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Socio-economic advantages and climate adaptation in sustainable vs. conventional cotton: evidence from Pakistan

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Two groups of cotton growers participated in this study; the first, referred as "conventional cotton producers" (CCPs), continues to use traditional techniques. The second group, known as sustainable cotton producers (SCPs), adheres to practices that are socially acceptable, economically feasible, and environment friendly. This study was designed to undertake a thorough socio-economic analysis of CCP and SCP in terms of cost of production, yield, and adaptations for climate change. The data were collected from a total of 275 farming households (138 SCPs and 137 CCPs) from two districts, namely, Bahawalpur and Rajanpur, Punjab, Pakistan. The data were analyzed using the benefit–cost ratio (BCR), paired sampled *t*-test, and log–log regression model in SPSS. The results of the study revealed that the cost of production for SCP was significantly less than CCP and the value of BCR for SCP is higher than CCP. The results of the study also revealed that the land preparation costs, irrigation costs, and fertilizer and pesticide costs decrease the cotton yield of CCP, while land area owned and picking costs showed no significant influence on the yield of CCP. On the other hand, all cost items except fertilizer cost have a positive impact on CCP's cotton yield. The results also indicated that SCP farmers adopted more of adaptation practices for climate change than CCP. This study concluded that SCP has significant advantages over CCP. Therefore, it is recommended that the government should prioritize incentives for SCP adoption to enhance yield and environmental sustainability in cotton farming.

KEYWORDS

better cotton, environment, yield, cost of production, benefit–cost ratio

1 Introduction

Cotton is a substantial kharif crop that is grown in more than 100 countries across the globe. It plays a vital role in job creation and supports the livelihoods of millions of people. In addition, it serves as a crucial raw material for industries in the agricultural sector (Hussain et al., 2007). Thus, it is the biggest natural fiber produced and sold, with an annual economic effect of over $600 billion globally (Khan et al., 2020). The cotton business is comprised of the cotton industry, which is industrialized in approximately 150 nations and offers a means of subsistence for roughly 100 million families; it employs 250 million people globally, including 7% of developing country workers (Ashraf et al., 2024). The top ten cotton-producing nations in the world include India, China, the United States, Pakistan, Brazil, Australia, Uzbekistan, Turkey, Turkmenistan, and Burkina Faso. These nations are responsible for producing more than 80% of the world's cotton due to their favorable temperature ranging from 11°C to 40°C (Shahzadi et al., 2023). Cotton production is expected to rise by 1.6% per year, from 126.5 million bales in 2022–23 to 141.3 million in 2031–32 (Ashraf et al., 2024).

The growth and yield of cotton are experiencing fluctuations and declines worldwide due to the changing climatic conditions. The temperature continues to increase, exacerbating the challenges faced by cotton production due to droughts, salinity, and greenhouse gas emissions (Nadeem et al., 2023; Sultana et al., 2023). This, in turn, affects the adaptations required for successful cotton cultivation (Mai and Liu, 2023). Extreme climatic conditions decrease yield at greater risk in regions that are already struggling with climate change (Noman and Azhar, 2023; Shi et al., 2021), such as Pakistan, a significant contributor to global cotton production, ranked as the fifth-largest producer (Ashraf et al., 2024). Its contribution amounts to 5% of the total global production. In Pakistan, cotton holds a significant position as the most important cash crop and plays a crucial role in Pakistan's economy, especially in its agro-based industry, which employs approximately 50% of the industrial workforce (Abbas and Waheed, 2017). Approximately 1.7 million farmers across Pakistan rely on cotton cultivation to support their livelihoods cotton growers (USDA Foreign Agriculture Services, 2019; Shar et al., 2021; Shuli et al., 2018), but unfortunately, Pakistan experiences its highest annual temperature during the flowering and boll-forming stages. During 2022–23, the cotton crop is drastically damaged due to the climatic changes. Cotton production went down by 41.0% (4.910 million bales from 8.329 million bales the previous year) despite an increase in sown area (2,144 thousand hectares compared to 1,937 thousand hectares) (Government of Pakistan, 2023). This decline was attributed to the worst-hit flood and insect pests, particularly pink bollworm, whitefly, and thrips. In addition, with the changing environment, there is an increase in the presence of pathogens and insect pests, which decrease the yield and increase the use of pesticides (Ashraf et al., 2024).

Cotton farming contributes 6% of the world's pesticide consumption and 16% of insecticide (EJF, 2024). It is the third most water-consuming crop, with 67% of its output coming from unsustainable water use (Mekonnen and Hoekstra, 2020). Similarly, seed, fertilizer, and other input costs are lowering the profits of cotton growers and making cotton production unsustainable, but the injudicious use of inputs and orthodox approaches to cultivation (Zafar et al., 2024b; Zulfiqar et al., 2017) have increased the cost of production and decreased cotton yield, consequently deteriorating the earnings of cotton growers. Many studies revealed that conventional cotton producers incur high costs of production and have low resource use efficiency (Watto and Mugera, 2015; Zulfiqar et al., 2017; Rashidov and Shermatov, 2023).

Apart from the climatic issues, farmers' socio-economic characteristics also have a great effect on the yield of cotton (Ahmad et al., 2021; Hashmi et al., 2016). For example, the size of the farm had a significant impact on the production of the cotton crop. Based on the USDA's findings from 2019, a significant portion of farmers, approximately 81%, fall into the category of small landholders in Pakistan. On average, these farmers possess less than 5.7 hectares of land (Nawaz et al., 2023). The report indicates that the more prominent farmers in Pakistan possess a significant level of influence and enjoy convenient access to resources and modern technology. However, small farmers encountered difficulties in accessing essential services and resources, which were also scarce in availability (Kousar et al., 2017). It is worth noting that farmers' decisions were influenced by factors such as access to resources, extension services (Dabiah et al., 2023), availability of inputs, government support, and affordability. Consequently, the small farmers faced challenges in making important decisions that would have improved cotton productivity. The insufficient availability of essential information, and high costs of inputs such as pesticides, soil reclamation materials, and organic manures, coupled with a limited understanding of technical aspects, exacerbated the difficulties and hurt cotton production (Gohil et al., 2016). Various challenges, such as financial limitations, credit obstacles, limited access to advisory services, and a lack of formal education, have been recognized as factors that impede cotton yield (Wei et al., 2020).

