EVALUATION OF WHEAT PRODUCTIVITY UNDER REGENERATIVE MANAGEMENT IN RAINFED AREAS OF POTHOWAR

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ABSTRACT: Wheat (*Triticum aestivum* L.) is an important cereal crop, significantly contributing to global dietary protein and calorie intake. In semi-arid rainfed regions, drought, irregular rainfall, low soil organic matter, and weed infestations severely limit yields. Conventional farming, which relies on chemical fertilizers and pesticides, depletes soil nutrients and degrades soil health, posing risks to both environmental sustainability and human well-being. Regenerative agriculture, emphasizing low-input practices such as mulching, chisel plowing, and raised beds, offers a sustainable alternative to enhance soil fertility and crop resilience on marginal soils. A two year filed experiment was conducted at University Research Farm Koont, Chakwal to assess the effects of regenerative agriculture practices on the productivity of wheat under rainfed conditions. Performance of various treatments on different soil and agronomic parameters including soil organic matter, soil moisture content, soil pH, plant height, 1000-grain weight and yield $kgha^{-1}$ were determined. Results showed that regenerative farming has significantly enhanced both soil fertility and crop yield in T_6 (Raised bed & Mulch) as compared to T_0 (Control). The Raised Bed & Mulch treatment (T6) consistently yielded the most favorable outcomes, recording the highest soil moisture content (18.2% and 18.9% in consecutive years), soil organic matter (1.82% and 1.74%), while maintaining a lower soil pH (6.6 and 6.4) compared to the control. These soil improvements directly translated to superior agronomic performance: T6 produced the tallest plant height (84.2 cm and 85.4 cm), the highest 1000-grain weight (44.2 g and 38.0 g), and consequently, the highest estimated grain yield (4420 kg ha^{-1} and 3800 kg ha^{-1}). The results highlight the increase in wheat productivity, showing regenerative farming potential, and supporting food security and environmental sustainabilty.

Keywords: Regenerative agriculture; wheat productivity; mulching; minimum tillage; water conservation; semi-arid systems;

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INTRODUCTION

Wheat (Triticum aestivum. L.), as one of the most important staple crop, accounted for 219 million hectares of cultivation globally in 2020, equal to about one-third of the world's total area for cereal agriculture, with 760 million tons of production. It provides approximately 20% of the calories and 20% of the protein required for the human diet [1].

The Pothohar region heavily relies on rainwater for agriculture. With a population of over 2 million, approximately 70% reside in rural areas and engage in small-scale farming on less than 5 hectares of land. However, water scarcity poses a significant challenge, leading many farmers to explore alternative occupations. It is crucial to find sustainable solutions to support the farming community in the region. Wheat is a vital crop in Pothowar, Pakistan, where rainfed agriculture is prevalent. Ensuring adequate wheat yield and maintaining the planting area of this essential food crop are crucial for food security and social stability [2][3][4][5].

Regenerative agriculture (RA) is a farming strategy that uses natural processes to increase biological activity, enhance soil health, improve nutrient cycling, restore landscape function, and produce food and fiber, while preserving or increasing farm profitability. The strategy is based on a set of guiding principles, and practitioners use a variety of tactics that integrate biological and ecological processes with the objective of increasing production and restoring landscape functionality. The incorporation of mulch is a fundamental sustainable practice where its breakdown process contributes to soil health. This addition of organic matter and nutrients enhances the soil's structure, nutrient balance, and microbial activity, directly supporting greater crop productivity [6][7].

According to [8][9], growing recognition of the adverse environmental impacts associated with traditional agriculture is driving the adoption of sustainable alternatives. Conventional practices reliant on heavy chemical application, large-scale monocultures, and

extensive land clearing have been significantly linked to soil erosion, diminished biodiversity, and climate change. The adoption of permanent raised beds facilitates the strategic management of crop residues, which helps maintain continuous soil cover. This practice significantly improves the efficiency of rainwater harvesting and soil moisture conservation. Under rainfed conditions, the integration of permanent raised beds with crop rotation and residue retention resulted in grain yields equivalent to those achieved with zero tillage on flat land over a six-year period, demonstrating its viability as a core conservation agriculture practice.

