Contribution of Eco-Friendly Agricultural Practices in Improving and Stabilizing Wheat Crop Yield: A Review

Nazih Y. Rebouh 1,*, Chernen V. Khugaev 1, Aleksandra O. Utkina 1, Konstantin V. Isaev 1, Elsayed Said Mohamed 2, and Dmitry E. Kucher 1,*

1 Department of Environmental Management, Institute of Environmental Engineering, RUDN University, 6 Miklukho-Maklaya St., 117198 Moscow, Russia
2 National Authority for Remote Sensing and Space Sciences, Cairo 11843, Egypt; salama55@mail.ru
* Correspondence: n.yacer16@outlook.fr (N.Y.R.); kucher-do@rudn.ru (D.E.K.); Tel.: +7-977-4188644 (N.Y.R.)

Abstract: Wheat is considered to be a strategic crop for achieving food security. Wherefore, one of the current objectives of today’s agriculture is to ensure a consistent and sustainable yield of this particular crop while mitigating its environmental footprint. However, along with the genetic potential of varieties, agricultural practices play a key role in ensuring a high and stable yield of wheat. Under changing climatic conditions, new eco-friendly practices were adopted in the wheat farming system in recent decades. In this review, a large number of peer-reviewed articles have been screened during the last 15 years to evaluate the potential of some environmentally friendly agricultural practices such as tillage system, biological crop protection, crop rotation, intercropping systems, and the integration of resistant varieties in achieving a high and stable wheat yield. The present investigation unveiled that embracing eco-friendly agricultural methods in the wheat farming system holds the potential to engender high and sustainable wheat yields, contingent upon a normative strategy that comprehensively addresses multiple factors. These include the intrinsic attributes of the grown wheat cultivars, plant nutritional parameters, soil agrochemical characteristics, and specific climatic conditions. Further in-depth investigations under field conditions are necessary to help in the discernment of appropriate environmentally agricultural techniques that can efficaciously optimize the yield potential of the different cultivated varieties.

Keywords: tillage system; biological plant protection; crops rotation; intercropping system; wheat crop

1. Introduction

Wheat is one of the most widely cultivated and important cereal crops worldwide [1]. It is a staple food for billions of people and a vital source of nutrition and calories. Due to its high nutritional value and versatility, wheat plays a crucial role in global food security and agriculture. It is a fundamental component of the human diet and a key commodity in international trade. The cultivation and consumption of wheat have significant economic, social, and cultural implications [2].

The wheat cropping system encounters various limitations and difficulties, which can differ based on the geographical location and specific agricultural methods. These challenges include environmental factors such as abiotic stresses (drought, heat, cold, and water logging), biotic stresses like pests, diseases, and weeds, as well as concerns related to soil health and fertility [3,4].

In order to address these challenges, the concept of wheat cultivation intensification was developed. This concept revolves around enhancing cultural practices for increasing the productivity and efficiency of wheat production through various means. This approach aims to maximize yields and optimize resource utilization while taking into account the constraints and challenges associated with the wheat cropping system [5].

Throughout its history, the concept of intensifying wheat farming has consistently been associated with the use of chemicals like fertilizers and pesticides as crucial tools to attain
consistent and stable wheat crop yields. However, the intensification of agriculture has resulted in both favorable and adverse effects on the environment and human well-being. On one hand, it has contributed to increased yields and enhanced food security, but on the other hand, it has also presented considerable challenges, including soil degradation, water scarcity, greenhouse gas emissions, loss of biodiversity, and various concerns related to human health [6–8].

To tackle these issues, sustainable agricultural practices and innovations were involved [9]. These include agroecological approaches, precision agriculture, integrated pest and diseases management, conservation tillage, crop rotation, and the promotion of organic farming practices [10–14]. Adopting these practices can lead to acceptable yields as well as help in mitigating the negative impacts of agricultural intensification on environment and safeguarding human health [15,16]. However, achieving high wheat production using eco-friendly techniques to ensure food security remains the subject of ongoing discussion and consideration. The research results suggest that organic wheat yields are generally lower than those of conventional methods but the extent of the difference varies depending on the study and the inputs used (Table 1).

In the present study, we firstly present the most important environmentally friendly agricultural practices suitable for an integrated wheat crop management approach. In addition, we review conducted studies to determine the specific increase in wheat yields resulting from the implementation of these agricultural techniques, highlighting their positive impact on sustainable wheat production. Finally, we provide a brief overview of the advantages associated with adopting these eco-friendly agricultural methods on agrosystem biodiversity and propose recommendations for future studies.

### Table 1. Main cropping system characteristics for wheat in Europe and North America for conventional, low-input, and organic farming systems [17].

