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Impact of Global Warming on Crop Production: Example from Farmers' Insight and Adaptation Measure

Muhammad Usman[a], Zhoujie[b*], Muhammad Imran[c]

a.b Department of Economics and management Mongolia Agricultural University Hohhot, China
c. Department of Economics and management Inner Mongolia University Hohhot, China

Abstract: Globally, existing social, economic, and agricultural systems foster extreme inequity and irrationality, leading to problems such as poverty, racial discrimination, misogyny, and environmental degradation. Many of these problems are getting worse, increasing the likelihood of social and environmental collapse. However, climate change has severely affected the social, economic agricultural sectors of the world including Pakistan. This article examines the autonomous climate change adaptation approaches adopted by farmers in Punjab, Pakistan, and assesses their influence on crop yield. The study utilizes a simultaneous equation model to analyze the effects of various adaptation measures on both adapters and non-adapters. Findings based on data collected from 390 sugarcane growers reveal a high level of awareness among farmers regarding the current climate condition, leading them to undertake appropriate adaptation measures. However, challenges such as the availability of knowledge on climate change and the limited arable land area significantly affect farmers' adaptive decision-making. While some farmers employ strategies such as improved irrigation and increased fertilizer use, many still lack sufficient adaptation measures. The study establishes that non-adapted growers experience a negative impact on sugarcane production. Therefore, the article recommends that policymakers focus on addressing the gaps in adaptation strategies adopted by sugarcane growers to mitigate the effects of climate change. Moreover, policymakers should develop suitable adaptation strategies to assist farmers in coping with climate-related disasters, thereby enhancing farmers' income and promoting the revitalization and modernization of agriculture in rural areas.
Keywords: Environmental justice; economic justice; crop; climate change; rural; Pakistan

1. Introduction

Agriculture is the most significant sector of emerging economies, including "Pakistan's economy," providing direct and indirect support to the country's people and accounting for 21% of the Gross Domestic Product (GDP). Agriculture is under pressure to boost output levels to satisfy rising demand as the population grows. Sugarcane is Pakistan's principal cash crop. It is a C4 crop that is grown mostly in tropical and subtropical countries and is the world's primary source of bioenergy [1]. It is one of the most significant crops, accounting for approximately 75% of global sugar production for human consumption [2]. In Pakistan, sugarcane was grown on 1260 thousand hectares in the 2021-22 crop year, compared to 1160 thousand hectares last year, with a production of 88.651 million tons [3]. Colombia (123.0 tons' ha-1), Australia, Egypt, and the United States are all large sugar cane producers (99.3, 87.3-, and 74.6 tons ha-1, respectively) [4]. Pakistan's ha-1 output is around 43 tons, which is slightly lower than that of other major crop-producing countries. Sugarcane is grown in Sindh, Khyber Pakhtunkhwa (KPK), and Punjab in Pakistan, with Punjab being the main producer [5].

Sugarcane provides money not only to sugar mills but also to sugar and sugar product dealers in Pakistan. However, this crop provides revenue for around 64% of Sindh's total agricultural production [6]. There are 9 sugar plants in KP, 48 in Sindh, and 91 in Punjab, producing around 3.2 million tons of sugar to supply Pakistan's needs. There is a significant gap between supply and demand. This disparity can be ascribed to poor farming methods, poor atmospheric conditions, and other factors such as unfavorable stakeholders and governments [7]. Climate change has various reasons, not all of which affect rural sugarcane output [8]. It is

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Corresponding email: zhoujie@imau.edu.cn (Zhoujie)
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critical to identify the major reasons for impeding sugar cane output, particularly climate change. However, it is vital to inspect the detrimental climate change impact on sugar cane output in Pakistan.

Environmental change is becoming a more pressing concern across the globe [9]. Climate change and related calamities are affecting agricultural production and growth patterns, threatening the income flexibility and sustainability of farms. Climate change is an incontestable reality of life, and Pakistan is the most impacted nation. Between 1999 and 2018, Pakistan lost a total of US$3.79 million owing to climate challenges, ranking Pakistan as the fifth mainly highly impacted nation worldwide [10, 11]. An observed upsurge in temperature of 0.6 to 1.0°C and an increase in rainfall of 18% to 32% during the last century might affect agricultural productivity in secondary economies that rely on agriculture, such as Pakistan [12].

Some analysts anticipate that this condition may worsen in the future, causing substantial challenges for Pakistan's agricultural industry [13]. Emerging countries are likewise affected by environmental issues. However, because of inadequate adaptation, the impacts are more obvious and fatal in underdeveloped nations [14, 15]. While mitigation is the greatest strategy to handle climate concerns, it is expensive in terms of money, time, and effort. Adaptation to varied climatic scenarios is an effective approach in emerging nations such as Pakistan to prevent severe climate repercussions in the agriculture sector [16-18]. Agriculture makes up the majority of Pakistan's economy, accounting for 18.9% of the yearly GDP [References]. Although this industry is critical to the Pakistani economy, as well confronts many limitations related the food, natural disasters, climate change, and drought [19, 20].

