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ORIGINAL ARTICLE

Comparative analysis of environmental impacts of wheat and potato production in conventional and organic systems

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Abstract

Agricultural production has a direct impact on the environment, both by consuming natural resources and by generating hazards in the form of emissions of various substances into the environment. Increased demand for plant products on global food markets contributes to heightened environmental pressure on agriculture. Agriculture, along with other sectors, should adhere to sustainability principles. Ongoing global development hinges on achieving a balance between economic growth and natural resource conservation. To fulfill the goals of sustainable development, agriculture should strive to minimize energy and natural resources consumption, thereby reducing its environmental impact. In the above context, research on the environmental effects of different agricultural production systems is needed. The aim of this study was to assess the environmental effects of two cultivation systems, conventional and organic, throughout the life cycles of winter wheat and potato production. The research employed a life cycle assessment (LCA) methodology from cradle to farm gate for assessing environmental impacts of crop cultivation across different farming systems, with respect to the functional unit of 1 tonne. Organic farming was shown to have lower environmental impacts than a conventional production system. The results confirm the sustainable nature of organic farming and its ability to mitigate the effects of farming activities. The LCA of conventional wheat and potato production showed that fertilizer application was the main environmental concern, highlighting the need to optimize fertilization to reduce environmental impacts. Furthermore, the results indicated that acidification and depletion of abiotic fossil fuel resources were significant environmental threats within the systems analyzed.

Keywords: environment, farming systems, life cycle assessment, potato, wheat

Introduction

Agriculture occupies an area representing about 40% of the Earth's surface and uses about 70% of its freshwater resources. With its high production potential, agriculture provides food for humans, fodder for animals, and raw materials for processing industries (Foley *et al.* 2005; FAO 2022). Crop production is not equally efficient everywhere due to spatial variations in soil, water and climate quality, as well as the technologies used (Tandzi and Mutengwa 2020). Consequently, intensive crop production aimed at achieving high crop yields is needed to ensure food security. This is based on the conventional production system, which uses highly efficient machinery, cultivation techniques, mineral fertilizers and chemical plant protection products. The conventional production system is characterized by its active impact on the state of the environment, with various effects. It is often associated with environmental impacts related to greenhouse gas emissions, soil degradation, water eutrophication and reduction of biodiversity, among others. The rise in environmental hazards from agricultural activities is not only the result of the conventional production system itself, but also comes from resource mismanagement and imprudent use of industrial inputs (Kopittke *et al.* 2019). Unsustainable agricultural practices lead to a deterioration in the state and quality of the environment, and their long-term effects can be irreversible and pose a serious threat to agricultural productivity (Shankar *et al.* 2021; Kheiralipour *et al.* 2024).

As environmental problems escalate, agricultural activities are increasingly tasked with a responsible role in safeguarding the environment, climate, and human health (Foley *et al.* 2011). In response, international and national regulations mandate the use of sustainable production methods, with the aim of reducing energy and natural resource consumption to minimize environmental impact (Sanyé-Mengual and Sala 2022). Organic farming pursues these objectives. By dispensing with chemicals, organic farming has a positive impact on the soil, promoting its ability to maintain fertility, biological activity, and biodiversity (Gomiero 2021). In addition, conversion to organic production can be a way to reduce energy consumption and greenhouse gas emissions, due to the fact that the production of mineral fertilizers is very energy-intensive and their use in crop production is highly carbon-intensive (Skowrońska and Filipek 2014; Holka *et al.* 2022). Organic farming is considered to be one way to minimize the adverse environmental impacts of agricultural production. Due to its lower productivity and limited scale of production, it is not a viable alternative to conventional agriculture. Today, organic production is growing rapidly worldwide, especially in Europe (Willer *et al.* 2022). Continued expansion of organic farming can positively contribute to the protection of soil, water, air, and living organisms (Gamage *et al.* 2023).

Currently, environmental protection during production is shifting from a set of requirements outlined in codes of good practices to minimizing environmental burdens throughout the entire life cycle of agricultural products (Baum and Bieńkowski 2020; Kheiralipour 2022). To determine appropriate environmental protection steps in agriculture, it is necessary to recognize the potential impacts of plant production in various agricultural production systems. This can be achieved through the application of life cycle assessment (LCA) methodology. LCA is a tool used to assess the environmental impact of products, services, or processes based on material and energy balances and environmental assessment in multiple impact categories throughout their life cycles. LCA considers the environmental impact from the extraction of raw materials for a given product and also includes its recycling (Alhashim *et al.* 2021; Dekamin *et al.* 2022; Fan *et al.* 2022). LCA is a globally recognized method for assessing production sustainability. The European Commission has recognized this method as the most appropriate way to assess the potential environmental impact of products. The results of LCA serve as the basis for decision-making in product design, help streamline production, and are utilized in environmental labeling systems, providing information to consumers. LCA studies in various agricultural production systems can make a significant contribution to combating adverse effects of agricultural activities in the context of current environmental and climate challenges (Sonnemann *et al.* 2018; Nitschelm *et al.* 2021; Sala *et al.* 2021).