<table>
<thead>
<tr>
<th>Crops</th>
<th>Number of Yield Data</th>
<th>Mineral N (Kg N t.h(^{-1}))</th>
<th>Yield t.h(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Europe</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional farming</td>
<td>7</td>
<td>163</td>
<td>6.96</td>
</tr>
<tr>
<td>Low-input</td>
<td>15</td>
<td>126</td>
<td>5.94</td>
</tr>
<tr>
<td>Organic farming</td>
<td>3</td>
<td>0</td>
<td>4.15</td>
</tr>
<tr>
<td><strong>North America</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional farming</td>
<td>3</td>
<td>59</td>
<td>3.43</td>
</tr>
<tr>
<td>Low-input</td>
<td>4</td>
<td>32.5</td>
<td>3.43</td>
</tr>
<tr>
<td>Organic farming</td>
<td>1</td>
<td>0</td>
<td>1.81</td>
</tr>
</tbody>
</table>

In the present study, we firstly present the most important environmentally friendly agricultural practices suitable for an integrated wheat crop management approach. In addition, we review conducted studies to determine the specific increase in wheat yields resulting from the implementation of these agricultural techniques, highlighting their positive impact on sustainable wheat production. Finally, we provide a brief overview of the advantages associated with adopting these eco-friendly agricultural methods on agrosystem biodiversity and propose recommendations for future studies.

### 2. Tillage System

In the agricultural cycle, tillage plays a crucial role as it establishes a favorable environment for crop growth. It accomplishes this by managing soil moisture and temperature, as well as incorporating crop residues to enhance soil organic matter content through residue cover manipulation. Tillage can occur before sowing and during crop development, and it significantly influences the quality of future yields [18]. However, with the impact of climate change, selecting the appropriate tillage system has become essential to mitigate the adverse effects caused by this phenomenon.

Within the realm of farming, various types of tillage are employed. Among them, conservation tillage practices such as no-tillage (NT) or minimum tillage (MT), which are considered to be environmentally friendly. These practices have the beneficial effect of reducing the rate of soil organic carbon (SOC) mineralization while enhancing SOC sequestration and water retention in the soil [19–22]. However, it is crucial to understand
the efficacy of these tillage methods in achieving consistently high and stable wheat grain yields, as this knowledge is essential for effective wheat cropping system management.

In this context, Baiamonte et al. (2019) [23] conducted an analysis to investigate the relationship between durum wheat yield under no-tillage (NT) management and the aridity index across different cropping systems and residue management practices. The study revealed that under semi-arid conditions, NT resulted in higher wheat yields compared to conventional tillage (CT) management. Similarly, De Vita et al. (2007) [24] reached a similar conclusion for the Foggia region in Italy, where rainfall is limited, stating that NT is more suitable than CT for achieving higher wheat yields.

The authors explained their findings by highlighting that NT reduces water evaporation from the soil and enhances soil water availability when compared to CT. Many other researchers have also demonstrated that the higher wheat yields achieved with NT were observed under water-deficient conditions, while the yields decreased when the water deficit decreased [25–27]. Furthermore, in a study conducted by Dalal et al. (2013) [28], the variation in wheat grain yield under a semi-arid rainfed environment was investigated in relation to two tillage practices: no-tillage (NT) and conventional tillage (CT). The researchers observed that NT resulted in a higher wheat yield. They found that the NT practice allowed for greater water storage in the soil compared to CT, leading to improved water use efficiency and, consequently, better nitrogen (N) uptake.

These findings align with the research carried out by Toliver et al. (2012) [29], who examined wheat yields in 442 paired tillage experiments across the United States, considering various environmental factors like geographic location, annual precipitation, and soil texture. They concluded that no-till practice is more suitable for wheat cultivation in semi-arid regions due to its water conservation effects and increased water use efficiency.

Additionally, a meta-analysis conducted by Pittelkow et al. (2015) [30] supported these conclusions, confirming that NT practices result in higher wheat yields under rainfed conditions in dry climates when compared to conventional tillage methods.

Hence, the selection or adoption of a specific tillage system relies on the unique attributes of the soil and the prevailing climate conditions (Table 2). Consequently, these tillage practices are specific to particular locations. Given the climatic changes observed in recent decades and the projected temperature rise in the near future, the prospect of implementing no-tillage (NT) management remains appealing, provided that suitable areas for this approach are identified and determined.

Table 2. Influence of tillage systems on wheat yield according to the average annual rainfall.

