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INTEGRATING CLIMATE RESILIENCE AGRICULTURAL PRACTICES INTO WHEAT CULTIVATION AND TRAINING OF GROWERS ON INNOVATIVE SOWING PATTERNS

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ABSTRACT
In order to integrate climate resilience agricultural practices into wheat cultivation, the impact of innovative vs conventional sowing systems was compared by evaluating agronomic performance and economic efficiency of wheat as mono-crop and intercropped with other crops in three wheat growing districts (Sanghar, Badin, Umarkot) of Sindh province. Twelve wheat growers were selected to adopt innovative sowing systems i.e. 4 growers in Sanghar (Raised bed, Ridges, Ridges-Intercrop Brassica); 3 growers from Badin (Raised bed, Ridges, Ridges-Intercrop Brassica, Drilling-ZT), Umarkot (Raised bed, Ridges, Drilling, Ridges-Intercrop Brassica, ridges-intercrop [Fresh Sugarcane], Drilling-ZT Intercropping (Ratoon Sugarcane).At all 12 demonstration plots through a comprehensive training program, 600 growers were trained to meet the climate change challenge and integrating climate resilience agricultural practices. The results revealed that grain yield of wheat under at growers' fields varied between 24.66 and 33.22 maunds/acre among 12 growers and ridge sowing yields were slightly lower than those from raised beds but still offer a marked improvement over conventional system. However, Brassica offered some agronomic benefits, but did not consistently maximize grain yield. The drilling technique also shows promising results in certain fields. When comparing sowing techniques, raised bed sowing emerges as the most effective for increasing wheat grain yield, with yields often exceeding 60 maunds/acre. Ridge sowing also offers substantial improvements over traditional practices, though it generally results in slightly lower yields than raised beds. Wheat-Brassica intercrop on ridges and drilling provided alternative options. Across selected growers, growers' yields remained low, ranging between 24.66 and 33.22 maunds/acre. In contrast, the demonstration plots using techniques such as raised beds, ridges, and drilling showed significant yield increases, often exceeding 50 maunds/acre, with some plots reaching as high as 63.2 maunds/acre. Raised beds, such as, improve root aeration and reduce water logging, while ridge sowing ensures better drainage and moisture retention. However, while these techniques clearly outperformed growers' practices, their adoption may be influenced by factors such as cost, labor requirements, and farmer familiarity, which can affect their practical implementation. Results on wheat production from various planting combinations (such as zero-tillage, drilling, and sugarcane) and farmer techniques sheds important light on the ways in which these methods affect crop productivity. The yield that was predicted and the yield obtained using standard procedures differed. Drilling and zero-tillage combined with even little tillage changes can improve soil structure, improve moisture retention, and increase wheat production. These figures do a good job of illustrating the trade-offs involved with mixed cropping systems.
Keywords: wheat, climate resilience, innovative sowing system, raised bed, drilling, zero tillage, intercropping, agronomic performance, economic efficiency

INTRODUCTION

The term "Climate change "describes the enduring changes in temperatures and weather patterns, largely associated with human activity including deforestation, burning of fossil fuels, and industrial processes (Carroll et al., 2021; Farooq et al., 2023). The concentrations of greenhouse gasesin the atmosphere (carbon dioxide and methane) are increased substantially, leading to global warming (Gao et al., 2017; Glavan et al., 2020). Such state of warming alters natural systems, resulting in more frequent extreme weather events like heat waves, droughts, and floods, and disrupting ecosystems and agriculture.It also accelerates sea-level rise and affects biodiversity, threatening the balance of both natural and human systems worldwide (Gu et al., 2023; FAO, 2023a; Hafeez et al., 2023; Leibniz, 2023; FAO, 2023b; WMO, 2022). Due to altered temperature and precipitation regimes, the cropping patterns are significantly in change. The rising temperatures in temperate regions have resulted in earlier planting seasons and the replacement of traditional crops with drought-resistant crops. The elements of change may demand that farmers apply new strategies and tools in order to alter the characteristics of farming. This is because areas that may experience extremely heavy rainfall, or flooding, may start growing crops that are known to grow well when flooded. This can lead to the disruption of the existing agricultural practices, lower yields, and food insecurity (Singh et al., 2022; Wang et al., 2023). From the study conducted by Schauberger et al. (2017), it is evident that sowing practices are more vulnerable to climate change effects on agriculture. As stated by Derpsch et al. (2010), more efficient and innovative seed sowing technologies have to be developed and applied in order to maintain the yields of the crop production in conditions of fluctuating precipitation, increasing temperatures, and unfavorable climate. The availability of moisture in the soil depends on the temperature and rainfall and therefore affects the crop germination, application of fertilizers and yield. According to Aggarwal et al. (2019), conventional methods of seed dispersal are slowly becoming impractical in areas with unreliable rainfall and high temperatures. This is because the above mentioned strategies are less effective in retaining and conserving soil moisture and avoiding heat stress. The effects of climate change on the growth of wheat are numerous and they affect the growing environment in one way or the other. This predicament might occur in several ways. According to Asseng et al. (2015) global yield reductions of wheat have been observed due to change in precipitation patterns, increase in intensive precipitation, and increase in global temperature. Lobell and Field (2007) report that grains that are affected by temperature stress during important plant development phases such as flowering and grain-filling are of inferior quality and proportionately smaller than the rest of the plant. Long duration of dryness have a negative effect on the nutrients and root development and reduces the water content in the soil. Another threat is related to viral and parasitic infections that are more effective at high temperatures and have a negative impact on the yield of wheat production. Higher levels of atmospheric CO2 could lead to earlier maturity of the wheat crop, shortening the time required for the development of healthy kernels and decreasing the overall yield and quality. Global climate changes negatively impacts food production and security (Liu et al., 2016; Zampieri et al., 2017).

Wheat is an example of an annual crop, which should be sensitive to these challenges. Farmers are beginning to use practices that seek to reduce the effects of climate change such as direct sowing, terraced or raised bed planting, and conservation tillage. Conservation tillage, for instance, reduces evaporation losses and allows agricultural trash on the land's surface by avoiding soil inversion (Lal, 2020). Ridge planting serves as a good way of enhancing soil aeration to the roots and control of water runoff especially after a down pour. In their study conducted in 2022, Jat et al highlighted that planting system such as ridge-furrow and use of elevated beds enhance the soil permeability, reduce water logging and minimize the impacts of climate change. The time of plant sowing is also affected by climate change. Fluctuation in temperatures may affect the growth and germination of new seedlings or plants. It may be required to sowseeds at different times of a day or with the rise or decline in the sowing time. The rationale for this is that the time of growing seasons could be affected by changes in weather patterns. They can be planted on time to minimize yield reductions at sensitive growth stages due to drought or heat stress (IPCC, 2021). As Hatfield et al. (2011) and Meena et al. (2023) noted, it is crucial to adjust the sowing practices to consider a potential shift in the climate conditions for enhancing the stability and sustainability of agricultural products.