The LCA methodology has been applied in the agricultural production sector to assess the environmental impacts of wheat (Van Stappen *et al.* 2015; Pishgar-Komleh *et al.* 2020; Verdi *et al.* 2022; Pourmehdi and Kheiralipour 2023) and potatoes (Mattsson and Wallén 2003; Moudrý *et al.* 2013; Timpanaro *et al.* 2021). Different life cycle impact assessment (LCIA) methods have been used in the literature studies, with CML 2001 (midpoint) and ReCiPe 2008 (midpoint and endpoint) being the most commonly applied approaches. The use of different LCIA methods limits the comparability of results across studies. Notwithstanding existing LCA studies of wheat and potato production, further studies are required, given the limited up-to-date and comprehensive data on the environmental impacts of conventional and organic systems. In light of climate change and the development of new agricultural techniques, it is essential to obtain updated insights to better understand the discrepancies in emissions and resource utilization between different production systems. Such studies can support the identification of more sustainable agricultural practices and recommend how to minimize negative environmental impacts. The present work aimed to assess the environmental impacts of crop production in organic and conventional farming systems using the LCA approach.

Materials and Methods

Research materials

Materials for analysis consisted of winter wheat and potato production data in two systems, conventional and organic, from the Field Experimental Station of the Institute of Plant Protection – National Research Institute in Winna Góra (N 52°23’48.471”, E 16°51’20.585”) from 2019 to 2022. The scope of the research included the following data: type of agrotechnical operations performed, their duration, agricultural machinery used, consumption of seed, fertilizers, plant protection products, fuels, and other materials, as well as the amount of crop yields obtained in the analyzed systems. The inputs and main yields of

Table 1. Data on the consumption of production means and yields of the analysed plants per hectare

Input	Unit	Conventional wheat	Organic wheat	Conventional potato	Organic potato
Seeds	kg	200.0	200.0	2500.0	2500.0
Nitrogen fertilizers	kg N	137.9	–	89.8	–
Phosphorus fertilizers	kg P_2O_5	70.0	–	72.0	–
Potassium fertilizers	kg K_2O	105.0	–	196.7	–
Organic fertilizers	kg N	9.8	27.8	9.8	27.8
Organic fertilizers	kg P_2O_5	21.0	35.6	21.0	35.6
Organic fertilizers	kg K_2O	48.8	87.8	48.8	87.8
Lime fertilizers	kg CaO	400.5	310.0	400.5	310.0
Herbicides	kg a.s.	0.75	–	0.23	–
Fungicides	kg a.s.	0.23	–	3.43	–
Insecticides	kg a.s.	0.01	–	0.05	–
Biofungicides	kg	–	0.46	–	2.99
Bioinsecticides	kg	–	0.11	–	0.10
Machinery	kg	14.2	14.6	30.5	35.1
Diesel oil	kg	88.6	102.4	119.3	130.3
Lubricants	kg	3.5	4.1	4.8	5.2
Main yield	t	7.2	4.7	33.0	21.3

a.s. – active substance

the analyzed production of conventional and organic plants are presented in Table 1.

LCA method

Analysis of the environmental impact of crop cultivation in two different farming systems was carried out using the LCA method (Guinée *et al.* 2002). Following International Organization for Standardization standards for LCA (ISO 2006a, b), the study was conducted in four interdependent phases: 1) goal and scope definition, 2) inventory data, 3) impact assessment, and 4) interpretation (Fig. 1).

In the first phase of LCA, the goal and scope of the analysis are defined, considering the reasons for undertaking the study, future application of the results, and their recipients. This stage also involved delineating the scope of the research, specifying the product system under investigation, its boundaries, the chosen functional unit, as well as outlining any assumptions and constraints. The product system includes unit processes related to each other in terms of materials and energy. The system boundary determines the temporal and spatial scope of the system under study. The functional unit represents the smallest quantifiable aspect of the system under scrutiny, providing a basis for comparing different scenarios. Life cycle inventory (LCI) analysis, the second phase of LCA, entails gathering comprehensive data on inputs and outputs of the system to construct an inventory table. Building upon the LCI findings, a LCIA, i.e., the third phase of LCA, is conducted. This phase consists of the following mandatory stages: selection of impact categories and indicators, classification, and characterization. Optional stages include: normalization, grouping, weighting, and quality analysis. During the classification stage, LCI data is categorized into appropriate impact categories. Subsequently, characterization models are employed to calculate impact category indicators (characterization). The final phase of LCA is interpretation, where conclusions are drawn

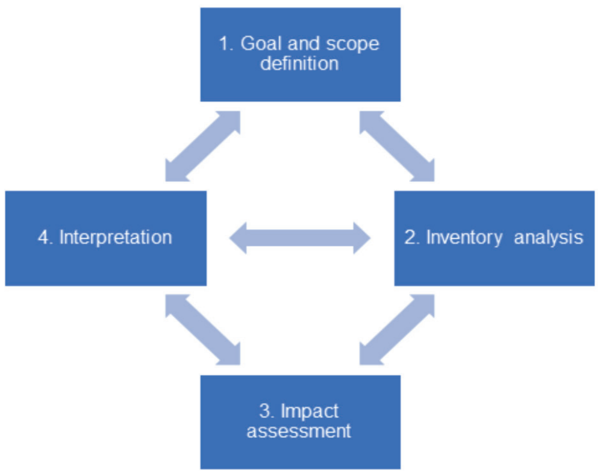


Fig. 1. Life cycle assessment (LCA) phases

in alignment with the established research objectives (Guinée *et al.* 2002).

