweł Kifer

University of Siedlce, Faculty of Agricultural Science, Institute of Agriculture and Horticulture, Prusa 14, 08-110 Siedlce, Poland, e-mail krzysztof.pakula@uws.edu.pl

Sediments form on the bottom of water bodies as a result of the sedimentation of mineral and organic suspensions derived from the erosion of adjacent areas, as well as components precipitating from the water. The chemical composition of bottom sediments depends on natural factors (the geological structure of the water body bed, geomorphology, and climatic conditions) and anthropogenic factors (land-use patterns of surrounding areas, as well as industrial and agricultural pollution) (Kiani et al., 2021). Bottom sediments are an essential ecosystem component in the cycling of elements in the aquatic environment, serving as a site for their deposition, chemical transformation, and redistribution.

Macronutrients and micronutrients, including heavy metals, contained in sediments can accumulate in the trophic chain as a result of natural processes or dredging of water bodies. To determine the quality of sediments, chemical parameters are primarily used, as they indicate their ecological status and the possibility of their rational management (Kazberuk et al., 2021). A high heavy metal content may pose an obstacle to their agricultural utilization. Therefore, it is crucial to systematically examine the chemical composition of bottom sediments regarding the presence of various chemical forms of elements (sequential fractionation analysis), and the concentrations of heavy metals must not exceed the permissible limits for this type of material (Szara-Bąk et al., 2023).

The aim of this study was to determine the chemical composition of bottom sediments from small field reservoirs and assess their quality in terms of their potential use in improving soil fertility. Eight reservoirs, each with an area of 0.2-0.4 ha, located on agricultural land in the South Podlasie Lowland were selected for the study, from which average bottom sediment samples were collected from a depth of up to 20 cm. The macroelement content in the studied bottom sediments varied and, on average, fell into a series of decreasing values: Ca > N > P > Mg > K. A very high and high abundance of available forms of phosphorus, potassium, and magnesium was found, as determined by the Mehlich-3 method (Kęsik, 2016). The total heavy metal content varied and fell into a series of decreasing values: Zn > Pb > Cr > Ni > Cu > Cd. The content of these elements did not exceed the geochemical background value and did not pose a threat to the aquatic environment. A sequential fractionation analysis conducted according to the BCR procedure (Rauret et al., 1999) revealed the highest content of the tested heavy metals in the potentially stable fractions (F2 – reducible, oxide, and F3 – oxidizable, organic) and stable fractions (F4 – residual) in the environment, and the lowest in the readily soluble exchangeable fraction F1. This distribution indicates the stability of the chemical composition and the relatively low activity of the metal fractions in biogeochemical circulation. A quality assessment of the studied bottom sediments showed that they constitute a rich source of organic matter and available forms of macroelements, while the heavy metal content does not pose a barrier to their agricultural use.

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45. 40-year field experiments with crop rotations at the Agricultural Experimental Station in Grabów

Dorota Pikuła

Department of Fertilization and Nutrient Management , Institute of Soil Science and Plant Cultivation State Research Institute, Czartoryskich 8, 24-100 Puławy Poland, dpikula@iung.pulawy.pl

In agricultural research, strict field experiments are the most commonly used type of experiment. The oldest experiment still ongoing in Poland, which continued even during World War II, is a fertiliser and crop rotation experiment established in 1923 at the Experimental Station in Skierniewice, which belongs to the Warsaw University of Life Sciences (Marks et al., 2018). A similar experiment was set up in 1979 at the Agricultural Experimental Station in Grabów to study the effect of manure and mineral nitrogen on plant productivity and soil fertility. The Agricultural Experimental Station in Grabów is located in the Przyłęk municipality (Masovian Province), on the Radom Plain, close to the Kozienice Plain. The terrain is flat (Kondracki, 2009). Arable land accounts for 72% of the agricultural area, with the remainder consisting of average-quality meadows and pastures. The soils of the permanent grasslands are degraded black earth and muck soils. Arable land is dominated by medium podzolic soils (approximately 70%), which are mainly classified as good wheat and rye complexes (classes IIIa, IIIb and IV) (Witek, 1993). The agrometeorological conditions are close to optimal, with dry periods. Covering an area of over 2 hectares, the experiment includes two four-field crop rotations, A and B.In rotation A, which is defined as 'depleting' the soil of organic matter, the following crops are grown: grain corn (until 2007, potatoes); winter wheat; spring barley; and silage corn.

In rotation B, which is described as 'enriching' the soil with organic matter, the following crops are grown: grain corn (until 2007, potatoes); winter wheat and mustard, which are ploughed in as a catch crop; barley with clover undersown; and a mixture of clover and grasses. During the first two four-year crop rotations, the second factor in the experiment, apart from the rotation itself, was the level of manure fertilisation. This fertiliser was applied at doses of 0, 20, 40, 60 and 80 t for potatoes in both rotations (currently 0, 15, 25, 35 and 45 t) $t \cdot ha^{-1}$ every 4 years. From the third rotation onwards, another factor was introduced into the experiment: varying levels of mineral nitrogen fertilisation (N0, N1, N2 and N3, at 0, 50, 100 and 150 kg N per kg, respectively), adjusted to the nutritional requirements of the crops grown. The presentation introduced the most significant findings from 40 years of research into changes in the fertility of sandy soil.

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46. Structure of mineral fertilizers consumption in farms of the Podkarpackie Voivodeship

Anna Podleśna[1], Janusz Podleśny[2]

[1]Institute of Soil Science and plant Cultivation – State Research Institute, Czartoryskich 8 Str., 24-100 Puławy, Poland e-mail: ap@iung.pulawy.pl
[2]Institute of Soil Science and plant Cultivation – State Research Institute, Czartoryskich 8 Str., 24-100 Puławy, Poland e-mail:jp@iung.pulawy.pl

In the last years rapid changes taking place in Poland regarding the functioning of farms. One of them is concentration of production caused by its high specialization. It means decrease of total number of farms and origins farms with larger area and larger number of farms which conduct only plant or animal production. In regard to great dynamic ongoing changes there is lack of detailed data concerning the methods of plant production leading, in that mainly the use of mineral fertilization in modern farms differentiated in aspect of area and the size/kind of leading production. It was a cause of a analyse of the Podkarpackie Voideship, which is characterized with a great fragmentation of farms and the least amount of NPK consumption (Matyka et al., 2013).

The aim of these studies was the evaluation of mineral fertilizers use in farms of Podkarpackie Voideship in dependence on area size, crop structure and the level of obtaining yields.

The material source were the results of survey research performed at 40 farms in Podkarpackie Voideship, which were choose on the base of strictly defined criteria. This ensures both homogeneity control and variation of a sample. In spite of same limitations , the purposeful selection is frequently use to this kind of research because allows to know various dependences occurring in the studied population (Kołoszko-Chomentowska, 2013).

In these analysis were included typical agricultural farms with area from 10 to above 100 ha of arable land. To the analytical purpose farms were divided into five groups in dependence on their area: 10-20, 21-30, 31-50, 51-100 and above 100 ha. In the evaluation was also included crop structure, dose of NPK fertilization on 1 ha, structure of mineral fertilizers use and the level of yields obtained.

The analysis of farms carried out showed a great differentiation in the range of selected indicators concerning the mineral fertilizers use in dependence on crop structure and size of a farm. In the most farms the highest doses of nitrogen were applied, followed by smaller doses of potassium, and the smallest doses of phosphorus. It was found the significant dependency between area of arable lands and the amount of NPK used in plant fertilization. The least amounts of NPK were applied in the group of farms with 10-20 ha of area. With increasing surface area fertilizer use increased and it achieved the biggest value at farms with area above 100 ha. It was found the significant correlation between the amount of NPK application and the yield of selected crops. The analysis showed that the use of higher doses of NPK was economic justified because the increase of costs connected with higher dose of NPK was lower than the value of obtained yield increase. The conducted analysis gave important information on amount and structure of NPK used at farms of Podkarpackie Voivodeship. Moreover, the obtained data are the good base useful to another analysis concerned the evaluation of plant production in this region.

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47. The effect of mineral and organic fertilization on phosphorus concentration in different type of soils

Anna Podleśna[1], Janusz Podleśny[2]

[1]Institute of Soil Science and plant Cultivation – State Research Institute, Czartoryskich 8 Str., 24-100 Puławy, Poland e-mail: ap@iung.pulawy.pl
[2]Institute of Soil Science and plant Cultivation – State Research Institute, Czartoryskich 8 Str., 24-100 Puławy, Poland e-mail:jp@iung.pulawy.pl

Phosphorus is an essential nutrient for plant and animal life. However, in the last years share of soils with low and very low content of available phosphorus in some regions of Poland exceeds 40-50% (Rutkowska and Kopiński 2022). As the most important factors effecting phosphorus changes are assumed soil reaction and presence of other ions in the soil solution (Lemanowicz and Koper 2009). The aim of undertake studies was to evaluate the phosphorus concentration in different soils in effect of applying of sulfur fertilizers and manure.