To meet above mentioned challenges, a prominent initiative working on sustainable cotton production practices in Pakistan and all over the world is the Better Cotton Initiative (BCI), which focuses social, economic, and environmental sustainability of cotton (ICAC, 2011). It involves multi-stakeholders and ensures sustainable cotton as a mainstream commodity, and fortunately, it is growing proficiently in Pakistan. This study considers BCI cotton producers as sustainable cotton producers (SCPs) and farmers who were not registered with BCI as conventional cotton producers (CCPs). Sustainability efforts in cotton production have made progress, but there is still a gap between firms prioritizing sustainability and those not, influencing environmental and ethical issues (Zhao and McBee-Black, 2022). Hence, the main objective of the study was to investigate the basic differences in production costs, yields, factors influencing the output of BCI and conventional farmers, and the adoption of adaptation practices by farmers to ensure the sustainability of cotton production and the environment. This research has important implications for scholars, decision-makers, and the business sector, providing valuable insights into revitalizing sustainable cotton production in the core cotton region.

2 Materials and methods

2.1 Study area and sampling technique

The Punjab province of Pakistan produces 80% of the total cotton produced in the country, followed by the Sindh province (Zulfiqar et al., 2017). This study was conducted in the Punjab province using a multistage sampling technique. The inclusion criteria for the district were (a) it must be one of the top cotton producer districts of Punjab and (b) have SCP and CCP farmers. Therefore, in the first stage, based on criteria, Bahawalpur and Rajanpur were selected purposively as these districts are among the top cotton producers and had SCP and CCP farmers. Bahawalpur is the most suitable area for cotton in terms of climate (max 40°C and min 26°C), soil (loam, medium clay, and sandy loam), and water (500–800 mm) (Ahmad and Hasanuzzaman, 2020), whereas Rajanpur is an economically most suitable district with maximum returns of 13,487 Rs/hectare (Ahmad and Hasanuzzaman, 2020). In the second stage, one sub-district (Ahmadpur East) from District Bahawalpur and one sub-district (Rajanpur tehsil) were randomly chosen from District Rajanpur.

The sample size was determined using the formula developed by Yamane (1967).

$$n = \frac{N}{\left(1 + Ne^2\right)}$$

where n is the sample size, N is the total number of farming households in the study area, and e is the precision which was set at 5%. By using the formula mentioned above, the sample size was calculated based on the total number of cotton households in each sub-district as a population. The sample size calculated for Ahmadpur East and Rajanpur was 188 and 87, respectively. The overall sample size was determined to be 275 after combining the sample sizes of two sub-districts.

In the third stage, a group of respondents who had been registered with BCI for the past 3 years were selected as SCP, while another group of farmers who had not been registered with BCI for the past 3 years were selected as CCP farmers using proportionate sampling technique from Ahmadpur East (94 SCPs and 94 CCPs) and Rajanpur (44 SCPs and 43 CCPs) (see Table 1).

2.2 Analytical approach

2.2.1 Benefit–cost ratio

A financial indicator called the benefit–cost ratio (BCR) is used to assess the efficiency or profitability of a project or investment. It is computed by dividing the investment's overall projected benefits by its total expected expenditures. This study used the benefit–cost ratio for comparison of SCP and CCP as this technique is broadly used in several studies (Zangeneh et al., 2010; Berawi, 2017; Jagdhuber and Rahnenführer, 2021). Following is the formula for calculating the benefit–cost ratio.

$$BC\ Ratio = \frac{GB}{TC}$$

where *BC* is the benefit–cost ratio, *GB* is the gross benefit, and *TC* is the total cost.

2.2.2 The paired samples' *t*-test

The mean value of a variable related to two different groups, two values taken for the same group, individual, or object can be compared by this test. The "paired measurements" denote the case like a magnitude taken at different points of time (e.g., scores of an individual before test and after test with an interference dispensed between two different points of time), a measurement noted in two distinct environments (e.g., experimenting with a "control" situation and a "trial" situation), and the measurement of two sides or halves of an experimental unit or subject (e.g., gaging loss of hearing in an individual's right and left ears). The main purpose of the paired *t*-test is to ascertain that there is any statistical proof that the average difference among paired observations is different (significantly) from zero or not. As the paired sample *t*-test is a kind of parametric test, there are two different ways (that denote the identical impression and are mathematically alike) in which its hypotheses can be shown:

> H_0: $\mu1 = \mu2$, the paired population means are equal.
>
> H_1: $\mu1 \neq \mu2$, the paired population means are not equal.

OR

> H_0: $\mu1 - \mu2 = 0$, the difference between the paired population means is equal to 0.
>
> H_1: $\mu1 - \mu2 \neq 0$, the difference between the paired population means is not 0.

where μ1 is the population mean of variable 1, and μ2 is the population mean of variable 2.

2.2.3 Log–log regression model

Log–log model or log–log linear regression is a type of regression model in which the dependent variable and predictor (at least one) are log-transformed. Transforming different variables in the regression models is a common practice to know circumstances where we face a non-linear relation between the outcome and predictor variables. Using the logarithm of one or more variables instead of an unlogged form makes the effective relationship non-linear while preserving the linear model yet. Logarithmic changes are also an easy means of converting an extremely slanting variable into one that is almost normal (Benoit, 2011). In cases where the response and stimulus variable(s) are transformed into a log form, then the explanation is simple and more elaborative (percentage change in the dependent variable due to percentage increases in the independent variable). Those relationships where both dependent and independent variables are log-transformed are called elastic in the sense of econometrics because the coefficient of the independent variable is stated as elasticity (Benoit, 2011). Log–log model was used for the yield of SCP and CCP, and it was also used in previous studies (Vanslembrouck

TABLE 1 Distribution of population and sample size.

Districts	Sub-districts (Tehsils)	Total rural households	Sample
Bahawalpur	Ahmadpur East	138,432	188
Rajanpur	Rajanpur	63,769	87
Total	2	202	275

TABLE 2 Comparison of socio-economic and farm indicators of SCP and CCP.

