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ECONOMIC IMPACT OF COTTON-RAYA RELAY CROPPING ON CROP YIELD AND SOIL HEALTH: A STRATEGIC APPROACH TO CLIMATE RESILIENCE AND PROFIT MAXIMIZATION

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ABSTRACT

Climate change, soil degradation, and depletion of natural resources challenge agricultural productivity and economic sustainability. Developing resilient agricultural systems is crucial for food security amid these changes. Relay cropping, where one plant species is inter-seeded into an established crop, maintains continuous plant cover, optimizes resource use, and enhances climate resilience. Therefore, the objective of research was to assess the economic benefits of relay cropping systems in enhancing crop yield and improving soil health. It aims to identify how these practices contribute to climate resilience and maximize farm profitability, offering strategic insights for sustainable agriculture in the face of climate change. Brassica (Raya/Mustard) was sown in standing cotton as a relay crop on first week of October- using 3 kg seed/acre, and also a sole crop to compare the results. Economic analysis over three seasons shows that relay cropping consistently achieved higher net profits compared to sole cropping. Results showed that in 2022-23, cotton relay cropping yielded higher with a net profit of Rs. 66,950, compared to sole cotton and a net profit of Rs. 39,200. Relay cropping also improved soil health, with higher soil organic matter levels observed; for example, in 2022-23, cotton relay cropping had 0.78% soil organic matter compared to 0.63% in sole cotton. Although sole cropping offered higher yields for Brassica, relay cropping resulted in better soil nutrient levels. Overall, the relay cropping system yielded a combined net profit of Rs. 130,630 in 2022-23. These findings highlight relay cropping's potential to enhance farm profitability and sustainability by addressing resource use inefficiencies, reducing input costs, and stabilizing yields, making it a strategic choice for climate resilience and economic stability.

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INTRODUCTION

Agricultural systems worldwide are increasingly vulnerable to climate change, which exacerbates issues such as soil degradation, water scarcity, and extreme weather events. These challenges can reduce crop yields and threaten food security, particularly in vulnerable regions like South Asia and Pakistan (Aryal et al., 2020; Fahad and Wang, 2020). Climate change impacts, including rising temperatures and erratic rainfall, have led to heat stress, altered growing seasons, and increased risks of droughts and floods, thereby affecting agricultural productivity (Kogo et al., 2021; Hussain et al., 2023). Cotton, a key cash crop for Pakistan, faces significant challenges including soil degradation and pest pressure (Ashraf et al., 2024), necessitating the adoption of sustainable practices to maintain productivity (Leisner, 2020). Relay cropping, a technique where a new crop is sown before the current crop is harvested, presents a promising solution (Tariq et al., 2022). This method enhances resource use efficiency, improves soil health, and potentially increases overall profitability (Malhi et al., 2021). Investing in climate-smart agriculture and resilient farming practices is crucial for mitigating the impacts of climate change and ensuring food security (Corwin, 2021).

Relay cropping, where a second crop is planted before the first is harvested, emerges as a strategic approach to counter the adverse effects of climate change (Lamichhane et al., 2023). This practice optimizes the use of available resources such as water and nutrients, thereby enhancing productivity and stabilizing yields even under unpredictable weather conditions (Farooq et al., 2020). Relay cropping provides numerous benefits, including improved soil fertility and increased economic returns (Parenti et al., 2024). Relay cropping introduces crop diversity into the soil ecosystem, promoting biodiversity and fostering a more resilient soil structure (Singh et al., 2020). Different crops with varying root depths and nutrient requirements utilize soil resources more efficiently, reducing the need for synthetic fertilizers and mitigating environmental pollution (Daigh, 2022). Moreover, relay cropping enhances soil organic matter, which improves soil fertility, microbial activity, and water retention (Jat et al., 2020). The continuous presence of plant roots also minimizes soil disruption, leading to better soil health and a more favorable environment for crop growth (Khan, 2024). Economically, relay cropping increases farm resilience and stability by maximizing land productivity and minimizing the risks of crop failure due to adverse weather (Sekhar, 2020). This practice reduces fallow periods and enhances overall output per unit area, making it a profitable strategy for farmers (Malhi et al., 2021). Efficient resource use and staggered planting and harvesting further contribute to economic stability by optimizing nutrient uptake and minimizing input costs (Zhang et al., 2022). Successful implementation of relay cropping requires careful consideration of crop compatibility, timing, and management practices to maximize benefits and ensure sustainable farm operations (Fahad and Wang, 2020). By focusing on the economic advantages and practical considerations of relay cropping, this paper aims to provide a comprehensive analysis of its potential as a climate-resilient strategy that enhances both agricultural productivity and profitability.