The experiment was conducted at lysimetric station of Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, in the 3 successive years. The lysimeter plots have an area of $1m^2$ and depth of 1,3m. The first experimental factor was the type of soil: sandy, loess and loam. The second factor was fertilization: NPK, NPK + sulfur (S), NPK + farmyard manure (FYM) and NPK+S+FYM. The pH_{KCl} of soils before applying of fertilizers amounted: 6.1, 6.5 and 6.2, respectively for sandy, loess and loamy soil. Concentration of phosphorus (P_2O_5) in manure was 1,58 % at dry mass, and in soils: 31,9, 12,5 and 9,2 mg $\cdot 100\ g^{-1}$ soil, respectively for sandy, loess and loamy soil. Potato, pea and spring wheat were cultivated in the following years of research. Doses of N, P_2O_5 and K_2O were established on the base of soils fertility and nutritive requirements of plants and they amounted for potato: 90-90-90, 60-90-90 and 135-135-135 kg$\cdot$ ha^{-1}, for pea: 30-30-30, 20-25-40 and 65-90-65 kg$\cdot$ ha^{-1} and for wheat: 90-90-90, 40-60-80 and 120-140-120, respectively for sandy, loess and loamy soil. Manure in a dose 40t ha^{-1} was applied in the autumn 2008, before planting of potatoes, while doses of sulfur were the same for all soils and amounted 15, 20 and 25 kg$\cdot$ ha^{-1}, respectively for potato, pea and wheat. Triple superphosphate was used as phosphorus fertilizer in this research. The experiment was conducted at 3 replications for each fertilizer object. Concentration of available phosphorus (P_2O_5) at soil was performed according to Egner-Riehm colorimetric method and pH_{KCl} was evaluated with using the potentiometric method.

Applied fertilization caused the increase of P resources, especially in the loamy and loess soils, and in a consequence almost all soils showed high or very high content of this element. The highest mean concentration of phosphorus was further found in the sandy soil while the lowest in the loess soil. Beneficial effect of mineral sulfur (S) and manure (FYM) with NPK in comparison to alone NPK fertilization on P_2O_5 content was found mainly in the case of sandy soil, whereas the increase of phosphorus content after applying of NPK+S+FYM was observed in the sandy and loamy soils. There are some cases (especially in loess and loamy soils) where lower content of P was accompanied lower pH of these soils. A certain interaction between P content and pH of a soil was observed in loess soil fertilized with NPK+FYM.

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48. Effect of long-term differential fertilisation on physiological properties and yield of pea (*Pisum sativum* L.)

Dominika Radzikowska-Kujawska[1], Andrzej Blecharczyk[1], Przemysław Łukasz Kowalczewski[2], Zuzanna Sawinska[1]

[1] Department of Agronomy, Poznan University of Life Sciences, 60-637 Poznań, Poland, dominika.radzikowska@up.poznan.pl
[2] Faculty of Health Science, Andrzej Frycz Modrzewski University in Krakow, 30-705 Krakow, Department of Food Technology of Plant Origin, Poznań University of Life Sciences, 60-637 Poznań, Poland

Climate change is accelerating, both globally and locally, and its consequences are increasingly felt in agricultural practice. The trend of rising average temperatures and their significant fluctuations within a season and even within a day, combined with inconsistent rainfall, favors the expansion of drought-affected areas, causing stress during plant growth. The depletion of soil organic matter further contributes to the decline in crop productivity. To improve water availability in the soil, solutions should be implemented that improve its long-term chemical, physical, and biological properties. Such solutions include the introduction of effective pro-environmental fertilization, such as the use of long-term organic fertilization or/and the introduction of legumes into crop rotation.

This study aimed to compare the impact of long-term, varied mineral and organic fertilization on the physiological condition and yield potential of field pea, as well as on the development of their underground biomass and water availability for plants during the dry season.

The described experiment was established in 1957 at the Brody Agricultural Experimental Station belonging to the University of Life Sciences in Poznań (Poland) on a soil classified as an Albic Luvisol, while the described measurements were carried out in the 2025 season. Pea of the 'Batuta' cultivar were grown in a seven-field rotation: potato - spring barley - winter triticale - peas - winter wheat - winter wheat - winter rye. Four fertilization levels were assessed: unfertilized control, manure, NPK, and PK.

Physiological measurements were conducted at two pea development stages: BBCH 51 and 61. NDVI, chlorophyll content and fluorescence, as well as the content of flavonoid and anthocyanin were measured. Plants were also collected at both development stages for biometric measurements (weight and protein content of above-ground plant parts, root weight, weight and number of root nodules). Simultaneously, soil moisture, air and soil temperature were measured in each plot. After harvest, yield and yield components, as well as grain protein content, were measured.

The pea vegetation period in 2025 was characterized by insufficient hydration (interpretation based on the Sielianinow hydrothermal coefficient K). Physiological measurements carried out in the experiment indicate higher adaptation abilities of plants fertilized with manure to dry conditions, as well as better soil hydration with this fertilizer. However, no significant positive effect of organic fertilization on yield and yield components was demonstrated in the studied season. Plants fertilized with manure had the highest dry weight of the aboveground part. A positive effect of pea fertilization with manure on the number and weight of root nodules was also demonstrated.

49. Wood biomass ash (WBA) as a secondary source of nutrients in hemp cultivation

Elżbieta Rolka[1], Wiesław Szulc[2], Mirosław Wyszkowski[1]

[1]University of Warmia and Mazury in Olsztyn, Faculty of Agriculture and Forestry, Department of Agricultural and Environmental Chemistry, Łódzki 4 Sq., 10-727 Olsztyn, Poland, elzbieta.rolka@uwm.edu.pl
[2]Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska St, 166, 02-787 Warsaw, Poland

The increasing use of woody biomass in the heating sector is contributing to the increase in the amount of combustion waste in the form of ash (WBA) [Pei et al., 2024]. Considering the assumptions of the circular economy and the high macronutrient content of WBA, this waste is increasingly being considered as a potential secondary source of nutrients in plant cultivation [Chojnacka et al., 2025] and a material that can stabilize soil properties [Rolka et al., 2025].

The presented pot study examined the effect of WBA applied in conjunction with post-fermentation mass (PFM) of agricultural origin on selected soil properties as well as the yield and chemical composition of hemp. The experiment was conducted in two series: 1) WBA and 2) WBA+PFM. WBA doses were 0.25, 0.5, and 1.0 HAC. PFM was applied at constant doses in each pot in series 2. Both series included a control treatment, without WBA application. The experiment included 24 treatments, each with three replicates. The test plant was hemp of the Białobrzeskie variety. After harvesting the plants, their yield was estimated, divided into above-ground mass and roots, and soil samples were taken. Chemical analyses were performed to determine the following: soil pH, electrolytic conductivity (EC), sorption properties (SBC – total exchangeable base cations, HAC – hydrolytic acidity, CEC – sorption complex capacity, BS – sorption complex saturation with base cations), C and N content, and available macronutrients content (P, K, and Mg). The macronutrient content (P, K, Mg, Ca and Na) was then determined in the plant biomass, as well as the C, N and S content in the aboveground mass. Based on the C determinations, the content of phytoliths (Phyt) and C-occluded on phytoliths (PhytOC) was calculated.

In both experimental series, increasing WBA doses resulted in an improvement in soil properties (significant increases in pH, SBC, BS, and decreases in HAC). In both series, application of the highest dose of WBA also resulted in an increase in the soil content of available forms of P, K, and Mg. Furthermore, in series 1 (WBA), after application of the highest dose of WBA (1 HAC), an increase in C content and an increase in the C/N ratio in the soil was observed. As a result of applying WBA alone (series 1), a higher average content of N and available forms of Mg was observed. Meanwhile, the combined use of WBA and PFM (series 2) increased soil salinity but also promoted a higher content of available K in the soil. The change in soil conditions resulting from the application of WBA and PFM significantly influenced the increase in hemp aboveground mass yields and the content of Ca, S, and PhytOC. Furthermore, in series 1 (WBA), an increase in C content and in the C/N ratio in the soil was observed after application of the highest dose of WBA (1 HAC). Regardless of the experiment series, with increasing WBA doses, a significant decrease in P content was observed in both the aboveground mass and roots of hemp. The recorded increase in PytOC content may suggest that soil application of WBA together with PFM in hemp cultivation may play an important role in long-term C sequestration, which is also emphasized by other researchers [Rutkowska et al., 2024].

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50. The impact of long-term unbalanced fertilization with nitrogen, phosphorus and potassium on plant productivity and soil fertility

Agnieszka Rutkowska

Institute of Soil Science and Plant Cultivation - State Research Institute, ul. Czartoryskich 8, 24-100, Puławy, Poland, agrut@iung.pulawy.pl

The sixteen years of field experiments on the productive and environmental effects of unbalanced mineral fertilization (NPK) were carried out between 2003-2018 in the Experimental Stations in Eastern (Grabów) and Western Poland (Baborówko). Four crops were grown in the rotation: winter oilseed rape, winter wheat, maize, spring barley. In the split-plot layout, the first variable was P or K fertilizer in the P-plus, K-plus and P-minus, K-minus (control) treatments. The second variable was six levels of N fertilizers (N0-N6), varied depending on the specific crop requirements. In Grabów, the initial content of available P in the topsoil was 69.8 mg $P \cdot kg^{-1}$ soil and 85 mg $K \cdot kg^{-1}$ soil, and in Baborówko 113 mg $P \cdot kg^{-1}$ soil and 124 mg K kg^{-1} soil, respectively. In the both locations the soils were classified as light with a regulated pH. In the P-minus and K-minus treatments, no P or K fertilizers were applied since 2003. In the P-plus and K-plus fields plants were supplied with PK fertilizers in a form of superphosphate and potassium sulphate each year.

The results of the experiments indicate that several years without P fertilizer addition did not exhaust the available soil P to levels that limit crop productivity in Baborówko, even at the highest rates of applied N fertilizer. In Grabów, a tendency for grain yield reduction together with N rates was found, in particular for maize, however, the interaction between the two experimental factors has not been statistically proven. Similarly, there was no effect of long-term soils potassium depletion on the yield of plants grown in Baborówko, but a slight reduction in the yields of maize and barley in Grabów was noted in the last crop rotation.