<table>
<thead>
<tr>
<th>Tillage System</th>
<th>Yield t.h⁻¹</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average annual precipitation 397 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>1.46</td>
<td>[31]</td>
</tr>
<tr>
<td>No-till</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average annual precipitation 401 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>2.9</td>
<td>[32]</td>
</tr>
<tr>
<td>No-till</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average annual precipitation 470 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>2.8</td>
<td>[33]</td>
</tr>
<tr>
<td>No-till</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average annual precipitation 680 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>5.73</td>
<td>[34]</td>
</tr>
<tr>
<td>No-till</td>
<td>4.25</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Tillage System</th>
<th>Yield t. ha⁻¹</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average annual precipitation 800 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>3.4</td>
<td>[35]</td>
</tr>
<tr>
<td>No-till</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average annual precipitation 840 mm</td>
<td></td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>6.9</td>
<td>[36]</td>
</tr>
<tr>
<td>No-till</td>
<td>6.6</td>
<td></td>
</tr>
</tbody>
</table>

3. Biological Wheat Crop Protection

The use of biological methods for wheat crop protection involves employing living organisms, such as beneficial insects, microbes, plants, and other natural predators, to manage pests and diseases in wheat fields. This approach is a part of integrated pest management (IPM) strategies that aim to reduce the reliance on synthetic pesticides and promote sustainable agricultural practices [37].

A wide range of microorganisms exhibit mutualistic relationships with plants, including rhizobia, endo- and ectomycorrhizal fungi, as well as plant growth-promoting bacteria and fungi (Table 3). These microorganisms can promote plant growth and confer resistance against pathogenic agents. Understanding the pivotal functions of these microorganisms in enhancing wheat crop yields holds utmost importance for their integration into cropping systems, thereby fostering the advancement of sustainable agricultural practices. There are many studies that illustrate the influence of these microorganisms on wheat yields. For instance, El-Gremi et al., 2017 [38] observed a noteworthy augmentation in wheat grain yield by employing the B28 strain of *Bacillus amyloliquefaciens* for the management of pathogens linked to wheat kernel black point disease. The researchers substantiated that the introduction of this specific bacillus resulted in a remarkable 16.77% increment in the weight of 1000 kernels, as compared to the control. Likewise, within the arid steppe region of the Lower Volga area, Ivanchenko et al. (2023) [39] noted a substantial elevation in the yield potential of winter wheat, registering an upsurge of 27.5%. Moreover, there was a pronounced enhancement of the phytosanitary condition of the crops by 48.1%, coupled with a discernible amplification in profitability when subjected to biological treatment, as juxtaposed with the outcomes observed in the control group.

Furthermore, Omara et al., 2019 [40] reported that *Bacillus subtilis* and *Trichoderma viride* showed high antifungal activity against leaf rust caused by *Puccinia triticina* f.sp. *tritici* in wheat crops, where they led a significant increase in incubation and latent periods of the pathogen resulted by an increase of 1000 kernel weight and yield. The authors explained these results by the fact that the treatments led to an increase in catalase activity (CAT) and peroxidase (POX). Similarly, another study showed that *Pseudomonas fluorescens* and *Bacillus subtilis* exhibited a stripe rust disease control of 41.83 and 39.92%, which generated an increase in wheat grain yield by 39.06% and 41.81, respectively [41]. Further, within controlled greenhouse environments, the fungicidal capacity of *Coprinopsis urticicola* against take-all disease, attributed to *Gaeumannomyces graminis* var. *tritici* (Ggt), were scrutinized. The investigation also encompassed the assessment of its effectiveness in reducing disease severity and concurrently augmenting wheat crop yield [42].

Vera Palma et al., 2019 [43] investigated the influence of pre-sowing treatment of wheat seeds using two strains of *Pseudomonas* spp., both individually and in conjunction with a fungicide, aiming to manage take-all disease in wheat. Their results reported that the impact of *Pseudomonas* protegens on the assessed parameters was not prominently evident. Nevertheless, when these strains were coupled with a fungicide, they demonstrated the capacity to enhance yield, grain attributes, test weight characteristics, biomass accumulation, and initial plant height. Furthermore, their concurrent application resulted in a reduction in disease severity. Similarly, Ayed et al., 2021 [44] found that coating wheat seeds with a
mixture of *Bacillus* spp., *Trichoderma* spp. and endomycorrhiza increased grain yield by 27% over the control.

In our previous study, to control the common wheat diseases for enhancing the productivity and profitability of winter wheat crops under field conditions, a comparative analysis was undertaken involving three distinct treatments, namely biological, which included bio-agents; combined treatments, which contained bio-agents coupled with lower doses of fungicides; and chemical comprised only fungicides. The combined treatment exhibited higher grain yield, protein content, 1000 grain weight, and net income. However, the biological treatment demonstrated lower values but very close to those of the combined treatment, thus making it possible to achieve stable wheat yields, as well as healthy products [45].