Socio-economic and farm indicators		Mean	Std. Deviation
Pair 1	AGE[B] – AGE[C]	−0.12*	0.81
Pair 2	EDUCATION[B] – EDUCATION[C]	2.67**	1.15
Pair 3	FARMING EXPERIENCE[B] – FARMING EXPERIENCE[C]	−0.72[ns]	0.09
Pair 4	FAMILY MEMBERS[B] – FAMILY MEMBERS[C]	−0.04*	0.15
Pair 5	TOTAL LAND[B] – TOTAL LAND[C]	0.74[ns]	0.19
Pair 6	LAND UNDER COTTON[B] – LAND UNDER COTTON[C]	0.20**	0.03

B = SCP, C = CCP. ** $p < 0.05$ and * $p < 0.10$, ns = non-significant, respectively, for paired sample *t*-test assuming unequal variances.
Source: Calculations from the author's data collected through a survey of farmers.

et al., 2005; Ritter et al., 2020; Kastratović, 2019; Parvathi and Waibel, 2016; Rehman and Bashir, 2015; Djokoto et al., 2016; Chandio et al., 2019).

2.2.4 Log–log model for productivity

$$\ln Y = \alpha + \beta_1 \ln AGE + \beta_2 \ln EDU + \beta_3 \ln FEx + \beta_4 \ln FM + \beta_5 \ln TL + \beta_6 \ln TLC + \beta_7 \ln LPC + \beta_8 \ln SSC + \beta_9 \ln TWC + \beta_{10} \ln IC + \beta_{11} \ln FC + \beta_{12} PC + \beta_{13} PiC + \varepsilon,$$

where ln Y = log of cotton output (mounds/acre); Ln AGE = log of age of the respondents (years); Ln EDU = log of education of the respondents (no. of years of schooling); Ln FEx = log of farming experience of the respondents (years); Ln FM = log of family members of the respondents; Ln TL = log of the total land area of the respondent (acres); Ln TLC = log of land area under cotton production (acres); Ln LPC = log of land preparation cost (PKR/acre); Ln SSC = log of seed and sowing cost (PKR/acre); Ln TWC = log of thinning and weeding cost (PKR/acre); Ln IC = log of irrigation cost (PKR/acre); Ln FC = log of fertilizer cost (PKR/acre); Ln PC = log of pesticide cost (PKR/acre); Ln PiC = log of picking cost (PKR/acre); ε = error term.

3 Results and discussion

3.1 Comparison of socio-economic variables of SCP and CCP; paired sample *t*-test results

To check the mean difference among socio-economic variables of both types of farmers, a paired sample *t*-test was used (Table 2). The results showed that the average age of CCP was more than that of SCP, and our findings are contradicted with Imran et al. (2018) who found that farmers practicing climate smart agriculture in the study area had a higher average age. The difference in mean education of SCP and CCP was positive and significant; it gives a notion that most of the educated farmers had adopted BCI and registered themselves for this purpose. CCP had more average farming experience. The difference in mean area under cotton for SCP and CCP was significant and positive, which showed that SCP had more land under cotton. Several researchers reported similar findings that SCP had greater land area and farming experiences than conventional farmers (Imran et al., 2022). The economic status of farmers can be influenced by the size of their landholding, as highlighted by Razzaq et al. (2019). A more sustainable agricultural sector is emerging as a consequence of farmers' increased adoption of SCP methods, which are driven by factors such as their farming experience and landholding (Maraddi et al., 2014; Imran et al., 2022).

3.2 Difference in input usage between SCP and CCP

Overuse of inputs raises the cost of production and increases the risk of health and environmental issues. The term "climate adaptation" has a derived meaning in relation to sustainable activities being carried out by SCP. The objective of this study is to identify the implementation of these practices for a more sustainable agriculture sector. This article has covered all three dimensions of sustainability—economic, social, and environmental—although they have been discussed in different ways. Thus, in this study, a comparison is made between input usage, cost reduction, and increased returns by two types of farmers, that is, SCP and CCP. Table 3 shows the comparison of the means of input used by both types of farmers. The average seed rate used by SCP and CCP was 7.11 kg per acre and 9.86 kg per acre which shows that CCP was using more seed and ultimately incurring more cost on seed. In the case of land preparation, conventional farmers used many plows and planking which consequently increased their production costs. In the case of the simple plow, SCP used the plow 2.51 times on average while for CCP this average was 3.82 which is significantly higher than that of SCP. The average no. of planking for SCP and CCP was 1.67 and 3.02 and significant at a 10% level of significance. The average no. of rotavator for SCP was 0.95, and for CCP, it was 1.10 but non-significant. Laser leveling is usually done after 5 years, but BCI recommended its farmers to use laser leveler after every 3 years. The average no. of laser leveling by SCP and CCP was 1.25 and 0.30, respectively, and it is significant at a 5% level of significance. The deep plow is mostly needed to break the hard pan created under the surface of the land. Most of the farmers did not use it and considered it as an extra cost item, but BCI staff recommends applying deep plow after every 3 years. The average no. of deep plow used by SCP and CCP was calculated as 0.19 and 0.14, respectively, which is statistically not significant.

According to Maqsood et al. (2016), the majority of Punjab's soils lack nitrogen; it is always necessary to increase soil fertility by adding fertilizer to balance nutritional deficiencies, but fertilizer usage is also a

TABLE 3 Input usage by SCP and CCP.

Input category	Cotton farmers	
	SCP	CCP
Seed (Kgs)	7.11**	9.86**
Land preparation		
Plow (No.)	2.51**	3.82**
Planking (No.)	1.67*	3.02*
Rotavator (No.)	0.95ns	1.10ns
Laser leveler (No.)	1.25**	0.30**
Deep plow (No.)	0.19ns	0.14ns
Fertilizer (one bag = 50 kg)		
Urea (Bags)	2.21**	3.52**
DAP (Bags)	1.44*	2.61*
NP (Bags)	0.54*	0.09*
Other (Bags)	0.30ns	0.05ns
FYM (No of trollies)	1.81**	0.11**
Irrigation (No.)		
Canal (No.)	4.98ns	5.10ns
TW (No.)	7.44**	10.16**
C + TW (No.)	1.11*	2.78*
Thinning (No.)	1.08*	0.02*
Spray		
Weedicide (No.)	0.69**	1.98**
Pesticide (No.)	5.87**	9.02**