Long-term soil phosphorus depletion had a very strong impact on changes in the content of available forms of this element in the soil (Rutkowska, 2017). The average content of available P dropped to 63.3 mg $P \cdot kg^{-1}$ soil in Grabów and to 107 mg $P \cdot kg^{-1}$ soil in Baborówko. In Grabów this effect was the stronger the higher N dose was applied. In the treatment without P additions, the content of its available forms dropped to 51.5 mg $P \cdot kg^{-1}$ in N0 treatment, and to 40 mg $P \cdot kg^{-1}$ in N0 treatment. In contrast, this trend was not seen in Baborówko which had much higher soil P levels than in Grabów, even though the P content was about 20% lower in the P-minus treatment (Rutkowska and Skowron, 2020). Conversely, the year-to-year addition of P fertilizers resulted in an unnecessary accumulation of available P in the soil.

Sixteen years of cessation of potassium resources from soil led to a significant depletion of available K in the topsoil. The mean content of potassium dropped to 44 mg $K \cdot kg^{-1}$ soil in Grabów and to 70 mg $K \cdot kg^{-1}$ soil in Baborówko. In contrast to phosphorus, in both sites there was a relationship between potassium content in the soil and the nitrogen dose. Under the highest rates of nitrogen applied in these experiments the content of available K was 39.3 mg $K \cdot kg^{-1}$ while in N0 treatment was 60 mg $K \cdot kg^{-1}$. This indicates that the use of the highest doses of nitrogen resulted in a decrease the soil K classification level to very low. It should be expected that the further process of soil potassium depletion and intensive nitrogen fertilization, especially in the conditions of removing of straw after harvest, will result in reduced yields of cultivated plants, especially the species with high requirements for both potassium and nitrogen.

Results of sixteen-year studies carried out in two regions of Poland, differing in soil-climatic conditions, show that the process of depletion of soils of excess phosphorus is very slow and does not affect the lowering of plant productivity caused by unbalanced nitrogen and phosphorus fertilization, even when large doses of nitrogen are applied.

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51. The influence of the choice of tillage method and shortening of crop rotation on the abundance of earthworm populations in Central Lithuanian Cambisol

Vytautas Seibutis[1] , Irena Deveikytė[1]

[1]*Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344, Kėdainiai dist., Lithuania, vytautas.seibutis@lammc.lt*

Earthworms are essential organisms for maintaining soil health and fertility in agroecosystems. They provide multiple ecosystem services, including nutrient cycling, improvement of soil structure, and decomposition of organic matter (Bertrand et al., 2015). Research has demonstrated that earthworm activity can increase crop yields by up to 25% and aboveground biomass by up to 23% (Eriksen-Hamel et al., 2009; Van Groenigen et al., 2014). Because earthworms occupy several trophic levels and contribute to numerous soil functions, their presence and abundance are widely recognized as key indicators of soil biodiversity and overall soil health in agricultural systems (Lavelle et al., 2016).

This five-year study investigated the effects of reduced tillage and shortened crop rotations on soil physical properties and earthworm populations in Central Lithuanian Cambisol. The experiment was carried out from 2010 to 2014 using a split-plot design. Conventional tillage and no-till systems were compared under three crop rotation schemes: three-field rotation, two-field rotation, and monoculture.

Soil samples were collected from winter wheat fields at two depths (5–10 cm and 15–20 cm). Significant differences in physical soil properties were observed between tillage systems. Conventional tillage resulted in higher soil moisture content in the upper layer (20.0 ± 0.3%) compared to no-till (17.9 ± 0.3%) at 5–10 cm depth ($p < 0.001$). Differences in bulk density were more pronounced in the deeper layer, reaching 1.42 ± 0.02 Mg m^{-3} under conventional tillage and 1.47 ± 0.01 Mg m^{-3} under no-till at 15–20 cm depth.

Earthworm abundance showed a strong negative correlation with bulk density ($r = -0.612$, $p = 0.041$) and a positive correlation with total porosity ($r = 0.583$, $p = 0.044$) in the topsoil. Despite observable differences in soil physical properties, earthworm populations did not differ significantly between conventional and no-till systems ($F_{1,108} = 1.414$, $p = 0.237$), indicating unexpected resilience to tillage intensity.

Crop rotation had a more pronounced effect than tillage. Both two-field and three-field rotations sustained similar earthworm abundance and biomass (127.5–131.2 ind. m^{-2} and 32.8–35.4 g m^{-2}), whereas monoculture resulted in significantly lower values (105.0 ± 13.2 ind. m^{-2} and 25.6 ± 2.7 g m^{-2}; $p < 0.048$).

Overall, these findings challenge traditional assumptions regarding the dominant role of tillage intensity in shaping soil fauna communities. The results suggest that crop diversification within rotation systems is a more important factor for maintaining stable earthworm populations than tillage intensity or rotation length. Although soil structural properties significantly influenced earthworm abundance, their role was secondary compared to crop rotation effects.

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52. Structure and yield of *Helianthus tuberosus* tubers in response to mineral fertilization

Dominika Skiba[1], Ewelina Flis-Olszewska[1]

[1]University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland,
dominika.skiba@up.edu.pl

Jerusalem artichoke (Helianthus tuberosus L.) was brought by the Tupi Guaranis, Tupinambas, and Tupinamboux tribes to Mexico and Brazil from the eastern United States or Canada in the late 17th century, and likely reached Europe in the 17th century [Stauffer et al. 1980]. Jerusalem artichoke is highly polymorphic, allowing it to adapt to various environmental conditions and production regions [Dima et al. 2023, Kaszás et al. 2022]. This plant has underground stolons, at the ends of which tubers form, varying in shape, size, and surface color depending on the variety. These tubers can range in color from white, yellow, or red to purple, and the flesh is white or yellow. Their quantity depends on fertilization, soil resources, and water quantity. Jerusalem artichoke has a wide range of industrial uses, including: food, pharmaceutical and energy [Stachowiak et al. 2023].

A field experiment was conducted between 2022-2024 at the Experimental Station of the University of Life Sciences in Lublin. The experiment was established using the split-split-plot method with three replications. The first-order factors were the cultivars, and the second-order factor was mineral fertilization (N0P0K0 – as the control, and N100 and N100P43K124), calculated as elemental fertilizers, against a full dose of manure [30 t/ha]. Nitrogen in the form of urea was applied in two doses: half before planting and the remaining half when the plants were in the BBCH14 stage. Tubers were planted every 40 cm in the row, with the distance between rows being 62.5 cm. The study included two Polish Jerusalem artichoke varieties: Albik and Rubik, and the Lithuanian Šiauliai. The tubers were planted in the third decade of March on plots of 20 m^2.

The Albik variety achieved the highest average tuber yield, while the Rubik variety achieved the lowest. Significantly higher yields of fresh tuber mass and dry tuber mass were achieved after full fertilization, both compared to the use of nitrogen fertilization alone and without fertilization in all years of the study. All experimental factors modified both the share and number of tubers in the total yield. The Albik variety was characterized by the highest share of the number and the highest number of the smallest tubers, those with a diameter of <3 cm and 3-4 cm. The Šiauliai variety proved to have the most favorable structure, i.e., the highest number of tubers with a diameter of 4-5 and 5-6 cm. The Rubik variety had three times fewer tubers with a diameter of <3 cm than the Albik variety, while simultaneously producing the most large tubers with a diameter of >6 cm. Mineral fertilization significantly modified the structure of the tuber mass and individual fractions. Significantly fewer tubers were recorded for fractions up to 3 and 3-4 compared to the control treatment. Nitrogen fertilization had a positive effect on fractions 4-5 and above 6, and NPK fertilization on fractions 5-6 and above 6, compared to the treatment without fertilization.

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53. Removal of biological contaminants from fertilization-grade organic waste using phytosanitation techniques

Piotr Skowron[1], Damian Wach[1], Monika Karsznia[1], Tomasz Cencek[2], Jolanta Zdybel[2]

[1]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland, pskowron@iung.pulawy.pl
[2]National Veterinary Research Institute (NVRI), Partyzantów 57, 24-100 Puławy, Poland

Municipal wastewater treatment plants and agricultural biogas plants are facilities that align with pro-environmental policy. The main task of treatment plants is to improve the quality of surface waters, while biogas plants focus on managing organic waste by producing biomethane. However, although they address very important environmental issues, they paradoxically become a source of new ones. In the case of wastewater treatment plants, the main problem is the large quantities of dewatered sewage sludge, and in the case of biogas plants – digestate.

The introduction of sewage sludge and digestate into soil in the form of organic fertilizers is possible only after meeting several very strict requirements. The most difficult to satisfy are the standards concerning biological and chemical safety. Sludge and digestate produced with the participation of excreta and animal by-products may contain numerous pathogens: pathogenic viruses, rickettsiae, bacteria and fungi, as well as dispersive forms of parasites. According to national regulations, for municipal sewage sludge to be used in agriculture, it must not contain eggs of intestinal parasites of the genera Ascaris, Toxocara and Trichuris. For applications in land reclamation, cultivation of plants intended for compost production, and plants not intended for consumption or feed, the total number of eggs of these parasite genera must not exceed 300 per kg of dry matter. Additionally, fertilizers containing processed animal by-products must be tested for the presence of E. coli and/or bacteria from the Enterobacteriaceae group, whose count must not exceed 1000 CFU/g.

The OrgSafety project aimed to develop an innovative technology for the hygienization of municipal sewage sludge and digestate from agricultural biogas plants using phytosanitary plants, enabling these materials to meet safety requirements that determine their suitability for use as organic fertilizers.