**Table 3.** The main microorganisms with antifungal activity against the common wheat pathogens.

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>Wheat Pathogens</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Fusarium</em> sp.</td>
<td></td>
</tr>
<tr>
<td><em>Blumeria graminis f.</em> sp.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Septoria tritici blotch</em></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Puccinia</em> sp.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Gaeumannomyces tritici</em></td>
<td>+</td>
<td>[46–51]</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>−</td>
<td>[52,53]</td>
</tr>
<tr>
<td><em>Bacillus amyloliquuefaciens</em></td>
<td>+</td>
<td>[54,55]</td>
</tr>
<tr>
<td><em>Pseudomonas fluorescens</em></td>
<td>+</td>
<td>[56–59]</td>
</tr>
<tr>
<td><em>Trichoderma</em> sp.</td>
<td>+</td>
<td>[60–62]</td>
</tr>
</tbody>
</table>

Arbuscular mycorrhizal fungi (AMF) have shown potential for enhancing wheat crop protection through their symbiotic interactions with the plant. When AMF establish mycorrhizal associations with wheat roots, they can contribute to various aspects of crop protection and resilience [63,64]. These fungi are used in agricultural practices through AMF inoculation to promote healthier plant growth and reduce the need for chemical fertilizers [65].

Yadav et al., 2020 [66] documented that the application of indigenous plant growth-promoting bacterium *Bacillus subtilis* and treatment with arbuscular mycorrhizal fungi (AMF) yielded the most favorable outcomes concerning macro-nutrients, micro-nutrients concentrations within wheat kernels, as well as yield-related metrics such as thousand grain weight, grain count per spike, and total tiller count per plant across examined wheat cultivars. Furthermore, Spagnoletti et al., 2021 [67] investigated the effectiveness of utilizing the arbuscular mycorrhizal fungus (AMF) *Rhizophagus intraradices* as a potential bio-control agent against *Fusarium pseudograminearum* in wheat plants. The outcomes of the study indicate that the introduction of AMF led to a noteworthy reduction in the population density of *F. pseudograminearum* as well as a decrease in the disease severity. Moreover, AMF inoculation had a significant mitigating effect on the detrimental influences exerted by *F. pseudograminearum* on various crucial plant parameters, encompassing traits such as aboveground and belowground biomass, number of spikes, and plant height.

It is important to acknowledge that a limited number of investigations have delved into the impact of beneficial microorganisms on pest management and their subsequent implications for enhancing wheat productivity. Among these studies, Pawar et al., 2023 [68] documented a notable wheat yield of 3729.02 kg/h, signifying a substantial increase of 10.30% in comparison to the control. This achievement was attributed to the utilization of *Trichogramma chilonis* as a biocontrol agent against wheat’s borer pests.
In recent years, considerable research endeavors have been dedicated to the investigation of plant extracts as viable biological agents for controlling various fungal diseases. Plant extracts are recognized as substantial reservoirs of phytochemical compounds, including phenols, flavonoids, and essential oils, which exhibit significant potential for utilization as biological agents for the management of fungal diseases [69]. In this context, Afzal et al., 2023 [70] examined the efficiency of two plant extracts, namely Neem, Moringa, and bioagent *Trichoderma herzianum* to control leaf rust in wheat crops. The results have indicated that the application of Neem, Moringa extracts, and *Trichoderma harzianum* resulted in notable improvements in 1000 kernel weight, with enhancements of 36%, 22%, and 26%, respectively. Also, research findings have indicated that extracts derived from clove, Brazilian pepper, neem, and garlic exhibited notable efficacy as treatments, yielding substantial improvements in 1000 kernel weight of wheat. Specifically, these treatments yielded enhancements of 19.13%, 19.11%, 19.06%, and 19.06%, respectively, surpassing the control. Remarkably, their impact was comparable in significance to that of the tested fungicide, which resulted in a 20.23% increase in 1000 kernel weight [71].

In conclusion, the results obtained from a limited number of field experiments and the identified biological agents have not shown complete control of common wheat diseases. Wherefore, further studies are required to evaluate the effectiveness of bio-agents and their contributions to wheat yield improvement, especially under field conditions.

4. Crop Rotation

Crop rotation is a valuable agricultural practice that involves the systematic sequencing of different crops on the same field over multiple growing seasons. Implementing crop rotation can significantly contribute to enhancing wheat yield and overall agricultural productivity.

Crop rotation breaks the cycle of diseases that are specific to certain crops. By rotating wheat with non-host crops, the pathogen population declines, minimizing the risk of disease outbreaks in subsequent wheat crops. Furthermore, planting different crops in rotation can help disrupt the life cycles of pests that target wheat. Some crops act as natural pest repellents or inhibit the growth of specific pests, reducing their populations and potential damage to the wheat crop. In this section, we present these hypotheses and examine the primary mechanisms through which crop rotation can contribute to the regulation of pests and diseases, as well as the enhancement of soil health. Additionally, we provide some examples of the most suitable crops that can be utilized to enhance wheat yield (Table 4).