Mulching plays a crucial role in retaining nutrients near plant roots, promoting efficient utilization and minimizing fertilizer leaching. Uniform mulching is also aesthetically beneficial, contributing to a more visually appealing landscape. Furthermore, as organic mulch decomposes, it enriches the soil's organic content, leading to improved water storage capacity [10][11][12].

Research by [13] links wheat stubble mulching to improved cotton yield and water conservation. Their field experiment recorded a 35% increase in lint yield, along with reduced evaporation and greater water use efficiency, when compared to non-mulched control plots.

The adoption of environmentally friendly farming systems has been on the rise in response to concerns about the environmental impact of intensive farming practices. These systems, including organic farming, integrated farm management, regenerative agriculture, sustainable intensification, and agroecological practices, aim to address these concerns. While they may vary in techniques, they share a common goal of improving environmental management in agriculture. This includes enhancing biodiversity, regenerating damaged land, diversifying crop rotations, and conserving soil. The focus on sustainable and eco-friendly farming methods is crucial for ensuring a more sustainable future. However, these systems are sometimes associated with reduced yields, and therefore the need to increase food production to meet the demands of a growing human population may pose a challenge to the adoption of environmentally friendly farming systems. However, in order to strike a balance between these potentially conflicting goals, it is imperative to develop a farming system that enhance agricultural sustainability while maintaining satisfactory yields and crop quality [14][15].

MATERIALS AND METHODS

The experiment was carried out at the University Research Farm, Per Mehr Ali Shah Arid Agriculture University, Rawalpindi, during the winter seasons of 2023-2024 and 2024-2025. The farm is situated in a rainfed sub-tropical area at 32.93^{o} north and 72.85^{o} east. In this experiment, the regenerative agricultural practices such as mulch, chisel plough, raised beds and their combination with mulch were examined on the Wheat. Raised bed preparation was done using a bed shaper, followed by a subsoiler and a cultivator. The overall land used in this experiment was two kanals and to separate treatments, RCBD with factorial arrangement was used in this experiment with six treatments and 3 replications. In control treatments, land preparation was done with tractor rotavator and sowing was done with mechanical seed drill without applying any mulch, while in Chisel plough and Chisel plough+mulch treatments, land preparation was done using Chisel plough to done deep tillage, which was followed by the cultivator and land leveler. Sowing was done with mechanical seed drill and mulch was applied on Chisel Plough + Mulch treatment. Raised beds preparation was done using cultivator and disc harrowing to break up the clods and leveling the soil. Bed shaper was used to make raised beds for cultivation of wheat. Again, sowing was done using mechanical seed drill and total four raised were created, two raised beds covering T_5 (raised bed) and other two beds covering T_6 (Raised bed + Mulch). Seed rate was used @40kg/acre. The plant samples were taken from five randomly selected plants per plot and three soil samples from the field to estimate soil moisture.

The treatments of this experiment were as follows:

T1= Control
T2= Mulching
T3= Chisel Plough
T4= Chisel plough + Mulch
T5= Raised Bed
T6= Raised Bed + Mulch

RESULTS AND DISCUSSION

The data recorded for various parameters were statistically analyzed. Performance of different treatments were expressed in term of soil organic matter, soil moisture content, soil pH, plant height, 1000 grain weight and yield kg ha^{-1}. Parameters are presented in (Figure 1-6) for proper understanding and discussion.