The research was carried out in several stages, beginning with the selection of appropriate phytosanitary plants and the determination of conditions for their growth on substrates composed of sludge or digestate mixed with structural additives. The second stage involved cultivating the selected phytosanitary plants for two growing seasons on micro-plots filled with a mixture of sludge or digestate and a structural additive, followed by an assessment of their ability to remove microorganisms and parasite eggs. The final stage of the study was the evaluation of the agricultural suitability of the organic fertilizers produced through the phytosanitation process.

As part of the first stage, four phytosanitary plant species were selected from among several potential candidates: oilseed radish, white mustard, French marigold and common buckwheat. All these plants demonstrated a positive sanitizing effect on the substrate, both against Salmonella bacteria, E. coli rods and parasites. However, the achieved sanitization effect was not uniform and depended on the pathogen, the plant species and the type of substrate; moreover, its effectiveness increased with longer sanitization time. Eight fertilizer products obtained through the phytosanitation process were used in a greenhouse experiment to fertilize test plants: maize, spring wheat, and white mustard. According to the two-year pot study, all fertilizer products produced from both sewage sludge and digestate had a positive effect on the yield of the test plants.

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54. Fractional deep tillage – an innovative, technical solution for climate mitigation in arable soils

Michael Sommer[1], Marisa R. Gerriets[1]

[1]Leibniz Center for Agricultural Landscape Research, 15374 Müncheberg, Germany, sommer@zalf.de

The melioration technique "fractional deep tillage" (FDT) was developed in the late 1950s to increase crop yields and crop yield security in East Germany (former GDR) by remediating subsoil compactions and increasing topsoil depth. It is characterized by an exchange of topsoil and subsoil material in a defined manner. Today, FDT is of particular interest due to its carbon sequestration effect (CO_2 sink).

By FDT C-enriched topsoil material is shifted into 50 cm deep shafts, which were created by special plough shares in 35 to 80 cm intervals. At the same time C-poor subsoil material is lifted into the topsoil. This reduces the SOC content of the topsoil and reinforces carbon sequestration due to the induced disequilibrium in the C cycle of the soil-plant-system. The C accrual until topsoil equilibrium is a quite fast process (Burger et al., 2023) – due to the admixture of highly reactive, unsaturated subsoil mineral phases. However, the CO_2 sink potential of a soil strongly depends on the long-term degradation of the SOC buried in the subsoil.

Here we present results from four historical field trials in NE Germany, which had been meliorated 40 years ago, and recent experiments set up with a newly developed CarbonFarming plough. Using a conservative calculation with 50% degradation of soil organic carbon (SOC) translocated into shafts, we calculated a sustainable, strong CO_2 sink of 10 t CO_{2eq} ha^{-1} in sandy soils and 30 t CO_{2eq} ha^{-1} in loamy soils by a one-time application of FDT.

As FDT also increases crop yields, especially on sites with subsoil compaction, fractional deep tillage offers an efficient and effective technological innovation for Carbon Farming on arable soils.

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55. Long-term complex effects of no-till, plant residues, and cover crops on soil health and crop yield

Vaida Steponavičienė [1], Giedrius Žiūraitis [2], Vaclovas Bogužas [2]

[1] Bioeconomy Research Institute Vytautas Magnus University, K. Donelaičio g. 58, LT-44248 Kaunas, Lithuania
[2]Department of Agroecosystems and Soil Sciences, Faculty of Agronomy, Vytautas Magnus University, K. Donelaičio g. 58, LT-44248 Kaunas, Lithuania

Maintaining healthy soil is a prerequisite for a sustainable ecosystem and competitive agricultural production. However, intensive agriculture disrupts soil ecosystems through mechanical disturbance and reduced organic matter inputs. This study aimed to evaluate the long-term complex effects of no-till, plant residues, and cover crops on soil health and crop yield. A stationary field experiment, established in 1999 at the Vytautas Magnus University Experimental Station (Lithuania), assessed agrocenoses of winter oilseed rape, winter wheat, and spring barley. The experimental design compared deep plowing (CP), no-till (NT), and no-till with cover crops (CCNT), evaluated both with and without the retention of chopped straw. The results demonstrated that long-term NT and CCNT, particularly combined with straw return, consistently improved agrochemical indicators by significantly increasing total nitrogen, mobile phosphorus, mobile potassium, and organic carbon in the topsoil. Biological soil health indicators also improved under conservation practices; NT and CCNT increased microbiota biomass carbon by up to 17.7% and substantially enhanced urease and saccharase enzymatic activities compared to CP. Furthermore, long-term NT and CCNT positively affected agrophysical properties by reducing soil density, increasing porosity, and improving moisture retention, with straw return further enhancing these benefits. Consequently, the Soil Quality Index (SQI) was 4.0 to 9.4 times higher in NT systems compared to deep plowing. These improved soil functions translated into higher agricultural productivity. In soils without straw, NT increased the yields of winter oilseed rape by up to 40%, winter wheat by 15.5%, and spring barley by 8.5% compared to CP. Additionally, a life cycle assessment revealed that the global warming potential of no-till is almost half that of conventional deep plowing. In conclusion, replacing deep plowing with no-till, cover crops, and straw retention creates a positive complex effect that enhances soil multifunctionality, increases crop yields, and mitigates the negative impacts of climate change.

56. The effect of weed and pathogen protection levels on the yielding of winter wheat grown in crop rotation and monoculture

Arkadiusz Stępień, Marek Marks, Wojciech Biniewicz

University of Warmia and Mazury in Olsztyn, 10-619 Olsztyn, Plac Łódzki 3, Polska,
arkadiusz.stepien@uwm.edu.pl

Grain yield and technological quality cereals are the result of numerous agrotechnical factors, among which the crop sequence system, the intensity of crop protection, and cultivar selection are of key importance. Modern agriculture faces the challenge of reconciling high productivity with reduced chemical pressure and rational management of environmental resources. In this context, it is particularly important to understand plant responses to simplified crop rotations, different protection strategies, and their effects not only on yield level but also on grain quality traits that determine its feed and food suitability.

The study was conducted within a long-term field experiment established in 1967, including continuous cultivation (monoculture) of winter wheat and a 6-year crop rotation. The results refer to winter wheat grown during the 2017–2022 growing seasons. The experiment was located at the Experimental Station in Bałcyny, Poland (53.60°N, 19.85°E).

The experimental design included three factors:

I. Crop sequence system: (a) 6-field crop rotation (sugar beet, maize, spring barley, field pea, winter oilseed rape, and winter wheat), (b) winter wheat monoculture.

II. Crop protection: (a) no protection (control), (b) herbicide protection, (c) herbicide and fungicide protection.

III. Cultivar: (a) Julius, (b) KWS Ozon.

The aim of the study was to assess the effects of the crop sequence system, level of chemical protection, and cultivar on grain yield and selected grain quality parameters.

The crop sequence system significantly differentiated grain yield. Under crop rotation conditions, a clearly higher grain yield per hectare was obtained (7.25 t ha^{-1}) compared with monoculture (4.10 t ha^{-1}). These differences indicate a beneficial effect of crop succession on the yield-forming potential of the studied crop. In monoculture, higher protein (11.16%) and gluten (22.02%) contents were recorded compared with crop rotation (9.69% and 18.32%, respectively).

Starch content was slightly higher in crop rotation (72.39%) than in monoculture (70.33%). The Zeleny sedimentation index reached higher values in monoculture, which may indicate better technological parameters of the grain in this system.

The applied protection variant significantly affected yield. The lowest grain yield was obtained in the no-protection treatment (4.32 t ha^{-1}), whereas the highest yield occurred in the herbicide + fungicide variant (7.01 t ha^{-1}). This indicates a clear yield-forming response of wheat to comprehensive chemical protection. Protein content was highest in the no-protection treatment (10.28%), while in the chemically protected variants it remained at a similar, slightly higher level (10.47% - 10.54%). Gluten content was highest in the herbicide-only variant (20.48%) and in the no-protection treatment (19.63%), whereas the lowest value was observed in the herbicide + fungicide combination (20.40% - a comparable value). Starch content showed slight variation among treatments; however, the highest values were recorded in the herbicide + fungicide variant (71.57%). The Zeleny index achieved the highest values under full chemical protection, indicating an improvement in the technological quality parameters of the grain.

The tested cultivars differed in both yield and quality traits. The cultivar KWS Ozon was characterized by a higher grain yield (5.88 t ha^{-1}) compared with Julius (5.67 t ha^{-1}). At the same time, the cultivar Julius exhibited higher protein (10.76%) and gluten (20.99%) contents, which may indicate better technological grain quality. Starch content was slightly higher in the grain of KWS Ozon (71.86%), whereas the Zeleny index reached higher values for the cultivar Julius.

57. The effect of agricultural organic waste amendments on the physical and chemical properties of light soil

Wiesław Szulc[1], Evelin Loit[6], Michel Mench[2], Virmantas Povilaitis[3], Francois Rineau[4], Beata Rutkowska[1], Peter Schröder[5], Kristjan Tiideberg[6], Tomasz Niedziński[1], Zydelis Renaldas[3]

[1] Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Nowoursynowska 159 St., 02–776 Warsaw, Poland, wieslaw_szulc@sggw.edu.pl
[2] INRAE, UMR BIOGECO 1202, University of Bordeaux, allée G. St-Hilaire, CS50023, 33615 Pessac cedex, France
[3] Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344, Kedainiai distr. Lithuania
[4] UHasselt, Martelarenlaan 42, 3500 Hasselt, Belgium
[5] Helmholtz Zentrum Muenchen, Ingolstädter Landstrasse 1, D-85764, Neuherberg, Germany
[6] Estonian University of Life Sciences, Chair of Crops Science and Plant Biology, Kreutzwaldi 1a, Tartu 51006, Estonia

By 2050 the world's population will exceed 9 billion requiring the increase of food production by 70-85% (Dhankher & Foyer 2018), while ensuring food security and safety. To combat the decreasing productivity of arable soils and progressive climate changes, must develop new opportunities to increase the amount and quality of food and feed crops in Europe using new strategies for sustainable growth of plant production and increasing climate change resilience of agroecosystems.The principal objective of the project was twofold to develop an efficient strategy for the rapid restoration of marginal soils to agricultural production.