Goal and scope definition

The goal of the study was to assess the environmental impacts associated with wheat and potato production in both conventional and organic systems, while pinpointing critical areas in various environmental impact categories.

Analysis of the life cycle of crop production in two systems followed the "from cradle to farm gate" approach, i.e., from the manufacturing of means of agricultural production through the crop cultivation process to its harvest (Fig. 2). Within the analyzed system, two stages of the crop production life cycle were distinguished, namely upstream and core. The upstream stage involved manufacturing material inputs (fuels, agricultural machinery, fertilizers, plant protection products, and seeds) related to crop production. The core stage concerned farm operations related to crop production such as cultivation, sowing, fertilization, plant protection, and harvesting. The functional unit chosen was 1 tonne of main yield.

Inventory analysis

In the second phase of LCA, input and output analysis was performed for two crop production systems. On the input side, the amounts of materials used were determined. The output data were gas emissions into the atmosphere and the amounts of substances polluting water and soil. The inventory data of upstream processes associated with materials supplied for crop production were obtained from the ecoinvent database (Ecoinvent Center 2024). Inventory analysis of the core processes related to wheat and potato production was carried out based on primary data from technological cards of the fields of the station in Winna Góra. Output data related to emissions from fertilization, plant residue management, and fuel combustion in farm operations were calculated based on models and indicators from the literature (van Beek *et al.* 2003; IPCC 2006, 2007; Dijkman *et al.* 2012; EEA 2013, 2016).

Impact assessment

The LCIA was conducted using the midpoint LCIA method of the Institute of Environmental Sciences (CML). The CML baseline version of this method from openLCA (GreenDelta, GmbH, Berlin, Germany) was used to calculate six indicators of environmental impact categories: abiotic resource depletion potential for fossil fuels, abiotic resource depletion potential for minerals, acidification potential, eutrophication potential, global warming potential, and photochemical oxidation potential (Table 2).

During the classification stage, inventory results were appropriately assigned to the analyzed impact categories, and then at the characterization stage, they were converted into indicator values tailored to the functional unit of 1 tonne. Additionally, a normalization procedure was used to present the share of analyzed environmental impacts in the overall problem of environmental burden (Sleeswijk *et al.* 2008).

Results

The calculated environmental indicator values for winter wheat and potato in two production systems per tonne of main yield are presented in Table 3. The life cycle assessment of crop production, from cradle to farm gate, demonstrated that conventional crops exhibited higher environmental impacts than organic crops.

In wheat production, the upstream stage, associated with the production of agricultural inputs, primarily contributed to the abiotic resource depletion potential for minerals (ADPm) and photochemical oxidation potential (POCP) impacts of organic and conventional wheat, as well as to the abiotic resource

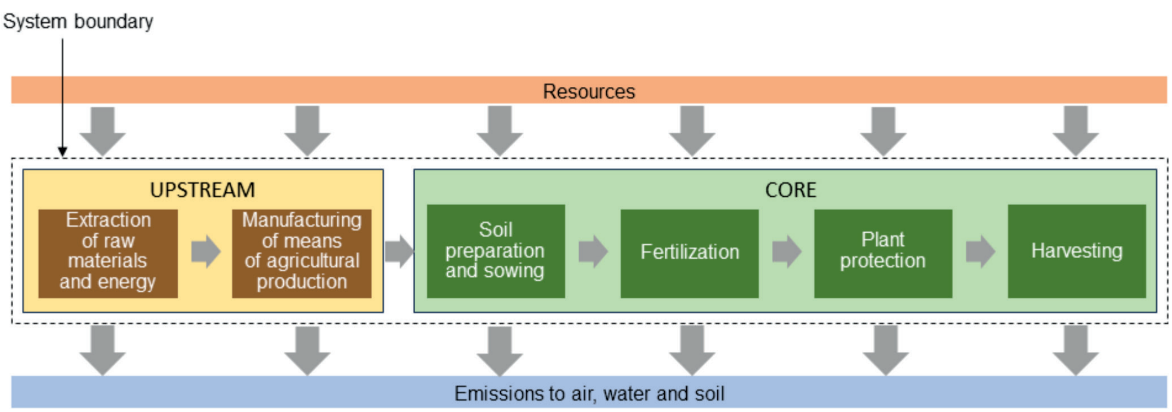


Fig. 2. System boundary of the studied crop production systems from cradle to farm gate

Table 2. Selected environmental impact category indicators, their abbreviations, and units