Table 4. Effect of some precursor crops on wheat grain yield [72].

<table>
<thead>
<tr>
<th>Precursor Crops</th>
<th>Grain Yield (t.ha⁻¹)</th>
<th>Grain Yield Increase (%)</th>
<th>Biomass Yield (t.ha⁻¹)</th>
<th>Biomass Yield Increment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat–wheat</td>
<td>3.1</td>
<td>-</td>
<td>7.3</td>
<td>-</td>
</tr>
<tr>
<td>Faba bean–wheat</td>
<td>5.3</td>
<td>71.1</td>
<td>12.6</td>
<td>72.2</td>
</tr>
<tr>
<td>Dekeko–wheat</td>
<td>4.7</td>
<td>52.3</td>
<td>11.6</td>
<td>58.7</td>
</tr>
<tr>
<td>Field pea–wheat</td>
<td>4.3</td>
<td>40.6</td>
<td>10.8</td>
<td>47.9</td>
</tr>
<tr>
<td>Lentil–wheat</td>
<td>4.1</td>
<td>34.5</td>
<td>10.2</td>
<td>40.1</td>
</tr>
</tbody>
</table>

Theron et al., 2023 [73], reported that implementing both crop rotation systems with non-host crops and zero tillage decreased incidence and severity of FCR (fusarium crown rot) disease, all the while maintaining grain yield and quality. In their observations, the researchers found that wheat grown in crop rotation systems involving medic, lupin, or canola, combined with zero tillage, led to reduced FCR levels.

These findings highlight the importance of managing diseases through practices such as crop rotation with non-host crops and appropriate tillage techniques. Similarly,
Campanella et al., 2020 [74] demonstrated that incorporating *Brassica carinata* as break crops could lead to substantial reductions in pathogens and disease incidence, along with enhancing the grain yield of wheat crops. According to Jalli et al., 2021 [75], they found that the severity of wheat leaf blotch disease, primarily caused by *Pyrenophora tritici-repentis*, was significantly reduced in the most diverse crop rotation. When wheat was grown once every four years instead of in continuous monoculture, the severity of wheat leaf blotch disease decreased by an average of 20%. The authors noted that the benefits of crop rotation on stem and root diseases became evident after a six-year rotation period, and the disease index was at its lowest in the most diverse crop rotation. They demonstrated that implementing a diversified crop rotation resulted in notable improvements in spring wheat yield, increasing up to 30% in no-tillage conditions and by 13% under plowing, compared to wheat grown in monoculture. In another investigation conducted by Stempkowski et al. in 2020 [76], it was found that specific crop rotation systems, namely vetch-white oats–wheat and black oats–barley–black oats–wheat, led to a significant 90% reduction in the incidence of soil-borne wheat mosaic disease compared to wheat grown in monoculture. Additionally, these crop rotation systems resulted in a noteworthy increase in wheat grain yield.

The introduction of various crops in a field or across the landscape can significantly influence how pests detect and choose their host plants or patches. Arthropod pests rely on specific visual and chemical signals emitted by their preferred crop plants to locate and select suitable areas. By increasing crop diversity within a field or in the surrounding landscape, these signals can become less clear or even confusing to the pests [77]. Many arthropod pests primarily rely on visual cues from the crop to identify and target their preferred host plants [78]. In theory, crop rotation offers a promising and sustainable approach for managing wheat pests effectively. However, there is a significant gap in research when it comes to studying the impact of various crop rotation systems on both pest control and potential yield improvements.

Crop rotation can help in managing weeds more effectively. Some crops suppress weed growth better than others, reducing competition with wheat for nutrients, water, and sunlight. This leads to fewer weed-related yield losses. Numerous studies have shown that the selection of specific crop rotation systems and the choice of crops used can effectively control weed populations and lead to increased wheat yield. For instance, in a study conducted by Minhas et al. (2023) [79], it was found that adopting a sorghum–wheat cropping system had several beneficial effects. The system resulted in reduced weed infestation, enhanced wheat productivity, and improved soil health, particularly when the appropriate tillage system is chosen. Furthermore, according to Shahzad et al. (2021) [80], the most effective approach to achieving higher wheat yields involves planting wheat after mungbean in an environment free of weeds. This weed-free condition can be attained through the use of chemical and/or mechanical methods.

Crop rotation contributes to the improvement of soil health by fostering a diverse microbial community and taking advantage of crop functions, root systems, and nutrient utilization. This diversity benefits the soil through enhanced nutrient cycling and fertility, reduced compaction, minimized erosion, and increased carbon sequestration. These positive effects, in turn, have favorable impacts on water quality and regulation. In a study conducted by Zou et al. in 2023 [81], it was observed that rotation systems W–P (wheat–peanut) and W–M/P (wheat–maize/peanut) resulted in higher wheat yield and net payback compared to the rotation system W–M (wheat–maize). The researchers explained that the introduction of peanuts in the rotation positively influenced bacterial communities and their functions, leading to better sequestration of soil organic carbon and improved labile carbon fractions. These factors had a beneficial impact on wheat yields.