The conducted studies demonstrated that marginal soils can be successfully restored to agricultural use within a relatively short period. To achieve this goal, data were collected on the most common organic waste streams generated by the project partners. Based on these findings, a compost was produced consisting of sewage sludge (30%), urban green waste (10%), sawdust (10%), and spent mushroom substrate (50%). The pelleted compost was subsequently used to establish field experiments in which the following fertilization treatments were evaluated: control (no fertilization); NPK (100 kg N ha^{-1}, 80 kg P ha^{-1}, and 140 kg K ha^{-1}); NPK + selenium; NPK + silicon (Intermag); organic fertilizer (100 kg N ha^{-1}); organic fertilizer (100 kg N ha^{-1}) + selenium; organic fertilizer (100 kg N ha^{-1}) + silicon; organic fertilizer + 75 kg mineral N ha^{-1}; organic fertilizer + 75 kg mineral N ha^{-1} + selenium; and organic fertilizer + 75 kg mineral N ha^{-1} + silicon.

The application of compost derived from waste organic matter at a rate equivalent to 170 kg N ha^{-1} significantly reduced soil acidification and increased the availability of phosphorus (from low to high availability class) and potassium (from low to medium availability class). Furthermore, within a three-year period, compost pellet application increased soil organic carbon content by 10–25% and total nitrogen content by 7–11%. On sandy soils (typical for many regions of Poland), the mineralization of soil organic matter predominates over humification processes, thereby limiting long-term carbon sequestration. Under such conditions, the frequency of organic matter inputs should be increased to maintain or enhance soil fertility.

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58. Effects of fertilization and crop rotation on arbuscular mycorrhizal colonization of wheat roots and glomalin-related soil proteins content

Magdalena Szymańska[1], Tomasz Sosulski[1], Marzena Sujkowska-Rybkowska[2], Anna Rusaczonek[2]

[1] Warsaw University of Life Sciences-SGGW, Institute of Agriculture, Division of Agricultural and Environmental Chemistry, Nowoursynowska 159, 02-776 Warsaw, Poland. magdalena_szymanska@sggw.edu.pl, tomasz_sosulski@sggw.edu.pl

[2] Warsaw University of Life Sciences-SGGW, Institute of Biology, Department of Botany and Plant Physiology, Nowoursynowska 159, 02-776 Warsaw, Poland, marzena_sujkowska@sggw.edu.pl, anna_rusaczonek@sggw.edu.pl

Recent studies have increasingly emphasized the role of glomalin-related soil proteins (GRSP) in soil carbon dynamics (Magurno et al., 2019). GRSP are operationally defined, hydrophobic proteinaceous fractions associated with arbuscular mycorrhizal fungi (AMF; *Glomeromycota*). These compounds contribute to soil aggregation and may indirectly influence carbon stabilization in soils, although their exact biochemical nature and ecological specificity remain debated (Rillig 2004; Qiang Wang et al., 2021). GRSP has been linked to improved soil structural stability, enhanced aggregate formation, and reduced susceptibility to erosion.

The aim of this study was to evaluate the effects of fertilization and crop rotation on the degree of wheat root colonization by AMF, as well as on the content of total glomalin (TG) and easily extractable glomalin (EEG) in soil. The research was conducted in two long-term fertilization experiments at the Experimental Station of the Institute of Agriculture of the Warsaw University of Life Sciences (SGGW), named after Prof. M. Górski in Skierniewice. Within both experiments, plots under crop rotation without legumes (Field A) and plots under a five-field crop rotation system including legumes (Field E) were selected. The study included different mineral fertilization treatments (Ca, CaNK, CaNPK, and NPK).

The results demonstrated that crop rotation exerted a stronger influence on wheat root colonization by AMF and on soil TG and EEG contents than mineral fertilization. The inclusion of legumes in the crop rotation significantly increased both AMF colonization of wheat roots and the content of TG and EEG in soil. Mean TG and EEG contents in Field A were 1.94 and 0.96 mg g^{-1}, respectively, whereas in Field E they reached 6.71 and 4.42 mg g^{-1}, respectively. Overall, TG and EEG were more strongly associated with soil nitrogen and sulfur content, and cation exchange capacity, than with plant-available macronutrients such as phosphorus and potassium. These findings suggest that glomalin plays a key role in the accumulation and stabilization of soil organic matter and in the formation of stable organo-mineral complexes, thereby contributing to the long-term stability of agroecosystems.

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59. Natural radioactivity and heavy metals in mineral fertilizers used in Poland

Mirosław Szyłak-Szydłowski[1] Aneta Łukaszek-Chmielewska[2], Barbara Piotrowska[3], Łukasz Uzarowicz[4]

1 Faculty of Environmental Engineering, Warsaw University of Technology, Nowowiejska 20,00-653 Warsaw, Poland: miroslaw.szydlowski@pw.edu.pl
2 Fire University, 52/54 Słowackiego St., 01-629 Warsaw, Poland: alukaszek@apoz.edu.pl, mrachwal@apoz.edu.pl
3 Central Laboratory for Radiological Protection, Konwaliowa St. 7, PL-03194 Warsaw, Poland: piotrowska@clor.waw.pl,
4 Warsaw University of Life Sciences – SGGW, Institute of Agriculture, Department of Soil Science, Nowoursynowska Str. 159, building 37, 02-776 Warszawa, Poland: lukasz_uzarowicz@sggw.edu.pl

Multi-component mineral fertilizers, widely used in agriculture, contain naturally occurring radioactive materials (NORM) derived from the raw materials used in their production. The elevated natural radioactivity of phosphorus-containing fertilizers is associated with the type of phosphate rock - apatite or phosphorite - used as feedstock. Typical activity concentrations of ^{238}U reach 1500 Bq kg^{-1} in sedimentary phosphate deposits, compared to 70 Bq kg^{-1} in apatite, while ^{232}Th and ^{40}K concentrations in sedimentary phosphate rocks are substantially lower and comparable to those found in soil.

This study presents the results of natural radionuclide activity measurements (^{226}Ra, ^{232}Th, and ^{40}K) and selected heavy metal concentrations (Cd, Ni, Pb, Cr, Zn, Cu) in seventeen commercially available multi-component mineral fertilizers (NPK). Activity concentrations were determined by gamma-ray spectrometry using two HPGe detectors (XTRa type, 30% and 40% relative efficiency), energy-calibrated across the 60–1836 keV range using a certified mixed gamma standard. Heavy metal content was determined by ICP-MS.

Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K ranged from 9.86 to 242.68 Bq kg^{-1}, 4.95 to 18.4 Bq kg^{-1}, and 1419 to 9381 Bq kg^{-1}, respectively. ^{40}K activity exceeded the global crustal average (400 Bq kg^{-1}) in all seventeen samples, while ^{226}Ra surpassed the crustal average in seven samples. Granulated phosphate fertilizers showed ^{226}Ra activities up to ten times higher than water-soluble NPK products. Among the heavy metals, cadmium showed a strong positive correlation with ^{226}Ra activity ($r = 0.98$), suggesting a common geochemical origin linked to phosphate rock type. Elevated nickel concentrations were identified as an additional concern in selected multi-component products.

Radiological hazard parameters - including radium equivalent activity (Raeq), outdoor and indoor dose rates (D_{out}, D_{in}), and annual effective doses (E_{out}, E_{in}, E_{tot}) - were calculated to assess occupational exposure of workers involved in fertilizer production, transport, storage, and application. All calculated parameters exceeded worldwide average reference values. The combined radiological and chemical findings indicate that phosphate-based fertilizers warrant systematic monitoring, and that radionuclide activity - particularly ^{226}Ra - may serve as a proxy indicator for cadmium contamination risk.

60. Long-term experiments as a foundation for researching and disseminating the regenerative agriculture approach

Stanisław Świtek[1], Dominika Radzikowska-Kujawska[1], Andrzej Blecharczyk[1], Zuzanna Sawinska[1]

[1] Poznań University of Life Sciences, Agronomy Department, Dojazd 11, 60-631 Poznań, Poland, stanislaw.switek@up.poznan.pl

Regenerative agriculture has emerged as a prominent and widely discussed paradigm of agricultural production in recent years. Rooted in agroecology and sustainable farming systems, it seeks to restore soil functionality, enhance soil quality, reduce the environmental footprint of agriculture, and promote resilient, adaptive management practices. Despite the absence of a single, universally accepted definition, regenerative agriculture consistently emphasizes both ecological regeneration and the economic viability of farms.

Beyond the implementation of specific practices, the regenerative approach promotes a holistic, systems-based perspective on farm management. It aims to improve profitability, strengthen local food systems, and adapt production strategies to site-specific environmental and socio-economic conditions. A key element of this transformation is active farmer engagement — encouraging experimentation, on-farm testing of innovative practices, and peer-to-peer knowledge exchange through initiatives such as farmer field schools.

