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Optimizing rabi crop diversification strategies for sustainable agriculture: A case study from Adilabad, Telangana

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Abstract
Adilabad, Telangana, a hub for cotton cultivation, faces challenges due to mono-cropping practices, impacting farmers' livelihoods and ecosystem integrity. Crop diversification post cotton termination aims to enhance yields and resource efficiency. Sorghum and wheat thrive under erratic rainfall, bolstering food security. Safflower and rapeseed mustard contribute to oil production, while coriander serves as a high-value crop. Efforts are ongoing to identify optimal cropping systems for sustainable livelihoods in Adilabad. The study at Adilabad's dry farming agricultural research station evaluated the most economical cropping system after cotton during two consecutive rabi seasons using five crop sequences such as Bt-Cotton-Jowar, Bt-Cotton-Wheat, Bt-Cotton-Coriander, Bt-Cotton-Mustard, and Bt-Cotton-Safflower using a split-plot design. The selected crops included Coriander (Kalimi), Mustard (Pusa Agrani), Wheat (Ankur Kedar), Jowar (VJH 540), and Safflower (Manjeera). The study results revealed that Safflower attained the highest net returns of Rs 100,575 per hectare with a benefit-cost ratio (B:C) of 3.7. Following Safflower, Jowar exhibited net returns of Rs 32,834 per hectare with a B:C ratio of 2.0.These findings underscore the potential economic viability of diversifying crops in Kharif Cotton fallow areas. Safflower and Jowar emerged as promising alternatives to Rabi Chickpea, offering favorable returns under irrigated conditions. Such crop diversification strategies hold promise for enhancing agricultural sustainability and income generation in the region.

Keywords: Crop diversification, irrigated crops, cotton fallow, safflower, jowar

Introduction
Adilabad, located in Telangana, India, serves as a critical hub for cotton cultivation, spanning 0.4 million hectares and supporting 90% of farmers' livelihoods (Poshadri *et al*., 2019; Poshadri *et al*., 2020) [11-12]. Predominantly small and marginal, with a significant tribal population, farmers rely heavily on rain-fed agriculture, primarily mono-cropping cotton during the Kharif season, which constitutes approximately 65% of crops (Ramadevi *et al*., 2020) [15]. The tropical climate sees scorching summers with temperatures ranging from 42 to 28 °C, contrasting with mild winters ranging from 29 to 15 °C. Annual rainfall, varying between 1089 mm to 1204 mm, is essential, with July being the wettest month, averaging 15–16 rainy days (CCAFS, 2020) [3]. Adilabad district's soil consists of black and red types, with clayey, gravelly, loamy, cracking, and calcareous clay types. Soil depth varies from shallow to deep black soil.
Crop rotation and diversification with important food crops are used worldwide to improve crop productivity in sustainable agriculture (David *et al*., 2011) [5]. Rotation has been demonstrated to effectively reduce constraints and increase crop yield (Lv Q *et al*., 2023) [8]. However, the traditional rotation is not attractive because most smallholder farmers in the Adilabad district prefer to prolong the cotton and harvest the cash crop by irrigating the crop, which results in not only lower economic benefits but also extending the pest and disease cycles in the district, especially the pink boll worm (Ramadevi *et al*., 2020) [15]. These conditions underscore the region's vulnerability to climate variability and emphasize the need for sustainable agricultural practices to ensure the resilience of Adilabad's farming communities and the integrity of its ecosystem. Crop rotation and diversification after the termination of cotton in the months of November and December are crucial strategies for boosting crop yield and the efficiency of agricultural resource use.

Rotational systems involving cotton have shown to enhance crop yields in diverse environments. Compared to continuous cotton cropping, rotations boosted yields by 2.6~4.5%, fostering improved vegetative and reproductive growth, including increased plant height, leaf and fruit branch numbers, and boll weight (Qi H *et al*., 2016) [14].