Previous studies have provided evidence of the advantages of crop rotation for improving both the yield and quality of wheat. For instance, legumes like peas or beans fix nitrogen in the soil, benefiting the following wheat crop by providing a natural source of nitrogen. This enhances the soil’s fertility, which is crucial for wheat growth and yield. Indeed, in the research conducted by Bezabeh et al. in 2022 [82], it was shown that when
wheat was rotated with faba bean, the wheat grain yield and nutrient concentrations in the grains were higher compared to continuous wheat plots. The authors attributed this outcome to the nitrogen fixation carried out by the faba bean, as the application of nitrogen fertilization has been known to enhance wheat yield by aiding the absorption and movement of nutrients into the grains, as demonstrated in the study carried out by Xue et al., 2016 [83]. In addition, unlike the use of fertilizers, growing specific crops in the previous season, such as chickpea, can encourage the colonization of wheat roots by arbuscular mycorrhizal fungi (AMF), leading to an increase in grain yield [84].

Long-term simulations conducted by Giménez et al., 2016 [85] on the rotation system involving garlic and wheat revealed that wheat crops, by utilizing the nitrogen left in the soil from the previous garlic cultivation, can achieve yields close to the maximum attainable yields. This means that farmers can use reduced fertilization rates for wheat compared to the conventional rates typically applied, while still obtaining highly productive results.

Likewise, Lago-Oliveira et al., 2023 [86] reported that the average wheat yield obtained in a continuous cropping system was 5 t·ha$^{-1}$. In contrast, in rotational system, the yield was 5.8 t·ha$^{-1}$, i.e., an increase of 16% following the chickpea crop. The authors noted that these findings were consistent with analogous rotation cropping systems documented in prior investigations [87–89].

Overall, crop rotation is a powerful tool that, when implemented effectively, can boost wheat yield, improve soil health, and contribute to sustainable agriculture practices. Farmers should carefully plan their crop rotation sequences based on local conditions, crop suitability, and pest and disease management strategies to maximize its benefits for wheat production.

5. Intercropping Systems

Intercropping is an agricultural practice in which two or more crops are grown simultaneously in the same field. This farming system has been used for centuries and offers several advantages over monocropping (growing a single crop on a field). Intercropping systems are designed to maximize land use efficiency, increase biodiversity, and enhance overall productivity [90].

Various studies have reported an increase in wheat yields through the implementation of intercropping systems compared to growing wheat in monocultures. For instance, Yin et al., 2018 [91] reported that the intercropping wheat and maize, along with the use of a straw covering, resulted in a remarkable boost in wheat grain yield, which was approximately 153% to 160% higher than what could be achieved through the traditional monoculture of wheat alone. Furthermore, Kaci et al., 2022 [92] noted that the wheat grain yield increased by approximately 7–8%, when intercropped with faba bean compared to the yield obtained from wheat grown in monoculture.

In contrast to maize and faba bean crops, there are other crops that do not exert a positive influence on wheat yield and, in some cases, may even result in a reduction in wheat productivity. For example, rapeseed intercropped with wheat reduced it yield compared to sole cropping of wheat as observed by Ebrahim et al., 2016 [93].

Furthermore, Pelzer et al., 2012 [94] demonstrated that there was no significant difference in the yield of wheat when it was grown alone (monoculture) compared to when it was intercropped with peas. However, the authors noted that when wheat was cultivated as an intercrop, it required less than half the amount of nitrogen fertilizer per ton of grain produced compared to wheat grown alone. This finding suggests that the intercropping of wheat with peas enhance the economic efficiency of the wheat crop. Similarly, due to the intercropping of wheat and chickpea, there was a notable increase in protein accumulation in the wheat grain, specifically by 30 kg per hectare, when compared to sole-cropped wheat. This effect was more pronounced under moderate nitrogen application [95]. However, despite the significant increase in protein content, the authors did not observe a significant difference in terms of overall grain yield between the intercropped and sole-cropped wheat.
Although the intercropping system does not always improve wheat yield, the benefits of this cropping system compared to growing single crops (monocultures) have been recorded to arise from several factors. Firstly, intercropping provides improved light conditions for the crops involved. Secondly, it reduces the negative impact of diseases and weeds on the crops [96,97]. Lastly, intercropping creates a positive interaction between the different crops during their co-growth period, enhancing their overall growth and productivity [98,99].