Relay cropping with Brassica species in cotton fields offers a strategic approach to enhance soil health, improve pest management, and ultimately maximize economic returns. Brassicas have growth patterns that complement cotton, allowing them to be integrated effectively into a relay cropping system. This approach provides several agronomic and ecological benefits that can improve both soil quality and crop productivity. Brassica plants contribute organic matter to the soil, enhancing its fertility, structure, and water retention capacity (Gesch et al., 2023). This enhancement in soil quality can reduce the need for expensive chemical fertilizers and irrigation, lowering overall production costs (Wu et al., 2021). Additionally, Brassica species have natural biofumigant properties that suppress soil-borne pathogens and pests common in cotton fields (Carrillo-Reche et al., 2023). This biological pest control reduces reliance on chemical pesticides, further cutting costs and promoting a healthier soil microbiome (Chapagain et al., 2020). Healthier soil and reduced pest pressure can lead to higher cotton yields and better crop quality, increasing farm income and marketability (Patel, 2020). Economically, the diversification achieved through relay cropping also helps stabilize farm income by providing an additional harvest and reducing financial risks associated with cotton price volatility or crop failures (Xie et al., 2022). By incorporating Brassicas into cotton fields, farmers can enhance system resilience and create a more sustainable, profitable agricultural model.

To evaluate the economic benefits of Brassica relay cropping in cotton fields, we conducted a comprehensive study. The research aimed to determine how integrating Brassica as a relay crop could improve farmers' livelihoods by enhancing soil health and reducing input costs. By focusing on both agronomic and economic outcomes, this study highlights relay cropping as a viable strategy for farmers to adapt to changing climate conditions, maximize profits, and ensure long-term sustainability.

METHODOLOGY

The experiment was conducted at the Cotton Research Institute in Khanpur over three cropping years (2019-20, 2020-21, and 2021-22) to evaluate the yield and cost-benefit ratios of two cropping systems: relay cropping of Brassica (Raya/Mustard) with cotton and Brassica as a sole crop after cotton harvest. Cotton was sown on raised beds with specific spacing of 75 cm between rows and beds, and 30 cm between plants. Recommended agronomic practices, including fertilization and irrigation based on crop water requirements, were followed.

For the relay cropping system, Brassica was sown in the first week of October by broadcasting Super Raya seeds at a rate of 3 kg per acre in the standing cotton crop after heavy irrigation, without any tillage. The cotton continued to complete its remaining growth cycle. By the end of November, when nearly all the cotton bolls had matured and opened, the cotton was harvested. After harvesting, the cotton sticks were removed from the field. Following this, fertilizer was applied to the Brassica crop. In the sole Brassica system, after the cotton was harvested, the remaining cotton sicks were rotavated, and the soil was plowed and cultivated to create a fine seedbed. Once the seedbed was prepared, Super Raya seeds were broadcast at a rate of 2 kg per acre. Fertilizers, including DAP, SOP, and Urea, were applied according to standard practices, and the crops were managed with normal agronomic practices throughout the season. The study aimed to compare these systems against a sole cotton crop maintained under similar conditions.

Observations

To conduct a comprehensive analysis, soil samples were meticulously collected from each treatment site, targeting two specific depths: 0-15 cm and 16-30 cm, using a soil auger. These depths were chosen to assess the availability of essential nutrients, including phosphorus (P), potassium (K), and soil organic matter (OM), as well as to measure pH levels. Each soil sample was carefully labeled with a unique identification number to ensure precise tracking and traceability. The collected samples were then submitted to the Government Soil and Water Testing Laboratory in Rahim Yar Khan for detailed analysis. In both cotton and brassica crops, plant height is a critical factor influencing yield, specifically affecting the formation of bolls in cotton and siliqua in brassica. To quantify this, ten plants were randomly selected from each plot, and their heights were measured from the soil surface to the plant's highest point, following the methodology outlined by Hussian et al. (2013). Subsequently, the number of bolls per plant in cotton and the number of siliqua per plant in brassica were recorded, with ten plants randomly chosen for assessment from each treatment group.