One of the most obvious effects of climate change on agriculture is likely to be a change in seasons that results from an increase as well as decrease in mean temperature. As pointed out by Cruafurd and Wheeler (2009), this leads to a change in the preferred planting period and increases the rate of agricultural development. When heat stress has reduced the number of growing cycles, farmers are sowing crops earlier in order not to have large growth phases during heat or drought (Zhao et al., 2017). Due to precipitation especially in the regions receiving more rainfall, planting may require the use of some techniques such as delaying planting (Waha et al., 2013). Seeding dates have been based on local climatic predictions of climate change that takes into consideration the differences in climate volatility (Tubiello et al., 2007; Meza et al., 2008). This implies that the significance of seeding dates is increasing. Flats planting or distributing, are conventional planting techniques that have extra challenges when the weather becomes hot, as this influences the soil moisture status and Evapotranspiration rates (Rana et al., 2011). These approaches are differentiated by higher implementation complexity. Minimum and zero tillage plowing techniques have greatly influenced the implementation of climate smart planting practices(Lal, 2012). The above strategies improve structural quality of soil, conserve water and increase the proportion of organic matter in the soil. These solutions decrease the susceptibility of wheat to heat and drought stress (Pittelkow et al., 2015). This is achieved by reducing water loss during the dry seasons and increasing the efficiency of the water available.

Different seed-sowing technologies have been reported to work in places where rainfall is not easily predicted. Some of them are Raised bed systems, ridge-furrow sowing, and minimum or nonexistent tillage drills. Singh et al. (2021) and Raza et al. (2019) suggest that these strategies enhance water infiltration and runoff under different precipitation rates and amounts. The purpose of this effort is to safeguard the crops from drought and water logging conditions. However, precision sowing enhances the efficient use of water, fertilizers, and seeds by changing plant density, seed depth, and row spacing with the help of present and future weather prediction (Sassenrath et al., 2008. This method enhances the chances of resource availability to the farmer which is a very vital factor. Pimentel (2006), Derpsch et al. (2010), Powlson et al. (2014), and Sapkota et al. (2015) have all noted that these innovations enable more precise modifications to planting strategies, enhancing crop resistance in regions with wider fluctuations in temperature.

Various studies have been conducted globally on the climate change and sowing strategies (Sayre et al., 2017). Such studies established that raised bed cultivation enhanced drainage and reduced compactness of the soil, thus enhancing water use efficiency. This led to improvements in the yield of wheat and rooting systems of plants that were used in the production of bread. In drilling, precision farming practices are employed to ensure proper distribution of seeds and an ideal plant population (Farooq et al., 2011). This strategy results in increased yields and reduced input prices. Moreover, the integrated use of the approaches makes it possible to achieve an optimum plant population. Inter cropping of wheat with legumes and other crops enhanced resource use efficiency, provided similar returns to both crops and increased profitability as reported by Ghosh et al. (2006). There are several benefits of ZT farming, which includes increased soil health, reduced cost of production and minimal soil turnover (Jat et al., 2019). It may be particularly helpful in such conditions since resources may be scarce in some regions.

The use of integrated production practices, for example, precision drilling with zero tillage or raised beds with crop rotation could make growers' operations more profitable by increasing grain yield and reducing inputs costs (Hobbs et al., 2008). To adapt climate change into wheat farming, the researchers studied the effects of the traditional and the new planting methods. These findings related to the previously mentioned points of view. Wheat was grown in three regions of Sindh: These experimental locations include Umarkot, Badin, and Sanghar; the economic efficiency and agronomic effectiveness of wheat was tested in all these sites.

METHODOLOGY

To ascertain the impacts of creative versus traditional planting strategies, an investigation was attempted on the agronomic performance and economic efficiency across three wheat-growing locations in Sindh province: Sanghar, Badin, and Umarkot. The innovative planting techniques were to be applied to twelve wheat producers. An intercrop of Ridges-Wheat-Brassica was to be carried out by four Sanghar farmers. Furthermore, the same intercrop was designated for three farmers in Badin, and the Ridges-Wheat-Brassica, Fresh Sugarcane, and Drilling-ZT intercrops were assigned to three farmers in Umarkot. The study's goal was to evaluate how these alternative seeding techniques affected wheat cultivation's productivity, economic advantages, and climate challenge. Agronomic performance will be evaluated by growth, tillering, and grain production contributing features. The economic efficiency will be examined by computing input costs, gross returns, and net income. In this complete investigation, the experiment design that follows was used.

DISTRICTS/ GROWERS	**SOWING SYSTEMS OF WHEAT SOLE AND INTERCROPS**		
SANGHAR			
F1=Mazhar Thaheem	Raised Bed	Ridges	Ridges-Intercrop Brassica
F2=Yasir Thaheem	Raised Bed	Ridges	Ridges-Intercrop Brassica
F3=Bhai Khan Laghari	Raised Bed	Ridges	Ridges-Intercrop Brassica
F4=Noor Ali Laghari	Raised Bed	Ridges	Ridges-Intercrop Brassica
BADIN			
F5=Amir Dakar	Raised Bed	Ridges	Ridges-Intercrop Brassica
F6=Habib Dakar	Raised Bed	Ridges	Ridges-Intercrop Brassica

F7=Nabeel M. Buledi	Ridges	Drilling	Drilling-ZT
UMARKOT			
F8=Rana Rameez	Raised Bed	Ridges	Drilling
F9=Farooq Ahmed	Raised Bed	Ridges	Drilling
F10=Sikandar Ali	Raised Bed	Ridges	Drilling
F11=Fateh M. Mangrio	Ridges	Ridges-intercrop Brassica	Drilling
F12=Nasir Hussain Arain	Ridges	Ridges-Sugarcane Intercrop(fresh)	Drilling-ZT, Sugarcane Intercrop(ratoon)

Split-plot layout design was employed in all the experiments with sowing techniques as the main factor and intercropping as k6 sub-factor. Each treatment was replicated three times across farmers' fields, making the individual in all three districts. The sowing was done in November 2023, with the crop cycle running until April, 2024. The innovative systems tested in each district varied; and in Sanghar, raised bed, ridges, and ridges-intercrop Brassica was compared; while in Badin, the systems include raised bed, ridges, ridges-intercrop Brassica, and drilling under zero tillage. The growers of Umarkot district were assigned to experiment raised beds, ridges, drilling, ridges-intercrop Brassica, ridges-intercrop fresh sugarcane, and drilling under zero tillage intercropped with ratoon sugarcane. These systems are expected to show differences in their impact on wheat growth, resource utilization, and profitability. Throughout the season, data were collected on post-harvest, yield were analyzed using statistical tools such as ANOVA and LSD tests to compare the performance of different treatments. In order to economic analysis, costs on mean labourers engaged for ploughing, irrigation application, fertilizer application, other interculturing operations, harvesting and threshing were assessed for the demonstration plots as well as for sample growers. Moreover, the capital costs accounted for included principal agricultural commodities such as seed fertilizer, insecticides and pesticides, use of tractor etc. The cost of these input varied actual expenditure as incurred by farm entrepreneurs.While the produce retained, valued at prices prevailing in the area, the quantity of wheat and intercrops was calculated with the per unit prices (Rs/40 kg maund) after threshing.

RESULTS

1. Crop yields

The wheat grain yield under traditional growers' practices varies between 24.66 and 33.22 maunds per acre across different farmers' fields (table 1). This variation could be attributed to differences in soil conditions, management practices, and local environmental factors. In demonstration plots, raised bed sowing consistently shows a significant increase in yield compared to growers' practices; where Mazhar Thaheem achieved a yield of 56.45 maunds per acre using raised beds, which is almost double compared to his yield of 31.33 maunds per acre under traditional practices. Similar trends are observed for other farmers, with the highest yield of 63.2 maunds per acre recorded by Rana Rameez. The ridge sowing method also results in higher yields than the growers' practices. For example, Yasir Thaheem's yield increased from 28.66 maunds per acre under growers' practices to 48.66 maunds per acre with ridge sowing. Intercropping Brassica on ridges showed diverse results; and it boosts yields in some cases, such as in Mazhar Thaheem's plot, where the yield was 42.22 maunds per acre.However, this method generally resulted in lower yields compared to raised beds or simple ridge sowing; but brassica intercropping in wheat offered considerable agronomic benefits.