Soil Organic Matter: Soil organic matter is an important factor that directly impacts crop growth, yield, and its production. Maintaining an optimal balance of soil organic matter essential for ensuring healthy plant development and maximizing productivity. The soil organic matter (SOM) data from the 2023-2024 and 2024-2025 growing seasons highlight striking differences across treatments, underscoring the efficacy of regenerative practices. In the first year, the control (T1) exhibited the lowest SOM at 1.18, reflecting typical soil degradation under conventional management. In contrast, T6 (Raised Bed + Mulch) led with a robust 1.82, a significant leap supported by an LSD0.05 of 0.07%. Treatments like T2 (Mulching, 1.52), T3 (Chisel, 1.32),

T4 (Chisel + Mulch), and T5 (Raised Bed, 1.45) showed moderate gains, with T4 and T6 suggesting a synergistic benefit from combining methods. By 2024-2025, SOM levels dipped slightly across all treatments, T1 at 1.10, T6 at 1.74, T2 at 1.45, T3 at 1.25, T4 at 1.61, and T5 at 1.38, with an LSD0.05 of 0.09%, possibly due to initial soil nutrient depletion. The consistent outperformance of T6 indicates that raised beds enhance mulch effectiveness, likely by improving aeration and water retention, offering promising insights for crop management under climate stress.

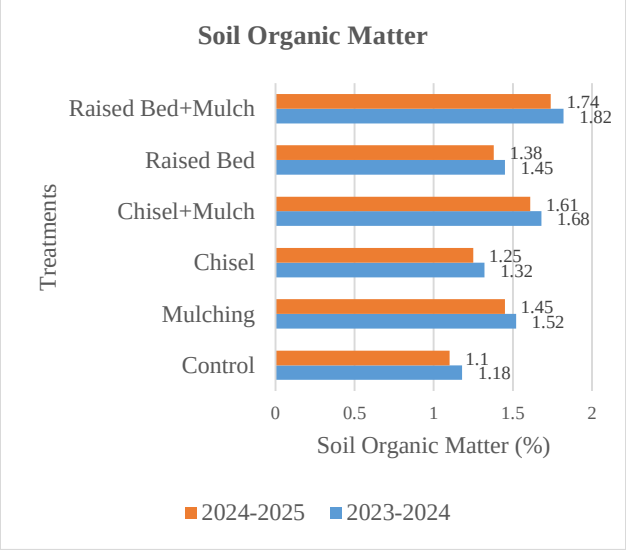

Figure 1. Soil organic matter (%) under regenerative agriculture in rainfed areas.

The results demonstrate that mulching with raised beds or chiseling significantly enhances SOM, aligning with findings of [16], who reported that legume-based mulches increase organic matter and nitrogen fixation in agroecosystems. The control's low SOM reflects typical degradation under conventional practices, while mulching alone or with tillage methods improves soil structure and moisture retention. The slight SOM decline in 2024-2025 suggest initial soil exhaustion, necessitating long-term monitoring. These findings support the adoption of regenerative practices to boost soil health, particularly for smallholder farmers facing climate stress, though further research on sustainability is warranted.

Soil Moisture Content: The soil moisture content varied significantly among different treatments in both years (2023–2024 and 2024–2025). In 2023–2024, the highest moisture content was recorded in T6: Bed+Mulch (18.2), followed by T4: Chisel+Mulch (16.9), while the lowest was in T1: Control (12.3). Similarly, in 2024–2025, T6: Bed+Mulch again showed the highest moisture content (18.9), whereas T1: Control had the lowest (11.8). Mulching alone (T2) and raised beds alone (T5) showed intermediate moisture retention, but combining mulching with chisel plowing (T4) or raised beds (T6) significantly improved moisture retention compared to individual practices. The LSD values (0.8 and 0.9 for 2023–2024 and 2024–2025, respectively) confirmed significant differences among treatments.

