A Review of Environmental Impacts of Wheat Production in Different Agrotechnical Systems

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Abstract: In light of the environmental challenges currently facing humanity, the issue of the environmental sustainability of crop production is becoming increasingly pressing. This is due to the fact that global population growth and the related demand for food are placing significant pressure on the environment. Wheat is a strategic crop globally due to its extensive cultivation area, high production and consumption levels, and vital nutritional properties. It is cultivated across diverse climatic conditions and within various agricultural production systems. It is of the utmost importance to pursue sustainable wheat production on a global scale, given the necessity to protect the environment and climate. The application of life cycle assessment (LCA) enables the identification of potential avenues for enhancing wheat production processes, thereby reducing the negative environmental impacts associated with these processes. This paper presents a synthesis of the existing literature on the environmental LCA of wheat grain production. It compares the impacts of different production systems, highlights critical stages in wheat cultivation, and provides recommendations for sustainable practices and directions for future research.

Keywords: grain crop; plant production systems; life cycle assessment; environmental burdens; sustainability

1. Introduction

Wheat is a crucial cultivated plant with key importance in the human nutrition strategy [1]. Next to barley, it is one of the two oldest grains. It has been cultivated by humans for about 10,000 years. The first domesticated wheat species were emmer grown in the Middle East. Over time, the importance of growing common wheat increased (Triticum aestivum L.), which is currently produced in almost all continents. Many varieties are cultivated and improved in terms of resistance to drought, high temperatures, and diseases. Production technologies are also being improved, which allow for high yields of wheat grain. As the productivity per unit of cultivated area increases, wheat production increases [2]. Both high wheat production and large areas for cultivation across the world are observed. In 2021, world wheat production amounted to 771 million Mg on 221 million hectares, which gave an average yield of 3.5 Mg per hectare [3]. About two-thirds of harvested wheat grain is consumed by humans. In addition to consumption, wheat grain is used for fodder and industrial purposes. Wheat grain is a valuable agricultural product in the case of energy, carbohydrates, protein, lipids, fiber, and mineral salts [4,5]. Thanks to its composition and properties, it is an important raw material for the production of various food products. The
main direction of using wheat grain in human nutrition is the milling and baking industry. Due to its importance in the production of bread, wheat is called bread grain [6,7].

Different material and energy inputs in various operations are used in wheat production, including fertilizer and fuel [8]. The sheer amount of agrochemicals and fuels associated with global wheat production has had severe environmental implications since the Industrial Revolution and, more recently, the Green Revolution [9]. Intensive agricultural production has contributed to an increase in the effectiveness and efficiency of plant production but also soil, water, and air pollution. The unsustainable use of industrial means of production contributes to environmental degradation and reduced biodiversity [10]. In asituation of deepening climate change and various environmental threats, there is a need to strive for sustainable food production systems that reduce the environmental impacts of agricultural activities [11]. Possibilities for action to protect the climate and the environment must be considered at every stage of food production, starting from the field [12]. Identification of critical points in different production stages and determination of areas for potential improvements are possible with the life cycle assessment (LCA), which is an environmental management tool for the evaluation of the ecological effects of production systems [13–15]. The quantitative and qualitative assessment of the impact of wheat production on the environment and the identification of its sources using the LCA methodology present opportunities for the improvement of the environmental sustainability of wheat production. Most previous reviews of LCA of wheat production focused on selected aspects, often in specific regions of the world. This paper reviews the results of LCA studies on wheat production across various parts of the world, taking into account a wide range of factors, not just selected ones.

Due to the importance of wheat in the global food system, the present paper aims to review the available literature of LCA studies on the impacts of different wheat production systems in the world and to identify critical points and areas for improvement for more sustainable food production.