The drilling technique showed promising yield results in certain fields; and Rana Rameez achieved 48.55 maunds per acre using drilling, which is higher than the yield from growers' practices and comparable to other improved methods like ridges. When all sowing methods were compared, raised bed sowing emerges as the most effective technique for increasing wheat grain yield across various fields, with yields often exceeding 60 maunds per acre. However, ridges with brassica and drilling provide alternative options, remained beneficial in some cases, do not consistently outperform the more established methods like raised beds or simple ridges. The results clearly indicated that modern sowing techniques such as raised beds and ridges significantly enhanced wheat grain yield compared to traditional growers' practices. These techniques likely contribute to better seed-soil contact, improved water management, and more efficient nutrient use, leading to higher productivity.

The yield data from demonstration plots revealed a substantial and consistent advantage of improved sowing techniques over traditional growers' practices. Across selected growers, the yields from growers' practices remain relatively low, ranging between 24.66 and 33.22 maunds per acre. The demonstration plots using raised beds, ridges, and drilling showed significant yield increases, often exceeding 50 maunds, with some plots reaching as high as 63.2 maunds per acre. These improved practices likely result in more uniform plant growth, better disease management, and enhanced grain filling, leading to higher yields.

It was further noted that drilling/zero-tillage and combinations with sugarcane, revealed major of these practices on crop productivity. Under growers' practices, the wheat yields for

Nabeel Mohyudin Buledi and Nasir Hussain Arain are 24.66 and 30.12 maunds per acre, respectively. This yield range, while typical for conventional methods, indicates room for improvement. When drilling or zero-tillage is employed, Nabeel Mohyudin Buledi achieves a modest increase to 29.55 maunds per acre. When wheat is intercropped with fresh or ratoon sugarcane using different patterns, yields showed significant variability. Nasir Hussain Arain adopted a ridge planting pattern alongside fresh sugarcane, wheat yield drops to 24.55 maunds, while sugarcane yielded a robust 668 maunds per acre.

Apparently, the wheat may suffer some competitive disadvantage in these intercropping systems; however, sugarcane not only recovered such disadvantage but significantly increased the benefit, likely due to high yields of sugarcane and optimized space and resource utilization in ridge system. On the other hand, wheat sown by drilling in ratoon sugarcane, wheat suffered from further yield loss to 22.28 maunds per acre, and sugarcane yield drops to 428 maunds per acre. However, the reduced yields in this scenario were well compensated by zero cost on sugarcane seed, and hence the treatment maximized the profit.

Table 1. Wheat and intercrop yields (mds/acre) achieved by the 12 growers in demonstration plots using various sowing techniques and farmers' practices

Grower #	Growers' practices	Raised bed	Ridges	Ridges + Wheat Brassica intercrop		Drilling	Drilling/ ZT	Ridges + Wheat S. cane (fresh) Intercrop		Drilling-ZT + Wheat S. cane (Ratoon) Intercrop	
				Wheat	Brassica			Wheat	Sugarcane	Wheat	Sugarcane
1.	31.33b	56.45 c	51.55 d	42.22 c	8.00 b	–	–	–	–	–	–
2.	28.66 c	54.66 d	48.66 e	41.33 a	6.22 c	–	–	–	–	–	–
3.	27.33 c	62.2 a	54.23 c	43.26 b	6.02 c	–	–	–	–	–	–
4.	26.25 d	61.55 b	57.88 b	38.24 d	5.89 d	–	–	–	–	–	–
5.	28.55 c	58.33 c	53.22 c	36.55 e	8.55 b	–	–	–	–	–	–
6.	30.20 b	53.44 d	46.77 e	38.2 d	9.12 a	–	–	–	–	–	–
7.	24.66 e	–	42.66 f	–	–	38.27 c	29.55	–	–	–	–
8.	33.22 a	63.2 a	59.45 a	–	–	48.55 a	–	–	–	–	–
9.	32.55 a	61.55 b	56.22 b	–	–	44.65 b	–	–	–	–	–
10.	28.33 c	57.66 c	51.44 d	–	–	47.88 a	–	–	–	–	–
11.	27.88 c	–	48.69 e	43.22 b	6.22 c	44.20 b	–	–	–	–	–
12.	30.12 b	–	44.33ef	–	–	–	–	24.55	668.00	22.28	428.00

Note: Each of the 12 growers used three sowing techniques (one acre for each sowing technique)

ECONOMIC ANALYSIS

(a) Raised bed

The total costs for cultivating wheat using the raised bed technique were almost consistent among growers, ranging from Rs 114,095 to 117,071 (table 2); and these costs included expenses for inputs such as seeds, fertilizers, labor, and equipment. The yields from raised bed cultivation were markedly higher, ranging from 53.44 to 63.2 maunds per acre in three districts (Sanghar, Badin, Umarkot). On the other hand, yields in the case of growers' practices were significantly lower, ranging between 24.66 and 33.22 maunds per acre. This variation in yield was mainly associated with the climatic variation in the districts of experiments. The profit comparison between demonstration plots using raised beds and growers' practices showed a clear advantage for the raised bed technique. Mazhar Thaheem, earned a profit of Rs 108,729 from raised bed cultivation, compared to Rs 49,145 from traditional methods; which represents a substantial increase in profitability. Bhai Khan Laghari, with the highest yield of 62.2 maunds per acre, achieved a profit of Rs 133,629 from the demonstration plot, which was significantly higher than the Rs 39,886 profit under growers' practices. On average, the profit from raised bed cultivation ranges from Rs 99,665 to 137,331 across sample growers, compared to profits from growers' practices, ranging between Rs 34,509 and Rs 54,786/acre. The raised bed method consistently yields nearly double the profit, signifying its economic lead (Fig 1).

Table 2: Economic analysis of wheat production (Rs/acre) under raised bed cultivation technique

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Yield	Income
Mazhar Thaheem	37500	12000	50149	8000	9422	117071	56.45	225800
Yasir Thaheem	37500	12000	50149	8000	9422	117071	54.66	218640
Bhai Khan Laghari	35600	12000	50149	8000	9422	115171	62.2	248800
Noor Ali Laghari	37500	12000	50149	8000	9422	117071	61.55	246200
Aleem Dakar	36500	12000	50149	8000	7446	114095	58.33	233320
Habibullah Dakar	36500	12000	50149	8000	7446	114095	53.44	213760
Rana Rameez	36500	12000	50149	8000	8820	115469	63.2	252800
Farooq Ahmed	36000	12000	50149	8000	8820	114969	61.55	246200
Sikandar Ali	36600	12000	50149	8000	8820	115569	57.66	230640
Average	**36689**	**12000**	**50149**	**8000**	**8782**	**115620**	**58.78**	**235129**