The possible climate-related threats are evident and genuine, but what is concerning is that the farming industry is disrupted and unclear; so, adaptation is not only an efficient strategy, but it also proportionally minimizes the negative consequences of ecological risk [21]. Almost every civilization has adaption measures, but climate awareness may play an essential role, and adaptation measures are directly tied to education, access to resources, and awareness. In addition, small-scale growers in Pakistan do not have access to these mechanisms. A bigger population proportion (29.5%) survives in poverty, limiting growers' ability to deal with climate challenges [10]. Adaptation is, therefore, a challenge for emerging countries, which is exacerbated by high levels of climate familiarity, poverty, and low capacity to adapt at the farm level [17, 22-24]. Furthermore, due to the low financial and technical capacity of farmers, unsuccessful climate strategies have limited existing sustenance for climate adaptation [25].

As a result, focused adaptation programs are required to identify the elements that impact farmers' knowledge and adaptive reactions [26, 27]. Despite the social, environmental, and economic repercussions of different adaption techniques utilized by farmers [28, 29], climate awareness is critical. Consequently, it is vital to investigate how growers realize climate and adapt to it. Furthermore, the type and degree of mitigation strategies adopted are critical to the prognosis [23]. Despite substantial studies on farmers' climate awareness and adaptable behavior, the factors of adaptive behavior still require more investigation [10, 17, 24, 30-32].

While the many adaption strategies used by farmers have social, environmental, and economic implications, climate knowledge is critical. Therefore, it is critical to investigate how sugarcane growers perceive climate and adapt to it. Furthermore, the extent of adaptation methods used to mitigate climate has an important influence on climate change, and while farmers' perceptions and adaptation behavior under climate conditions have been extensively studied, more research on the determinants of adaptation behavior is required. So far, climate research in Pakistan has been restricted to predicting climatic impacts on certain agricultural yields. As sugarcane is an industrial crop in Pakistan, this research intends to address a study vacuum in the field of agriculture. According to the Pakistan Statistics Authority's Workforce Survey (2017-2018), the agriculture industry employs 39% of the workforce (30.2% male and 67.2% female). Pakistan's average yearly temperature has increased considerably during the last century. Temperatures throughout the country are expected to climb between 0.6 and 1.0°C by the end of the twenty-first century [33]. Thus, identifying climate and its influence on sugarcane output is critical, especially given Pakistan's agricultural sector's change and several environmental disasters. The essential goal of the recent work is to evaluate growers' perspectives and adaptation techniques in the research area in response to the effects of climate change on sugarcane output.

The current paper is separated into six units, the first of which is the introduction. Section two explains the materials and procedures. Section three displays the study results. Section four contains the discussion, while section five describes the research's detailed conclusions.

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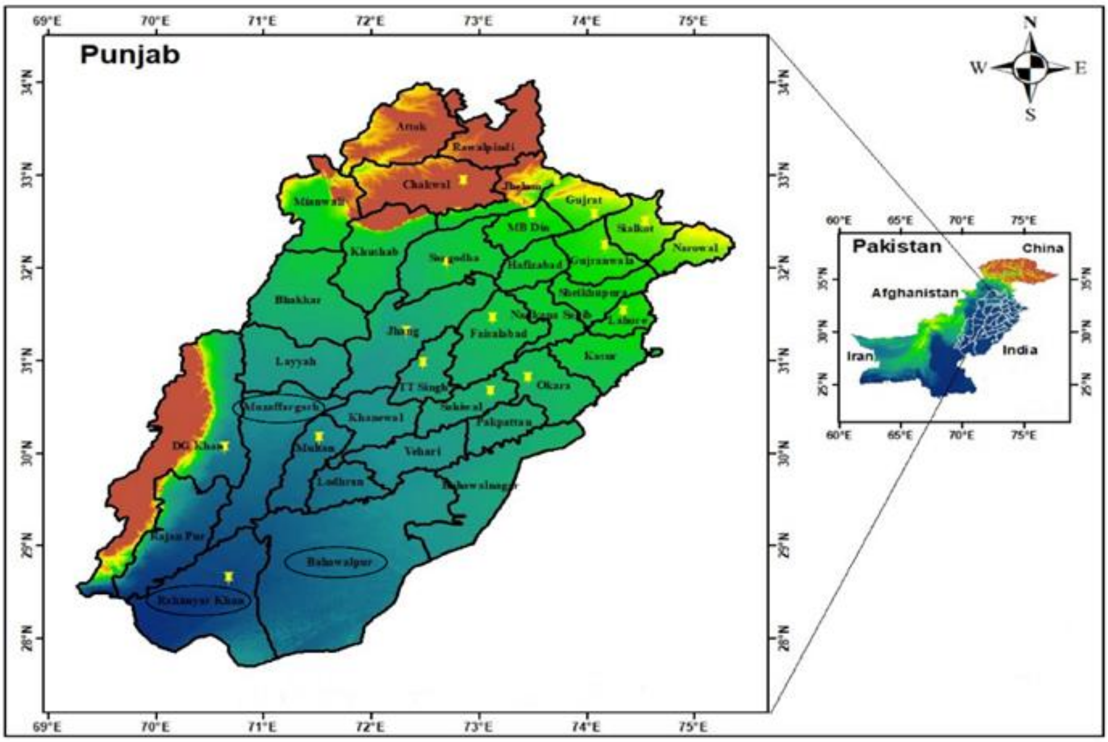
2. Materials and Methods