Long-term field experiments provide a unique scientific foundation for evaluating both the agronomic performance and systemic implications of regenerative practices. Between 2024 and 2026, research was conducted within a long-term crop rotation experiment in Brody to assess selected regenerative practices, including organic fertilization, liming, and diversified crop rotation. These practices were evaluated in spring barley, one of the cereal crops most sensitive to agronomic management, making it a robust indicator of management effects.

The study examined the impact of these practices on yield performance, root system development, and soil structure. The results demonstrated a statistically significant effect of fertilization type and crop rotation on crop yield, confirming the agronomic relevance of regenerative management strategies.

Importantly, the integration of long-term experimental evidence with participatory learning approaches creates a powerful framework for scaling regenerative agriculture. The documented outcomes form a scientific and educational basis for the development of field schools, where farmers and students can directly observe, evaluate, and critically assess the effects of regenerative practices under real production conditions. In this way, long-term experiments serve not only as research platforms but also as catalysts for knowledge transfer and systemic agricultural transformation.

61. Physicochemical properties of soil in agricultural crops as influenced by the application of rock cellulose pellets (RCP) and wood chips

Jadwiga Treder[1], Nowak Jacek[1], Magdalena Szczech[1], Beata Kowalska[1] Jarosław Kozak[2], Mateusz Szar[2], Wojciech Spisak[2]

[1]The National institute of Horticultural Research, ul Konstytucji 3 Maja 1/3, 96-100 Skierniewice, POLAND
Jadwiga.treder@inhort.pl
[2]Research Center , ALCOR, Opole, POLAND

Intensive cultivation of agricultural crops, especially on light soils, can pose negative challenges, especially when organic matter and beneficial microorganisms are low. The aim of the SoilLife Boats project was to investigate how soil properties can be improved in cultivation of potatoes and onions by applying materials such as rock cellulose pellets (RCP) and willow chips impregnated with fertilizers. RCP pellets are produced from waste materials from the stone industry (dust from cutting granite and basalt) and short-fiber cellulose from the paper industry. In case of wood chips from willow (*Vitis viminalis*) the products is impregnated with fertilizers before drying and application in the fields. The side effect of the both products applied in the fields in agriculture is the sequestration of CO_2 so, this factors can be very important for environment protection in regenerative agriculture.

Willow chips are primarily used in horticulture, but to a limited extent. After impregnation with fertilizers and drying, they can be spread on the field and then plowed into the soil. When applied to fields, both products can increase organic matter content, improve water retention, prevent mineral leaching, and improve the composition of the soil microbiome. Research conducted over two years on potato and onion cultivation (1 hectare plots) indicates that application of these products improves the fertility of light soils, increases organic matter content, and positively influences the composition of selected microorganisms.

In onion cultivation, a positive effect of the products on yield has been also demonstrated. Research will be continued on both crops: potatoes and onions, as well as on other crops (orchards, ornamental bulb plantations).

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62. Effects of long-term monoculture and crop rotation on soil mesofauna in potato and winter rye systems in Experimental Station in Skierniewice

Jacek Twardowski, Iwona Gruss, Michał Hurej, Olena Niszczak

Department of Plant Protection, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24a, 50-36 Wrocław, Poland, e-mail: olena.niszczak@upwr.edu.pl

Soil mesofauna are sensitive indicators of agricultural management and play a key role in decomposition processes. This study synthesises results from long-term field experiments examining the effects of monoculture and crop rotation on soil-dwelling springtails (Collembola) and mites (Acari) in potato and winter rye systems at the Experimental Station in Skierniewice of the Warsaw University of Life Sciences (SGGW), Poland, where permanent plots under 90-year monoculture and crop rotation have been maintained since 1923.

Soil samples were collected over three consecutive years (2011–2013) and mesofauna were extracted using Tullgren funnels. The abundance, diversity and community structure of Collembola and Acari were analysed in relation to crop species, cultivation system and fertilisation regime. Springtails were classified into epedaphic, hemiedaphic and euedaphic life forms, reflecting their vertical distribution in the soil profile and sensitivity to changes in soil structure and organic matter availability. Mites were identified to major taxonomic groups, including Oribatida, Gamasida, Prostigmata and Astigmata, which represent different trophic functions in the soil food web, from decomposers and microphytophages to predators.

In winter rye, crop rotation generally increased springtail abundance and species diversity compared with long-term monoculture, likely due to more diverse crop residues and improved soil biological conditions. Hemiedaphic Collembola dominated in crop rotation, whereas euedaphic forms prevailed in monoculture. In potato cultivation, higher total densities of springtails were often recorded in monoculture, particularly before planting, although species diversity and soil biological quality indices indicated more favourable conditions under crop rotation. Mite assemblages differed significantly between crops: Oribatida and Gamasida were more abundant in winter rye, while Prostigmata dominated in potato monoculture. Fertilisation with farmyard manure had a limited effect on total mite abundance but positively influenced selected taxonomic groups.

The results demonstrate that long-term monoculture leads to profound, crop-dependent changes in soil mesofauna communities, while crop rotation enhances soil biological quality and biodiversity. Both Collembola and Acari proved to be effective bioindicators of long-term management effects in arable soils.

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63. Cereal-legume intercropping effects on mycorrhizal abundance and C, N allocation within the root systems

Agnė Veršulienė[1], Aida Skersienė[1], Monika Toleikienė[1], Anke Herrmann[2]

[1]Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry (LAMMC), Instituto al. 1, Kėdainiai District, LT-58344 Akademija, Lithuania, agne.versuliene@lammc.lt
[2]Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU), Gerda Nilssons väg 5, 756 51 Uppsala, Sweden

Maintaining soil organic carbon (SOC) and nitrogen is a practical approach to sustainable crop production. Adopting cereal-legume intercropping captures mineral nitrogen, thereby reducing nitrate leaching and contributing to SOC buildup. Crop diversity also enhances soil biological activity, specifically mycorrhizal colonization intensity (M%), which plays a vital role in nutrient cycling and improves plant tolerance to drought and pathogens. However, there is a lack of field studies that assess the effects of intercropping on mycorrhizal intensity and relate it to the nitrate cycle and SOC accumulation. This field experiment was conducted to evaluate root mycorrhizal colonization and the allocation of carbon (C) and nitrogen (N) within cereal-legume intercropping systems.

The study was conducted at the Lithuanian Research Centre for Agriculture and Forestry (LAMMC), at the Institute of Agriculture, in the lowland regions of Central Lithuania (55°24′ N, 23°51′ E) within an organically managed cropping system. Three main crops: spring barley, oat and field pea were grown as monocultures. Spring barley and oats were also included, with two fertilization levels (with and without organic fertilizers) and legume intercropping (field pea and red clover). Mycorrhizal colonisation intensity (M%) of the root sample segments was determined by light microscopy (Trinchera et al., 2019). Quantification of root system architecture traits was analysed using the software "RhizoVision Explorer". The potential of C sequestration and N transfer in the system was estimated by incubating the intercropping systems using the 13C-CO2 pulse-labeling method (De Neergaard and Gorissen, 2004) and the 15N isotope dilution method (Rasmussen et al., 2012).

Intercropping with legumes significantly modified belowground traits of spring barley and oat, with the highest root length and biomass observed in the 0–15 cm soil layer in barley–red clover and oat–field pea systems. C allocation was root-size dependent, as C content remained unchanged in very fine roots but increased in coarse roots, with lower $\delta^{13}C$ enrichment in cereal–pea intercrops compared with monocultures. Nitrogen isotopic composition revealed contrasting legume effects, with red clover increasing $\delta^{15}N$ in cereal very fine roots and field pea reducing mean $\delta^{15}N$ in cereal–pea systems. Intercropping increased average N concentrations in cereal roots, indicating improved N acquisition through legume as-sociations. This practice and organic fertilization also affected mycorrhizal colonization and grain yield. The establishment of field pea intercrop has resulted in a higher M% on spring barley and positively affected spring barley and oat yields. The intercropping of red clover increased M% and grain yield only in oats. These results demonstrate that legume-based cropping systems can enhance both belowground functioning and crop productivity.

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64. Evaluation of struvite and ammonium sulphate solution recovered from biowaste processing in spring wheat and maize cultivation

Damian Wach[1], Piotr Skowron[1], Monika Karsznia[1]

[1]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland, dwach@iung.pulawy.pl

Fertilizers are essential for maintaining soil fertility and ensuring stable crop production, yet the reliance on mineral fertilizers raises concerns related to environmental impacts and the depletion of non-renewable resources. The transition toward sustainable agriculture has increased interest in recycled nutrient fertilizers (RNFs) derived from organic waste streams. These bio-based fertilizers support nutrient recycling by returning key macronutrients such as nitrogen and phosphorus to agricultural soils, reducing dependence on energy-intensive synthetic fertilizers. Their use not only helps close nutrient cycles within the circular economy but also decreases the environmental burden associated with managing nutrient-rich waste. RNFs therefore represent a promising pathway toward more resource-efficient and climate-friendly crop production.

This study assessed the agronomic performance of two such products—struvite recovered from wastewater treatment and ammonium sulphate obtained through ammonia stripping in biogas plants. Field experiments on spring wheat and maize silage compared these recycled fertilizers with conventional mineral fertilizers (ammonium nitrate and superphosphate). The results showed no significant differences in biomass accumulation during vegetation, SPAD values or final yield between recycled and conventional treatments, indicating comparable nutrient availability and crop response to fertilization treatments. Soil analyses confirmed that the recycled fertilizers did not negatively affect soil pH or nutrient status.

Overall, the findings demonstrate that struvite and recovered ammonium sulphate can be used as effective alternatives to conventional fertilizers, supporting nutrient recycling and contributing to more sustainable agricultural systems.