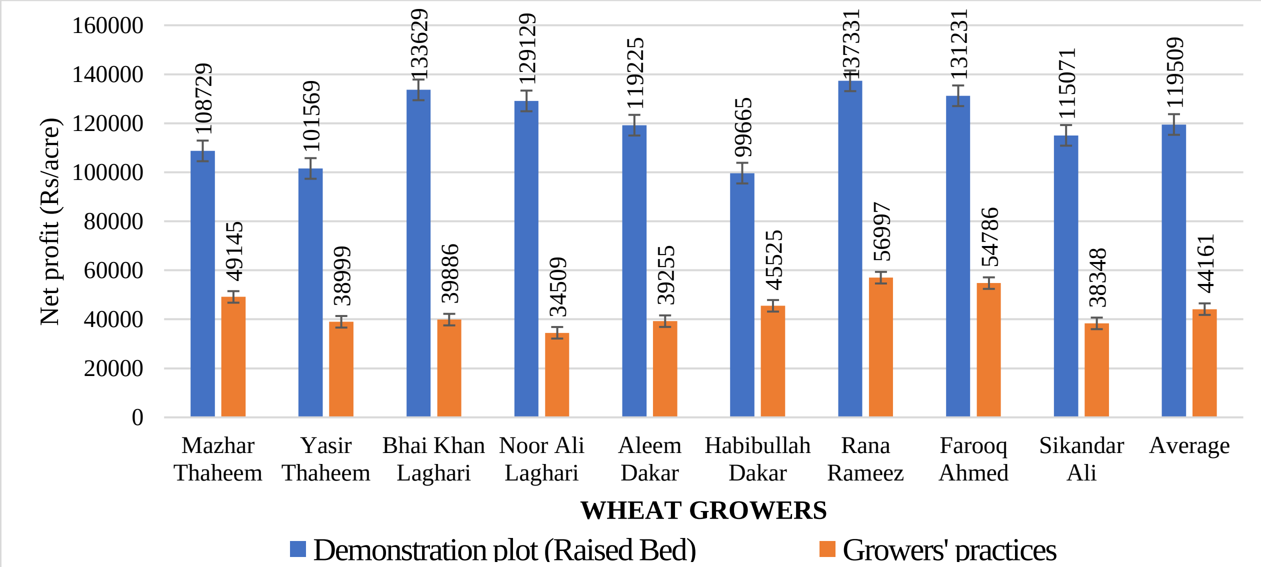

Fig 1: Net profit from raised bed wheat cultivation in Dem Plots vs Growers' Practices

(b) Ridges

The total costs for ridge cultivation among the growers range from Rs 104,763 to 117,071; and these costs are slightly variable but generally align with the costs of traditional practices (table 3). However, yields obtained from ridge cultivation range from 42.66 to 59.45 maunds per acre, showing improvement over growers' practices ranged between 24.66 to 33.22 maunds per acre. Rana Rameez achieved income of Rs 237,800 from a yield of 59.45 maunds per acre using ridge cultivation. Across sample growers, income from ridge cultivation ranges from Rs 170,640 to 237,800 illustrating financial benefits of this technique. Mazhar Thaheem's profit from ridge cultivation was Rs 89,129, compared to 49,145 from traditional methods. Similarly, Noor Ali Laghari earned Rs 114,449 from ridge cultivation, whereas his profit from growers' practices was only Rs 34,509. Even in cases lower total costs, such as for Nabeel Mohyudin Buledi, who had a cost of Rs 104,763, the profit from ridge cultivation was Rs 65,878, compared to Rs 30,726 under growers' practices (Fig 2).

Table 3: Economic analysis of wheat production (Rs/acre) under ridges cultivation technique

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Yield	Income
Mazhar Thaheem	37500	12000	50149	8000	9422	117071	51.55	206200
Yasir Thaheem	37500	12000	50149	8000	9422	117071	48.66	194640
Bhai Khan Laghari	35600	12000	50149	8000	9422	115171	54.23	216920
Noor Ali Laghari	37500	12000	50149	8000	9422	117071	57.88	231520

Aleem Dakar	36500	12000	50149	8000	7446	114095	53.22	212880
Habibullah Dakar	36500	12000	50149	8000	7446	114095	46.77	187080
Nabeel M. Buledi	27167	12000	50149	8000	7446	104763	42.66	170640
Rana Rameez	36500	12000	50149	8000	8820	115469	59.45	237800
Farooq Ahmed	36000	12000	50149	8000	8820	114969	56.22	224880
Sikandar Ali	36600	12000	50149	8000	8820	115569	51.44	205760
Fateh M. Mangrio	35700	12000	50149	8000	8820	114669	48.69	194760
Nasir Hussain Arain	27667	12000	50149	8000	8820	106636	44.33	177320
Average	**35061**	**12000**	**50149**	**8000**	**8677**	**113887**	**51.26**	**205033**

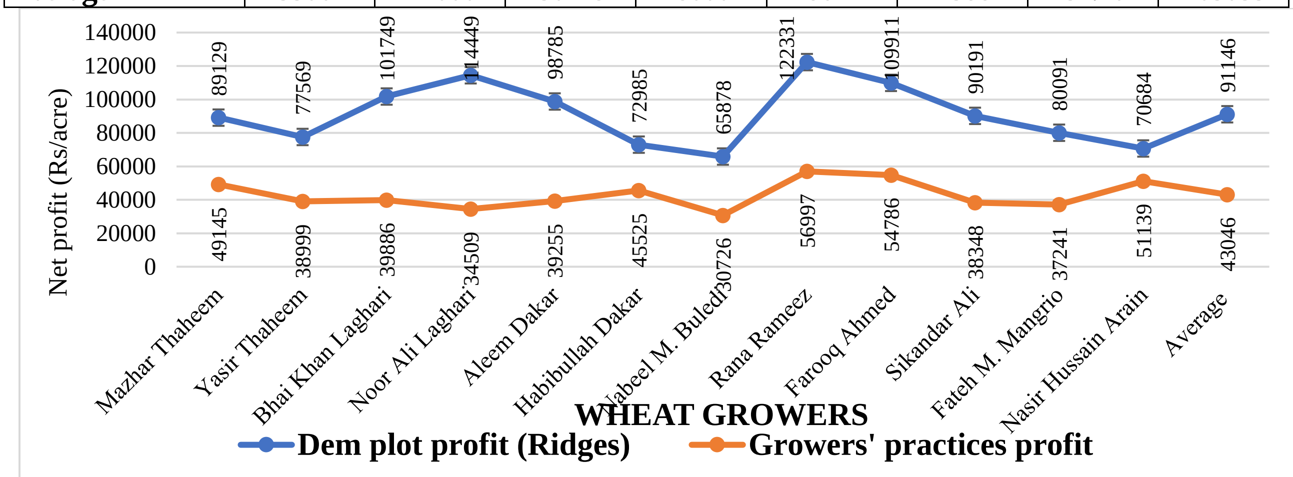

Fig 2: Net profit from ridges wheat cultivation in Dem Plots vs Growers' Practices

(c) Drilling

Total costs associated with drilling cultivation varied marginally among growers, ranging from Rs 104,762 to Rs 115,569 per acre (table 4); and were consistent with those of traditional practices, indicating that in drilling method costs did not change greatly. The yields achieved through drilling ranged from 38 to 49 maunds per acre, higher than growers' practices ranged between 24.66 and 33.22 maunds per acre. From drilling Rana Rameez achieved an income of Rs 194,200 from a yield of 49 maunds per acre; which was higher than income under traditional practices, while input costs were almost similar. The income from drilling across sample growers ranged from Rs 153,080 to 194,200 indicated positive impact of this method on financial benefit. The profit of Nabeel Mohyudin Buledi from drilling cultivation was Rs 48,318, compared to 30,726 from traditional methods. Likewise, Sikandar Ali earns Rs 75,951 from drilling based demonstration plot; whereas his profit from growers' practices was only Rs 38,348. However, from drilling the profit of Farooq Ahmed was Rs 63,631, compared to Rs 54,786 from traditional methods (Fig 3).