2.1 Area of Study

The available data were carried out in Punjab, Pakistan in 2022, focusing on sugarcane-producing areas. Punjab is the most populated province and an important agricultural area of Pakistan. Its population surpasses 110 million, the vast majority of whom reside in remote areas (80%) and are utilized in the agricultural sector. This province contributes more than 50% of the nation's entire agricultural GDP. The whole geographical area of the province is 5.03 million hectares, of which 4.2 million hectares are arable (approximately 83%). The agricultural system, public services, and trade are the main income sources for the province. Numerous crops significant to the farming sector are grown, including sugarcane, rice, barley, millet, maize, tobacco, wheat, etc. The province's atmosphere varies from region to region and includes most of Pakistan's climatic regions. Since most of the province belongs to the arid ecoregion [33], rainfall also varies greatly. On the contrary, the eastern part of the studied province is the wettest side of the country, mostly throughout the monsoon phase [34].

2.2 Technique for Data Assortment and Sampling

The existing data were gained in Pakistan's Punjab province; this analysis is based on the original data; in September 2022, a complete questionnaire survey of 390 sugarcane growers was done. To acquire basic information from sugarcane producers, a multi-stage random sample method was utilized. To assess current growers' perspectives of climate and its effect on sugarcane production in Punjab. Firstly, data were gathered in three districts (Bahawalpur, Muzaffargarh, and Rahimyar Khan) based on agriculture's contribution to output in these districts (Figure 1). Secondly, a tehsil was chosen to accomplish the study design questionnaire, and thirdly union council (UC) was selected from each nominated tehsil. Fourthly, four villages were arbitrarily selected for each UC, and basic data were collected from sugarcane producers in the selected villages. The design questionnaire for this study is divided into many parts. The main part of the program questionnaire included information on the socioeconomic and demographic attributes of sugarcane producers. The remainder of the questionnaire was planned to capture important information on producers' perceptions of climate and its impact on sugarcane productivity. The strategic questionnaire was first written in English and later was explained in the local language for ease of sugarcane producers. The study's objective and intended usage were clarified to all selected sugarcane farmers.



2.3 Estimating Climate Change Adaptation and Sugarcane Production

Worldwide, climate change's effects are already being felt. In terms of the incidence of extreme climatic events like extreme temperature events, unpredictable rains, floods, droughts, or crop diseases, climate change is described as felt or observed changes in the local environment during the previous ten to twenty years or more. Climate change and its influence on sugarcane production may be modeled using two-stage modeling. First, we utilized the selection model to choose climate change adaptation strategies. If hazard-averse farmers would adopt climate adaptation to generate revenue, the variable A* represents the net income.

$$A_i^* = Z_i a + \eta_i \text{ with } A_i = 1, \text{ if } A_i^* > 0 \text{ and } 0 \text{ otherwise} \quad (1)$$

The equation 1 where (Ai=1) if Ai* >1 and 0 then farmer i would adopt the climate adaption policy. The sugarcane producers' decision is influenced by the factors represented by vector Z. Farmers' characteristics and climatic information provided via extension workforces were chosen as dependent variables based on the elements of sugarcane producers' decision-making about climate adaptation [31, 34-37]. Their characteristics can be identified by their social and demographic characteristics such as their gender, age, educational background, labor contribution, available land for cultivation, and climate awareness. Notably, available data at the administration level is limited to environmental threads such as drought and frost.