Impact category	Abbreviation	Unit	Description	Reference
Abiotic resource depletion potential for fossil fuels	ADPf	MJ	indicator of the depletion of natural fossil resources	(Van Oers and Guinée 2016)
Abiotic resource depletion potential for minerals	ADPm	kg Sb eq	indicator of the depletion of natural minerals	(Van Oers and Guinée 2016)
Acidification potential	AP	kg SO_2 eq	indicator of the potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulfur oxides	(Huijbregts 1999)
Eutrophication potential	EP	kg PO_4 eq	indicator of the enrichment of the aquatic ecosystem with nutritional elements, due to the emission of nitrogen- or phosphor-containing compounds	(Huijbregts and Seppälä 2001)
Global warming potential	GWP 100	kg CO_2 eq	indicator of potential global warming due to emissions of greenhouse gases into the air	(IPCC 2006)
Photochemical oxidation potential	POCP	kg C_2H_4 eq	indicator of emissions of gases that affect the creation of photochemical ozone in the lower atmosphere, catalyzed by sunlight	(Andersson-Sköld *et al.* 1992; Derwent *et al.* 1998)

Table 3. Values of impact category indicators for the winter wheat and potato in both conventional and organic production systems per functional unit of 1 tonne yield

Impact indicator, unit	Conventional wheat	Organic wheat	Conventional potato	Organic potato
ADPf, MJ	2669.1	1989.7	687.8	676.5
ADPm, kg Sb eq	0.002	0.001	0.001	0.001
AP, kg SO_2 eq	6.53	2.21	1.69	0.78
EP, kg PO_4 eq	1.720	0.827	0.531	0.331
GWP 100, kg CO_2 eq	375.5	211.4	80.4	71.6
POCP, kg C_2H_4 eq	0.068	0.045	0.020	0.021

ADPf – abiotic resource depletion potential for fossil fuels; ADPm – abiotic resource depletion potential for minerals; AP – acidification potential; EP – eutrophication potential; GWP 100 – global warming potential; POCP – photochemical oxidation potential

depletion potentials for fossil fuels (ADPf) of conventional wheat (Fig. 3A). Meanwhile, the core stage had a more dominant role in shaping the acidification (AP) and eutrophication (EP) impacts of both conventional and organic wheat production, as well as the ADPf of organic wheat. In potato production, the upstream stage had the greatest impact on the total values of ADPm and POCP in both conventional and organic systems, ADPf of conventional wheat, and EP of organic wheat. In turn, the core stage had the greatest influence on the AP and EP of conventional potato (Fig. 3B). For the remaining impacts of organic and conventional potatoes, the percentage share of this stage was equal or smaller.

As shown in Figure 4A, among the operations in conventional wheat production, mineral fertilization had the most significant impact on the values of the six calculated indicators. Other operations, such as soil preparation, sowing, plant protection, and harvesting, contributed to a lesser extent to environmental impacts. The values of the environmental indicators for organic wheat, except for AP, were primarily influenced by activities associated with soil preparation and sowing. The AP indicator of organic wheat was primarily affected by organic fertilization.

In conventional potato production, the values of ADPf, GWP 100, AP, and POCP were primarily influenced by mineral fertilization, whereas ADPm was also dependent on soil preparation and sowing, and plant care and protection (Fig. 4B). Conversely, all analyzed indicators for organic potatoes were determined mainly by soil preparation and sowing.

The negative environmental impact of conventional wheat production stemmed mainly from the production and use of nitrogen fertilizers (Fig. 5A). In the organic system, the ADPf and GWP 100 indicators for wheat were determined by the production and use of machinery, ADPm and POCP by plant protection products, and AP and EP by organic fertilizers.