2. Evaluation of Environmental Impacts in the Life Cycle Assessment

Life cycle assessment (LCA) is an environmental management methodology. It is globally recognized and applied to assess different production systems. As an analytical technique, it is used for the identification, quantification, and evaluation of environmental impacts and the specification of potential pathways to improve environmental quality. In comparison to other environmental assessment methods, LCA offers a number of advantages. The comprehensive analysis provided by the LCA method considers all stages of a product’s life cycle. This ensures a broad view of environmental impacts and an identification of hotspots in the production system. This aids in more informed decision making. Nevertheless, the complexity and time-consuming nature of data collection and analysis represent a significant challenge. Furthermore, the accuracy of LCA results is contingent upon the quality and availability of data. The basic assumption of LCA is to examine environmental effects throughout the production systems’ lifespan in the so-called “cradle to grave” range, i.e., from raw material extraction to waste management stages [16]. The first mention of LCA comes from 1969, when, at the World Energy Conference, Harold Smith presented the results of research on the production of various types of energy in chemical processes. In the same year, Teasley analyzed the production and use of glass and plastic beverage containers for Coca-Cola, comparing the amounts of material/energy consumption and waste generated. In the 1970s, due to the energy crisis, similar studies appeared based on the input–output analysis. In addition to the issues of material and energy consumption, they also address environmental issues from the formation of the greenhouse effect and smog. The name “life cycle assessment” was introduced in 1990 at a conference in Vermont [17]. The Society of Environmental Toxicology and Chemistry (SETAC) contributed significantly to the development of LCA. The result of cooperation between the two SETAC schools, American and European, was the publication in 1993 of “A Code of Practice” describing the structure of LCA. In 1992, in the Centre of Environmental
LCA includes four main phases: (1) goal and scope definition, (2) inventory analysis (LCI, life cycle inventory), (3) impact assessment (LCIA, life cycle impact assessment), and (4) interpretation [19]. Figure 1 depicts the interrelation of the phases to each other. The purpose and scope of LCA analyses are determined in the first stage. While defining the scope, the application of the results as well as their recipients are specified. The research scope relates to the studied production system, determines the system boundaries, and defines the functional unit. The studied production system includes different unit processes that are related to each other by material and energy consumption, such as the wheat production system presented in Figure 2. The system boundaries define the tangent points between the studied system (techno-sphere) and the outside environment (eco-sphere). In determining the scope of research, it is also important to decide on the period (time) and spatial scope (geographical area) for the analyzed system. The smallest quantitative effect of a system against the estimated environmental impacts is called the functional unit. Most often, it is the quantity of the product, e.g., an Mg of wheat grain, but in plant production, it may also be a unit of plant cultivation area, e.g., a hectare of wheat cultivation [18–21].

The remaining LCA phases are subordinated to the stage explained above. The second phase (LCI) involves gathering both qualitative and quantitative information related to the inputs, outputs, and emissions of the studied system. The input data are the material and
energy consumed, and the output data refer to the environmental emissions. The emissions to water, soil, and air are due to the consumption of various substances. Environmental emissions related to various processes are often calculated based on LCI databases, such as Ecoinvent and AGRIBALYSE [22,23]. The results obtained within the LCI phase form a platform to conduct calculations in the third phase. The LCIA phase consists of mandatory stages, categorization, classification, and characterization of environmental indicators, and optional stages, including normalization, grouping, weighting, and quality analyses. Classification involves appropriately assigning LCI data to selected impact categories. Environmental indicators at the midpoint and endpoint levels are calculated in the impact assessment phase (LCIA) based on the LCI results using the LCIA methods, such as CML 2001, ReCiPé, Eco-indicator 99, and ILCD 2011 [24] (Figure 3). In the final phase of LCA, the outcomes of the previous stages are interpreted based on the predetermined purpose. The contribution of the different inputs to the indicators is ascertained to identify environmental hotspots. In this phase, recommendations are given [16].

Figure 3. Midpoint and endpoint indicators in LCA. Source: own elaboration based on [24].

3. Impact Categories of Wheat Grain Production

The environmental impacts of wheat grain production have been studied in several countries [Table 1]. The literature states that climate change is the most commonly assessed impact category indicator in LCA studies on wheat production in the world [25–31]. As shown in Table 1, LCA studies differ in the impact assessment methods used, system boundaries, and functional units.

Table 1. The system boundaries, functional units, and impact assessment methods used in LCA studies on wheat production.