The final yield for both cotton and brassica was documented post-harvest. The total yield was measured for each crop, and the harvest index was calculated using the following formula:

$$\text{Harvest index (\%)} = \text{Biology/ Economic Yield} * 100 \quad (1)$$

Economic Analysis

An economic analysis was conducted to evaluate the profitability of the agricultural system under study, with a particular focus on calculating the Benefit-Cost Ratio (BCR). This analysis was essential for determining the financial viability and efficiency of the different treatment practices applied to the cotton and brassica crops.

The economic analysis involved a detailed assessment of all costs associated with the production process, including inputs such as seeds, fertilizers, labor, irrigation, and other agronomic practices. These costs were systematically recorded for each treatment to ensure an accurate calculation of total expenses.

On the revenue side, the total income generated from the harvested yield of both cotton and brassica was calculated. This income was based on the market prices prevailing at the time of harvest. By comparing the total revenue with the total costs, the net profit for each treatment was determined.

Statistical Analysis

The data were analyzed using Statistix 8.1 software. A Least Significant Difference (LSD) test at a 5% significance level was applied to assess differences among treatments (Steel et al., 1997).

RESULTS AND DISCUSSION

Yield and Yield Related Traits

Results showed that relay cropping significantly enhanced the growth and yield of cotton during 2020-21 (Table 1). Cotton plants in the relay cropping system reached a height of 148 cm, compared to 120 cm in the sole cropping system. Relay cropping also led to a higher number of bolls per plant (35) in cotton and increased the yield to 948 kg/acre, surpassing the sole cotton cropping results of 780 kg/acre. The harvest index was also higher in the relay cotton cropping system (30.45%) compared to the sole cotton cropping system (29.10%). Alike, Brassica under relay cropping resulted in taller plants (143 cm) compared to sole cropping (132 cm). However, sole cropping produced a greater number of siliqua per plant (135) and a higher yield (816 kg/acre) than relay cropping (728 kg/acre). The harvest index for Brassica was also higher in the sole cropping system (27.20%) compared to the relay cropping system (26.60%). In the 2021-22 season, similar trends were observed for cotton (Table 2). Cotton under relay cropping resulted in taller plants (143 cm) with a higher number of bolls per plant (35) and greater yield (924 kg/acre) compared to sole cropping, which had plants of 131 cm in height, 28 bolls per plant, and a yield of 820 kg/acre. The harvest index was also higher in the relay cropping system (30.15%) versus the sole cropping system (29.10%). For Brassica, relay cropping plants were taller (149 cm) than those in sole cropping (145 cm). The number of siliqua per plant was similar in both systems (135 in sole cropping and 120 in relay cropping), but the yield was greater in sole cropping (768 kg/acre) compared to relay cropping (668 kg/acre). The harvest index for Brassica was higher in the sole cropping system (26.62%) compared to the relay cropping system (25.30%). In the 2022-23 season, relay cropping continued to show superior results for cotton (Table 3). Plants reached 143 cm in height, produced 35 bolls per plant, and yielded 888 kg/acre, outperforming sole cropping where plants were 131 cm tall, with 28 bolls per plant and a yield of 720 kg/acre. The harvest index for relay cropping was slightly higher (29.00%) compared to sole cropping (28.30%). For Brassica, relay cropping resulted in taller plants (149 cm) but yielded less (608 kg/acre) compared to sole cropping, which had plants of 145 cm and a yield of 720 kg/acre. The harvest index was also higher in sole cropping (26.58%) compared to relay cropping (25.10%). Overall, across the three seasons, relay cropping consistently improved plant height, number of bolls, and yield for cotton. In contrast, Brassica generally performed better in sole cropping systems, achieving higher yields and harvest indices. These results suggest that relay cropping can be advantageous for cotton production, while Brassica may benefit more from sole cropping to maximize yield and harvest index.

Table 1. Effect of relay and sole cropping on plant height, number of bolls, yield and harvest index during 2020-21.