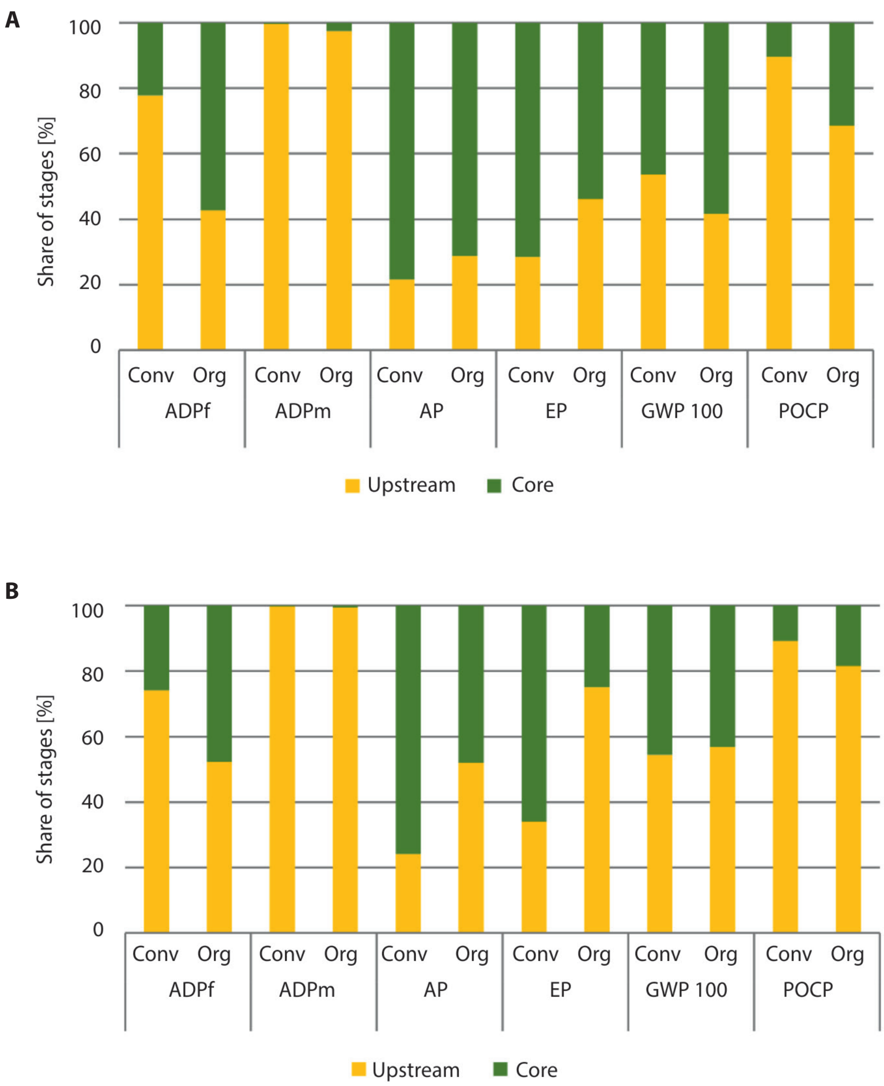


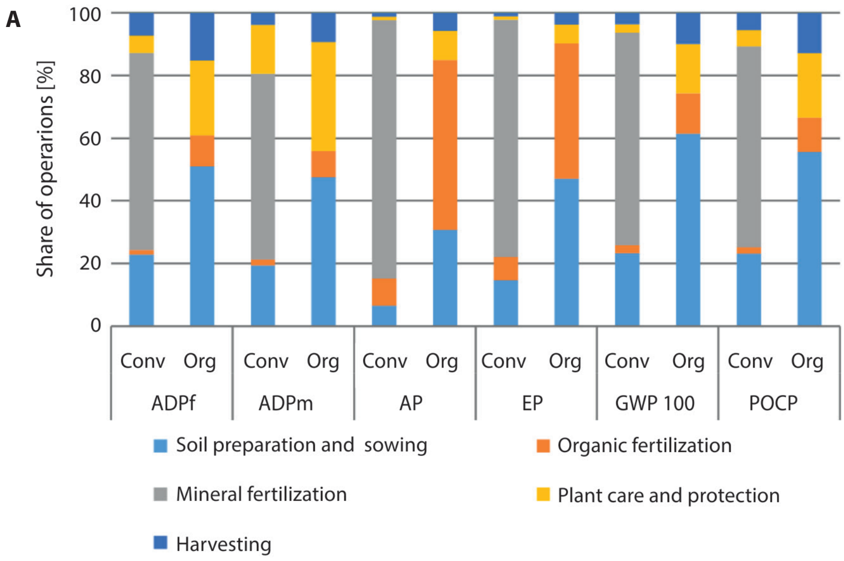
Fig. 3. Contribution of the life cycle stages to the environmental impacts of wheat (A) and potato (B) in conventional (Conv) and organic (Org) production systems.
ADPf – abiotic resource depletion potential for fossil fuels; ADPm – abiotic resource depletion potential for minerals; AP – acidification potential; EP – eutrophication potential; GWP 100 – global warming potential; POCP – photochemical oxidation potential

In conventional potato production, AP, EP and global warming potential (GWP 100) were mainly determined by nitrogen fertilizer usage, ADPf by fuel, ADPm by plant protection products and POCP by machinery (Fig. 5B). In the organic system, ADPm, EP and GWP 100 were determined by seeds, AP by seeds and organic fertilizers, ADPf by fuel and POCP by machinery.

To highlight the significance of the environmental impacts of the analyzed plant production systems, aggregated environmental indicators per functional unit of 1 tonne were calculated (Fig. 6A, B). The indicators for wheat and potato were higher in the conventional system ($1.56 \cdot 10^{-10}$ and $5.12 \cdot 10^{-11}$, respectively) compared to in the organic system ($7.80 \cdot 10^{-11}$ and $4.23 \cdot 10^{-11}$, respectively). The aggregated environmental indicators for crop production in two analyzed systems were primarily influenced by AP and ADPf.

Discussion

The present study demonstrated that crop production in the organic system had lower environmental impacts than in the conventional system. LCA studies indicated that the results of the comparison of these two farming systems were influenced by the choice of the functional unit. This can be an area unit related to the intensity of production or a product unit expressing production efficiency. In studies where the functional unit is a product unit, organic production may have less favorable environmental impacts than conventional systems due to the lower crop yields (Meier *et al.* 2015; Van Stappen *et al.* 2015). In studies where the LCA refers to an area unit, the environmental impact of organic crop production is often lower.