***$p < 0.01$, **$p < 0.05$, and *$p < 0.10$, ns = non-significant, respectively, for paired sample t-test assuming unequal variances.
Source: Calculations from the author's own data collected through a survey of farmers.

problem because farmers usually think that high fertilizer use is good for healthy and productive crops; nevertheless, BCI recommends judicious use of fertilizer. The average no. of urea bags used by SCP and CCP was 2.21 and 3.52, respectively, which was significant at the 5% level. Diammonium phosphate (DAP) is the second most used fertilizer by cotton growers in Pakistan, which is one of the costly items in the production of cotton. The average no. of DAP bags used by SCP and CCP was calculated as 1.44 and 2.61, respectively, and this difference is statistically significant at a 1% level of significance. Nitrophos (NP) is one the important fertilizers used in crops, but its use in cotton is less than that of urea and DAP. The average no. of NP bags used by SCP and CCP was 0.54 and 0.09, which are also significantly different from each other at a 10% level of significance. In the case of other fertilizers, the difference between SCP and conventional farmers was not significant. SCP's farmyard manure application is also significantly more than CCPs.

Irrigation is a vital factor for any crop, but cotton crops need sufficient water at every stage due to its deep root system. Farmers usually use water without caring for the method of irrigation. If furrow irrigation is applied, it can reduce the excessive use of irrigation water, and ultimately, the cost of irrigation can be lessened. The average no. of irrigations by the canal, tube well, and mixed (canal + tube well) for SCP and CCP was calculated as 4.98, 7.44, and 1.11 and 5.10, 10.16, and 2.78, respectively. The application of canal irrigation is not significant, while tube well irrigation and mixed irrigation are significant at 5 and 10%, respectively. It shows that CCP used more tube well irrigation which led to their higher costs of irrigation, and on the other hand, SCP based on sustainable water management practices, such as furrow irrigation and filling furrow up to half instead of full, reduced the cost of irrigation.

Thinning is also an important practice used by cotton farmers to improve the growth of crops. The average no. of thinning for SCP and CCP was 1.08 and 0.02, respectively, which is significant at a 10% level of significance. BCI trains its farmers to reduce the use of weedicide and recommends sustainable control methods. The average no. of weedicide used by SCP and CCP was calculated as 0.69 and 1.98, which is significant at a 5% level of significance. Pesticide usage is a vital element in producing cotton due to ever-increasing pest attacks. On the other hand, BCI recommends pesticides as the last option. The average no. of pesticide sprays by SCP and CCP in the study area was calculated as 5.87 and 9.02, respectively, which is significant at a 5% level of significance.

The two groups, that is, SCP and CCP, employ significantly different levels of input. Table 3 demonstrates that traditional farmers used more inputs than conventional cotton producers who utilized external inputs on average in significantly different amounts. The SCP farmers who practice sustainable cotton were observed to be using significantly lower amounts of inputs, including seed, micronutrients, fertilizers, irrigation water, and chemical controls, in comparison with conventional farmers, and these findings are supported by previous studies (Zulfiqar and Thapa, 2016; Hussain et al., 2017; Shah et al., 2020; Imran et al., 2022).

TABLE 4 Cost–benefit analysis of cotton production.

Cost and benefits	Cotton farmers	
	SCP	CCP
Seed and sowing cost (Rs/acre)	4783.89*	5289.95*
Land preparation cost (Rs/acre)	5971.82**	7498.98**
Irrigation cost (Rs/acre)	3721.24**	4468.18**
Thinning and weed control (Rs/acre)	2999.7**	2304.78**
Cost of fertilizer (Rs/acre)	5317.7**	6543.43**
Cost of FYM (Rs/acre)	1505.23*	1237.14*
Cost of pesticide (Rs/acre)	5375.15**	7543.43***
Picking cost (Rs/acre)	15030.88*	13010.01*
Labor cost	11103.34^{ns}	10711.76^{ns}
Total cost	55808.95*	58607.66*
Yield (kgs/acre)	998.47*	871.29*
Price (Rs/kg)	103^{ns}	102^{ns}
Total revenue/acre (Rs.)	79482.3**	71290.8**
Profit/acre (Rs.)	23673.35**	12683.14**
BCR	1.42*	1.21*

**$p < 0.05$ and *$p < 0.10$, ns = non-significant, respectively, for paired sample *t*-test assuming unequal variances.
Source: Calculations from the author's data collected through a survey of farmers.

3.3 Financial analysis of SCP and CCP

Computing the cost–benefit ratio and comparing it for two or more groups gives us the suitability of a given enterprise. This study calculated different cost items, price of outputs, revenue, and profit for SCP and CCP. Then, the benefit–cost ratio is calculated and analyzed using a paired sample *t*-test. The results showed (Table 4) that the costs of production and benefits of SCP and CCP are significantly different from each other. The CCP incurred significantly higher costs on external inputs such as irrigation, land preparation, pesticides, weedicides, and fertilizers compared to SCP. The SCP encountered lower costs for seed at the time of purchase because they sow lesser quantity of seed per acre as compared to conventional farmers who mostly use larger quantities of seed. In addition, SCP utilizes efficient sowing methods, so the combined cost of seed and sowing for SCP is significantly less than that of CCP. The CCP has an overall higher cost of production than that of SCP. The average yield of SCP is significantly higher than that of conventional farmers, and these results are supported by the findings of several researchers (Forster et al., 2013; Mukhtar, 2024), but the price of cotton received by both types of farmers is not statistically significant from each other. Overall SCPs enjoy significantly higher profits as compared to CCPs, so they have a relative advantage over CCPs.

3.4 Factors affecting the yield of SCP and CCP

The results of the log–log model presented in Table 5 show that the respondent's age, education, and farming experience have a positive impact on the yield of SCP, while the "number of family members" has no significant impact on it. The coefficients of total land area under cotton, land preparation cost, seed, and sowing cost, thinning and weeding cost, irrigation cost, pesticide cost, and picking cost are positively and significantly affecting the yield of better cotton producers. The value of coefficients for these variables such as 0.018, 0.023, 0.042, 0.027, 0.015, 0.012, and 0.020 show that a 1% increase in these inputs increases the yield of better cotton by 1.8, 2.3, 4.2, 2.7, 1.5, 1.2 and 2%, respectively. The reason for the significant impact of picking cost on the yield of better cotton is that SCP employs mature and skilled picking labor to protect the quality of produce and they pay more wage than CCP for binding the labor because CCP picks up the female cotton pickers before or right after sunrise, but SCP need picking labor 1–2 h after sunrise so that dew subsides and quality can be maintained at the time of harvest. The coefficient of fertilizer cost (−0.009) is significant at a 10% level of significance, which can be interpreted as a 1% increase in the cost of fertilizer causing about a 1% decline in the yield of better cotton. Total land area has no significant impact on the yield of SCP. The value of coefficient of determination (R^2) is 0.691 which means approximately 70% of the variation in yield was explained by the independent variables included in the model.