Table 4: Economic analysis of wheat production (Rs/acre) under Drilling cultivation technique

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Yield	Income
Nabeel M.Buledi	27167	12000	50149	8000	7446	104762	38	153080
Rana Rameez	36500	12000	50149	8000	8820	115469	49	194200
Farooq Ahmed	36000	12000	50149	8000	8820	114969	45	178600
Sikandar Ali	36600	12000	50149	8000	8820	115569	48	191520
Fateh M. Mangrio	35700	12000	50149	8000	8820	114669	44	176800
Average	**34393**	**12000**	**50149**	**8000**	**8545**	**113088**	**45**	**178840**

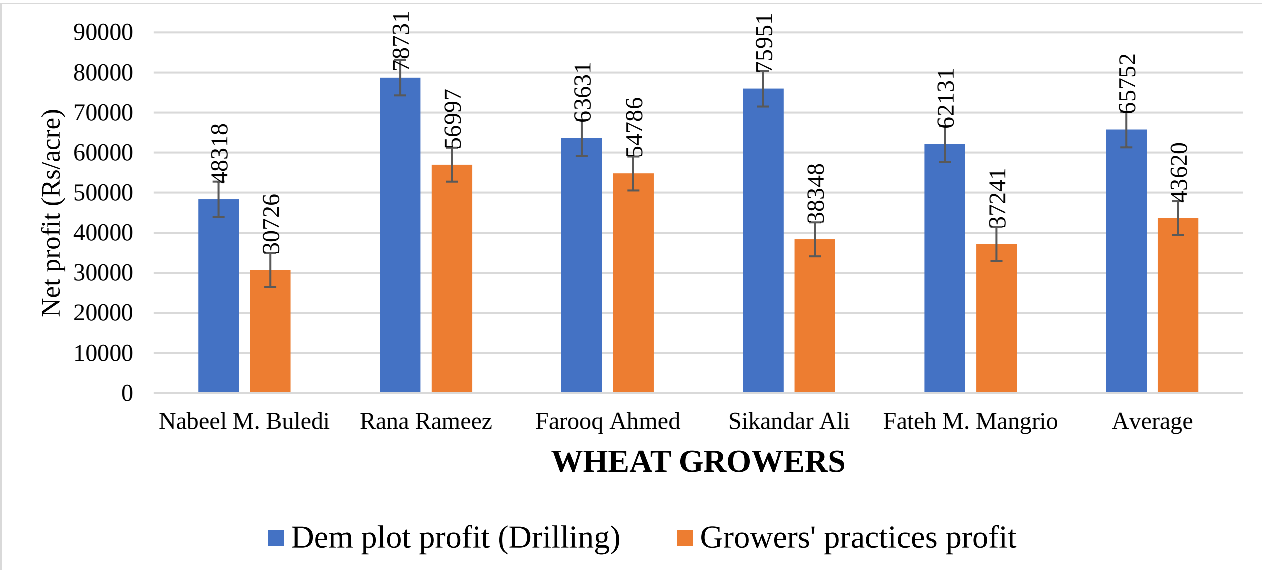

Fig 3: Net profit from drilling wheat cultivation in Dem Plots vs Growers' Practices

(d) Ridges + intercropping brassica sowing pattern

The economic analysis of the ridges + intercropping brassica sowing pattern for wheat revealed how this integrated approach impacts yield, income, and profitability compared to growers' practices (table 5). The total costs associated with this integrated sowing pattern ranged from Rs 114,095 to 117,071 per acre showing similarity to demonstration plots and traditional practices. The wheat yields under this method were rather lower, ranging from 36.55 to 43.26 maunds per acre, compared to other techniques like raised beds or drilling. However, the intercropping brassica added an extra yield component, with Brassica yields ranging from 5.89 to 9.12 maunds per acre.The income from this sowing pattern is driven by both the wheat and the brassica intercrop; and Mazhar Thaheem achieved a combined income from 42.22 maunds of wheat and 8.00 maunds of brassica was Rs 216,880; which was higher than wheat alone under traditional practices. Across sample growers, total income ranged from Rs 188,300 to 216,880, showing a clear financial benefit from integrating brassica with wheat. The profit from intercropping based demonstration plot showed significant improvement over growers' practices; and Mazhar Thaheem earned profit from demonstration plot was Rs 99,809, compared to Rs 49,145 under growers' practices. This significant increase was consistent across sample farmers from demonstration plots, where profits from intercropping system ranged from Rs 71,229 to 99,809; while profits from farmers' practices were considerably lower, between Rs 34,509 and 49,145. From demonstration plots, the growers (Fateh M. Mangrio) earned profit of Rs 95,531 from the intercropping method, compared to Rs 37,241 profit from traditional methods. The ridges + intercropping brassica sowing pattern offers a viable and profitable alternative to traditional wheat cultivation (Fig 4).

Table 5: Economic analysis of wheat production (Rs/acre) under Ridges + intercropping brassica cultivation technique

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Wheat Yield	Intercrop Yield	Income
Mazhar Thaheem	37500	12000	50149	8000	9422	117071	42.22	8.00	216880
Yasir Thaheem	37500	12000	50149	8000	9422	117071	41.33	6.22	202640
Bhai Khan Laghari	35600	12000	50149	8000	9422	115171	43.26	6.02	209160
Noor Ali Laghari	37500	12000	50149	8000	9422	117071	38.24	5.89	188300
Aleem Dakar	36500	12000	50149	8000	7446	114095	36.55	8.55	197500
Habibullah Dakar	36500	12000	50149	8000	7446	114095	38.2	9.12	207520
Fateh M. Mangrio	35700	12000	50149	8000	8820	114669	43.22	6.22	210200

Average	**36686**	**12000**	**50149**	**8000**	**8771**	**115606**	**40.43**	**7.15**	**204600**