Excessive nitrogen (N) fertilizer application in kharif cotton cultivation often exceeds crop uptake, leading to N surplus. This surplus can accumulate in soil, or be lost to the atmosphere or groundwater. Introducing safflower, a deep-rooted crop in crop rotations after cotton, can enhance water and N use efficiencies, mitigating nitrate leaching. This practice helps to optimize cropping systems, reducing environmental impacts associated with N loss and promoting sustainable agriculture (Bassil *et al*., 2002) [2].

Choosing an appropriate crop sequence after cotton in Adilabad district hinges on climate, water availability, and soil type to sustain yields and soil fertility. Water conservation is crucial due to diminishing irrigation supplies, emphasizing the need to enhance cropping intensity and productivity. Cropping systems impact farming practices and socioeconomic aspects for farmers (Anureet Kaur *et al*., 2018) [1].

Sorghum (*Sorghum bicolor* L.) exhibits remarkable adaptability to diverse environments, particularly thriving in regions with erratic rainfall and high temperatures. During the Rabi season (October–November to March–April), it serves as a vital crop for arid areas due to its drought tolerance. Sorghum grain is predominantly utilized for human consumption, fodder, feed, and fuel, while its seeds are used in popcorn and various culinary dishes (Saikat *et al*., 2012; Nagesh Kumar *et al*., 2022; Poshadri *et al*., 2023) [17, 9, 13]. Expanding sorghum cultivation to moisture-deficient zones could bolster food security, given its resilience and high yield potential under rainfed conditions, requiring minimal inputs. Introducing tolerant crops like sorghum presents an effective strategy to address agricultural challenges (Saddam Hossain *et al*., 2022) [16].

Wheat (*Triticum aestivum* L.) serves as a crucial food source and contributes significantly to national food security by bolstering food grain buffer stocks. Effective irrigation, though costly, directly impacts wheat growth and yield, with timely and adequate irrigation enhancing productivity. In Adilabad district, wheat ranks fourth among remunerative rabi crops, with its cultivation covering 4953 acres, yielding 32195 quintals, averaging 6.5 q/acre. Temperature fluctuations during wheat growth stages negatively affect growth rate, duration, and yield. Optimized irrigation timing can maintain favorable soil moisture levels, crucial for mitigating grain yield reduction under limited irrigation. Proper irrigation scheduling, considering crop water requirements, water availability, and root system storage capacity, is vital for maximizing water, energy, and input efficiency (Hrishikesh Nath *et al*., 2023) [6].

Safflower (*Carthamus tinctorius* L.) is considered tobe the deepest-rooted oil seed crop grown in the Adilabad district of Telangana during the Rabi season. And unlike most crops, it can explore a bigger volume of soil to meet its water requirements.

Rapeseed mustard (*Brassica rapa* L. var. brown sarson)), a vital oilseed crop in India, contributes one-third of the nation's oil production. Cultivated in both rain-fed and irrigated conditions during the annual rabi season, it bolsters rural economies, particularly for marginal and small farmers. However, its inconsistent performance is influenced by diverse environmental and economic factors (Narender Kumar *et al*., 2021) [10].

Coriander, a seed spice (*Coriandrum sativum* L.), is classified as a high-value, low-volume crop. It serves as a cash crop for farmers in India's arid and semi-arid regions during the rabi season (Chaudhary *et al*., 2020) [4].

Efforts are underway to establish optimal cropping sequences post early termination of cotton under irrigated conditions, focusing on wheat, sorghum, safflower, mustard, and coriander cultivation during the rabi season to ensure livelihood security while maintaining productivity and resource efficiency. This study aims to identify the most productive, resource-efficient, remunerative, and profitable cropping system among cotton-wheat, cotton-sorghum, cotton-safflower, cotton-mustard, and cotton-coriander-based systems in Telangana's Adilabad district.