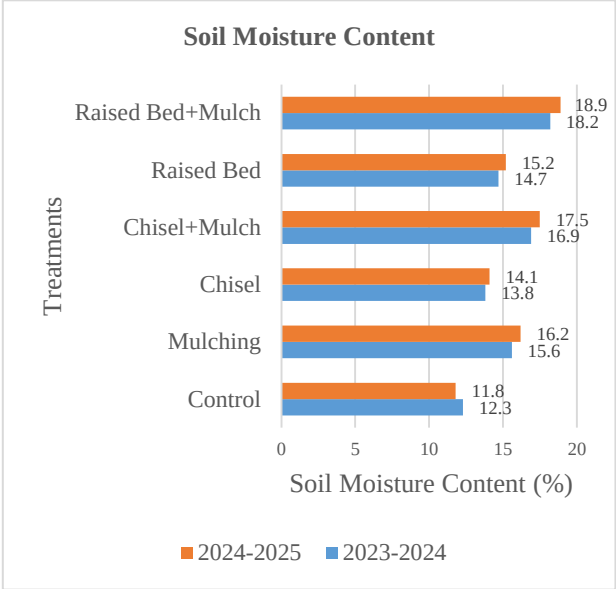

Figure 2. Soil moisture content (%) under regenerative agriculture in rainfed areas.

The results demonstrate that integrated soil moisture conservation practices, particularly combining mulching with raised beds or chisel plowing, significantly enhance soil moisture retention compared to individual practices or control. This improvement can be attributed to reduced evaporation (due to mulching) and improved water infiltration (due to chisel plowing or raised beds). Similar findings were reported by [12], who observed that mulching combined with tillage practices significantly increased soil moisture retention by reducing surface runoff and evaporation. The consistent superiority of T6 (Raised Bed+Mulch) across both years suggests that raised beds with mulch provide optimal conditions for moisture conservation, likely due to better water-holding capacity and reduced soil compaction.

Soil pH: The soil pH varied significantly among treatments in both years (2023–2024 and 2024–2025). In 2023–2024, the highest pH was observed in T1: Control (7.1), followed by T3: Chisel (7.0), while the lowest pH was recorded in T6: Bed+Mulch (6.6). Similarly, in 2024–2025, T1: Control again had the highest pH (7.2), whereas T6: Bed+Mulch exhibited the lowest (6.4). Mulching alone (T2) and chisel plowing combined with mulching (T4) consistently reduced soil pH compared to

the control. The LSD value (0.2%) confirmed significant differences among treatments in both years.

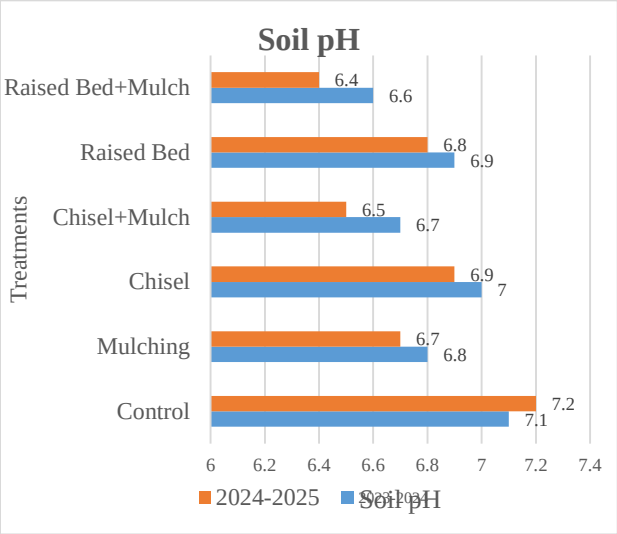

Figure 3. Soil pH under regenerative agriculture in rainfed areas.

The results indicate that mulching, especially when combined with raised beds or chisel plowing, leads to a slight but statistically significant reduction in soil pH compared to the control. This decrease could be attributed to the decomposition of organic mulch materials, which release organic acids, or improved microbial activity that enhances soil acidification over time. Similar findings were reported by [17], who observed that organic mulching slightly lowered soil pH due to the release of humic and fulvic acids during decomposition. The consistent trend across both years suggests that long-term use of mulching, particularly in combination with tillage or bed-forming practices, may contribute to gradual soil acidification, which could be beneficial in alkaline soils but may require monitoring in neutral or acidic soils.