The second-step method mimics the effects of adaptation on sugarcane production. The simplest and most suitable approach is the ordinary least squares (OLS) in the crop production equation which includes dummy variables. However, this technique could lead to several problems during the measurement of the adaption influence of sugarcane production. Such as, adaptation could be endogenous, consequently estimating biased results. Additionally, estimation inconsistency and biased sample selection might lead to skewness in the outcome [30]. An equation model for estimating climate adaptation and their impact on crop production in endogenously changed crops, utilizing occupancy info maximum likelihoods [30]. The present data uses variables associated with climate awareness and environmental information as selection models. As displayed in Table A1 climate change insight and perception pointedly disturbed sugarcane growers' adaptation selections, but not sugarcane productivity in non-adopters. Therefore, reproduced as beneficial selection instruments.

$$y_{1i} = \beta_1 x_{1i} + \varepsilon_{1i} \; if \; A_i = 1 \quad (2)$$
$$y_{0i} = \beta_0 x_{0i} + \varepsilon_{0i} \; if \; A_i = 0 \quad (3)$$

Where Y1i & Y_0i, respectively, represent the production per hectare of sugarcane determined by log adopters and non-adopters. Seed, technology, labor, and fertilizer are examples of input vectors Yi provided in the logarithmic form. The vector of a parameter to be evaluated is β and the error term is ε. Equations 1 and 3 assume that the error terms have a three-variable normal distribution with (η,ε_1,ε_0)~N(0,∑ [38].

$$\text{COV}(\eta, \varepsilon_A, \varepsilon_N) = \Sigma = \begin{cases} \sigma_n^2 & \sigma_{\eta A} & \sigma_{\eta N} \\ \sigma_{A\eta} & \sigma_A^2 & \sigma_{AN} \\ \alpha_{m1} & \sigma_{NA} & \sigma_N^2 \end{cases} \quad (4)$$

Predictable values of ε_1 and ε_0On-zero stated as [35, 36]

$$E\{\varepsilon_{1i}|A_i = 1\} = \sigma_{1i}\frac{\varphi(Z_{i\alpha})}{1-\phi(Z_{i\alpha})} = \sigma_{1\eta}\lambda_{1i} \quad (5)$$

$$E\{\varepsilon_{0i}|A_i = 0\} = -\sigma_{0i}\frac{\varphi(Z_{i\alpha})}{1-\phi(Z_{i\alpha})} = \sigma_{0\eta}\lambda_{0i} \quad (6)$$

The four conditional crop yield predictions can be studied using the Endogenous Switching Regression (ESR) method [36].

$$E(y_{1i}|A_1 = 0) = \beta_{1\chi 1i} + \sigma_{1i}\lambda_{1i} \quad (7)$$

$$E(y_{0i}|A_1 = 0) = \beta_{0\chi 0i} + \sigma_{0i}\lambda_{0i} \quad (8)$$

$$E(y_{0i}|A_1 = 1) = \beta_{0\chi 1i} + \sigma_{0i}\lambda_{1i} \quad (9)$$

$$E(y_{0i}|A_1 = 1) = \beta_{0\chi 1i} + \sigma_{0i}\lambda_{1i} \quad (10)$$

Equations seven and eight reflect the apparent projections in the sample. Equations nine and ten demonstrate that the alternative outcomes are inconsistent. Furthermore, the variation between equations seven and nine might be utilized to calculate the mean treatment effect on treated individuals (ATT). As a result, the difference between equations eight and ten could be considered the average treatment impact for untreated (UT) families. Equations seven and eight show prospective heterogeneity's influence on the "adopter" group ten. Additionally, the variation between (9) and (8) was used to analyze the influence of fundamental heterogeneity in the 'non-adopters' group. For further information on the ESR model, perceive [36].

3. Empirical Results

3.1 Study's descriptive statistics

Table 1 demonstrates an overview and descriptive information about the sugarcane growers questioned. The research revealed that, on average, 85.6% of growers are aware of the climate, 68.6% have developed adaptation plans for changes in sugarcane yield, and 41% have obtained climate change data from outside resources. Farmers have taken some stages to adapt their sugarcane to the climate. In general, important policies comprised augmented irrigation frequency, increased use of fertilizers and pesticides, and climate-adapted crop varieties. Furthermore, about 62% of farmers used more than one acclimation method, and 3% used more than three acclimatization methods. Farmers often knew that the research areas had higher temperatures and less rainfall. Additionally, we gathered complete production data for different manufacturing phases. Household labor and services are two categories of labor conflict. Sugarcane crops are typically sown over an area of 0.482 hectares, and the yield is 24319 kg/ha. Fertilizers, housekeeping, and technology are farmers' three main inputs, with minimal rent and labor costs. Sixty-one percent of the respondents, who were on average 55 years old, had more than nine schooling years.

Table 1. Detailed description, type, and unit of selected variables.