A similar log–log regression model was used to analyze factors affecting the yield of CCP. The results presented in Table 5 show that the age, education, and farming experience of farmers have a positive impact on yield, and the number of family members has no significant impact. The results show that the impact of education is more prominent in the case of SCP than CCP. The impact of total land under cultivation, land under cotton, land preparation cost, and thinning and weeding cost on cotton yield was positive (values of coefficients are 0.011, 0.012, 0.018, and 0.019) and significant at a 5% level of significance. This can be interpreted as a 1% increase in these variables increases the yield of cotton by 1.1, 1.2, 1.8, and 1.9%, respectively. While irrigation cost, fertilizer cost, and pesticide cost negatively affect the yield and are significant at a 5% level of significance. The values of coefficients of irrigation cost, fertilizer cost, and pesticide cost are

TABLE 5 Factors affecting yield of SCP and CCP: log–log regression model.

Model	B (SCP)	Std. Error	B (CCP)	Std. Error
(Constant)	8.303**	0.797	9.623**	1.572
Ln (Age)	0.060*	0.003	0.011*	0.005
Ln (Education)	0.071**	0.019	0.051**	0.006
Ln (Farming Experience)	0.042*	0.007	0.020*	0.008
Ln (Family Members)	0.021 ns	0.011	0.041 ns	0.022
yLn (Total land under cultivation)	0.119 ns	0.039	0.011	0.004
Ln (Total land under Cotton)	0.018**	0.005	0.012**	0.022
Ln (Land Preparation Cost)	0.023***	0.006	0.018**	0.010
Ln (Seed and Sowing Cost)	0.042**	0.002	−0.025 ns	0.015
Ln (Thinning and Weeding Cost)	0.027*	0.005	0.019**	0.003
Ln (Irrigation Cost)	0.015**	0.004	−0.049**	0.001
Ln (Fertilizer Cost)	−0.009*	0.003	−0.071**	0.043
Ln (Pesticide Cost)	0.012**	0.001	−0.091**	0.023
Ln (Picking Cost)	0.020**	0.102	0.025 ns	0.007
R^2	0.691		0.710	

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$. Dependent Variable = lnY = log of Yield.
Source: Calculations from the author's data collected through a survey of farmers.

TABLE 6 Seed management and land preparation.

Adaptations	F (%)			
	Not doing = 0	Not doing but considering = 1	Somewhat doing = 2	Doing fully = 3
Stress tolerant varieties	4(2.0)	17(8.5)	145(72.1)	35(17.4)
Registered varieties	38(18.9)	32(15.9)	89(44.3)	42(20.9)
Seed Treatment	2(1)	33(16.4)	95(47.3)	71(35.3)
Grading of own seed	145(72.1)	31(15.4)	21(10.4)	4(2.0)
Gap filling	14(7.0)	23(11.4)	44(21.9)	120(59.7)
Planter sowing	104(51.7)	94(46.8)	2(1.0)	1(0.50)
Use rotavator	3(1.5)	4(2.0)	20(10.0)	174(86.6)
Deep plowing	175(87.1)	15(7.5)	7(3.5)	3(1.5)
Laser leveling	94(46.8)	52(25.9)	49(24.4)	6(3.0)

Source: Calculations from the author's data collected through a survey of farmers.

−0.049, −0.071, and −0.091, which means a 1% rise in these factors reduces the yield by 4.9, 7.1, and 9.1%, respectively. These results show that conventional farmers were overutilizing water, chemical fertilizers, and pesticides. Seed and sowing costs, and picking costs had no significant impact on the yield of conventional (CCP) farmers. The value of R^2 is 0.810 which means approximately 81% of the variation in yield was explained by the independent variables included in the model. After analyzing the results of the log–log regression model in Table 4, one can say that conventional (CCP) cotton farmers were not considering input management due to a lack of awareness about the sustainable use of inputs, and it led to a negative effect on the yield of cotton. This is also supported by Naab (2015), who observed that farmers' negative attitudes toward input led to a considerable decrease in cotton production. Pallavi et al. (2017) segregated the farmers into beneficiaries of BCI and non-beneficiaries and also found that the former had more yield and net returns than later in the study period.

3.5 Adaptations related to seed management and land preparation by BCI farmers

The use of stress-tolerant varieties and registered varieties, seed treatment, grading of seed, gap filing if some spots are left empty, planter sowing, use of rotavator and deep plow at least after 3 years, and laser leveling are classified under adaptation practices related to seed management and land preparation. The results (Table 6) showed the frequency and percentage (in parenthesis) of respondents adopting a specific adaptation. Regarding the use of stress-tolerant varieties of cotton, only 2% of the better cotton farmers had not adopted it at all, while 8.5% were considering it to use only good stress-tolerant seeds in future, 72.1% of BCI farmers were fully using stress-tolerant varieties of cotton, and 17.4% had adopted this practice fully. In the case of using registered varieties only, 18.9% of farmers were not caring at all, 15.9%

had their mind to use shortly, 44.3% were practicing this to some extent, and 20.9% of BCI farmers were practicing it fully. Seed treatment before sowing is an important adaptation strategy to overcome many seed-borne diseases, and BCI recommends farmers treat their seeds. The results of this study showed that the majority of the BCI farmers were treating their seeds before planting, and only 1% of them were not doing this at all. Regarding grading seeds, the majority (72.1%) of the BCI farmers were not adopting this practice, while 21% had adopted it to some extent and only 2% of BCI farmers were grading their seeds to the full extent. BCI can ensure the grading of seeds by educating more about the importance of this practice. Filling gaps after the emergence of cotton crops is an important strategy to ensure optimum planting density and leads to desired yield. BCI farmers had adopted this practice to a great extent as 59.7% of them were doing this fully, while 21.9% were doing it to some extent, 11.4% were considering it, and only 7% were not doing it at all. In terms of planter sowing, 51.7% of BCI farmers were not using planters at all, 46.8% were considering using them in future, 1% were using them to some extent, and only 0.5% were using them fully. Planter is among the big agricultural machinery that is not affordable by the majority of farmers in Pakistan due to small land holdings. Our findings show that SCP farmers were using more stress-tolerant varieties than CCP, and this is due to the awareness created by BCI. Several studies have explored that stress-tolerant varieties are very important for high-yield cotton production (Zafar et al., 2024a; Sheoran et al., 2021; Noman and Azhar, 2023).