Plant height: The study evaluated six different soil management treatments over two consecutive years (2023–2024 and 2024–2025) to assess their impact on wheat plant height. The results demonstrated significant variations among treatments, with Bed+Mulch (T6) consistently producing the tallest plants, while the Control (T1) resulted in the shortest plants.

In the first year, T6: Bed+Mulch recorded the highest mean plant height (84.2 cm), followed by T4: Chisel+Mulch (81.7 cm). The Control (T1) exhibited the lowest mean height (72.4 cm). Intermediate treatments such as Mulching (T2) (78.5), Chisel (T3) (75.6 cm), and Raised Bed (T5) (77.4 cm) showed moderate growth. The Least Significant Difference (LSD= 1.8) confirmed that these differences were statistically significant.

Similar trends were observed in the second year, reinforcing the effectiveness of combined tillage and mulching practices. T6: Raised Bed+Mulch again led with a mean height of 85.4 cm, while T4: Chisel+Mulch followed closely (82.6 cm). The Control (T1) remained the least effective (71.5 cm). The LSD= 2.1 further validated the statistical significance of treatment effects.

These findings align with principles of conservation agriculture, which emphasize minimal soil disturbance, permanent soil cover (e.g., mulch), and crop rotation to enhance soil health and productivity. The superior performance of combined treatments (T6 and T4) supports the idea that integrating multiple conservation practices yields greater benefits than applying them individually. Similar results have been reported in studies evaluating conservation agriculture in various agroecological contexts. According to [9], he found that combining reduced tillage and mulching significantly increased maize and wheat yields in the Mexican highlands, with raised beds and mulching showing synergistic effects on soil moisture and yield stability. Their findings corroborate the current study's results, particularly the high performance of T6 and T4.

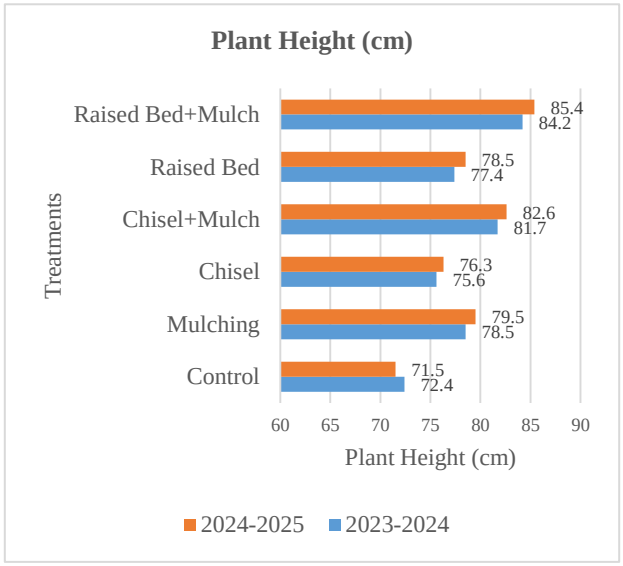

Figure 4. Plant height under regenerative agriculture in rainfed areas.

1000-grain weight: The experiment evaluated the effects of six tillage and mulching treatments on the 1000-grain weight of wheat across two growing seasons (2023-2024 and 2024-2025), with three replicates per treatment. In the 2023-2024 season, the Bed+Mulch treatment (T6) recorded the highest mean 1000-grain weight of 44.2 g, significantly surpassing all other treatments (LSD0.05 = 1.85; $p < 0.05$). The Chisel+Mulch treatment (T4) followed with a mean of 42.5 g, while Mulching (T2) and Raised Bed (T5) yielded 40.8 g and 39.7 g, respectively, with no significant difference between them. The Chisel

treatment (T3) recorded 38.3 g, and the Control (T1) had the lowest weight at 36.4 g. In the 2024-2025 season, T6 again achieved the highest mean 1000-grain weight (38.0 g), followed by T4 (36.3 g), T2 (34.5 g), T5 (33.5 g), T3 (32.1 g), and T1 (30.1 g) (LSD0.05 = 1.92; $p < 0.05$). The T3 and T5 treatments were not significantly different in 2024-2025, but both outperformed T1. The consistent ranking of treatments across both seasons indicates stable treatment effects on 1000-grain weight.