<table>
<thead>
<tr>
<th>Country</th>
<th>System Boundaries</th>
<th>Functional Units</th>
<th>Assessment Methods</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>Cradle-to-gate</td>
<td>1 Mg</td>
<td>CML 2000</td>
<td>[32]</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Gate-to-gate</td>
<td>1 kg</td>
<td>ISO14042 (2000)</td>
<td>[33]</td>
</tr>
<tr>
<td>Poland</td>
<td>Cradle-to-gate</td>
<td>1 Mg and 1 ha</td>
<td>CML-IA baseline</td>
<td>[34]</td>
</tr>
<tr>
<td>Poland</td>
<td>Cradle-to-gate</td>
<td>1 kg</td>
<td>CML-IA baseline</td>
<td>[35]</td>
</tr>
<tr>
<td>Iran</td>
<td>Cradle-to-gate</td>
<td>1 Mg</td>
<td>CML-IA baseline</td>
<td>[36]</td>
</tr>
<tr>
<td>Iran</td>
<td>Cradle-to-gate</td>
<td>1 Mg</td>
<td>CML-IA baseline</td>
<td>[37]</td>
</tr>
<tr>
<td>United States and Canada</td>
<td>Cradle-to-gate</td>
<td>1 kg</td>
<td>ReCiPé 2016</td>
<td>[38]</td>
</tr>
<tr>
<td>China</td>
<td>Cradle-to-gate</td>
<td>1 Mg</td>
<td>ReCiPé 2016</td>
<td>[39]</td>
</tr>
<tr>
<td>Spain</td>
<td>Gate-to-gate</td>
<td>1 ha</td>
<td>ReCiPé 2016</td>
<td>[40]</td>
</tr>
<tr>
<td>Iran</td>
<td>Gate-to-gate</td>
<td>1 Mg</td>
<td>ReCiPé 2016</td>
<td>[41]</td>
</tr>
<tr>
<td>Iran</td>
<td>Gate-to-gate</td>
<td>1 Mg</td>
<td>CML-IA baseline</td>
<td>[42]</td>
</tr>
</tbody>
</table>
The minimum and maximum values of environmental indicators of wheat grain production calculated based on the LCA methodology are listed in Table 2. Ref. [34] undertook an LCA study to assess environmental impacts on wheat production in an intensive production system in Poland. The authors indicated that the wheat production process in two analyzed farms had major effects on four indicators of acidification, eutrophication, and global warming potential. Ref. [51] calculated the environmental indicators of fourteen provinces in Iran using the official data from the Iran Ministry of Jihad Agriculture. The study revealed that global warming, abiotic depletion, eutrophication, and human toxicity had the greatest impacts resulting from wheat production. Ref. [52] calculated human health and ecosystem endpoint impacts of one Mg of wheat produced in 2016 and obtained their values as $5.15 \times 10^{-4}$ DALY and $37.17$ PDF·m²·yr./Mg, respectively. They reported that the environmental hotspots of wheat production in China were fertilizer production and consumption, diesel production, and water consumption. Based on the results, it is believed that efficiency improvement and consumption reduction of fertilizers, water, and diesel inputs can decrease the values of the environmental indicators. Ref. [33] calculated four environmental indicators of wheat production in Nigeria, including global warming potential, ozone layer depletion potential, acidification potential, and eutrophication potential in the country. The study included different operations, from tillage to flour and bran processing. Ref. [37] conducted a gate-to-gate study to calculate the environmental impacts of wheat grain production in Iran based on the CML-IA baseline V3.05/Netherlands 1997 model. They found that the main impacts were marine aquatic ecotoxicity (319.758 kg 1.4-DB eq./Mg), fossil abiotic depletion (6.673 MJ/Mg), and global warming (624 kg CO₂eq./Mg). Electricity had significant effects on five indicators, including fossil abiotic depletion, global warming, ozone layer depletion, freshwater aquatic ecotoxicity, and photochemical oxidation. Nitrogen was the main factor in abiotic depletion and human toxicity, phosphate was the main indicator of marine aquatic ecotoxicity, and the production process was the main factor in terrestrial ecotoxicity, acidification potential, and eutrophication potential. They calculated emissions of diesel fuel, fertilizers, and human labor. They calculated emissions of fuel to air as carbon dioxide (CO₂), sulfur dioxide (SO₂), methane (CH₄), benzene, cadmium (Cd), chromium (Cr), copper (Cu), dinitrogen monoxide (N₂O), nickel (Ni), zinc (Zn), benzopyrene, ammonia (NH₃), selenium (Se), polycyclic hydrocarbons (PAH), hydrocarbons (HC), nitrogen oxides (NOₓ), carbon monoxide (CO), and particulates (PM). The emission of fertilizers to air was NH₃, the emissions of fertilizers to water were nitrate and phosphate, and emissions of heavy metals of fertilizers to soil were Cd, Cu, Zn, lead (Pb), Ni, Cr, and mercury (Hg). The emission of N₂O from fertilizers and soil to air was nitrogen oxides (NOₓ), and the emission of human labor to air was CO₂.
Table 2. The values of the environmental indicators of wheat production to the functional unit of 1 Mg of grain.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>Minimum</th>
<th>Reference</th>
<th>Maximum</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic depletion (non-fossil)</td>
<td>kg Sb eq.</td>
<td>$2.00 \times 10^{-3}$</td>
<td>[34,36]</td>
<td>3.01</td>
<td>[32]</td>
</tr>
<tr>
<td>Abiotic depletion (fossil fuels)</td>
<td>MJ</td>
<td>0.50</td>
<td>[34]</td>
<td>$6.67 \times 10^3$</td>
<td>[37]</td>
</tr>
<tr>
<td>Global warming potential</td>
<td>kg CO₂ eq.</td>
<td>−4.39</td>
<td>[32]</td>
<td>160.00</td>
<td>[51]</td>
</tr>
<tr>
<td>Ozone layer depletion</td>
<td>kg CFC-11 eq.</td>
<td>$1.19 \times 10^{-7}$</td>
<td>[33]</td>
<td>$1.00 \times 10^{-4}$</td>
<td>[37]</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1.4 DB eq.</td>
<td>60</td>
<td>[42]</td>
<td>229.00</td>
<td>[42]</td>
</tr>
<tr>
<td>Freshwater aquatic ecotoxicity</td>
<td>kg 1.4 DB eq.</td>
<td>42</td>
<td>[42]</td>
<td>173.00</td>
<td>[42]</td>
</tr>
<tr>
<td>Marine aquatic ecotoxicity</td>
<td>kg 1.4 DB eq.</td>
<td>$1.23 \times 10^5$</td>
<td>[42]</td>
<td>$3.20 \times 10^5$</td>
<td>[42]</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1.4 DB eq.</td>
<td>0.46</td>
<td>[36]</td>
<td>12.79</td>
<td>[37]</td>
</tr>
<tr>
<td>Photochemical oxidation</td>
<td>kg C₂H₄ eq.</td>
<td>$4.55 \times 10^{-2}$</td>
<td>[42]</td>
<td>0.17</td>
<td>[36]</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO₂ eq.</td>
<td>$5.61 \times 10^{-6}$</td>
<td>[33]</td>
<td>15.28</td>
<td>[32]</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg PO₄ eq.</td>
<td>$3.59 \times 10^{-4}$</td>
<td>[33]</td>
<td>4.83</td>
<td>[32]</td>
</tr>
</tbody>
</table>