Treatments	Plant height (cm)	Number of bolls (cotton) and siliqua (Brassica) per plant	Yield (kg/acre)	Harvest index (%)
Cotton sole	120 b	28 b	780 b	29.10 b
Cotton relay	148 a	35 a	948 a	30.45 a
Brassica sole	132 b	135 a	816 a	27.20 a
Brassica relay	143 a	120 b	728 b	26.60 b
LSD at 0.05 P level	Between cotton = 6.20 Between Brassica = 5.30	Between cotton = 2.14 Between Brassica = 4.63	Between cotton = 38.51 Between Brassica = 34.50	Between cotton = 0.31 Between Brassica = 0.35

Table 2. Effect of relay and sole cropping on plant height, number of bolls, yield and harvest index during 2021-22.

Treatments	Plant height (cm)	Number of bolls (cotton) and siliqua (Brassica) per plant	Yield (kg/acre)	Harvest index (%)
Cotton sole	131 b	28 b	820 b	29.10 b
Cotton relay	143 a	35 a	924 a	30.15 a
Brassica sole	145 a	135 a	768 a	26.62 a
Brassica relay	149 a	120 b	668 b	25.30 b
LSD at 0.05 P level	Between cotton = 5.10 Between Brassica = 4.90	Between cotton = 2.23 Between Brassica = 5.30	Between cotton = 41.30 Between Brassica = 23.60	Between cotton = 0.34 Between Brassica = 0.30

Table 3. Effect of relay and sole cropping on plant height, number of bolls, yield and harvest index during 2022-2.

Treatments	Plant height (cm)	Number of bolls (cotton) and siliqua (Brassica) per plant	Yield (kg/acre)	Harvest index (%)
Cotton sole	131 b	28 b	720 b	28.30 b
Cotton relay	143 a	35 a	888 a	29.0 a
Brassica sole	145 a	135 a	720 a	26.58 a
Brassica relay	149 a	120 b	608 b	25.10 b
LSD at 0.05 P level	Between cotton = 5.68 Between Brassica = 6.10	Between cotton = 1.90 Between Brassica = 5.30	Between cotton = 40.20 Between Brassica = 35.70	Between cotton = 0.26 Between Brassica = 0.40

Soil Properties

Results showed that during the 2020-21 season, no significant differences were observed in soil properties between relay and sole cropping systems for both cotton and Brassica (Table 4). Available phosphorus (P) and potassium (K) levels remained constant at 6.53 ppm and 160 ppm, respectively, across all treatments. Soil pH was 8.10, and soil organic matter was 0.65% for both cropping systems. However, in the 2021-22 season, relay cropping systems showed increased available phosphorus and potassium compared to sole cropping systems (Table 5). For cotton, available P was higher in relay cropping (6.60 ppm) versus sole cropping (6.54 ppm), and available K was also higher (164 ppm vs. 159 ppm). Similar trends were observed for Brassica, with relay cropping having higher available P (6.60 ppm) and K (164 ppm) compared to sole cropping (6.55 ppm and 161 ppm). Soil pH remained stable at 8.10 across treatments. Soil organic matter was higher in relay cropping systems (0.70%) compared to sole cropping systems (0.64%). Similarly, in the 2022-23 season, relay cropping continued to show improved soil nutrient levels (Table 6). For cotton, available phosphorus was higher in relay cropping (6.72 ppm) compared to sole cropping (6.56 ppm), and available potassium was also higher (178 ppm vs. 161 ppm). Similarly, for Brassica, relay cropping had higher available P (6.72 ppm) and K (178 ppm) compared to sole cropping (6.58 ppm and 163 ppm). Soil pH was slightly lower in relay cropping (8.09) compared to sole cropping (8.10). Soil organic matter was higher in relay cropping systems (0.78%) compared to sole cropping (0.63% for cotton and 0.68% for Brassica). Overall, relay cropping generally led to higher levels of available phosphorus and potassium, improved soil organic matter, and slightly lower soil pH compared to sole cropping across the different growing seasons.