The Bed+Mulch treatment (T6) consistently yielded the highest 1000-grain weight (44.2 ± 0.6 g in 2023-2024; 38.0 ± 0.6 g in 2024-2025), indicating that combining raised beds with mulching enhances grain filling, likely due to improved soil moisture retention and nutrient availability.

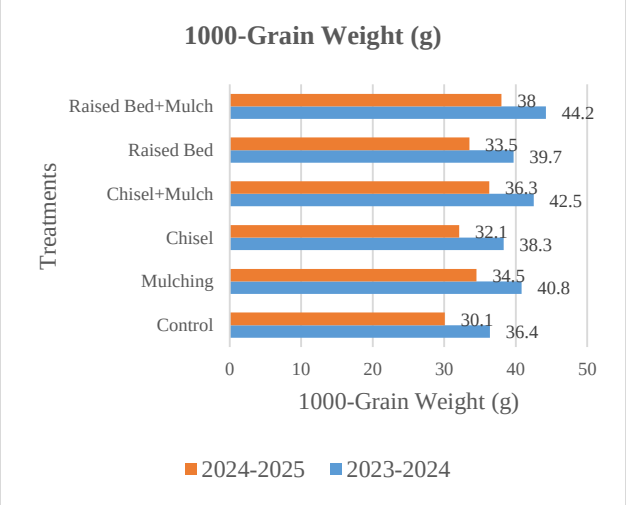

Figure 5. 1000 grain weight under regenerative agriculture in rainfed areas.

This aligns with [9], who found that conservation tillage practices, such as raised beds combined with residue retention, improve soil physical properties and water use efficiency, leading to enhanced wheat yield components. The Chisel+Mulch treatment (T4) also significantly outperformed standalone treatments, suggesting a synergistic effect of reduced tillage and mulching in optimizing soil conditions. The Mulching (T2) and Raised Bed (T5) treatments showed moderate improvements over the Control (T1), which consistently produced the lowest grain weights (36.4 ± 0.6 g and 30.1 ± 0.6 g), underscoring the limitations of conventional tillage without soil conservation practices. The lower grain weights in 2024-2025 across all treatments may be attributed to unmeasured environmental factors, such as reduced precipitation or temperature fluctuations. The study's findings are constrained by its focus on a single agroecological context and two seasons, limiting broader applicability. Future research should investigate the long-term impacts of these treatments on grain quality, yield stability, and soil health across diverse wheat varieties and environmental conditions, alongside economic assessments to evaluate their feasibility for widespread adoption.

Estimated Wheat Yield (kg ha^{-1}): The bar graph presents a comparative analysis of wheat yield (kg ha^{-1}) across six agricultural treatments during the 2023-2024 and 2024-2025 growing seasons. The data reveal significant treatment-induced variations in productivity. In the 2023-2024 season, the Raised Bed+Mulch (T6) treatment yielded the highest output at 4420 kg ha^{-1}, followed by Chisel+Mulch (T4) at 4250 kg ha^{-1} and Mulching alone (T2) at 4080 kg ha^{-1}. The Raised Bed (T5) and Chisel (T3) treatments yielded 3970 kg ha^{-1} and 3830 kg ha^{-1}, respectively, while the Control (T1) yielded the least at 3640 kg ha^{-1}.