4. Irrigated and Non-Irrigated Production Systems

The majority of wheat in the world is grown in dry, rain-fed agricultural production conditions. In these systems, precipitation provides the water necessary for wheat to grow. In irrigated agriculture, different irrigation methods are applied to provide the required water for the plants in addition to rain. Irrigation systems therefore consume electricity and fuel. More mechanization may be necessary for the tillage operations of such systems compared to dryland ones. Sowing implements used in dryland and irrigated systems differ slightly.

Ref. [53] studied the impacts of wheat grain production in both dryland and irrigated systems with the LCA methodology. The study included straw as a co-product, which dealt with economic allocation, and 80% of the impacts were considered for wheat grain and 20% for straw. They calculated NH₃, N₂O, CO₂, NOₓ, P, NO₃, and spray emissions based on the Intergovernmental Panel on Climate Change (IPCC) methodology. They calculated eleven environmental indicators using the CML-IA baseline V3.01/world 2000 method. The indicator values of irrigated farms were lower than dryland ones except for terrestrial ecotoxicity. The greatest difference between dryland and irrigated systems was observed for the ozone layer depletion indicator, with values of $3.24 \times 10^{-5}$ and $0.04 \times 10^{-5}$ kg CFC-11 eq./Mg, respectively.

Ref. [36] compared the impacts of wheat production in dryland and irrigated systems. The study reported that compared to irrigated farms, lower inputs were needed in dryland systems, except for herbicides. The value of the output in irrigated farms was around two times higher compared to dryland farms. Due to this, the values of the environmental impacts of irrigated farms were 10% (for photochemical oxidation) to 50% (ozone layer depletion) lower compared to dryland production. Phosphate in irrigated and dryland farms and electricity in irrigated systems had higher effects on the wheat grain indicators compared to other factors.

Ref. [41] compared the endpoint indicators of wheat produced in dryland and irrigated systems with conservation tillage operation in a gate-to-gate study based on the ReCiPe 2016 method. The farm inputs within dryland systems were machines, fuel, nitrogen, phosphate, potassium, manure, biocides, and labor. The inputs of irrigated farms were similar to those of the dryland farms. Additionally, electricity in irrigating operations was consumed. The average yields of the dryland and irrigated farms were 3.0 and 5.1 Mg/ha, respectively. Authors of the study reported that the values of human health, ecosystems, and resource indicators for the irrigated system (0.04 DALY, 4.91 × 10⁻⁵ species/yr., and USD 50.26, respectively) were lower compared to dryland wheat production farms (0.06 DALY, 6.46 × 10⁻⁵ species/yr., and USD 59.01, respectively) due to higher outputs.