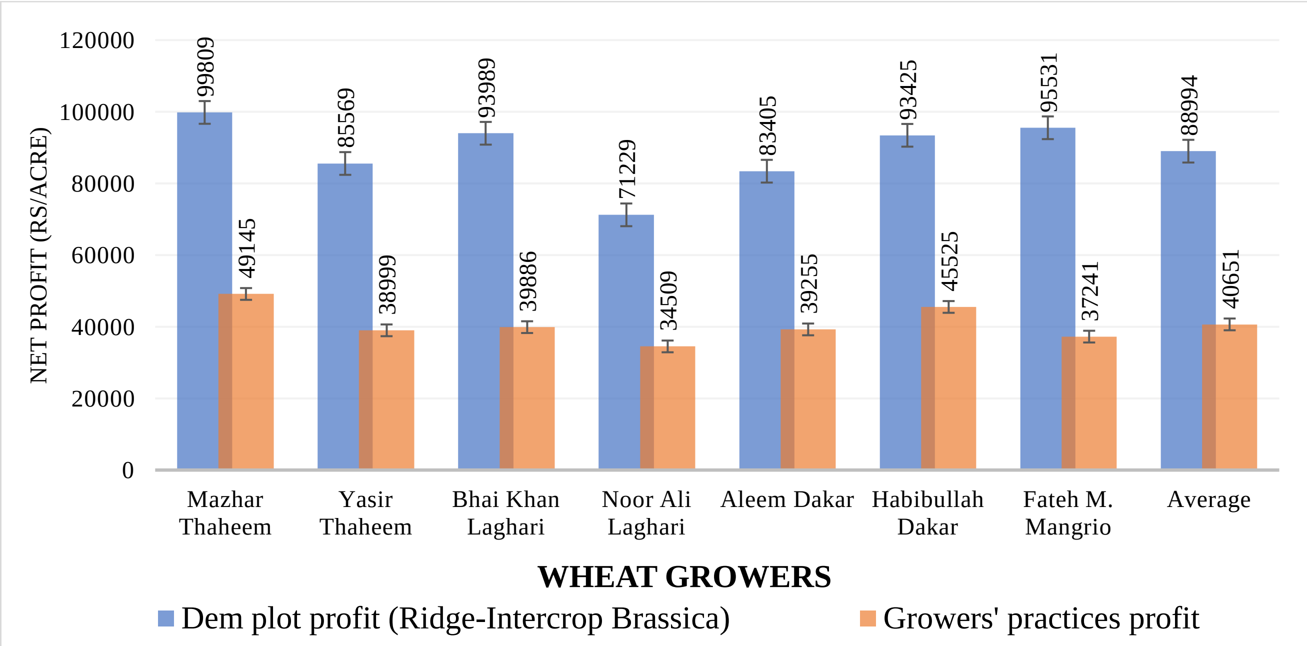

Fig 4: Net profit from ridges wheat-intercropped with brassica in Dem Plots vs Growers' Practices

(e) Drilling + Zero Tillage

The demonstration plots based on drilling + zero tillage method, the total costs incurred by Nabeel Mohyudin Buledi were Rs 81,059 per acre; which were significantly lesser than growers' practices as well as other modern wheat cultivation methods (table 6); where costs exceed Rs 100,000 per acre. The lower costs were mainly associated with reduced or zero land preparation costs in zero tillage. The yield achieved under this method was 29.55 maunds per acre; compared to modest yields of other modern techniques like raised bed or ridge sowing, slightly higher than the yields obtained under growers' practices ranged between 24.66 and 33.22 maunds per acre. The income from drilling + zero tillage method was Rs 118,200 per acre, which was realized from the yield of 29.55 maunds per acre. The profit from the demonstration plot (wheat) using drilling + zero tillage method was Rs 37,141 as compared to lower profit from growers' practices Rs 30,726. The drilling + zero tillage method present a cost-effective alternative to both traditional and other modern cultivation techniques. The significantly lower total costs are a key advantage of this method, allowing farmers to achieve reasonable yields and income without incurring high production expenses.

Table 6: Economic analysis of wheat production (Rs/acre) under Drilling + 0-tillage sowing technique

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Wheat Yield	Income	Dem plot profit	Growers' profit
Nabeel MohyudinBuledi	5000	12000	50149	8000	5910	81059	29.55	118200	37141	30726
Average	**5000**	**12000**	**50149**	**8000**	**5910**	**81059**	**29.55**	**118200**	**37141**	**30726**

(f) Ridge-Intercropping wheat with fresh planted sugarcane

The economic analysis of demonstration plot comprised of ridges-wheat intercropped with freshly planted sugarcane offered valuable understanding in relation to costs, yields, and profitability of demonstration plots compared to growers' practices (table 7). The total costs for this demonstration plot (intercropping system)at the fields of Nasir Hussain Arain, were Rs 211,467 per acre; which was significantly higher than the costs associated with traditional wheat cultivation, ranged around Rs 100,000 to 120,000 per acre. The elevated costs in this system are likely due to the combined expenses of cultivating both wheat and sugarcane, which include higher inputs for seeds, fertilizers, and irrigation, as well as labor and machinery costs associated with managing two crops simultaneously. In terms of yield, the wheat component of the intercropping system yields 24.55 maunds per acre, which is slightly below the yields for wheat under growers' practices. However, the system also produces a substantial sugarcane yield of 668 maunds per acre, which significantly enhanced the overall productivity of the land. The combined income from the wheat and sugarcane yields under this intercropping system was Rs 378,760 per acre, which is considerable income, primarily driven by the high yield of sugarcane. The profit from the demonstration plot using the ridges intercropping system is Rs 167,293 per acre, a substantial figure when compared to the profit of Rs 51,139 per acre from traditional wheat cultivation. This system's high profitability could encourage more farmers to adopt intercropping practices, especially in regions where both wheat and sugarcane are integral to the agricultural economy.

(g) Drilling + Wheat Intercropping in ratoon sugarcane

The total costs associated with demonstration plot (Drilling + wheat-ratoon sugarcane intercropping) conducted by Nasir Hussain Arain (Grower) were Rs 155,856 per acre; which were higher than wheat alone cultivated by the growers and their costs ranged from Rs 100,000 to 120,000 per acre (table 7); and the increased costs are due to the dual-crop system, which requires additional inputs, labor, and management for both the wheat and ratoon sugarcane. The yield from this intercropping system includes 22.28 maunds of wheat and 428 maunds of sugarcane per acre; while, the wheat yield was lower than in monoculture system, this deficit was well compensated by sugarcane yields, contributing to high overall productivity and profitability of the system. The combined income from this intercropping system was Rs 268,880 per acre; which was derived from both the wheat and sugarcane yields, with the ratoon sugarcane contributing significantly to the total revenue. The profit from demonstration plot was Rs 113,024 as compared to Rs 51,139 per acre profit from growers' wheat cultivation practices. The higher profit is primarily due to the added revenue from the sugarcane. The system's ability to generate higher income and profit, despite the increased costs, makes it a viable and attractive option for farmers seeking to maximize their returns per acre while maintaining crop diversity and resilience.

Table 7: Economic analysis of wheat production (Rs/acre) under Ridge intercropping wheat with fresh sugarcane plantation

Name of grower	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Wheat Yield	Intercrop Yield (mds)	Income	Dem plot profit	Growers' profit
Ridges-Wheat-fresh sugarcane intercropping system											
Nasir Hussain Arain	45000	42000	78157	41400	4910	211467	24.55	668	378760	167293	51139
Drilling-Wheat-ratoon sugarcane intercropping system											
Same	29500	12000	88500	21400	4456	155856	22.28	428.00	268880	113024	51139

(h) Economic Efficiency of different sowing techniques

Economic analysis of various wheat sowing techniques, including those with intercrops, revealed diverse variances in cost, income and profitability. The raised bed incurred a total cost of Rs 115,620 and resulted in a substantial income of Rs 235,129 per acre. Subsequently, the profit from demonstration plots was significant at Rs 119,509, substantially higher than Rs 44,161 per acre profit under traditional practices.

With a total cost of Rs 113,088, drilling method offered a balance between cost and income and the income was Rs 178,840, leading to a demonstration plot profit of Rs 65,752 per acre. This profit was notably higher than the Rs 43,620 per acre profit from growers' practices. The demonstration plot (ridge sowing) has a total cost of Rs 113,887, generating Rs 205,033 income; while the profit remained Rs 91,146, which was greater than Rs 43,046 per acre from traditional practices. Intercropping brassica in wheat on ridges increased the total cost to Rs 115,606, generating Rs 204,600 income with a demonstration plot profit of Rs 88,994; which is significantly greater than the profit of Rs 40,651 per acre under growers' practices. This method was cost-effective, with a total cost of Rs 81,059, generating income Rs 118,200 with a demonstration plot profit of Rs 37,141 per acre.