Intercropping systems have the potential to enhance sustainable agriculture by diversifying production, reducing pest and disease pressures [100–102], improving soil health, and optimizing resource use [103,104]. However, when establishing an intercropping system to enhance wheat yield, it is crucial to consider the crop compatibility with wheat. Therefore, careful selection and evaluation of the companion crops are essential to optimize the benefits of intercropping for wheat yield improvement.

6. Resistant Wheat Varieties

Introducing resistant wheat varieties is a valuable strategy to improve yield in wheat production. These varieties are specifically bred to possess genetic traits that make them less susceptible to pests, diseases, or environmental stresses, ultimately leading to higher crop yields. By adopting resistant wheat varieties, yield losses caused by pests, diseases, and environmental fluctuations can be reduced, leading to more stable and profitable wheat production. Additionally, using resistant varieties can decrease the need for chemical inputs like pesticides and fungicides, promoting sustainable agricultural practices, and environmental health.

Various studies have pointed out the importance of using resistant wheat varieties to enhance crop productivity. These wheat varieties have shown specific characteristics, including the ability to withstand pests, diseases, and other environmental pressures. For instance, a study conducted by de Oliveira et al. in 2023 [105] found that wheat varieties resistant to *Sitobion avenae* showed a positive relationship with increased grain weight and a higher number of grains per ear, which ultimately contributes to improved yield. On the other hand, according to Tomar et al. in 2014 [106], employing strategic planning to manage stripe rust by using resistant cultivars has played a vital role in maintaining wheat productivity levels in India. Recently, Sendhil et al., 2023 [107] demonstrated that rust-resistant wheat varieties exhibited a remarkable increase of 48% in grain yield compared to non-resistant varieties, when tested under field conditions. Moreover, Temirbekova et al., 2022 [108] conducted a study in the central non-black region of Russia and found that wheat varieties that exhibited a resistant and tolerant character to rot and pink snow mold recorded superior yields and grain quality compared to a wide range of other investigated varieties. Nevertheless, many studies have shown that the incidence of pest and diseases and weed infestations significantly reduce the agronomic traits of wheat [109–112], directly impacting the crop’s yield potential. These traits are closely related to the overall productivity of the wheat plant [113].

The primary approach to enhance and maintain wheat production is by developing new wheat varieties that can adapt to the specific soil and climatic conditions of various regions [114]. In this context, research conducted on winter wheat in Germany has revealed that ongoing innovations in breeding techniques have led to the development of higher-yielding crops. These new varieties demonstrate enhanced resistance and stability across different environments and under various treatment conditions [115,116]. Furthermore, in Russia, extensive research on wheat varieties has revealed that those with resistance and tolerance to various abiotic stresses, including frost, rapid temperature changes, thawing, ice, rotting, excessive soil and air saturation, and soil and atmospheric drought, showed significantly higher yield and 1000 grain weight compared to numerous other varieties that were studied [117]. Regarding drought stress, Anwaar et al., 2020 [118], found that the most resistant wheat varieties expressed the higher grain yield when explored 50 wheat genotypes for their sensitivity and tolerance against drought.
Alybayeva et al., 2023 [119] reported that the Mironovskaya 808 variety demonstrated the highest resistance to heavy metals compared to six studied winter wheat varieties. Consequently, it yielded the most significant harvest. The authors attribute this success to Mironovskaya 808’s ability to successfully overwinter and thrive during the summer growing season, even in soil contaminated with heavy metals. Moreover, this variety also exhibited faster developmental phases compared to the other varieties.

“Wheat genes yield-associated” refers to specific genes in wheat that are linked to or associated with grain yield. These genes play a crucial role in determining the productivity and yield of wheat plants. Scientists and researchers study these genes to better understand their function and potential for improving wheat crop yields through genetic modification or breeding programs. Identifying and characterizing these yield-associated genes can help in developing new and improved wheat varieties that produce higher yields and contribute to food security. Two research studies discuss the impacts of the genes TaGW8, Rht6, and Ppd-D1a on traits associated with wheat yield [120,121]. The researchers noted that these genes are directly linked to favorable agronomic traits in wheat, which in turn contribute to enhancing wheat crop yield.

Through the succession, innovation, and application of scientific breeding methodologies, it is possible to improve the yield of wheat crops. In this regard, Sandukhadze et al., 2021 [122] reported that in the Non-Chernozem zone the yield of winter bread wheat has significantly increased over the past century, rising from 1.0 to 12.0 or more tons per hectare. Likewise, breeding for resistance has substantial positive effects on the profitability of winter wheat production through reducing inputs such as fertilizers and pesticides [115,123].

The genetic potential of cultivars plays a crucial role in the establishment of an integrated wheat production system, however, the agricultural practices adopted have the role of exploiting this potential in order to obtain high yields. Therefore, the introduction of environmentally friendly farming methods can lead to high wheat yield and healthy products, as well as rational use of natural resources (Figure 1).