Ref. [42] compared the indicators of wheat produced in dryland and irrigated cropping pasturing farms. The indicators were selected and calculated for the functional unit of 1 Mg of grain based on the CML-IA baseline impact assessment method. The inputs of
the dryland systems were seed, machinery, fuel, lubricant oil, fertilizer, and sprays. In irrigated farms, those inputs of dryland farms were also used and, additionally, electricity was consumed. The outputs were grain and straw. The authors reported that the values of outputs of irrigated areas were higher than those of dryland production. Nonetheless, calculated indicators for wheat grain production in irrigated farms had lower values compared to the dryland wheat production system. The eutrophication potential had the highest difference (52%) with values of 1.8 and 3.6 kg PO₄ eq. per Mg for irrigated and dryland farms, respectively, and marine aquatic ecotoxicity potential had the lowest difference (33%) with values of $8.22 \times 10^4$ and $1.2 \times 10^5$ kg 1.4 DB eq. per Mg, respectively. They reported that the values of input to total output index for all inputs in irrigated systems were lower when compared to dryland wheat farms without consideration of electricity input because it was not consumed in the dryland system. The normalization process showed that the main indicator was marine water ecotoxicity followed by eutrophication and acidification.

Nitrogen fertilizer input had the highest contributor to all calculated environmental indicators in both production systems, except for eutrophication and acidification potential. In irrigated production, more wheat yield is obtained because more water is consumed by plants during the growing season, so the values of irrigated indicators will be lower when compared to dryland farms.

5. Conventional Versus Organic Farming Systems

In conventional agricultural production systems, agrochemicals with adverse environmental burdens are used. These inputs are not exploited in organic systems; instead, biological inputs are applied. Although the environmental impacts are lower than those of conventional farms, based on the production area, outputs of the organic wheat production system are disproportionately low [54]. Ref. [32] compared the values of four indicators (acidification, abiotic depletion, eutrophication, and global warming) in conventional and organic wheat production systems during the 2008–2009 production period in Chile. The grain yield in the conventional system (4.5 Mg/ha) was two times higher than that in the organic system (2.0 Mg/ha). They reported that the values of the studied indicators for the conventional system were higher compared to organic wheat production. Also, compost used in organic production had a positive impact, such that the value of the global warming indicator was equal to $-4.4$ kg CO₂ eq./Mg while the corresponding value for conventional production was 792.8 kg CO₂ eq./Mg. They reported results for other impacts, and acidification (15.3 kg SO₂ eq./Mg) and eutrophication (4.8 kg PO₄ eq./Mg) were the relatively worse indicators in the conventional system, whereas abiotic depletion (0.9 kg Sb eq./Mg) was the relatively worse indicator in the organic system. In their research, diesel fuel consumption in soil management was the main effective factor in both production systems. Among all factors in the conventional system, urea consumption had greater effects on acidification and eutrophication indicators, followed by phosphorous.

It is important to highlight that analyses of organic farming using LCA have certain limitations. Studies employing the LCA method in agriculture often neglect critical factors, such as soil carbon changes and the impact on biodiversity. Therefore, it is crucial to adapt the LCA method for research in organic farming [55].

6. The Impact of Fertilizers on the Environment

Different synthetic and biological fertilizers with different levels of usage per hectare are consumed in wheat production to provide nutrients for the plants. [56] studied the impacts of nitrogen (N) fertilizer usage on toxicity, resource depletion, global warming, acidification, eutrophication, and land use indicators in the United Kingdom. N fertilizer was consumed at seven levels ranging from 0 to 288 kg/ha. The output was grain and straw. The research showed that grain yield strongly increased from 2.07 to 9.25 kg/ha by increasing N fertilizer consumption from 0 to 192 kg/ha. It relatively increased to 192 kg N/ha for 244 kg N/ha and decreased to 9.11 kg/ha for 288 kg N/ha. It was observed that the value of the land use indicator was higher in the case of zero N consumption
(3865 m²·year/Mg), while it was the lowest in the case of consumption of 192–288 kg N/ha. Abiotic resource depletion studies showed that the phosphate and potassium values for different levels of fertilizer consumption were the same, while the fossil fuel depletion had the lowest value (1060 MJ/Mg) with N consumption of 96 and 144 kg/ha. Global warming potential increased from around 150 to 450 kg CO₂ eq./Mg with increasing N consumption. The toxicity indicator value was the same for all N levels. The lowest acidification potential value (1.11 kg eq. SO₂/Mg) was recorded at the consumption of 96 kg N/ha, and the highest (1.75 kg eq. SO₂/Mg) was recorded at the consumption of 288 kg N/ha. Terrestrial eutrophication had the lowest value (1.3 kg NO₃ eq./Mg) for 48 kg N/ha, whereas it had the highest value (2.09 kg NO₃ eq./Mg) for 288 kg N/ha. Aquatic eutrophication had the lowest value for 0–96 kg N/ha levels, and it had the highest value (2.22 kg PO₄ eq./Mg) for 288 kg N/ha consumption. The key indicators were land use and eutrophication potential. In conclusion, the authors stated that consumption of 96 kg N/ha had the lowest environmental impacts compared to other N levels. They suggested an increase in yield to decrease land use, a decrease in N consumption to decrease NO₃, a decrease in NH₃ consumption to decrease acidification and terrestrial eutrophication indicators, and a decrease in N₂O to decrease the global warming potential value.