Materials and Methods

The experiment was conducted on medium black soil under irrigated conditions at the dry farming agricultural research station (ARS), Adilabad, of Professor Jayashankar Telangana State Agricultural University (Telangana state), throughout the duration of two consecutive rabi seasons, from 2021–22 to 2022–23. The total amount of rainfall that was received on *rabi* season basis over the crop growing seasons of 2021–2022 and 2022–2023 was 136.7 and 107.1, respectively. The uppermost soil layer (0–30cm) had organic carbon at 0.33%, a pH of 6.8, an EC of 0.34 dS/m, nitrogen at 187.9 kg/ha, phosphorus at 14.7 kg/ha, and potassium at 254.8 kg/ha. In the main plots, five crop sequences—Bt-Cotton-Jowar, Bt-Cotton-Wheat, Bt-Cotton-Coriander, Bt-Cotton-Mustard, and Bt-Cotton-Safflower—were taken, each replicated three times, using a split-plot design. Each plot, covering 185 m^2, was part of an experimental area spanning 555 m^2, adhering to the designated schedule for cultivation to assess the most economical cropping system after cotton during two consecutive rabi seasons using five crop sequences. The cotton variety B-II RCH-689 and all other crop varieties, likewise Coriander variety Kalimi, Mustard variety Pusa Agrani, Wheat variety Ankur Kedar, Jowar variety VJH-540, and Safflower variety Manjeera, were sown. All other recommended agricultural practices were followed throughout the crop period (Table 1). Main product yield, cost of cultivation, and net returns were recorded at the time of crop harvest. The economics of all the treatments were worked out.

Table 1: Experimental Crop Details and Management Practices

Crop	Variety	Spacing	RDF (N-P-K)	No. of Irrigation	No. of hand weeding	No. of chemical sprays
Coriander	Kalimi	45 x 15 cm	40-0-0	4	1	2
Mustard	Pusa Agrani	45 x 15 cm	20-10-10	3	1	2
Wheat	Ankur kedar	30 x 10 cm	30-15-15	5	1	2
Jowar	VJH 540	45 x 15 cm	24-12-08	4	1	2
Safflower	Manjeera	45 x 20 cm	16-10-0	3	1	2

Results and Discussion

The results show that different rabi crops after cotton have varying timeframes to reach 50% flowering. For example, mustard takes the shortest time at 39 days, while jowar requires the longest time at 80 days. The harvesting data shows that wheat, jowar, and safflower all have the same time to harvest, indicating consistency in their growth and maturation patterns within the Rabi season. Although some crops like coriander and mustard have shorter days to harvest compared to wheat, jowar, and safflower, there is still diversity in the harvest periods among Rabi crops. This suggests flexibility in crop selection for farmers based on their specific needs and market demands. All listed Rabi crops incur the same cost (Rs. 7500) for land preparation. This suggests a standardization in the initial investment required for preparing land for cultivation, regardless of the specific crop chosen. The uniformity in land preparation costs ensures equitable opportunities for farmers cultivating different Rabi crops. It eliminates potential biases or disparities that could arise if certain crops required significantly higher or lower investments for land preparation. Based on the provided data on the cost of inputs for Rabi crops, mustard has the highest input cost at Rs. 6955, while wheat has the lowest at Rs. 3250. This suggests differences in the types and quantities of inputs required for each crop. The disparities in input costs reflect the unique agronomic needs of each Rabi crop. For example, mustard might require specialized inputs or higher quantities of certain inputs compared to wheat or jowar, leading to higher overall input expenses. With a labor cost of Rs. 27950, mustard is the most cost-intensive crop; at Rs. 22050, wheat and jowar are cheapest to grow. This implies that the amount of labor needed to cultivate various crops varies. Higher labor-cost crops like safflower and mustard probably need more intensive human labor for tasks like planting, weeding, harvesting, and post-harvest processing. Mustard cultivation required the highest total cost at Rs. 42405, while wheat has a relatively lower total cost of cultivation at Rs. 32800. Total costs of cultivation encompass various expenses, including land preparation, inputs, labor, machinery, and other operational costs. The yield shows variations for different Rabi crops. Jowar has the highest yield at 2432 kg/ha, while coriander and mustard have the lowest yield, both at 1243 kg/ha. Crops with higher yields, such as jowar and safflower, may be better suited and adapted to the prevailing agro-climatic conditions and management practices. Understanding the yield potential of each crop allows farmers to make informed decisions about crop selection and cultivation strategies. High-yielding crops contribute to improved food security and agricultural sustainability by increasing overall production efficiency and resilience to environmental stressors.