In case of demonstration comprised of wheat-sugarcane fresh crop under ridges system, highest costs were associated, totaling Rs 211,467, generating highest income of Rs 378,760, resulting in a demonstration plot profit of Rs 167,293 against growers' practices profit of Rs 51,139 per acre. With a total cost of Rs 155,856, drilling + 0-Tillage (wheat-sugarcane ratoon intercropping) offered a combined income of Rs 268,880 earned a net profit of Rs 113,024 per acre. Methods with intercrops showedgreater profitability due to increased income, though with higher costs.

The economic efficiency of Drilling + 0-Tillage method remained most cost-effective with lowest total costs of Rs 81,059 per acre, but its income and profit margins were relatively lower than other techniques. Raised Bed and Ridges methods, while involving higher costs (Rs 115,620 and 113,887 per acre respectively), offered significantly greater income and profit, particularly in demonstration plots, due to enhanced yield and improved management practices.

The Ridges + Intercrop Wheat-Sugarcane Plant Crop and wheat drilling + 0-Tillage, Intercrop Wheat-Sugarcane Ratoon methods, despite their higher costs (Rs 211,467 and 155,856 per acre respectively), provided the highest income and profit potential due to the dual crop system, though they require careful management to balance the increased costs.

Table 9: Economic analysis of wheat crop under sowing patterns/techniques (Rs/acre)

Sowing technique	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Income

Raised bed	36689	12000	50149	8000	8782	115620	235129
Drilling	34393	12000	50149	8000	8545	113088	178840
Ridges	35061	12000	50149	8000	8677	113887	205033
Ridges + Wheat Brassica intercrop	36686	12000	50149	8000	8771	115606	204600
Drilling + ZT	5000	12000	50149	8000	5910	81059	118200
Ridges + Wheat-S. cane plant crop	45000	42000	78157	41400	4910	211467	378760
Drilling-ZT+Wheat-S. cane Ratoon Intercrop	29500	12000	88500	21400	4456	155856	268880

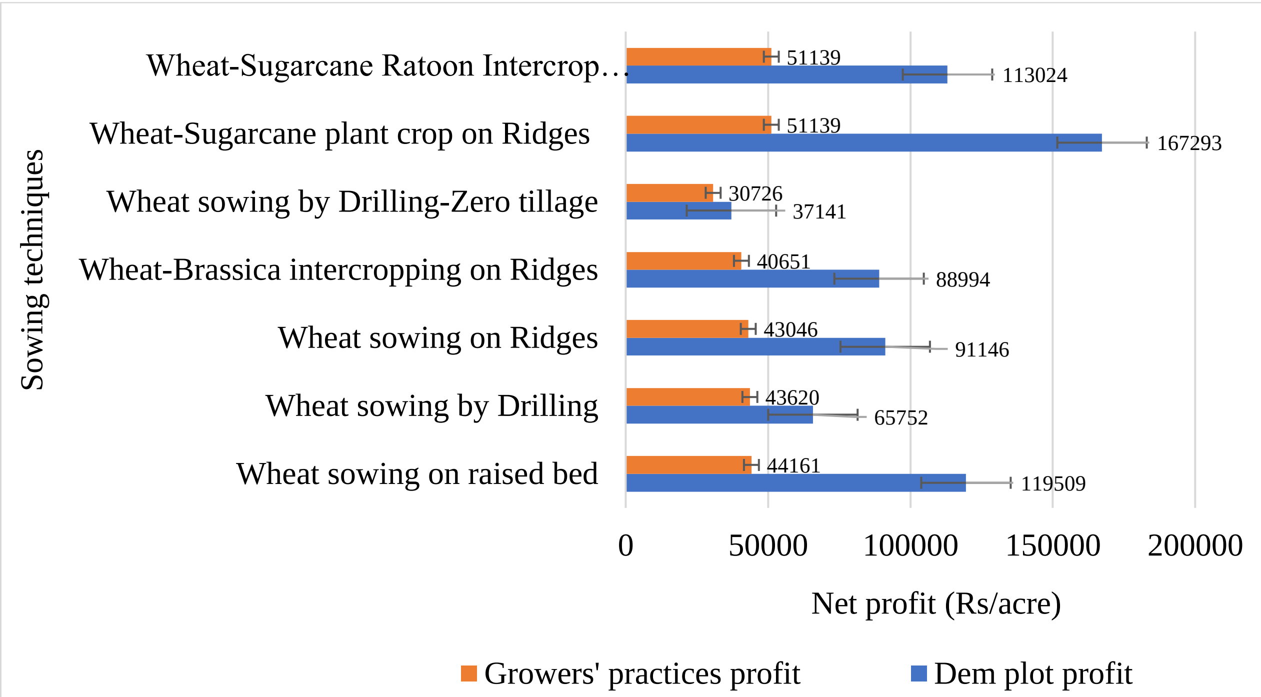

Fig 5: Effect of different sowing techniques of wheat on the net profit (Rs/acre)

Table 10: Economic analysis of wheat cultivation under grower's practices

Grower's names	Land Prep	Seed	Fertilizer	Harvesting	Threshing	Total costs	Yield	Income	Growers' Profit
Mazhar Thaheem	25125	11000	25784	8000	6266	76175	31.33	125320	49145
Yasir Thaheem	25125	11000	25784	8000	5732	75641	28.66	114640	38999
Bhai Khan Laghari	23852	11000	21116	8000	5466	69434	27.33	109320	39886
Noor Ali Laghari	25125	11000	21116	8000	5250	70491	26.25	105000	34509
Aleem Dakar	24455	11000	25780	8000	5710	74945	28.55	114200	39255
Habibullah Dakar	24455	11000	25780	8000	6040	75275	30.20	120800	45525
Nabeel M. Buledi	18202	11000	25780	8000	4932	67914	24.66	98640	30726
Rana Rameez	24455	11000	25784	8000	6644	75883	33.22	132880	56997
Farooq Ahmed	24120	11000	25784	8000	6510	75414	32.55	130200	54786
Sikandar Ali	24522	11000	25784	8000	5666	74972	28.33	113320	38348

Fateh M. Mangrio	23919	11000	25784	8000	5576	74279	27.88	111520	37241
Nasir H. Arain	18537	11000	25780	8000	6024	69341	30.12	120480	51139
Average	**23491**	**11000**	**25005**	**8000**	**5818**	**73314**	**29.09**	**116360**	**43046**

TRAINING OF GROWERS

A comprehensive training program was conducted to equip 600 wheat growers at 12 demonstration plots across Sanghar, Badin, and Umarkot districts with the knowledge and skills necessary to integrate climate-resilient agricultural practices into their wheat cultivation. The training sessions, which were held at four demonstration plots in Sanghar, three in Badin, and five in Umarkot, focused on innovative sowing patterns as a key strategy to enhance crop resilience against climate-related challenges. Each demonstration plot hosted approximately 50 farmers, providing a platform for direct interaction and hands-on learning. The training program covered a wide range of topics, including the selection of appropriate wheat varieties, optimal sowing dates, sowing techniques/methods, zero tillage and intercropping, focusing as climate-smart agricultural techniques. By empowering farmers with this knowledge, the program aimed to contribute to the development of more resilient and sustainable wheat production systems in the region, enhance farmers' net profit and minimizing the risk of crop failure (table 11).