Ref. [39] conducted a study to assess the impact of different types of fertilizers on the environment. They calculated eighteen midpoint and three endpoint environmental indicators based on the ReCiPe 2016 model. The fertilizer types were chemical (CF), manure compost (MC), and 5% biochar-amended manure compost (MCB5) and 10% biochar-amended manure compost (MCB10). They consumed 316 kg/ha of N fertilizer for the CF treatment and 158 kg N/ha for other treatments. In the MC treatment, 7.6 Mg/ha of manure compost was consumed, whereas in the MCB5 and MCB treatments, the same amount of biochar-amended manure compost with corresponding biochar addition rates was used (8.83 Mg/ha). In the case of midpoint environmental impacts, the highest and lowest values of global warming potential indicators were obtained for the MC (1.33 × 10³ kg CO₂ eq.) and MCB10 (6.33 × 10² kg CO₂ eq.) treatments, respectively. In the case of endpoint impacts, the values of human health, ecosystems, and resources for CF treatment were 4.33 × 10⁻³ DALY, 1.72 × 10⁻⁵ species/yr., and USD 58.7 in 2013, respectively. These values for MCB5 were decreased by 13.60, 16.90, and 3.53%, respectively. The researchers concluded that biochar–manure compost with a 5% addition of biochar was better for reducing the environmental impact of wheat production and constructing an ecological agriculture model due to recycling of agricultural wastes, such as straw and manure. Biogenic (CH₄ and N₂O) emissions into the air are the main hotspots of composting and biochar production systems.

The influence of N fertilizers on nine environmental impacts (aquatic ecotoxicity potential, global warming potential, human toxicity potential, fossil fuel depletion, renewable usage potential, water use, terrestrial ecotoxicity potential, acidification potential, and eutrophication potential) was evaluated in the North China Plain [57]. The authors examined five levels of N fertilizer during the study years. They reported that the values of acidification and eutrophication potentials were increased by an increase in N consumption whereas those of global warming potential and fossil fuel depletion were initially decreased and then increased such that the sub-optimal treatment had the lowest value for the two indicators. Moreover, this treatment had the lowest value for aquatic ecotoxicity, renewable potential, human toxicity potential, water resources, and terrestrial ecotoxicity potential, as well as the aggregated indicator (0.39 EcoX./Mg), due to the highest wheat yield.

The literature shows that excessive use of chemical fertilizers reduces the activities of soil microorganisms and soil micronutrients, degrades soil texture properties, and reduces yield. It increases acidification potential because of soil and environmental pollution. From an economic perspective, it increases the production costs of crops. Organic fertilizers improve soil fertility due to their positive effects on biological, chemical, and physical properties. Organic fertilizers increase the pH and organic matter of soil, improve the chemical properties of soil, and increase the activity of microorganisms and nutrient utilization. Biofertilizers as biological input are more environmentally friendly and more
cost-effective than chemical fertilizers [58]. Plant and animal residues contain the nutrients needed for wheat plants and regularly feed the plant during the decaying process when decomposed organic fertilizer is added to the soil; some of the nutrients are immediately provided to the plant so the remains gradually become ready to be absorbed by the plant over the time. Organic matter improves the soil properties in such a way that the plant roots can easily penetrate the soil and may benefit from the presence of air, water, and nutrients in farm soil [59]. Therefore, using biological inputs, such as organic fertilizers, increases soil nutrients’ absorption by the plants, maintains the stability of soil resources, increases production, and reduces environmental pollution. Compost as a biological input is a beneficent alternative that can be consumed instead of fertilizers and chemical pesticides. Besides the mentioned positive effects on soil, it prevents soil erosion. Also, it has a positive effect on maintaining soil moisture, it increases the soil organic matter, and it consequently increases yield in the long run [60,61].