Variable Name	Variable type and Description	Mean	S.D
Adopt	Dummy (1= growers adapt to climate change, 0 = No)	0.685	0.352
SP	Sugarcane production kg/ha	24319.72	2557.27
LA	Land area under sugarcane (ha)	0.482	0.791
SU	Seeds usage kg/ha	2413.04	687.32
TC	Technology cost (per hectare, PKR)	1526.853	701.715
HL	Household labor input (per hectare, PKR)	2638.080	2135.371
EC	Employment cost expenditure (per hectare, PKR)	180.419	581.991
FU	Fertilizer usage (per hectare, PKR)	2476.440	697.026
PU	Pesticides usage (per hectare, PKR)	542.944	296.527
IC	Irrigation cost (per hectare, PKR)	463.738	459.876
G	Dummy (1 = farmers is male, 0 = No)	0.723	0.448
A	Farmers' age	55.123	10.210
ES	Dummy (1 = farmers' education status, 0 = No)	0.614	0.477
HS	Household size (number)	7.060	2.51
CM	Dummy (1 = farmers are cooperative members, 0 = No)	0.765	0.425
WS	Workforce as a share of the total household population	0.603	0.222
ES	Dummy (1 = farmers receive extension service, 0 = No)	0.721	0.435
CP	Dummy (1 = farmers perception about climate change, 0 = No)	0.919	0.286
CC	Dummy (1 = farmers trust climate change impact on sugarcane production, 0 = No)	0.867	0.352
CI	Dummy (1 = farmers gained warning climate information, 0 = No)	0.978	0.121

In this analysis, farmers who opted for at least one adaptation method were called "adopters," while those who adopted none were called "non-adopters." Table 2 exposes variances in features of households between adopters and non-adopters who had pointedly higher average sugarcane yields than adopters. Some aids of non-adopters, such as irrigation and employment costs are much higher than those of adopters. Additionally, adopters' growers are more aware of the climate and their impact on sugarcane productivity and have access to climate knowledge.

Tables 2. Sugarcane cultivator's characteristics of adopters and non-adopters.

Variable Name	Adopters		Non-Adopters		Difference
	M	S.D	M	S.D	
Adapt 1/0	1.000	0.000	0.000	0.000	
SP	2420.887	6822.167	2357.206	6829.708	636.81**
LA	0.809	2.146	0.588	0.948	0.221
SU	1129.629	306.923	1127.578	375.437	12.051
TC	1548.522	651.598	1427.338	906.063	120.184
HL	2708.825	2219.873	2297.456	1644.566	411.369
EC	408.226	905.401	133.105	478.036	275.121 **
FU	544.795	300.001	534.028	281.712	10.767
PU	2520.898	721.167	2467.206	692.978	53.692
IC	593.72	469.75	436.741	454.060	156.979 **
G	0.731	0.444	0.685	0.469	0.046
A	56.238	10.256	55.574	11.241	0.664
ES	0.612	0.488	0.63	0.487	−0.018
HS	0.175	0.127	0.175	0.127	0.038
CM	0.587	0.947	0.808	2.147	0.210
WS	0.597	0.218	0.637	0.236	−0.040
ES	0.621	0.495	0.64	0.491	−0.019
CP	0.977	0.150	0.63	0.487	0.347 ***
CC	0.977	0.150	0.278	0.452	0.699 ***
CI	0.508	0.501	0.056	0.231	0.452 ***

Note: ** and *** indicate statistical significance at 5% and 1%, respectively.

Table 2 presents the characteristics of sugarcane cultivators, based on several factors. Most farmers fall within the 31-40 years old category (49.6%), followed by those aged 41-50 years old (30.8%). In terms of extension services, most farms reported no engagement (92%), while a small percentage had a rating of 1 (4.6%). When considering the number of workers, most farms employed 2-3 workers (40.11%), followed by 4-5 workers (23.83%) and 6-10 workers (24.70%). Regarding the cultivated area, the highest proportion of farms fell within the 11-20 acres category (34.96%). These findings provide valuable insights into the age distribution of farmers, engagement with extension services, worker count, and cultivated area, which can inform agricultural support and decision-making processes within the sugarcane farming industry.

3.2 Measurements for Adaptation to Climate Change and Sugarcane Production Equations

The following equations are generated and adaptively chosen using the ESR model estimations [35]. The findings of the ESR model are shown in Table 3, and the findings of the adaptation selection equation's assessment are shown in the second column, which illustrates the factors that influence climate adaptation. The statistically significant and positive area coefficient shows that growers with larger parcels of land are more likely to use climate adaptation approaches. Both the optimistic and statistically substantial impacts of climate knowledge and perception suggested that sugarcane farmers who were aware of and exposed to climate were more inclined to adjust. The ESR for crop yield was calculated using the evaluated values in columns 3 and 4 of Table 3. Because the observed correlation coefficients were not statistically distinct from zero, sample selection bias might not have existed in the research population [39]. Furthermore, it was suggested that the samples were heterogeneous by changes in the coefficients of the sugarcane production equation between adopters and non-adopters [36, 39, 40]. According to Table 3 findings, both adopter and non-adopter groups' lower sugarcane yields can be attributed in part to area. The yields of sugarcane for adopters and non-adopters, however, appeared to be affected differently by factors such as education, gender, housekeeping, organic manures, irrigation facilities, and cost. Results in three columns showed that irrigation systems and schooling are crucial determinants of adopters' ability to produce sugarcane. Additionally, home labor input seems to affect non-adopter sugarcane production.