Table 11: Trainings imparted on climate resilience agricultural practices with reference to wheat cultivation patterns

Demonstration plot	Location/Farmers' field	No. of growers trained
Sanghar-1	Mazhar Thaheem	50
Sanghar-2	Yasir Thaheem	50
Sanghar-3	Bhai Khan Laghari	50
Sanghar-4	Noor Ali Laghari	50
Badin-1	Aleem Dakar	50
Badin-2	Habibullah Dakar	50
Badin-3	Nabeel M. Buledi	50
Umarkot-1	Rana Rameez	50
Umarkot-2	Farooq Ahmed	50
Umarkot-3	Sikandar Ali	50
Umarkot-4	Fateh M. Mangrio	50
Umarkot-5	Nasir H. Arain	50
	Total	**600**

DISCUSSION

The economic analysis of various wheat sowing techniques underscores notable differences in cost structures, income generation, and profitability, particularly when comparing conventional practices with innovative approaches such as raised bed planting, drilling, ridge sowing, and intercropping. Raised bed technology yields 235,129 rupees per acre, which makes it amazing even if it only costs 115,620 rupees. As a result, there is a significant profit of 119,509 rupees per acre—much more than the profit of 44,161 rupees per acre that could be made using more traditional techniques. Research indicates the use of a raised bed technique improves root development, nutrient absorption, and water consumption efficiency. Jat et al. (2012) and Ahmad et al. (2019) suggest that when all of these elements work together, yields improve, which ultimately raises profitability. Jat et al. (2021) found in their study that this technique reduces the amount of weed pressure, which reduces the need for pesticides and the overall cost of operations.

The drilling method also showed an impressive economic performance, yielding a profit of Rs 65,752 per acre. The drilling technology produced income of Rs 178,840, while its total cost per acre was Rs 113,088. This methodology identified a significant advancement over the previous planting methods, which only provided Rs 43,620 per acre. To increase wheat yields, drilling is essential for both precise seed planting and improved population management of plants (Sattar et al., 2020). Plant population control is improved by drilling. In order to balance their expenses for operations and income, farmers may find this method of operation exciting, according to Singh and Chaudhary (2017). This method can reduce the cost of drilling-related inputs and increase the rate of natural resource utilization. Another method that has proven effective is the planting of ridges. Against an investment of Rs 113,887 per acre, it produced a profits of Rs 91,146 per acre, a significant improvement over the profit of Rs 43,046 connected to standard methods. This method works most effectively in areas with limited access to water because its use improves both the aeration of roots and maintaining of soil moisture (Sharma et al., 2021). Ridge planting is particularly important in high-yielding wheat varieties because it reduces lodging risk (Lal et al., 2020). Ridge planting becomes economically viable due to this decrease in the risk associated with lodging.

When brassica was interplanted with wheat on ridges, the total cost increased to Rs 115,606 per acre. However, the method still produced an income of Rs 204,600, yielding a profit of Rs 88,994 per acre, which was further more than the return of Rs 40,651 per acre from traditional approaches. Intercropping is widely acknowledged to have the potential to maximize the use of nutrients, water, and light (Lithourgidis et al., 2011). Brassica's short growing season promotes soil health by supplying more organic matter, and harvesting it results in more money (Matusso et al., 2014). According to Olsen et al. (2012), intercropping can increase its cost-effectiveness by lowering the prevalence of diseases and pests. In the wheat-sugarcane intercropping scenario, the ridges system for fresh sugarcane incurred the most costs per acre at Rs 211,467, but it also yielded the highest return at Rs 378,760 per acre. As a result, profit per acre was Rs 167,293. Sugarcane high value makes it possible for farmers to grow two crops at once, increasing the amount of land they can use efficiently (Singh & Rana, 2016). According to Pandey et al. (2014), the peaceful cohabitation of sugarcane and wheat is contingent upon the careful management of this system, especially with respect to the distribution of water and nutrients. Due to the fact that the bigger initial investment is more than paid for by the future profits, the economic benefits of this dual-crop system become even more obvious in areas where sugarcane is in high demand.

The more economical selection was taken through the use of wheat-sugarcane ratoon intercropping with drilling and zero-tillage technology. The whole amount produced was 268,880 rupees, while the total amount spent was 155,856 rupees. There was a profit of 113,024 rupees per acre. As to the 2020 research conducted by Gathala et al., the zero-tillage method is widely recognized for its ability to save resources like fuel and labour costs, all the while maintaining the soil's health and moisture content. According to Hobbs et al. (2008) and Erenstein et al. (2012), farmers looking for a way to reduce production costs without sacrificing profitability should give this strategy some thought. Long-term benefits include improved water absorption and an increase in the amount of organic matter in the soil. According to Lal (2015), in areas where erosion is a major problem, zero-tillage farming may help protect the health of the soil structure and stop its loss.

At Rs 81,059 per acre, the zero-tillage and drilling methods proved to be the most economical among the choices that were evaluated. The profits per acre of Rs 37,141 and profits of Rs 118,200 were less than those of labour-intensive techniques like raised beds or ridge sowing. Several crops were grown using these methods. Hobbs and Govaerts (2010) suggest that among conservation agriculture, zero-tillage agriculture is unique due to its ability to improve carbon absorption, reduce emission of greenhouse gases, and improve crop resistance to the effects of climate change. This is but one of conservation agriculture's many positive environmental effects.

Zero-tillage farming may not be highly profitable right now, but it helps promote sustainability in the future, and is beneficial to farmers with little resources or those who work in environmentally sensitive regions (Pretty et al., 2011).

Both the ridge sowing method and the raised bed method had more potential yield, which made them more profitable. This is a result of the improved soil management, more effective use of water, and decreased threat from pests found in raised bed and ridge sowing techniques. Jat et al. (2021) stated that these strategies work most effectively in environments in which crop yields are high and farmers have the resources to increase the amount of material they apply to their crops. However, smaller farmers or those facing difficult agricultural conditions may find them more challenging due to the increased input costs (Baudron et al., 2019). For this reason, even if these techniques have significant financial benefits, they must be customized to each farmer's personal situation. An economic review of various wheat sowing techniques shows a wide range of profitability; ridge and raised bed sowing give greater profits because of the opportunity for higher yields.

Intercropping systems, like wheat-Brassica and wheat-sugarcane, improve profitability even more by maximum resource use and varying sources of income. To fully realize their potential, these strategies do, however, also come with higher costs and demand careful management. Even though it has a smaller initial return on investment, zero-tillage is a low-cost, long-term sustainable method to maintain environmental sustainability and increase soil health. In the end, the farmer's resources, the agro ecological the conditions and the long-term sustainability objectives will determine the planting methods.

Conclusions

In contrast, the demonstration plots using techniques such as raised beds, ridges, and drilling showed significant yield increases, often exceeding 50 maunds/acre, with some plots reaching as high as 63.2 maunds/acre. Raised beds, such as, improve root aeration and reduce water logging, while ridge sowing ensures better drainage and moisture retention. However, despite the clear superiority of these techniques over growers' practices, factors like cost, labor requirements, and farmer familiarity may impact their practical implementation. Results on wheat production from various planting combinations (such as zero-tillage, drilling, and sugarcane) and farmer techniques shed important light on the ways in which these methods affect crop productivity. There was a discrepancy between the anticipated yield and the yield achieved through standard procedures. Drilling and zero-tillage combined with even little tillage changes can improve soil structure, improve moisture retention, and increase wheat production. These figures do a good job of illustrating the trade-offs involved with mixed cropping systems.

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