7. Conventional and Conservation Tillage Methods

Preparing the soil for sowing by using both primary and secondary tillage tools is called conventional tillage. It decreases fertility and organic matter of soil and increases compaction, water, and wind erosion of soil, fuel consumption, environmental impacts, and production costs. In contrast, conservation tillage means a reduction in tillage operations and leaving plant residuals on the farm surface to protect soil against water and wind erosion. It results in an increase in organic matter value and nitrogen retention in soil, decreases machinery use, fuel consumption, and environmental impacts, prevents soil erosion and evaporation, and decreases the moisture content of topsoil and soil compaction [62,63]. The application of reduced tillage strategies in wheat production farms causes a decrease in fossil fuel consumption and greenhouse gas emissions [35]. Consumption of chemical fertilizers and plant protection products in the first 5 to 10 years during the adoption of the no-till system may increase compared to conventional farming [64].

Ref. [41] compared the conventional and conservation tillage operations from the perspective of the endpoint indicators for wheat grain in irrigated production through a gate-to-gate study in 2021–2022 in Qazvin, Iran. The researchers calculated the indicators’ values using the ReCiPe 2016 impact assessment method. Within the farms using conventional and conservation tillage systems, in terms of the average yields, small differences were noted (5.0 and 5.1 Mg/ha, respectively), but the difference in the indicators’ values was significant. They reported that the values of human health, ecosystem, and resource indicators for conservation-tilled farm systems (0.04 DALY, $4.91 \times 10^{-5}$ species/yr., and USD 50.26, respectively) were lower than those of conventionally tilled farms (0.07 DALY, $7.7 \times 10^{-5}$ species/yr., and USD 76.051, respectively) due to lower emissions.

8. Crop Rotation Effect

The cultivation of different plants around the same piece of land in a sequence of years is called crop rotation. Crop rotations decrease the dependency on farm inputs, increase yield, increase long-term productivity and sustainability due to improved nutrient circulation and soil health, structure, and biota, decrease diseases and pests, and enhance water use efficiency compared to crop-fallow systems [65].

Ref. [38] analyzed environmental impacts, such as energy, land use, global warming potential, freshwater ecotoxicity, and eutrophication, for dryland wheat production during two to six years covering fourteen no-till crop rotations in the Northern Great Plains, Canada. The authors found out that the multi-crop rotations are more sustainable in the case of global warming potential [66] calculated the values of global warming potential and eutrophication potential in wheat production based on the data from the Ministry of Agriculture, Forestry and Fisheries of Japan. The author compared the two growing conditions in paddy farms with inferior drainage performance (crop rotations of rice, wheat, and soybean) and upland farms (crop rotations of sugar beet, pulses, potato, and wheat) in two regions: Hokkaido and Tofuken. It was noted that the values of the global warming
potential in the Hokkaido and Tofuken regions of paddy fields (3305 and 2545 kg CO$_2$ eq./ha, respectively) were higher than those of upland farms (2896 and 2410 kg CO$_2$ eq./ha, respectively) due to lower yield. This trend was observed for eutrophication in paddy fields (7.0 kg PO$_4$ eq./ha) and upland farms (5.6 kg PO$_4$ eq./ha) in the Tofuken region, but the reverse trend was observed for the Hokkaido region (20.7 kg PO$_4$ eq./ha for paddy and 26.6 kg PO$_4$ eq./ha for upland farms).

Ref. [15] compared the values of eight environmental impacts of wheat production in monoculture and potato rotation systems. The authors considered mass (kg), land (ha), revenue (EUR), and energy (MJ) as functional units. They calculated the following indicators: human toxicity, particulate matter, climate change, marine and freshwater eutrophication, land use, fossil fuel depletion, and terrestrial acidification. The rotation system included the production of potato, commercial wheat, and Galician wheat in sequential years. They reported that native Galician wheat production had the lowest values for the indicators of wheat grain considering the financial-, land-, and energy-based functional units. They noted that the indicator values of the rotation system were lower than those of the monoculture reported by [67].

Ref. [40] compared the values of nine indicators for the production of wheat grain in Spain in potato, maize, and rapeseed rotation systems based on the ReCiPe 2016 impact assessment method. The indicators were global warming potential, terrestrial ecotoxicity, ozone layer depletion, fossil fuel depletion, freshwater and marine ecotoxicity, and freshwater and marine eutrophication. Considering the land-based functional unit, the authors reported that rapeseed was the best rotation, followed by potato and maize rotation systems.