Table 3. Displays the outcomes of a regression analysis on the production of sugarcane and the endogenous switching of climatic adaptability.

Variable	Adaptation		Sugarcane Production (Log)			
			Adopters		Non-Adopters	
	M	S.D	M	S.D	M	S.D
G	0.263	1.10	−0.003	−0.07	0.118 **	2.55
A	−0.002	−0.20	0.001	0.58	0.000	0.06
ES	−0.017	−0.07	0.065 *	1.91	0.060	1.15
HS	0.029	0.062	0.022	0.027	0.005	0.023
CM	0.588	0.948	0.809	2.146	0.219	0.588
WS	−0.616	−1.36	0.070	0.98	0.138	1.48
ES	0.028	0.063	0.021	0.026	0.005	00.023
LA	0.298 *	1.85	−0.021 **	−2.55	−0.073 **	−2.17
SU (log)	0.005	0.023	−0.053	−1.28	−0.098	−0.85
TC (log)	−0.003	−0.07	−0.007	−1.10	−0.006	−1.13
HL(log)	0.002	0.59	−0.009	−1.19	−0.105 ***	−2.97
EC (log)	0.022	0.027s	−0.007	−1.35	−0.001	−0.10
FC (log)			0.068	1.26	0.045	0.64
PU (log)			0.042	1.57	0.051	1.27
IC (log)			0.012 ***	4.88	−0.002	−0.27
Rent (0/1)	0.157	0.43	−0.007	−1.35		
CP	1.877 ***	4.91	0.029	0.062		
CI	1.259 ***	4.65				
CONS	−0.923	−1.34	8.189 ***	16.63	9.613 ***	9.81
σ1			−1.402 ***	−29.70		
σ0					−1.999 ***	−10.83
p1			0.347	1.54		
p0	Adaptation				0.584	0.70

Note: The symbols *, **, and *** denote statistically significant differences at 10%, 5%, and 1%, correspondingly.

The possibilities for sugarcane output by growers are shown in Table 4 together with estimates of the impacts of average treatment and possible heterogeneity. The predicted sugarcane yield shown in columns (a) and (b) is seen in the sample. If the adopter chooses not to adopt, column (c) represents the anticipated sugarcane yield, and cell (d) represents the potential sugarcane yield if the non-adopter decides to adopt. Adopters will enhance yields if they do not adapt. Additionally, if non-adopters adapted, they would lose. Additionally, Table 4 final row demonstrates that under the counterfactual scenario, adopters' productivity will be noticeably higher than that of non-adopters. Significant heterogeneity effects imply that irrespective of climate concerns, adopters are more "productive wells" than non-adopters because of some significant heterogeneity source. These results suggested that, if it raises growers' yields, climate change adaptation has a beneficial effect on agricultural output. Our findings are consistent with those made public in Nepal [36], which also indicated that crop production is increased by adaptation. The influence of adaptation on agricultural productivity, however, varies in strength. For instance, Khanal et al [36] indicated that adaptor farmers in research produced a considerably greater production (33%) compared to our example, which saw a 24% boost. Comparable, their analysis indicated that farmers who did not adapt would have had a 22% better output if they had, however in our instance, this number is far lower at 5%. The disparity in estimates may be brought on by variations in agricultural practices and ecological characteristics.

Table 4: Effects of treatment and heterogeneity on adaptation's potential effects on average sugarcane production.

Sub-samples	Stage of Decision		Effects of Treatment
	To-Adapt	Not-to-Adapt	
Adopters	(a) 1177.12 (11.301)	(c) 1214.530 (12.010)	TT= −37.41 *** [−2.677]
Non-adopters	(d) 1331.575 (21.238)	(b) 1486.767 (26.423)	TU= −155.192 *** [−5.168]
Heterogeneity influences	BH_I = 189.192 *** [1.765]	BH_2 = 360.212 *** [1.628]	TH = −171.02 [−4.289]

Note that the *** symbol denotes 1% statistically significant. TT stands for the treatment effect (adaptation) on the treated (for example, rural households that adapted); TU stands for the treatment effect (for example, adaptation) on the untreated (i.e., farm households that did not adapt); BHi stands for the effect of base heterogeneity for rural households that adapted I = 1) and did not adapt I = 2); and TH stands for (TT-TU), or transition phase heterogeneity.

4. Discussion

Past information has shown that several agriculture sector adaptation strategies have produced erratic results [19, 41]. Why did adaptation strategies result in negative findings and fail to reduce environmental risk? Here are some significant reasons why essential adaptation measures have fallen short. First, according to the exploration performed by Liu et al. [42], the volume and frequency of watering should be appropriately reduced throughout the crop growth phase [42]. Therefore, if intense irrigation is used at the wrong periods, adaptive activities taken by producers to raise irrigation frequency and volume in response to decreased rainfall might have a negative influence on sugarcane production. Second inputs of fertilizers are important for cumulative crop yields in Ethiopia and Nepal [35, 36]. However, the use of inorganic fertilizers in Pakistan is higher than in Ethiopia and Nepal [43]. Numerous observed findings have revealed that small farmers face high risks and are ready to utilize extra fertilizers to avoid possible drastic effects of climate risks on farming productivity [19, 44-46].