3.6 Adaptations related to soil, water, and crop management by BCI farmers

Management of soil, water, and crops using different adaptation practices is done by BCI-registered farmers under the guidelines of organizations working for the implementation of better cotton. Table 6 gives the frequency and percentage of different adaptations related to managing crops, soil, and water. The results showed that cultivation on bed and furrow was not adopted by 21.4% of farmers, 71.1% of growers were considering it for the future, 6.5% had adopted it to some level, and only 1% of BCI farmers were cultivating fully using bed and furrow technique. Furrow irrigation is one of the techniques to save water in crops; these results witnessed that the majority of BCI farmers (81.1%) were using furrow irrigation, and only 18.9% were considering it to use this practice in future for saving water in cotton production. Water scouting is one the most important adaptation practices for judicious use of irrigation water along with lowering the cost of irrigation which leads to profitability of BCI farmers. The results showed that 6% of BCI farmers were not practicing water scouting, 9.5% of farmers were still not doing but had their mind to use in future, 80.1% were practicing it to some extent, and 4.5% of BCI farmers were doing it fully. This shows that BCI farmers are efficient farmers who are saving water resources as well as their cost of production. It is necessary to get nutrient testing for soil for proper use of inputs like fertilizers; this adaptation was fully adopted by 6% of farmers, 34.8% of growers were doing it to some extent, 50.7% are considering this practice, and 8.5% were doing it fully among BCI farmers.

On a global scale, water is a valuable resource and the success of agricultural production relies heavily on its availability and efficient utilization for growing crops (D'Odorico et al., 2020). In addition, effectively utilizing the available water is a matter of management, and, as such, it necessitates farmers' motivation to use water at the appropriate time and in the necessary amount (Li et al., 2020). To manage excessive use of water, filling furrows up to half is the best adaptation strategy which leads to saving water without compromising on the requirement of irrigation. The results of this study showed that 66.7% of farmers were not considering it at all, 20.9% were considering it seriously, 8% were caring for this to some extent, and 4.5% were practicing it completely among all BCI farmers. These findings contradict the study conducted by Khan et al. (2021) which reported that respondents in the study area saved 13 to 22% of water. Adjustment at the time of sowing is a good adaptation to save the crops from the adverse effects of climate change and other risks. This study found that 16.9% of farmers were adjusting the time of sowing, 18.4% were not doing but considering, 61.2% were adjusting to some extent, and 3.5% were fully adjusting their time of sowing according to expectations/forecast of risks. Mulching is an excellent way of saving moisture and reducing the effect of weeds, and these results showed that 64.2% of farmers were not using this at all, 32.3% were pondering over it, 3% were doing it to some extent, and only 0.5% were using this adaptation fully. BCI staff can put more focus on increasing the use of mulching because it can save a substantial quantity of resources. Green manure was used to some extent by only 1.5% of farmers, 11.4% were planning to use it, 87.1% were not doing it at all, and no farmer was doing it fully. Converting animal dung into organic manure is a good substitute for chemical fertilizers, but the majority of farmers (74.1%) were not using it, 21.9% were considering implementing it in future, and only 0.5% were doing it to the full extent (see Table 7).

3.7 Adaptations related to growth management and pest/weed controlling by BCI farmers

BCI stresses the social and health protection of farmers growing cotton, and it makes sure that protective and safety equipment and tools for farmers as well environment must be used during the growing and harvesting season of cotton (Goyal and Parashar, 2023). Table 8 shows that 48.3% of the BCI farmers allowed for spray if the spraying person was more than 18 years of age, 44.3% of farmers cared for this to some extent, and 7.5% of all BCI farmers were thinking of following this in future. The use of protective and safety equipment during spray application is one the most important practices which was fully adopted by ~5% of the BCI farmers, while 7% had adopted it to some level, 48.3% were considering it for next time, and 39.8% had not adopted it at all. BCI farmers are trained to avoid pesticide spray if the weather is not supportive, and the results of this study regarding this practice showed that 45.8% of BCI farmers had adopted it fully, 49.3% were doing it to some extent, 3.5% were thinking to adopt it, and only 1.5% were not complying with this guideline. Burring of used pesticide and fungicide bottles and related things is also recommended to BCI farmers, but the results showed that only 1.5% of them follow it completely, 7.5% were doing it to some level, 33.8% were planning to adopt it, and 57.2% were not considering it at all possibly because of no care about its damages but Khan and Damalas (2015) found opposite findings. Using fertilizer in split doses or by ridges are also important adaptations that were mostly followed fully or up to some extent by BCI

TABLE 7 Soil, water, and crop management.

Adaptations	F (%)			
	Not doing = 0	Not doing but considering = 1	Somewhat doing = 2	Doing fully = 3
Cultivate on bed and furrow	43(21.4)	143(71.1)	13(6.5)	2(1.0)
Furrow irrigation	0(0)	0(0)	38(18.9)	163(81.1)
Practice water scouting	12(6.0)	19(9.5)	161(80.1)	9(4.5)
Soil nutrient testing	17(8.5)	102(50.7)	70(34.8)	12(6.0)
Fill furrow up to half	134(66.7)	42(20.9)	16(8.0)	9(4.5)
Adjustment in sowing time	34(16.9)	37(18.4)	123(61.2)	7(3.5)
Mulching	129(64.2)	65(32.3)	6(3.0)	1(0.5)
Green manuring	175(87.1)	23(11.4)	3(1.5)	0(0)
Conversion of animal dung into organic manure	149(74.1)	44(21.9)	7(3.5)	1(0.5)

Source: Calculations from the author's own data collected through a survey of farmers.

farmers. Fertigation was fully done by 48.8, and 49.3% were doing it somewhat. In the case of using organic manure, BCI farmers were not following to some considerable level. The majority (69.7%) were not using organic manures at all, while only 1.5% had adopted them fully. Using organic manures is preferred in the BCI program, but the results of this study showed that the majority of the BCI farmers (69.7%) were not using organic manures, 20.9% were considered, 8% were using up to some extent, and only 1.5% had adopted it fully. The use of compost is suggested by BCI staff and farmers try to follow it, but the results showed that 67.2% of the BCI farmers were not using the compost due to a somewhat technical procedure of making compost.