The work was carried out as part of the CiNURGi project „Circular nutrients for a sustainable Baltic Sea Region", EU-funded Interreg Baltic Sea Region (BSR) core project #C049, under the 2021-2027 PROGRAMME, Priority 3: Climate-Neutral Societies, Objective 3.1: Circular Economy

65. Agronomic value of plant-based digestate pellets in maize cultivation

Damian Wach[1], Piotr Skowron[1], Monika Karsznia[1]

[1]Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), Czartoryskich 8, 24-100 Puławy, Poland, dwach@iung.pulawy.pl

Fertilizer use is fundamental to maintaining soil fertility and ensuring stable yields, yet continued reliance on mineral fertilizers raises concerns about environmental impacts and the depletion of limited resources. In the pursuit of more sustainable agricultural systems, increasing attention is being directed toward recycled nutrient fertilizers (RNFs) produced from organic waste materials. These bio-based products return essential nutrients such as nitrogen and phosphorus to agricultural soils, reducing the need for energy-intensive synthetic fertilizers and lowering the environmental burden associated with nutrient-rich waste streams. As a result, RNFs are becoming an important component of circular and climate-smart agricultural practices.

This study evaluated the agronomic performance of a plant-based digestate pellet derived from biomass residues. In field trials with maize grown for silage, this recycled fertilizer was compared with dairy cow manure and conventional mineral fertilizers. No significant differences were observed in biomass accumulation during vegetation, SPAD readings or final yield across treatments, indicating similar nutrient uptake and crop response to fertilizers. Soil analyses also confirmed that the digestate pellets did not negatively affect soil pH or nutrient levels. A positive effect of organic fertilizers (RNF and manure) on soil organic matter stabilization was additionally observed.

In summary, the results indicate that plant-based digestate pellets can partially replace conventional fertilizers while supporting nutrient recycling and contributing to more sustainable crop production systems.

The work was carried out as part of the CiNURGi project „Circular nutrients for a sustainable Baltic Sea Region", EU-funded Interreg Baltic Sea Region (BSR) core project #C049, under the 2021-2027 PROGRAMME, Priority 3: Climate-Neutral Societies, Objective 3.1: Circular Economy

66. Effects of spring barley cultivation system on soil physical properties

Roman Wacławowicz[1], Magdalena Giemza[2], Piotr Kuc[1], Anna Lehmann-Skoczylas[1]

[1]Institute of Agroecology and Plant Production, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24A, 50-363 Wrocław, Poland, roman.waclawowicz@upwr.edu.pl
[2]DLF Beet Seed ApS, Højbygårdvej 31, 4960 Holeby, Denmark

The present study is embedded in the principles of sustainable agriculture, one of whose key objectives is the protection of the soil environment while maintaining high and stable crop productivity. In recent years, increasing attention has been drawn to the progressive deterioration of the physical condition of agricultural soils, resulting from the intensification of tillage operations, simplification of crop rotations, and reduced inputs of organic matter. These processes contribute to increased soil compaction, deterioration of soil structure, and disruption of soil water–air relations.

In response to these unfavorable trends, agronomic practices aimed at reducing tillage intensity and integrating cover crops into cropping systems have gained importance as measures to improve soil physical properties. Numerous studies have demonstrated that both reduced tillage systems and the use of cover crops can beneficially affect soil bulk density, porosity, and water retention capacity (Koudahe et al., 2022; Sinkevičienė et al., 2024; Yan and Arthur, 2025). Under conditions dominated by cereal-based rotations, the field management of cover crop biomass is particularly important, especially in combination with modifications of the tillage system, as this determines the direction and magnitude of changes occurring in the arable soil layer (Gajewski et al., 2025).

This study aimed to evaluate the effects of the spring barley cultivation system, which is understood as the combined influence of tillage practice, field management of a stubble cover crop of white mustard (Sinapis alba L.), and nitrogen fertilization rate, on selected physical properties of the soil. It was hypothesized that the method of incorporating cover crop biomass into the soil, particularly under reduced tillage intensity, affects the development of selected soil physical properties, including parameters describing the structural condition of the arable layer.

The field experiment was conducted in a factorial design including diversified tillage systems (from conventional plow-based tillage through reduced tillage to no-tillage), different methods of cover crop biomass management, and varying nitrogen fertilization rates applied to spring barley (40, 80, and 120 kg $N \cdot ha^{-1}$). The impact of the studied factors on the soil environment was assessed based on analyses of selected soil parameters in the arable layer, including bulk density, porosity, soil moisture content, degree of compaction, and indicators characterizing the soil structure.

The results showed that reduced tillage intensity combined with leaving cover crop biomass on the soil surface or shallow incorporation generally improved soil physical properties. Simplified tillage systems were characterized by lower compaction of the arable layer, higher porosity, and greater soil moisture than conventional plow tillage. Reduced soil disturbance and increased organic matter input contributed to improved soil structural parameters. The effects of increased nitrogen fertilization on the analyzed soil physical properties were variable and, relative to the influence of tillage practices and cover crop management, played a secondary role in this study. Significant changes were mainly observed in selected parameters related to soil structure and aggregate stability.

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67. The relationship between soil organic matter and soil aggregate stability

Elizaveta Watzlová[1], Pavel Čermák[2]

[1]Czech University of Life Sciences Prague (CZU), Kamýcká 129, 165 00 Praha - Suchdol, Prague, elizaveta.watzlova@seznam.cz
[2]Institute of Animal Science Prague, Přátelství 815, 104 00 Praha - Uhříněves, Prague, Czech Republic

Soil organic matter (SOM) is a critical component of productive soils. Soil organic matter plays a key role in forming and stabilizing soil structure, improving soil physical properties and recycling nutrients. The low content of organic substances in the soil due to insufficient organic fertilization has a negative effect on water management in the soil and increases the risk of soil compaction. Soil organic matter is often associated in the literature with soil aggregates, which are considered the basic unit of soil structure. The breakdown of soil aggregates results in the release of organic matter trapped inside and its subsequent loss through mineralization. Coagulated clay minerals, their complexes with humus and soil organic matter are of great importance in the formation of soil aggregates. Aggregate stability is negatively affected by soil cultivation under unsuitable conditions (unsuitable humidity, passage of heavy equipment, peptizing effect of mineral fertilizers and irrigation). Better soil structure and higher stability of aggregates are important for improving soil fertility, sustainability of land management.

The stability of organic carbon in different size aggregates is different. Organic carbon in the micro-aggregates is less susceptible to change than it is in the macro-aggregates.

The stability of soil aggregates was measured according to the wet sieving method. Soil oxidizable carbon was determined by various methods, such as Loss-on-Ignition (LOI), Walkley-Black (WB) wet oxidation, thermogravimetric analyses (TGA). The relationship between the stability of soil aggregates and soil oxidizable carbon was determined.

68. The effect of the interaction of mushroom substrate with mineral fertilization on the bioaccumulation of phosphorus and calcium in the biomass of *Festulolium braunii* (K.Richt.) A. Camus

Beata Wiśniewska-Kadżajan, Andrzej Wysokiński

University of Siedlce, Prusa 14, 0-110 Siedlce Poland, beata.wisniewska-kadzajan@uws.edu.pl

The use of spent mushroom substrate (SMS) as fertilizer aligns with the European Green Deal strategy, enabling the recycling of biomass rich in organic matter, phosphorus, and calcium. In Poland, a leading mushroom producer, managing the vast amounts of this waste poses a significant operational and ecological challenge. Research on the use of SMS in the cultivation of the *Festulolium braunii* hybrid is justified by the high nutritional requirements of forage grasses and the specific functional characteristics of this species (Staniak and Harasim, 2018).

The aim of this study was to assess the impact of combined use of mushroom substrate (SMS) and mineral fertilization (NPK) on the dynamics of P and Ca uptake and utilization efficiency of the studied grass biomass.

A two-year field experiment (2017–2018) was conducted at the University of Siedlce experimental facility, using horticultural soil. The effect of increasing doses of SMS (10, 15, and 20 $Mg \cdot ha^{-1}$) supplemented with mineral NPK was tested on the forage grass *Festulolium braunii*. The applied waste (SMS) was characterized by a neutral pH and high phosphorus (8.53 $g \cdot kg^{-1}$ D.M.) and calcium (20 $g \cdot kg^{-1}$ D.M.). Chemical analyses of the biomass, including determination of P content using the colorimetric method and Ca content using the ASA method, allowed for the calculation of the uptake of these nutrients and their efficiency. Statistical analysis of the results was performed in MS Excel, verifying the significance of the effects of the studied factors using the Fisher-Snedecor test. Tukey's test was used to assess differences between means.

The use of mushroom substrate (SMS) combined with NPK significantly increased the phosphorus content in grass biomass by 24–29% compared to mineral fertilization alone. This increase resulted from both the provision of an additional P pool and the improvement of soil moisture conditions through organic matter (Kumar and Chugh, 2022). Despite the high calcium supply in the SMS treatments, mineral phosphorus proved to be the main factor determining calcium accumulation in biomass (Marschner, 2012). Medina et al. (2012) confirmed that the use of SMS had a stabilizing effect on the Ca:P ratio, maintaining it within the optimal range (1.7:1–2.6:1). P uptake was significantly higher (by 35–48%) with mixed fertilization (NPK+SMS), suggesting synergy between organic matter and mineral nutrients. The highest P use efficiency was observed at the lowest and medium doses of SMS, while higher doses limited P use efficiency due to the "reservoir" nature of this waste (Prasad and Shivay, 2020). For Ca, its use efficiency was nearly five times higher when fertilized with NPK alone than in combination with SMS.