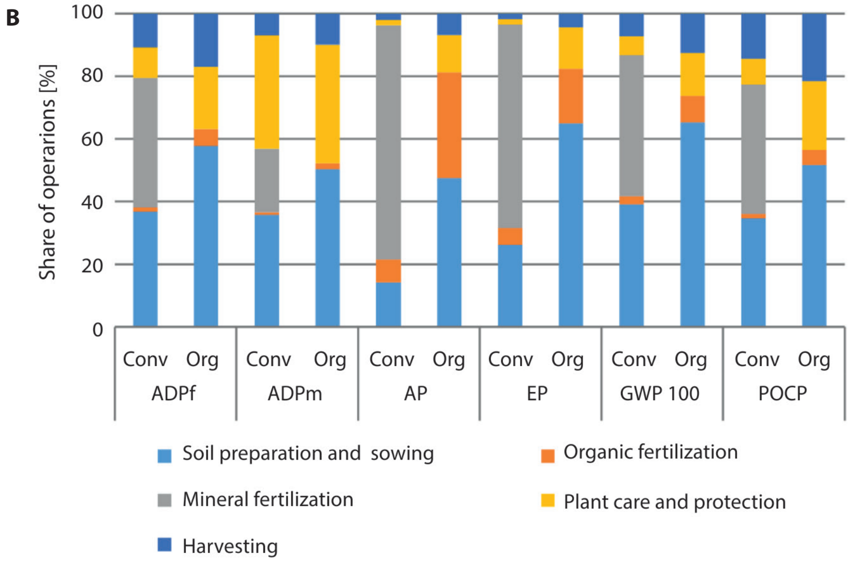


Fig. 4. Contribution of various operations to the environmental indicators' values of winter wheat (A) and potato (B) in conventional (Conv) and organic (Org) production systems.
ADPf – abiotic resource depletion potential for fossil fuels; ADPm – abiotic resource depletion potential for minerals; AP – acidification potential; EP – eutrophication potential; GWP 100 – global warming potential; POCP – photochemical oxidation potential

In the research presented, cultivation of wheat and potatoes in the organic system, despite lower yields, resulted in less environmental impact per tonne than in the conventional system. It is important to note that the observed differences in environmental impact can be attributed to the absence of nitrogen fertilizers, which have been identified as a significant contributor to the environmental impacts of conventional production. Brentrup *et al.* (2004) demonstrated that emissions from the production and use of nitrogen fertilizers are responsible for a range of environmental threats.

Mukosha *et al.* (2023) conducted LCA studies using the ReCiPe Midpoint method for winter wheat cultivation in Slovakia, in four variants: organic unfertilized, organic fertilized, conventional unfertilized, and conventional fertilized. The scope of the analyses included processes from cradle to farm gate. The calculated environmental impact indicators per unit of grain yield were higher in the fertilized variants. In the climate change impact category, unfertilized organic wheat exhibited the lowest environmental impact (0.131 kg CO_2 eq per kilogram), while fertilized organic wheat exhibited the highest (0.267 kg CO_2 eq per kilogram).

It should be noted that organic fertilizers are highly emissive. However, their use in crop fertilization allows for the reduction of mineral fertilizer amounts, thereby avoiding greenhouse gas emissions in the upstream and core stages of the crop production life cycle and consequently reducing the impact on global warming.