Thinning is good practice for healthy crops and ultimately more output, and BCI farmers were also recommended to use thinning. The results showed that 29.9% of farmers used thinning fully, 44.3% were doing it to some extent, 16.9% of farmers were planning to do it next time, and only 9% were not doing it at all. Pest scouting is another important adaptation strategy given by the BCI program to its farmers. The results witnessed that 11.4% of farmers adopted it completely, 34.8% were acting upon this to some extent, 33.8% were considering it, and 19.9% were not acting upon this adaptation strategy at all. Using banned pesticides is avoided in BCI by guiding farmers about them, and the results of this study confirmed this behavior of BCI farmers as the majority (94.5%) of them were not using those pesticides at all. Using a pest-specific spray is good practice to save biodiversity in the agricultural systems, and BCI recommends pest-specific sprays to its farmers. This study showed the results that 5.5% of the farmers were practicing it completely, 59.7% were acting upon it to some extent, 27.4% were considering it seriously, and 7.5% of them were not doing it at all. These results are contradicted with some previous studies (Imran et al., 2018; Goyal and Parashar, 2023; Imran et al., 2022) as they found that BCI farmers are adopting these practices to a great extent.

Planting border crops for resistance from various risks, biological control methods for pests, physical control methods, cultural control methods, and keeping pesticides as the last option are recommended to BCI farmers (Khan et al., 2023), but the results of this study showed that the majority of BCI farmers were not complying with these instructions. BCI farmers are required to use only registered and properly labeled pesticides in cotton production. The results of this study showed that 9.5% of the BCI farmers were fully using only registered and labeled pesticides, 7.5% were caring for this practice to some extent, 37.8% were considering it, and 45.3% were not acting upon this practice. Spray rotation is also a very important adaptation strategy, but the majority of the BCI farmers were not following this practice. Spraying only as per real need saves the cost of production as well as personal and environmental health, and the results showed that 18.1, 31.8, and 28.9% of the BCI farmers were taking care of real need fully, somewhat, and not at all respectively, while 20.9% were considering this practice for next time in future. Using pesticides below the label rate is recommended to BCI farmers, and this study found that a minority (10%) of the BCI farmers cared for this completely, while 41.3% were practicing this to some level, 39.8% were not using but considering it, and 9% had not adopted it at all. Applying pesticides before the emergence of a disease is an important adaptation to save excessive resources when the disease spreads too much and to avoid loss of total produce. The results of this study showed that only 4% of the BCI farmers were practicing this strategy to the full extent, 13.9% were doing it somewhat, 44.3% were not applying before disease but had mind to do it for future, and 37.8% of the farmers were not using pesticide before disease occurs, and these findings are similar to some extent with Tokel et al. (2022) because they found better results than these findings. Overall BCI farmers had adopted crop growth and pest control measures very well which leads to the sustainable production of cotton.

3.8 Adaptations related to harvest and post-harvest practices by BCI farmers

Harvesting of cops is a careful task that most of the farmers do not consider very important in terms of care. BCI has much focus on harvesting cotton and trains the registered farmers accordingly (Ahmad et al., 2023). Various adaptations that are needed during and after harvest and their adoption were analyzed in this study.

TABLE 8 Growth management and pest/weed controlling.

Adaptations	F (%)			
	Not doing = 0	Not doing but considering = 1	Somewhat doing = 2	Doing fully = 3
Pesticide applied by skilled and > 18 years old person	0(0)	15(7.5)	89(44.3)	97(48.3)
Protective and safety equipment usage	80(39.8)	97(48.3)	14(7.0)	10(4.9)
Pesticide applied in proper weather	3(1.5)	7(3.5)	99(49.3)	92(45.8)
Burying of used pesticide bottles	115(57.2)	68(33.8)	15(7.5)	3(1.5)
Split doses of fertilizer	3(1.5)	22(10.9)	104(51.7)	72(35.8)
Use of fertilizer by ridges	3(1.5)	6(3.0)	100(49.8)	92(45.8)
Fertigation	0(0)	4(2.0)	99(49.3)	98(48.8)
Use organic manures	140(69.7)	42(20.9)	16(8.0)	3(1.5)
Use compost	135(67.2)	55(27.4)	10(5.0)	1(0.5)
Thinning	18(9.0)	34(16.9)	89(44.3)	60(29.9)
Pest scouting	40(19.9)	68(33.8)	70(34.8)	23(11.4)
Use of Banned pesticide	190(94.5)	0(0)	9(4.5)	2(1.0)
Pest specific spray	15(7.5)	55(27.4)	120(59.7)	11(5.5)
Plant border crops	177(88.1)	18(9.0)	5(2.5)	1(0.5)
Biological/botanical control methods	170(84.6)	27(13.4)	4(2.0)	0(0)
Physical control methods	175(87.1)	22(10.9)	4(2.0)	0(0)
Cultural control methods	153(76.1)	42(20.9)	6(3.0)	0(0)
Keep pesticide at last option	143(71.1)	46(22.9)	10(5.0)	2(1.0)
Registered and labeled pesticide use	91(45.3)	76(37.8)	15(7.5)	19(9.5)
Spray rotation	134(66.7)	52(25.9)	11(5.5)	4(2.0)
Spray according to real need	42(20.9)	58(28.9)	64(31.8)	37(18.4)
Use pesticide below the label rates	18(9.0)	80(39.8)	83(41.3)	20(10.0)
Apply fungicide before disease occurs	76(37.8)	89(44.3)	28(13.9)	8(4.0)

Source: Calculations from the author's own data collected through a survey of farmers.