Economic Analysis

Outcomes showed that during 2020-21 season, relay cropping provided higher economic returns than sole cropping (Table 7). Cotton relay cropping achieved a net profit of Rs 49,215, compared to Rs 34,615 from sole cotton. Brassica sole cropping had a net profit of Rs 39,626, while relay Brassica yielded Rs 35,806. The combined relay cropping system of cotton and Brassica resulted in a total net profit of Rs 85,021. Similar trend was recorded during 2021-22 (Table 8) where cotton relay cropping generated a net profit of Rs 73,540, exceeding the Rs 59,847 net profit from sole cotton. Sole Brassica achieved a net profit of Rs 56,535, while relay Brassica had a net profit of Rs 49,739. The overall relay cropping system resulted in a net profit of Rs 123,279. Similarly, in the 2022-23 season, cotton relay cropping provided a net profit of Rs 66,950, compared to Rs 39,200 from sole cotton (Table 9). Sole Brassica had a net profit of Rs 76,000, while relay Brassica earned Rs 63,680. The combined performance of cotton and Brassica in relay cropping resulted in a total net profit of Rs 130,630. Overall, the combined performance of cotton and Brassica in relay cropping resulted in higher net profit, reflecting the continued economic superiority of relay cropping systems.

Table 4. Effect of relay and sole cropping on P, K, pH and soil organic matter during 2020-21.

Treatments	Available P (ppm)	Available K (ppm)	Soil pH	Soil organic matter (%)
Cotton sole	6.53	160	8.10	0.65
Cotton relay	6.53	160	8.10	0.65
Brassica sole	6.53	160	8.10	0.65
Brassica relay	6.53	160	8.10	0.65
LSD at 0.05 P level	Between cotton = non-significant Between Brassica = non-significant	Between cotton = non-significant Between Brassica = non-significant	Between cotton = non-significant Between Brassica = non-significant	Between cotton = non-significant Between Brassica = non-significant

Table 5. Effect of relay and sole cropping on P, K, pH and soil organic matter during 2021-22.

Treatments	Available P (ppm)	Available K (ppm)	Soil pH	Soil organic matter (%)
Cotton sole	6.54 b	159 b	8.10	0.64
Cotton relay	6.60 a	164 a	8.10	0.70
Brassica sole	6.55 b	161 b	8.10	0.65
Brassica relay	6.60 a	164 a	8.10	0.70
LSD at 0.05 P level	Between cotton = 0.030 Between Brassica = 0.030	Between cotton = 0.90 Between Brassica = 0.89	Between cotton = non-significant Between Brassica = non-significant	Between cotton = 0.030 Between Brassica = 0.031

Table 6. Effect of relay and sole cropping on P, K, pH and soil organic matter during 2022-23.

Treatments	Available P (ppm)	Available K (ppm)	Soil pH	Soil organic matter (%)
Cotton sole	6.56 b	161 b	8.10	0.63 b
Cotton relay	6.72 a	178 a	8.09	0.78 a
Brassica sole	6.58 b	163 b	8.09	0.68 b
Brassica relay	6.72 a	178 a	8.09	0.78 a
LSD at 0.05 P level	Between cotton = 0.031 Between Brassica = 0.031	Between cotton = 0.88 Between Brassica = 0.90	Between cotton = non-significant Between Brassica = non-significant	Between cotton = 0.032 Between Brassica = 0.030

Table 7. Economic analysis of sole cotton, brassica and relay cropping during 2020-21.

Treatments	Yield (kg/acre)	Income (Rs/acre)	Production cost (Rs/acre)	Net profit (Rs/acre)
Cotton sole	780	90550	55935	34615
Brassica sole	816	60180	20554	39626
Cotton relay	948	109650	60435	49215
Brassica relay	728	53460	17654	35806
Overall system performance (Cotton + Brassica relay cropping)	1676	163110	78089	85021

Table 8. Economic analysis of sole cotton, brassica and relay cropping during 2021-22.

Treatments	Yield (kg/acre)	Income (Rs/acre)	Production cost (Rs/acre)	Net profit (Rs/acre)
Cotton sole	820	126500	66653	59847
Brassica sole	768	80064	23529	56535
Cotton relay	924	142100	68560	73540
Brassica relay	668	69639	19900	49739
Overall system performance (Cotton + Brassica relay cropping)	1592	211739	88460	123279

Table 9. Economic analysis of sole cotton, brassica and relay cropping during 2022-23.