However, local farmers in Pakistan continue to misuse fertilizers due to limited technical information, the absence of an agricultural workforce, and the recurrent usage of old practices. Chemicals and pesticides cause serious harm to the environment [47]. The unnecessary use of biochemical manures reduces arable land fertility, pollutes water resources [43, 44, 47], and undermines sustainable agricultural advancement [47]. Hence, adaptation activities that enhance fertilizer usage in response to climate change hazards can raise food production in conditions of poor soil fertility. However, excessive usage of chemical fertilizers and pesticides by growers can be used by growers can drastically impact sugarcane yields and undermine the ecosystem. Third, in reaction to low rainfall and an increase in pests and illnesses, many producers have switched to the deficit and disease-resistant sugarcane types. However, improved sugarcane varieties tailored to complicated ecological settings may result in crop failure and disease- and drought-resistant sugarcane varieties may not provide high yields.

Adaptation is essential to reduce climate damage, maintain farmers' incomes, and ensure sustainable agricultural advancement [48]. Pakistani agricultural sector faces serious ecological and resource restrictions, for example, scarce irrigation systems and degraded ecosystems, which may not be feasible despite the adaptive capacity of small farmers. Consequently, the local government of Punjab should take the necessary steps to help rural farmers take appropriate and appropriate adaptation measures, and the government should closely monitor infrastructure development, farming classes, farming discipline, and "water-saving organizations, agricultural information, and quality management systems for agricultural products. Then, rural small growers may waste energy and resources and even suffer losses if they fight alone. The results of further research show that, on the one hand, for the sake of growers, the supportable growth of farming requires the design of irrigation and fertilization engineering approaches to expand the efficiency of fertilizer and water use. Also, focus on research and hybridization of varieties with better genetic resources, which can help increase tolerance to abiotic or biotic stresses and improve sugarcane production under adverse ecological conditions. In addition, governments need to ensure that scientific knowledge, guidance on prevention and use, and materials are easily and safely communicated to farmers and local rural areas to attain the finest outcomes in the present climate. This experiment examines rural growers' perceptions of climate change, adaptation, and its influence on sugarcane yields. Further research will be done on the explanation for this miracle and whether it suggests a widespread issue affecting several regions or breeds.

5. Conclusions

Climate change is an environmental risk common to all commercial sectors, particularly agriculture. In addition, in Pakistan, decades of subtle changes in worldwide and local environments strictly influenced production systems and incomes. Probable defeats at the farm level could be mitigated through appropriate adaptation to climate change. Pakistan is facing dangerous weather phenomena for instance unusually heavy rains and flash floods causing major damage to crops and growers' property. These sufferers are likely to rise as climate impacts intensify in the future. Given the significance of the agricultural sector to the economy and rural sources of revenue, the implications of climate adaptation approaches are far-reaching. While adaptation approaches are vital, not all small farmers apply them. Most farmers and related urban populations in developing republics, including Pakistan, are heavily dependent on agriculture. Hence, adapting to the major influences of climate change could be detrimental to improving rural food security and protecting the livelihoods of households.

The key aim of the current research was to examine the climate self-adaptation of rural growers and its effect on sugarcane production. The study based on a survey of 390 respondents in Panjab, Pakistan, indicated that about 80% of growers are climate aware and about 70% have implemented their adaptation strategies. Area, climate perception, and information provided by farmers largely find out their adaptation assessments. However, sugarcane farmers have inadequate adaptation procedures, mainly resulting in more irrigation and the use of composts and pesticides. The outcomes show that growers' climate adaptation guidelines have largely increased sugarcane yields, suggesting that there may be farmers' maladaptive behavior in climate adaptation. Overall, climate change has negatively impacted the production of staple crops, for instance, sugarcane in the world including Pakistan. With a rapidly and large growing population living under the deficiency stroke, the country is facing food challenges. Governments should develop supportable approaches to this problem to maintain common ground for food security.