![Diagram of integrated wheat farming system according to pedoclimatic conditions.](image)

**Figure 1.** Diagram of integrated wheat farming system according to pedoclimatic conditions.

In conclusion, the integration of resistant wheat varieties into crop management strategies is a crucial step towards achieving higher and more consistent wheat yields while ensuring food security and sustainability in agricultural systems.

7. Effect of Eco-Friendly Agricultural Practices on the Agrosystems Biodiversity

Biodiversity contributes to the overall health, resilience, and sustainability of agricultural systems. It provides a range of ecological, economic, and social benefits that are essential for addressing current and future challenges in food production and environmental conservation [124]. Agricultural practices can have significant impacts on the biodiversity of agroecosystems, influencing the variety and abundance of living organisms.
within these landscapes [125]. The effects are complex and can vary depending on factors such as the specific practices employed, the local environment, and the overall management approach [126]. For instance, the extent and intensity of tillage can have significant impacts on biodiversity within agrosystems. Different tillage systems influence the composition and abundance of organisms, as well as the overall ecosystem dynamics [127].

It has been reported in previous studies that long-term conventional tillage can disrupt soil habitats and reduce soil biodiversity, impacting organisms like earthworms, microbes, and insects, unlike reduced tillage/no-till that minimize soil disturbance, promote soil health and increase the diversity of soil organisms, helping to improve nutrient cycling and the ecosystem [128]. Manuel et al., 2018 [129] observed greater biodiversity levels in no-till systems when compared to a traditional conventional tillage system. Furthermore, Gailis et al., 2017 [130] demonstrated that ground beetle biodiversity (Carabidae) might show a noticeable increase in soils that have been harrowed in comparison to those that have been plowed, knowing that ground beetles provide various benefits within agricultural ecosystems, including natural wheat pest control, consumption of weed seeds, improvement of soil aeration and turnover, contribution to decomposition and nutrient cycling, as well as the promotion of biodiversity [131–134]. Moreover, several studies have discussed the role of tillage systems in increasing soil fungal communities. Korniłłowicz-Kowalska et al., 2022 [135] observed that there was a notable increase in the overall count of rhizosphere fungi within the no-tillage system when contrasted with the conventional tillage. More so, Brito et al., 2012 [136] noted that traditional tillage led to a 40% reduction in the diversity of arbuscular mycorrhizal fungi compared to the no-till method. The researchers’ findings suggest that AM fungi were differently vulnerable to soil disruption.

The impact of pesticide use on the diversity of agricultural ecosystems is a topic of significant concern within the field of environmental science and agriculture. Indeed, prolonged and extensive use of pesticides can lead to a reduction in the diversity of species within an agroecosystem [137]. However, biological crop protection offers several benefits for biodiversity within agricultural ecosystems [138] through involving agents, which are often species-specific, meaning they primarily target particular pests without affecting non-target organisms. This precision helps to maintain a more balanced ecosystem by avoiding the widespread destruction of beneficial insects, microorganisms, and other organisms. Moreover, beneficial organisms that are encouraged through biological crop protection contribute to ecosystem services such as pollination, soil health improvement, and pest regulation [139]. These services further enhance the resilience and productivity of agricultural systems. In addition, biopesticides typically have lower toxic effects on non-target organisms, reduced persistence in the environment, and lower potential for contaminating water sources compared to synthetic chemical pesticides [140]. This leads to a reduced negative impact on biodiversity.

The impact of crop rotation and intercropping systems on agroecosystems biodiversity is profound and far-reaching. By creating diverse habitats, regulating pests naturally, fostering soil health, conserving beneficial organisms, and promoting sustainable practices, crop rotation offers a holistic solution to the complex challenge of maintaining biodiversity while meeting the demands of food production [141–144]. As we navigate the complexities of modern agriculture, the adoption of crop rotation emerges as a vital step towards cultivating a harmonious relationship between human activities and the ecosystems that sustain us.

8. Conclusions

The current study revealed that adopting environmentally friendly agricultural practices, such as specific tillage systems, biological crop protection, crop rotation, intercropping, and utilizing resistant wheat varieties, can lead to sustainable and stable wheat yields as well as maintain agroecosystem biodiversity. However, it is essential that the normative approach considers various factors, including the specific characteristics of the chosen wheat
varieties, plant nutrition conditions, agrochemical properties of the soil, and meteorological factors.

In order to achieve this goal, it is advised to conduct individual studies for each wheat variety under field conditions, considering the specific pedoclimatic characteristics of the region. This involves implementing a no-till system solely in arid and semi-arid regions, selecting suitable precursor and intercropped crops, and establishing an efficient integrated crop protection system. This approach will help in selecting suitable eco-friendly agricultural practices that will effectively maximize the yield potential of the studied variety.

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