Treatments	Yield (kg/acre)	Income (Rs/acre)	Production cost (Rs/acre)	Net profit (Rs/acre)
Cotton sole	720	159000	101800	39200
Brassica sole	720	121500	45500	76000
Cotton relay	888	172500	107800	66950
Brassica relay	608	102600	38920	63680
Overall system performance (Cotton + Brassica relay cropping)	1496	277350	146720	130630

Discussion

For cotton, relay cropping consistently outperformed sole cropping in terms of plant height, number of bolls, yield, and harvest index across all three seasons. This superior performance can be attributed to several factors. Relay cropping allows for better utilization of available resources, such as light, water, and nutrients, due to the staggered planting times of different crops. The taller plant height and higher yield observed in relay cropping are likely a result of reduced competition between plants for these resources, leading to more robust growth and increased productivity (Patel, 2020). Additionally, the higher harvest index in relay cropping systems suggests more efficient allocation of resources towards cotton production rather than vegetative growth.

The higher availability of phosphorus (P) and potassium (K) in relay cropping systems indicates better nutrient management and availability. This is supported by Tariq et al. (2022), who found that relay cropping of cotton in wheat significantly improves the productivity of the cotton-wheat cropping system by enhancing nutrient availability and use efficiency. The increased soil organic matter in relay cropping systems suggests that the combination of different crops enhances organic matter input into the soil, leading to improved soil structure and nutrient-holding capacity (Farooq et al., 2020). This is crucial for maintaining soil health and fertility, especially in regions where soil degradation is a major concern due to intensive agricultural practices.

Economic analysis across the three seasons underscores the financial benefits of relay cropping systems over sole cropping. Relay cropping consistently resulted in higher yields, incomes, and net profits for cotton compared to sole cropping, indicating enhanced resource utilization and productivity. The increased yields and net profits from relay cropping can be attributed to the improved efficiency in resource use, as relay cropping systems typically offer better integration and timing of crop growth (Gesch et al., 2023). This is further supported by Hussain et al. (2023), who emphasize that cotton-based intercropping as a climate-smart approach not only enhances productivity but also contributes to food and fiber security by optimizing the use of resources.

Relay cropping systems provide a more sustainable and profitable approach to farming by leveraging the benefits of multiple crop integration and efficient resource management. This is particularly important in the context of climate change, where farming systems need to be resilient and adaptable to changing environmental conditions. According to Leisner (2020), diversified cropping systems, including relay cropping, play a vital role in enhancing food security and nutritional value, especially under climate change scenarios. They contribute to agricultural sustainability by improving soil health, water use efficiency, and overall crop productivity (Malhi et al., 2021). In addition to improving yields and economic returns, relay cropping systems also offer significant ecological benefits. For instance, relay cropping can help reduce soil erosion and improve water infiltration and retention, which are critical for maintaining soil health and reducing the risk of nutrient leaching (Daigh, 2022). This is particularly beneficial in areas prone to soil degradation and water scarcity, where maintaining soil health and water conservation are crucial for sustainable agricultural production. The integration of multiple crops within a single growing season allows for better use of environmental resources and improves the economic viability of farming operations, making it a valuable approach in the context of climate change adaptation (Kogo et al., 2021). By diversifying crop production, relay cropping systems can help buffer against market fluctuations and provide a steady income stream for farmers, thereby enhancing farm resilience and reducing vulnerability to economic and climatic shocks (Aryal et al., 2020). Furthermore, relay cropping systems are particularly effective in improving nutrient cycling and reducing the need for chemical fertilizers. By integrating different crops with varying nutrient requirements and growth patterns, relay cropping can enhance nutrient uptake and reduce nutrient losses, leading to more efficient use of inputs and reduced environmental impact (Chapagain et al., 2020). This aligns with the findings of Xie et al. (2022), who demonstrated that relay cropping, when combined with appropriate crop management practices, can significantly enhance nutrient uptake and reduce the risk of nutrient runoff and pollution.

CONCLUSIONS

The economic analysis over the three seasons highlights the financial advantages of relay cropping systems compared to sole cropping. Relay cropping consistently yielded higher net profits for cotton, attributed to better resource utilization and crop integration. While relay cropping improved overall profitability and resource efficiency. The improved soil nutrient levels and organic matter in relay cropping suggest long-term soil health benefits. These findings emphasize the need to choose cropping systems that align with the specific requirements of each crop to optimize both economic returns and soil quality.

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