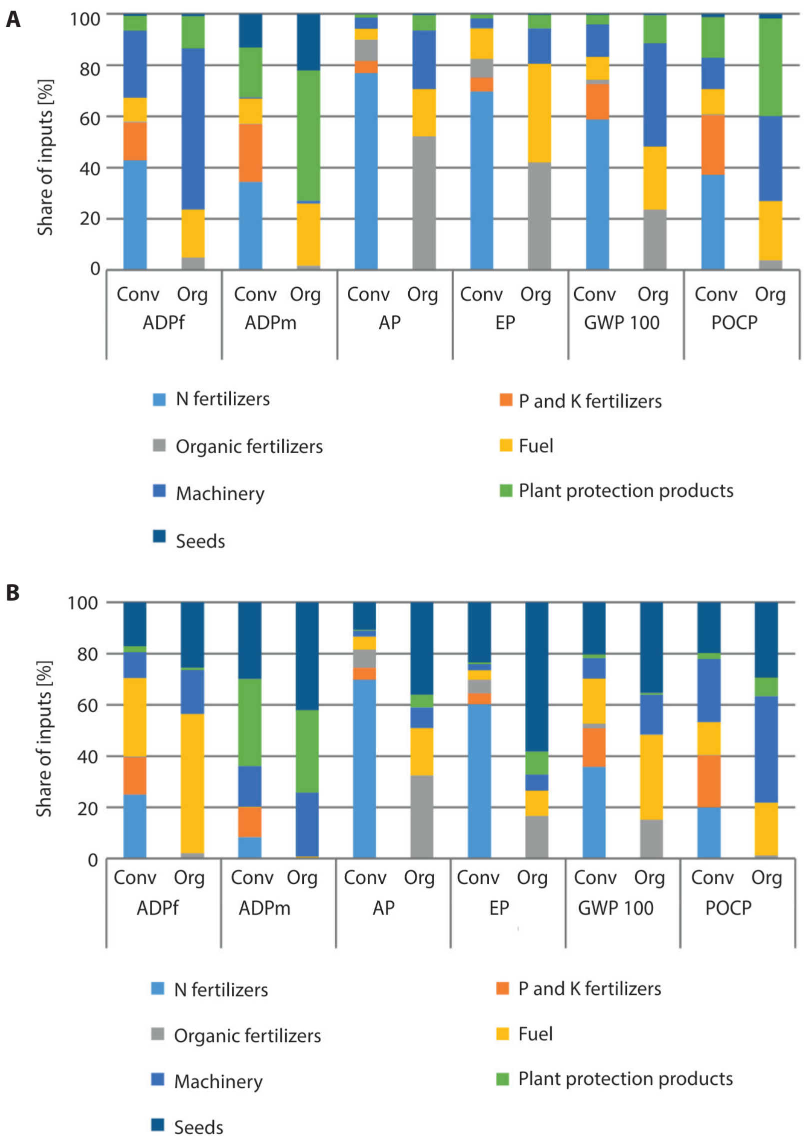


Fig 5. Contribution of various inputs to the environmental indicators of winter wheat (A) and potato (B) in conventional (Conv) and organic (Org) production systems.
ADPf – abiotic resource depletion potential for fossil fuels; ADPm – abiotic resource depletion potential for minerals; AP – acidification potential; EP – eutrophication potential; GWP 100 – global warming potential; POCP – photochemical oxidation potential

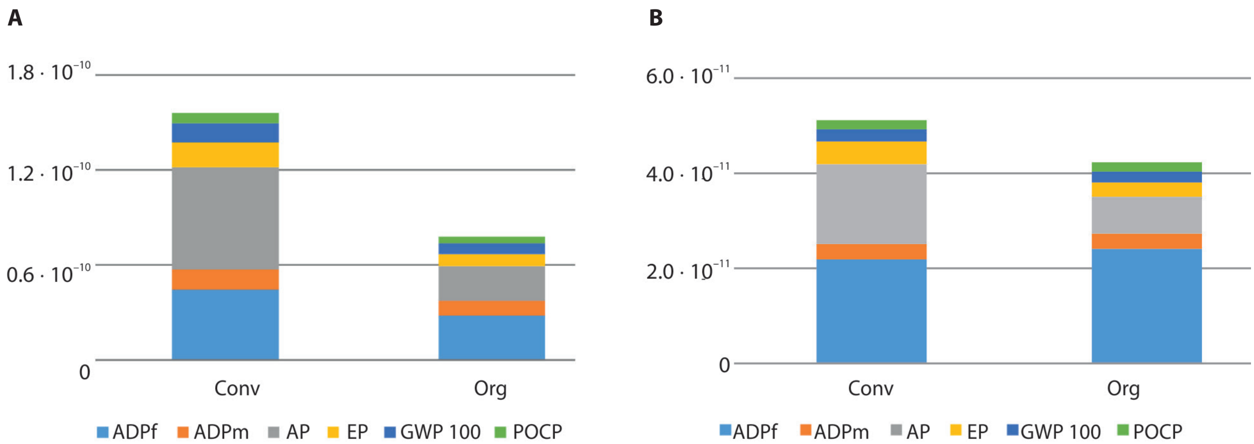


Fig. 6. Aggregated environmental indicator values of winter wheat (A) and potato (B) in conventional (Conv) and organic (Org) production systems per 1 tonne of yield
ADPf – abiotic resource depletion potential for fossil fuels; ADPm – abiotic resource depletion potential for minerals; AP – acidification potential; EP – eutrophication potential; GWP 100 – global warming potential; POCP – photochemical oxidation potential

Kowalczyk (2019) conducted a cradle to gate LCA of conventional potato production in Małopolska, Poland, using the ReCiPe Endpoint method. In these studies, the factors and structure of the environmental impact of potato cultivation were analyzed. The author concluded that organic fertilizers, such as manure, are more environmentally friendly than mineral fertilizers, even when their consumption is relatively high. It was stated that the primary environmental factors influencing potato cultivation are the utilization of seed potatoes and the consumption of diesel. This aligns with the present findings of LCA analysis of potatoes.

Crop production as one of the sources of greenhouse gas emissions contributes to global warming and climate change, and at the same time is also affected by climate change. Therefore, the need for mitigation and adaptation measures in agriculture is emphasized. In the analyzed production of conventional and organic winter wheat, the GWP 100 indicator values were 375.5 kg CO_2 eq and 211.4 kg CO_2 eq per tonne of grain, respectively. In the study by Holka *et al.* (2016), conducted in an intensive conventional wheat production system in the Wielkopolska region, Poland, the average value of the GWP 100 indicator was at a similar level of 364.1 CO_2 eq per tonne. Pishgar-Komleh *et al.* (2020), based on wheat production data on Polish farms, calculated the GWP 100 indicator to be in the range of 0.25 to 0.67 kg CO_2 eq per kilogram of wheat grain, with an average of 0.45 kg CO_2 eq.