The results showed that 18.4% of farmers used labor who covered their heads during picking fully, 42.3% did this to some extent, 31.3% did not urge their laborers to cover their heads but they were considering it for future, and only 16% did not follow this adaptation at all. BCI made sure that picking must start after sunrise so that due subsides and quality of fiber must be best. The results revealed that 13.4% of farmers were acting upon this completely, 30.8% were doing it to some extent, 35.3% were not doing it but considering it for the future, and 20.4% had not adopted it at all. As conventional farmers tend to start picking right after dawn, labor goes with them to ensure wage, so labor usually did not wait for BCI farmers, and it became difficult for BCI farmers to find labor after sunrise. Picking from the bottom up is a recommended practice by BCI, and the results showed that 45.3% of farmers adopted it completely, 45.8% were doing it to some extent, 7% were considering it, and only 2% were not doing it at all. Picking after 50% of bolls are open is another related adaptation practice that was fully adopted by 50.7% of farmers, while 43.3% were doing it to some level other than complete, 6% were considering it, and 0% were not doing it at all. Storage at dry place was done fully by 44.8% farmers, while 46.8% were doing it to some extent, 7.5% were considering it, and only 1% had not adopted it at all. BCI program makes sure use of cotton cloth or proper sheet for storing cotton which saves the quality of fiber and helps in earning a good price for it. Only 11% of farmers were using this fully because small farmers were the majority among all sampled BCI farmers, and they did not have the resources to use proper cloth or sheet for storage. Approximately 52% of the farmers were using cloth or sheet to some extent, 29.4% were considering it for the next crop, and 7% had not adopted it at all. Storing cotton variety wise was adopted by only 2% of farmers, 10.4% were doing it to some extent, 25.4% were not doing it but considering, and 62.2% were not doing it completely. Storage of

TABLE 9 Harvest and post-harvest practices.

Adaptations	F (%)			
	Not doing = 0	Not doing but considering = 1	Somewhat doing = 2	Doing fully = 3
Labor cover head properly	16(8.0)	63(31.3)	85(42.3)	37(18.4)
Picking start after sunrise	41(20.4)	71(35.3)	62(30.8)	27(13.4)
Picking from bottom up	4(2.0)	14(7.0)	92(45.8)	91(45.3)
Start picking after 50% bolls open	0(0)	12(6.0)	87(43.3)	102(50.7)
Storage at dry place	2(1.0)	15(7.5)	94(46.8)	90(44.8)
Store cotton on cloth or sheet	14(7.0)	59(29.4)	104(51.7)	24(11.9)
Store cotton variety wise	125(62.2)	51(25.4)	21(10.4)	4(2.0)
Store cotton in small heap	135(67.2)	20(10.0)	36(17.9)	10(5.0)
Cover cotton heap properly	24(11.9)	45(22.4)	86(42.8)	46(22.9)

Source: Calculations from the author's own data collected through a survey of farmers.

cotton in small heaps rather than big heaps is advantageous for keeping quality of seed cotton. It was calculated that only 5% of farmers were stored in the small heap due to limited farm building, while 17.9% were keeping in small heap to some extent, 10% were thinking about it, and 62.2% were not doing it at all. Covering cotton heap properly is fully practiced by 22.9% of farmers, while 42.8% were doing it to some extent, 22.4% were not doing but having mind to do it in future, and 11.9% were not covering properly at all. These results portray in the case of harvest and post-harvest practices that most of the BCI farmers were practicing up to some extent or completely. It means BCI is playing its role fully to make cotton production sustainable and profitable.

This study revealed that the adoption of sustainable and climate adaptation practices resulted in significantly higher net income compared to conventional methods (Khan et al., 2021; Zulfiqar et al., 2017; Ali et al., 2024). To address the challenges posed by climate change, it is crucial to make significant changes in the way we approach cotton production (Zafar et al., 2022; Ashraf et al., 2024). This includes improving seed management and land preparation, implementing effective soil, water, and crop management techniques, adopting better growth management and pest/weed control methods, and implementing proactive strategies for harvest and post-harvest practices (Zafar et al., 2024c). These measures have been identified by SCP as effective ways to mitigate the impact of climate change on cotton production and concluded that better cotton is economically and environmentally sustainable, and they recommended public–private partnerships to spread better cotton technology to farmers. Imran et al. (2022) also found that adopters of climate-smart agricultural practices have fast adaptation behavior to climate change, and therefore, economically they are better off than non-adopters (see Table 9).

4 Conclusion

In conclusion, there is a significant difference in cost of production, yields, and climate change adaptability between conventional cotton producers (CCPs) and sustainable cotton producers (SCPs). SCP showed cheaper production costs, higher yields, and better climate change adaptation strategies than CCP. To improve sustainability and resilience in cotton production, policymakers ought to focus on SCP and support it with incentives, education, and resource allocation. Encouraging the use of sustainable techniques in cotton production can improve both economic viability and environmental stewardship.

This study contributes to the existing body of literature by offering a thorough analysis of CCP and SCP, with a specific emphasis on climate adaptation and socio-economic impacts. Our research offers a fresh perspective on the relationship between sustainable cotton practices and improved livelihoods, particularly in developing nations where cotton is highly valued. Our research has clear insights for local and international audiences such as (a) it provides practical directions to the farming community by adopting sustainable cotton practices along with economic benefits, (b) it contributes to a global discussion on climate change and sustainable agriculture, and (c) it provides data to NGOs and development agencies for designing and implementing cotton sustainable practices. However, our research does have a few limitations. First, it was confined to a specific area, which means its implications on a global scale may be limited. Second, the study was conducted over a relatively short time, which prevented us from fully capturing all the data related to climate change adaptation. Finally, the interpretation of "sustainable" and "conventional" can differ among researchers, leading to complex discussions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Institute of Agricultural and Resource Economics. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

HM: Conceptualization, Data curation, Methodology, Writing – original draft. YS-A: Formal analysis, Resources, Writing – review & editing. AhA: Data curation, Formal analysis, Writing – review & editing. AsA: Conceptualization, Data curation, Formal analysis, Writing – original draft. SA: Formal analysis, Writing – review & editing. MM: Methodology, Writing – original draft. SS: Investigation, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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