A consistent trend was observed in the 2024-2025 season, although a notable overall yield reduction occurred, potentially attributable to abiotic stressors such as moisture deficit. Despite this decline, T6 maintained its superiority with a yield of 3800 kg ha^{-1}, followed again by T4 (3630 kg ha^{-1}) and T2 (3450 kg ha^{-1}). The yields for T5, T3, and T1 were 3350 kg ha^{-1}, 3210 kg ha^{-1}, and 3010 kg ha^{-1}, respectively. The consistent ranking of treatments, with integrated practices (T6, T4) outperforming singular amendments (T2, T3, T5) and the control, underscores the synergistic benefits of combining soil moisture conservation (mulch) with improved soil structure (raised beds or chisel plowing) for optimizing wheat yield in semi-arid, rainfed systems.

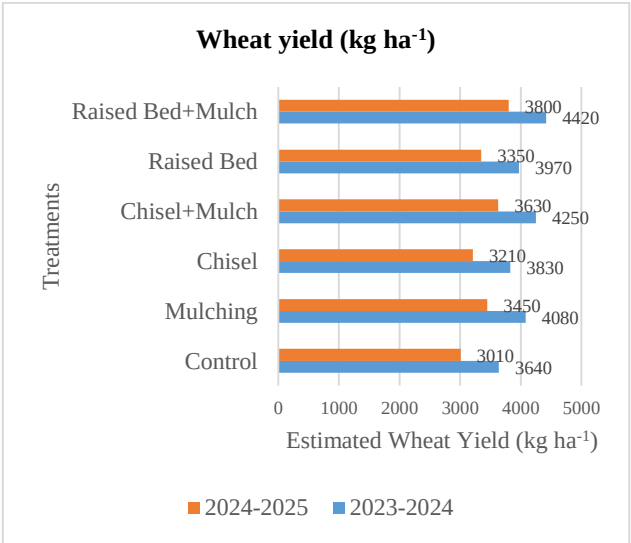

Figure 6. wheat yield kg ha^{-1} under regenerative agriculture in rainfed areas

This aligns with research by [18], who demonstrated that conservation agriculture practices,

including residue retention and reduced tillage, significantly enhance wheat yields in semi-arid South Asia by improving soil health and water retention. The chart underscores regenerative practices' potential to boost productivity and resilience, offering a sustainable path for rainfed wheat farming.

Conclusion: The two-year field study conclusively demonstrates that regenerative agriculture practices significantly enhance soil health and wheat productivity in the semi-arid, rainfed conditions of the Pothwar region. Among the various treatments evaluated, the integrated application of Raised Bed + Mulch (T6) emerged as the most effective strategy, consistently delivering superior results across all measured parameters. This treatment led to a substantial improvement in soil properties, including the highest soil organic matter (1.82% and 1.74%) and moisture content (18.2% and 18.9%), while also contributing to a slight reduction in soil pH, which can be beneficial in alkaline soils. These improved soil conditions directly translated into enhanced crop performance, with T6 producing the tallest plants, the heaviest grains (44.2 g and 38.0 g 1000-grain weight), and consequently, the highest estimated grain yields (4420 kg ha^{-1} and 3800 kg ha^{-1}). The synergistic combination of raised beds, which improve aeration and water infiltration, with mulching, which conserves moisture and adds organic matter, proved far more effective than any practice applied alone. While a general yield decline in the second year highlighted the vulnerability of rainfed systems to climatic variability, the treatment rankings remained consistent. This underscores the role of regenerative practices in building crop resilience against abiotic stresses. The consistent underperformance of the control treatment (T1) reaffirms the limitations of conventional tillage-based systems in these fragile ecosystems. Therefore, this research strongly advocates for the adoption of integrated regenerative practices, particularly the Raised Bed + Mulch system, as a sustainable and productive alternative for wheat farmers in rainfed areas. This approach offers a viable pathway to bolster food security, enhance climate resilience, and promote long-term soil sustainability, crucial for the agricultural future of the Pothwar region and similar semi-arid environments. Future research should focus on the long-term economic viability and scalability of these practices for smallholder farmers.

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