Agricultural policy should consider organic fertilization not only as a nutrient supply but also as a land improvement measure that increases soil water capacity by increasing humus content (Quisth et al., 2025). Investing in organic soil management should be a key element of drought adaptation strategies.

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69. Colour-based predictors of susceptibility to seed shattering in meadow fescue (*Festuca pratensis* Huds.)

Tomasz Wójtowicz, Andrzej Zieliński

University of Agriculture in Krakow, Faculty of Agriculture and Economics, Department of Plant Breeding, Physiology and Seed Science, Łobzowska 24, 31-140 Kraków, Poland, tomasz.wojtowicz@urk.edu.pl

In grass seed production, one of the main unsolved problems is seed shattering. Although the phenomenon of shattering itself is mainly genetic in origin, the effect of genotype×environment interaction on this phenomenon is significant (Maity et al., 2021). The occurrence of shattering may be influenced by weather conditions, especially high temperatures during seed ripening (Fjellheim et al., 2014). The structure of the spikelets and the rate of abscission layer formation are also important. Wójtowicz and Zieliński (2021) and Kavka et al. (2024) demonstrated, that in genotypes with low susceptibility to shattering in meadow fescue the formation of the abscission layer is slowed down. The literature suggests that the main predictors of shattering may be genes regulating the rate of formation of the abscission zone (Di Vittori 2019), as well as the content of hormones (Gunko et al., 2025). However, there is no literature available concerning the use of peduncle colour analysis and pigment content in grass organs as indicators of susceptibility to shattering.

The aim of the study was to determine the usefulness of peduncle colour measured using computer image analysis and chlorophyll and carotenoid content in panicles as predictors of susceptibility to seed shattering in meadow fescue (*Festuca pratensis* Huds.). The predictors were tested in 2016–2018 on two populations with different shattering tendencies, obtained through divergent selection based on yield structure elements and visual assessment of panicle maturity (Andersen scale). During the three-year research period, panicles were harvested at medium and full maturity, and the populations showed a strong impact of year-to-year variability. In 2016 and 2017, the population with a low susceptibility to shattering was characterised by a significantly higher yield, while only in 2017 the share of shattered seeds in the yield was significantly higher in the population with a higher susceptibility to shattering. Colouration of the peduncle measured using image analysis was significantly negatively correlated with panicle maturity assessed during harvesting ($r=-0.44$) and positively correlated with carotenoid content in panicles ($r=0.49$). PCA analysis showed that the first principal component was strongly influenced by the tested predictors, while the second principal component was influenced by the degree of panicle maturity and the weight of shattered seeds. The clustering analysis showed inconclusive results, as the clusters also included plants with opposite susceptibility to shattering. The model taking into account the image analysis of the peduncle showed a non-intuitive direction of prediction, as the modelling indicated an increasing tendency to shattering with decreasing peduncle maturity. In contrast, in the model taking into account pigment content, only the β parameter for carotenoid content was found to be significant, and the model allowed the prediction of the susceptibility to shattering with a probability of approximately 5%. The tested regression models did not negate usefulness of the studied predictors to predict the susceptibility of plants to shattering but they undoubtedly need improvement, particularly in the number and quality of the predictors used.

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70. The effect of different soil tillage systems on the weed infestation of cereals and sugar beet

Anna Wysmułek, Agnieszka Ciesielska, Irena Suwara

Warsaw University of Life Sciences, Institute of Agriculture, Department of Agronomy, St. Nowoursynowska 159, 02-776 Warszawa, e-mail: anna_wysmulek@sggw.edu.pl

Plant production is greatly influenced by natural and economic factors, agricultural technology, including tillage systems, biodiversity and degree of weed infestation. Since the beginning of the 21st century, there has been an increasing interest in various ways of simplifying tillage. Traditional plow cultivation is replaced by less labor-intensive cultivation procedures, or direct sowing or strip-till methods are introduced. Diversified tillage affects the species composition and degree of weed infestation of crop fields. Traditional plow cultivation reduces weed infestation thanks to the use of numerous cultivation treatments, while the introduction of simplifications in tillage results in an increase in weed infestation, especially perennial and monocotyledonous weeds (Minhas et al., 2023; Orzech et al., 2011; Santín-Montanyá and Sombrero Sacristán, 2019).

The aim of the research was to evaluate the weed infestation of cereals: winter wheat, spring wheat, spring barley and sugar beet depending on farming system (integrated or intensive) and the tillage system: conventional tillage (plow tillage), simplified tillage and strip-till. Winter wheat was cultivated in both integrated and intensive farming systems. Spring wheat and sugar beet were cultivated in integrated farming systems, and spring barley was cultivated only in intensive farming systems. Field experiments were carried out in 2019-2025 at the Experimental Station of the Institute of Agriculture in Skierniewice, in the field in Miedniewice (51˚58’05”N i 20˚11’22”E), on a luvisols made of light clay sands on light clay, a very good rye complex (Chojnicki et al., 2016). Since 2011, plots with dimensions of 45x30 m have been designated for research. In each of them, three experimental objects have been investigated: plow tillage (UP), simplified tillage (UB), direct sowing (SB) - replaced in 2020 by strip-till (ST). In the experiments the species composition, weed density and dry mass of weeds were determined on two times, depending on the crop, using the frame-weight method.

The weed infestation varied depending on the crop, farming and tillage system and assessment date. In winter wheat fields, from 3 to 12 weed species were distinguished, but greater biodiversity was observed in the integrated system. In spring barley, 8 to 15 weed species were recorded, and in spring wheat the highest biodiversity of weed species was observed among all cereals (from 12 to 18). In cereals cultivated in an intensive farming system, the highest weed density, in both wheat and barley, were observed under plough tillage. However, in integrated farming systems, both winter and spring wheat were most infested with weeds under strip-till. In cereals, irrespective of the tillage systems the dominant weeds species were: in winter wheat – *Viola arvensis*, *Apera spica-venti* and *Geranium pusillum*; in spring barley - *Viola arvensis*, *Geranium pusillum*, *Matricaria inodora* and *Echinochloa crus-galli* and in spring wheat – *Viola arvensis* and *Chenopodium album*. In sugar beet plots, lower biodiversity was observed compared to cereal weed infestation, from 5 to 9 weeds species and the highest number of weeds was observed in simplified tillage and strip-till compared to plough tillage. The dominant weeds, regardless of the tillage system, were *Chenopodium album* and *Echinochloa crus-galli*. in beet cultivation,

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71. Selected sulphur management indicators from the four-leaf stage to full maturity of pea (*Pisum sativum* L.)

Andrzej Wysokiński, Beata Wiśniewska, Izabela Łozak

[1]*University of Siedlce, Konarskiego 2 Str., 08110, Siedlce, Poland, andrzej.wysokinski@uws.edu.pl*

Sulphur plays a special role in legumes, both in the biological process of nitrogen reduction and protein formation. A good supply of sulphur in legumes leads to the proper development and functioning of nodule bacteria and to effective N_2 fixation [Zhao et al., 1999, Smytkiewicz-Buzak, 2024]. Sulphur deficiency reduces the synthesis and level of sulphur-containing storage proteins, while simultaneously increasing the synthesis of storage proteins low in cysteine and methionine [Schroeder, 1984]. Historically, high sulphur availability to plants resulted from high soil resources and atmospheric deposition [Kolbe, 2024]. Currently, due to a significant reduction in S availability from these sources, sulphur fertilization has become important. Sulphur is often applied in the -SO_4^{2-} form [Degryse et al., 2021], which easily migrates from the soil [Erkisen, 2009]. This form, introduced into the soil before sowing, may not ensure adequate S availability in the final stages of plant growth. Furthermore, sulphur is generally poorly relocated from old plant organs to young ones [Hawkesford, 2000]. The aim of this study was to determine selected indicators illustrating sulphur management by pea throughout its growing season. In a two-year field experiment, sulphur content (Sc), sulphur uptake (Sup), sulphur internal efficiency index (SIE), and sulphur harvest index (SHI) were determined in multi-purpose cultivar 'Batuta' and fodder cultivar 'Milwa' of peas. Measurements were taken at six developmental stages: four-leaf stage, three-internode stage, first bud stage, full flowering stage, 50% of pod stage, and full maturity. Harvested plants were separated into roots and above-ground parts, and seeds were additionally separated at full maturity. Peas were fertilized pre-sowing with sulphur and nitrogen at a rate of 34 kg·ha^{-1} S and 30 kg·ha^{-1} N, in the form of $(NH_4)_2SO_4$.

The studied pea parameters most often varied significantly across the developmental stages and study years. The average Sc in the whole pea mass increased between the four-leaf and three-internode stages and then decreased until the 50% bud stage. No significant changes in Sc values were noted between the 50% bud stage and full maturity. The sulphur content in the whole pea mass was not significantly influenced by the study years or the cultivars tested. Total uptake by the whole plant increased from the four-leaf stage to the flowering stage. From the flowering stage to full maturity, no significant changes were noted in the amount of sulphur accumulated in the whole pea mass. Between the 5% pods and maturity stages, peas primarily redistributed sulphur from vegetative organs to seeds. In the first year of the study, peas accumulated 58% more sulphur in the whole plant mass than in the second year. Total sulphur accumulation in the whole pea plant mass at full maturity did not differ significantly between cultivars. The SHI index value shows that slightly less than half of the sulphur taken up by peas (45%) was found in the main crop (seeds) and removed from the field, while the rest (55%), accumulated in crop residues, and could be returned to the soil. The SIE index value of an average of 140 kg of seeds per 1 kg of S accumulated in whole peas (7.1 kg of sulphur accumulated in 1 ton of seeds) indicates that the test plant was adequately supplied with this macronutrient.

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