There are significant variations in market prices across different Rabi crops. Coriander commands the highest price at Rs. 8000 per quintal, while wheat has the lowest price at Rs. 2500 per quintal. This indicates diverse market demand and value for each crop. Farmers need to consider both yield potential and market price when evaluating the profitability of cultivating Rabi crops. Crops with lower yields but higher market prices may yield comparable or even higher returns than high-yielding crops with lower market prices. There are significant variations in gross returns across different Rabi crops. Safflower generates the highest gross returns at Rs. 137,515 per hectare, while coriander and wheat yield relatively lower returns at Rs. 54,000 and Rs. 54,040 per hectare, respectively. Gross returns are influenced by both the yield and the market price of each crop. Crops with high yields and favorable market prices, such as safflower, can generate substantial returns, while those with lower yields or lower market prices may yield comparatively lower returns. Gross returns provide an indicator of the revenue potential of cultivating each Rabi crop. Farmers need to evaluate gross returns relative to production costs, including inputs, labor, and land preparation expenses, to assess the profitability of different crop options. There are significant variations in net returns across different Rabi crops. Safflower generates the highest net returns at Rs. 100,575 per hectare, while mustard and coriander yield relatively lower net returns at Rs. 18,953 and Rs. 19,165 per hectare, respectively. Net returns reflect the profitability of cultivating each Rabi crop after accounting for production costs such as inputs, labor, land preparation, and other operational expenses. Farmers should consider net returns as a crucial metric when evaluating the financial viability of different crop options.

There are notable variations in the benefit-cost ratios across different Rabi crops. Safflower has the highest B:C ratio at 3.7, indicating that for every unit of cost incurred in cultivation, the returns are 3.7 times higher. Conversely, mustard has the lowest B:C ratio at 1.4, suggesting a lower return relative to the investment. The benefit-cost ratio is a critical metric for assessing the profitability and efficiency of cultivating each Rabi crop. A higher B:C ratio indicates a more profitable investment, while a lower ratio suggests a less favorable return on investment. Farmers can use the benefit-cost ratio as a decision-making tool to prioritize crop selection and optimize resource allocation. Crops with higher B:C ratios may be preferred as they offer better returns relative to the investment, helping farmers maximize profitability and manage risks.

Table 2: Number of pest and disease occurrence in different crop under crop diversification

Insects per meter row length & 10 plants	Coriander	Mustard	Wheat	Jowar	Safflower
Thrips	-	0.36	-	-	0.35
Whitefly	2.28	2.43	1.65	1.93	0.37
Leaf webber	-	0.17	-	-	-
Leaf hopper	2.13	2.37	2.18	2.03	0.63
Defoliators	-	-	-	-	--
Stem borer	-	-	-	-	-
Wilt	-	-	-	0.5	-

Mustard and safflower appear to be susceptible to Thrips infestations, as indicated by the recorded occurrences. Mustard and coriander exhibit relatively higher occurrences, with 2.43 and 2.28 Whiteflies per meter row length, respectively, indicating greater susceptibility to Whitefly infestations compared to other crops such as safflower, which has a much lower occurrence at 0.37. Among the listed Rabi crops, only mustard has a recorded occurrence of Leaf Webber, with 0.17 insects per meter row length. This suggests that Leaf Webber infestations are relatively uncommon in mustard compared to other crops. The data indicates varying levels of Leaf Hopper occurrences across different Rabi crops. Mustard has the highest