Moudry *et al.* (2013) showed that organic potato production is associated with lower GWP 100 (0.126 kg CO_2 eq per kilogram) than conventionally grown potatoes (0.145 kg CO_2 eq per kilogram). It was also stated that this benefit is reduced by the higher greenhouse gas emissions associated with transporting organic products over long distances. It can be assumed that the range of variability of the GWP indicator in wheat and potato production systems is mainly due to differences in the level of nitrogen fertilization. Other authors also emphasize the large impact of this factor on GWP 100 (Bernas *et al.* 2023). The lower GWP in the analyzed organic crop production systems resulted from the lack of nitrogen fertilizers. Failure to use mineral fertilizers and chemical plant protection products may result in lower yields. Therefore, organic farming may have a higher GWP per unit of product. However, it is also worth mentioning that carbon sequestration, which was not considered in these studies, is expected to be greater for organic products, which may reduce the value of the climate change impact of organic products (Smith *et al.* 2019). Meena *et al.* (2020) emphasized the need to include carbon sequestration potential in studies assessing the GWP of plant production.

Mattsson and Wallén (2003) found that organic potato production is responsible for the majority of emissions contributing to eutrophication and acidification. The study identified key areas for potential improvement of the eco-efficiency of organic farming, including reducing nitrogen emissions that contribute to these problems and reducing yield losses in potato production due to poor quality. In our study, the normalization of indicator values demonstrated that AP and ADPf are the most significant environmental threats associated with crop production in each of the analyzed systems. Baum and Bieńkowski (2020) confirm the gravity of these issues.

Research shows that organic farming has many environmental benefits. On the other hand, the absence of mineral fertilizers and chemical plant protection products may lead to lower yields. According to Meemken and Qaim (2018), the transition to an organic system will not bring tangible environmental benefits because a larger area of land will have to be devoted to crop production to ensure an adequate level of production. Verdi *et al.* (2022) estimated that $192 \cdot 10^6$ ha of organic farming would be needed to maintain current wheat production in the European Union, compared to only $99 \cdot 10^6$ ha of conventional farming. According to these authors, in order to maintain adequate efficiency of agricultural production while minimizing its negative impact on the environment, efforts should be made to increase yields in organic farming and to reduce emissions in conventional farming.

Conclusions

All agricultural activity involves human interference in the environment. Since the purpose of this activity is significant, it should not be limited but rather developed towards more sustainable practices. Sustainable production of wheat and potatoes not only ensures that the population has access to adequate food but also has a positive impact on the natural environment and the stability of agricultural systems. A tool that enables the assessment of the sustainability of plant production is life cycle assessment (LCA). LCA can assist in understanding the actual environmental impacts of growing plants using technologies and systems. Studying the environmental effects of crop production is of great importance to ensure that food production respects the natural environment and human health, as well as to ensure the sustainable use of natural resources.

The presented research determined the environmental impacts of crop production in two different production systems: conventional and organic, using LCA methodology. Studies showed that the environmental impact of wheat and potato production varied significantly depending on the production system. The impact of organic production was more environmentally friendly than the conventional system, despite lower plant yields, was determined by differences in the use of production methods, in particular the absence of mineral fertilizers. The process of nitrogen fertilization, which is integral to mineral fertilization, has been identified as a critical factor influencing the environmental impacts of plant cultivation in a conventional system. The results for normalized environmental impacts showed that acidification and the depletion of abiotic resources, particularly fossil fuels, are significant environmental concerns in crop production.

Optimizing fertilizer use is crucial to reducing emissions from conventional crop production. One of the most important activities in rational fertilization is soil testing and analysis. Based on soil tests results and the plant's nutrient requirements, it is possible to develop a fertilization plan specifying nutrient doses and liming requirements. The appropriate technique and timing of fertilizer application is also important. This also applies to natural fertilizers. The sooner the fertilizer is mixed with the soil, the less nutrients are lost and the fewer compounds are released into the environment. It is recommended that liquid fertilizers are best applied directly to the soil to reduce emissions from application and increase fertilizer efficiency. Conventional agriculture can become more environmentally friendly if synthetic inputs are partially replaced by bio-based alternatives. Precision farming techniques, such as targeted application of plant protection products and fertilizers, can further reduce emissions and improve resource efficiency in conventional systems. To reduce the environmental impact in both organic and conventional farming, regenerative practices such as crop rotation, cover crops and minimum tillage should be adopted. These sustainable practices help decrease reliance on external inputs such as synthetic fertilizers and plant protection products. Organic farming, while it poses less environmental pollution and fewer risks to living organisms, still presents challenges in terms of lower productivity, which limits its viability as a complete substitute for conventional production. Nevertheless, increasing yields in organic farming is possible through effective soil management, rational fertilization, and the use of plant protection products approved for organic production, contributing to greater eco-efficiency within the system. By optimizing the balance between resource utilization and crop yields, it is possible to work towards securing a reliable supply of organic food.

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