9. Consequences for Social and Political Systems of Wheat Production

Wheat has become one of the most important crop plants. It has a large impact on the economy and it influences the functioning of social and political systems. Taking this into account, concentration on cultivation of only this type of grain brings numerous risks. Governments have been introducing different strategies in order to cope with uncertainties regarding the dependency on wheat production through alternative crops and natural resource management strategies [68].

Researchers look at the problem of wheat dependence and its implications for social and political systems from the angle of different risks. One of them is its vulnerability to plant pathogens. Global food security is under constant threat of potential plant disease epidemics. There are studies considering the complex problem of food security and its impacts on the sustainability of the system, which includes ecological, agronomical, social, and economic standpoints [69]. A large number of components and their interactions require the application of a systems modeling approach in order to mitigate the vulnerability of food production due to climate change, globalization, and crop health.

The problem of monocropping refers not only to wheat production. In research by [70], there is a focus on banana production. The shift towards intensified production of one cultivation plant is assessed. The scholars found that during a 20-year analyzed period, while the economic dimension due to the shift improved, the other dimensions of sustainability, such as agricultural productivity, the environment, and social and human dimensions, decreased. The authors underline that monocropping leads to unsustainable development with all of its implications for social and political systems.

Monocrops are vulnerable to diseases and abiotic stress, but they also have a negative environmental impact. Therefore, crop diversification is seen as having high importance for food security [71]. In addition, this approach is seen as a way to mitigate climate change effects in the agricultural sector. However, the implementation of different crops may be associated with difficulties because of risk avoidance, land suitability, social norms, and changes in income level.
10. Conclusions

The literature demonstrated the influence of various agrotechnical factors, including crop rotation, irrigation, tillage method, production system, and fertilizer use, on the environmental impact of wheat grain production. In most of the analyzed wheat production systems, diesel fuel, chemical fertilizers, and electricity were identified as the main hotspots in wheat production. Diesel fuel is mainly consumed for soil preparation and sowing. Fuel consumption can be decreased by applying the aggregation of agrotechnical treatments and through the implementation of simplified technologies of soil cultivation, such as minimum tillage and no tillage. The value of the global warming potential can be reduced with the use of renewable fuels, such as biodiesel. This may decrease emissions associated with not only soil preparation but also other operations, such as protection, harvesting, and transportation. Excessive use of chemical fertilizers incurs high energy consumption and risk of soil and atmospheric pollution. To reduce the energy within the inputs due to the use of chemical fertilizers that have a high production cost and due to the risk of environmental pollution, agricultural land should be sampled, and the soil test should determine the amount of fertilizer used for the land. Because the preservation of crop residues improves the soil structure and the burning of crop residues of the previous crop is associated with air pollution, using agricultural machinery for direct sowing is recommended to retain the plant residues on the farmland surface. Due to the adverse environmental impacts of chemical fertilizers, there is a need to replace them with organic fertilizers, such as compost. This is to reduce the effects of chemical fertilizers, decrease production costs, and increase farm yield. The amount of used chemical fertilizers in the farms is mainly influenced by macro-agricultural and environmental policies and can be optimized through the introduction of efficient laws and knowledge-building attempts.

Different operations in wheat production, including soil preparation, sowing, irrigation, fertilization, plant protection, and harvesting, need to be properly managed to decrease input consumption and decrease environmental emissions. Selecting inputs to be used in these operations and the manner of applying them within the farms are important to increase productivity. For example, the selection of wheat varieties has to be appropriate for the cultivated region, and the use of improved varieties may increase yields. The application of precision agriculture to produce wheat grain would be beneficial because it can decrease environmental impacts by reducing inputs and emissions and increasing outputs by using inputs based on the farm’s requirements and demands and conducting proper and in-time operations.

Future research may identify novel strategies to mitigate the environmental consequences of wheat grain production. As different factors, including soil characteristics, climate conditions, and management, affect wheat yield, these factors can be considered in conducting research. The application of different analytical methods, such as data envelopment analysis (DEA), artificial neural networks (ANNs), and the multi-objective genetic algorithm (MOGA), can be employed to identify further solutions for reducing the environmental impact of wheat production. It should be noted that the environment is one of three pillars of sustainable development, along with society and the economy. The LCA method is employed to support environmental protection. In addition to the environmental LCA, there are two other complementary methods: social life cycle assessment (S-LCA) and life cycle costing (LCC). The integration of LCA, S-LCA, and LCC methods in future research will facilitate a broader analysis of the impact of wheat production on the environment and society, as well as an analysis of the costs generated at each stage of the product life cycle. By combining these methods, sustainability aspects of wheat production can be addressed in a more comprehensive manner.

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