occurrence at 2.37 insects per meter row length, followed by coriander (2.13), wheat (2.18), and jowar (2.03). In contrast, safflower has a substantially lower occurrence at 0.63. Crops with higher occurrences of Leaf Hoppers, such as mustard, coriander, wheat, and jowar, may require more intensive pest management efforts to control infestations and minimize potential damage to crop health and yield. Integrated pest management (IPM) practices, including cultural, biological, and chemical control methods, can be employed to mitigate Leaf Hopper populations effectively. Among the listed Rabi crops, only jowar has a recorded occurrence of Wilt, with 0.5 occurrences per meter row length. This suggests that Wilt infestations are relatively uncommon in jowar compared to other crops. The absence of recorded occurrences of Wilt in other Rabi crops such as coriander, mustard, wheat, and safflower indicates that these crops may either have natural resistance to Wilt or are less susceptible to Wilt infestations. In first date of sowing the major incidence of defoliators, white fly and leaf hopper were recorded in safflower Coriander, Mustard, Wheat and Jowar during crop growth period. The incidence of wilt observed in Jowar only. The more whitefly incidence observed in Coriander, more in Mustard followed by Wheat, leaf hopper in mustard, wheat and Jowar. Low pest incidence was recorded in safflower crop and the wilt was observed in Jowar crop only.

Table 3: Days to 50% flowering, Days to harvest, yield and economics of different crops under crop diversification, Rabi, 2021-22 and 2022-23

	Days to 50% flowering	Days to harvest	Cost on land preparation (Rs.)	Cost of inputs (Rs.)	Cost of labour (Rs.)	Total costs of cultivation (Rs.)	Yield (kg ha^{-1})	Market price / quintal	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C
Coriander	46	97	7500	4775	22560	34835	1243	8000	54000	19165	1.6
Mustard	39	100	7500	6955	27950	42405	1243	5050	61358	18953	1.4
Wheat	70	120	7500	3250	22050	32800	2162	2500	54040	21240	1.6
Jowar	80	120	7500	3280	22050	32830	2432	2700	65664	32834	2.0
Safflower	70	120	7500	3643	25797	36940	2594	5414	137515	100575	3.7

A demonstration trial on crop diversification in *Kharif* Soybean fallow was taken up during *yasangi*,2021-22 .The crops viz, Coriander (Kalimi), Mustard (Pusa Agrani), Wheat (Ankur Kedar), Jowar (VJH 540), Safflower (Manjeera) were choosen as alternate to *Rabi* Chickpea for evaluating yield and economics under irrigated situation. The results indicated that, the highest net returns of Rs/- 100575 per ha^{-1} with B: C of 3.7 was recorded with safflower followed by Jowar recorded net returns of Rs/- 32834 per ha^{-1} with B: C ratio of 2.0.

Conclusion

The comprehensive analysis of various parameters related to Rabi crops post-cotton cultivation offers valuable insights into crop performance, profitability, and pest management strategies. Mustard emerges as a quick flowering crop with a short span of 39 days, while jowar exhibits a longer duration of 80 days to reach 50% flowering. Wheat, jowar, and safflower show consistency in their harvesting times, suggesting uniform growth patterns within the Rabi season. Despite uniform land preparation costs, there are significant variations in input expenses, labor costs, and total cultivation costs across different crops. Mustard incurs the highest input and labor costs, reflecting its higher resource requirements. Conversely, wheat and jowar are relatively cost-effective to cultivate. Yield variations among Rabi crops highlight their adaptability and suitability to diverse agro-climatic conditions. Crops like jowar and safflower demonstrate higher yields, contributing to improved food security and sustainability. Market prices vary significantly, with coriander commanding the highest price and wheat the lowest. Gross and net returns also vary, with safflower exhibiting the highest returns per hectare, emphasizing the importance of considering both yield potential and market prices in crop selection. Benefit-cost ratios provide insights into the profitability of cultivating each crop, with safflower offering the highest returns relative to the investment. Pest and disease occurrences, such as Thrips, Whitefly, and Leaf Hopper, underscore the importance of effective pest management strategies tailored to specific crop needs. Overall, the study highlights the diversity and flexibility in Rabi crop selection, allowing farmers to optimize returns while mitigating risks associated with pest pressures and market fluctuations. Cultivating high-yielding, resilient crops like safflower and implementing integrated pest management practices are crucial for sustainable agricultural practices and enhancing farmer livelihoods.

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