Sugarcane yields may increase because of adaptation to climate change. Crop output can be maintained in the immediate term by having access to info about the resources that are available and the adaptation strategies that can be taken. Combinations of adaptation measures outperform individual adaptation measures in terms of supporting adaptation. The country's sugarcane production would increase because of adaptation utilizing climate levels, which would also enhance producers' net financial situation and improve their standard of living. Based on regional farmer demands and climate concerns, recommendations for the proper use of adaptive assistance must be created. As the study's observations show, increased yields are a huge advantage when using adaptations. Inadequate developmental and adaptation steps and incomplete information are important barriers to accessing support for potential adaptation. With the cooperation and active involvement of governmental and non-governmental organizations, it is reasonable to address the limitations of adaptation by providing comfortable access to climate knowledge, increasing the perception of adaptation strategies, educating sugarcane growers, and strengthening their measurements. Given the significance of smallholder farmers in many Pakistani rural areas, proper strategy actions to alleviate the resource limitations of smallholder farmers should get special consideration. Agriculture involves research and macro-level resources, for instance, resource availability, product charges, and ecological implications, in addition to being precisely suited to the local climate. All of these more effective adaptation approaches to environmental change include political decisions that will have a significant long-term influence on agricultural output. Therefore, we advise future research to take these constraints into account. However, this analysis adds to the body of knowledge on the need for climate-smart agriculture planning in low-income and emerging economies, primarily Pakistan. The knowledge and abilities of smallholder farmers are essential for reducing the effects of climate change on sugarcane yields because they influence how well institutional programs work. We advise including these elements in the design and development of future policies. Overall, more study at the national level may considerably influence the design of future policies for viable adaption choices for Pakistani small farmers.

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Table A1. Estimates of the parameters, and validity evaluations of the assessment methods.

Variables Name	Probit Model [a]	OLS Model [b]
	Adopt 1/0	**Non-Adopt Yield/ha**
	Mean (S.D)	**Mean (S.D)**
G	0.244 (0.236)	0.117 ** (2.08)
A	−0.003 (0.0012)	0.000121 (0.04)
ES	0.033 (0.0230)	0.089 (1.45)
WS	−0.437 (0.0335)	0.144 (1.31)
ES	0.444 (0.110)	0.207 (1.48)
LA	0.015 (0.010)	−0.059 (−1.38)
CP	1.878 *** (0.0333)	0.011 (0.056)
CI	1.229 *** (0.262)	−0.136 (0.0109)
(log) SU	0.144 (1.31)	−0.029 (−0.30)
(log) TC	0.124 (1.21)	0.034 (0.40)
(log) HL	0.205 (1.41)	0.00365 (0.s)
(log) EC		−0.071 * (−3.02)
(log) PU		0.00104 (0.12)
(log) FP		−0.0138 (−0.22)
(log) IC		0.054 (1.14)
Rent (0/1)	0.121 (0.224)	
CONS	−0.640 (0.512)	8.725*** (8.25)
Valid test on data sources	χ^2 = 77.55 ***	F-stat. = 1.77
Number of respondents	390	51

Models a and b are (pseudo R2 = 0304; R2 = 0.445). Statistical validity is indicated by the symbols *, **, and *** at 10%, 5%, and 1%, respectively.

Table. A2. Perception of sugarcane growers on climate change and its impact on sugarcane production and adaptation actions

Climatic limitations	Related Climate risks	Growers have a substantial influence on sugarcane productivity	Farmers' adaptation activities
Temperature	Improved temperature	A greater need for irrigation results from increased evapotranspiration. increased insect and disease infestation, new pests and illnesses introduced, reduced grain quality decreased yield	cultivate short-lived cultivars, cultivate pest- and insect-resistant cultivars, Variety planting locations should be changed in the irrigation system increasing the amount of weeding, put additional pesticides to use

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Precipitation	The rainfall schedule has changed, with the monsoon starting later than usual, and less access to the surface, and groundwater Long periods of drought, Floods, and landslides are brought on by infrequent but strong rainfall.	Poor germination, Reduced tiller count, delayed panicle start, and decreased grain and panicle due to water stress implantation delay water shortage for irrigation crop loss brought on by heavy rain or hailstorm destruction of irrigation canals and water resources eroding soil decline in soil quality, Reduced yield.	Techniques for conserving the soil minimize tillage, Seed priming, relocating varieties' planting sites, Changing the date of planting, sowing, or harvesting cultivation of crops with direct seeding, increasing seed production short duration growth, Varieties cultivate drought-resistant plants. To enhance/increase usage of chemical fertilizers, Improve/increase the usage of farmyard manure, build waterways while there is a lot of rain cultivate flood-resistant plants, Change to a different crop

Table. A3. Growers' awareness of climate change and its impact on sugarcane production and proportion of growers' adaptation measures.

Climate change perception	%	**Climate change effect on sugarcane yield**	%	**Adaptation approaches**	%
No change	8	No impact	16	No change	17
Reduced precipitation	62	Climate change effects on sugarcane yield	13	Change sugarcane varieties (drought tolerant and disease)	23
Enhanced drought consequences	64	No impact	30	Expand pesticide and fertilizers utilization	48
Enhanced perception	11	More infestation of insects and diseases	41	Afforestation	6
Enhanced temperature	45	Required more irrigation	63	Purchase climate protection	10
Enhanced heavy rainfall (flood)	4	Sugarcane loss due to precocity	27	Drill the deep well	3
Reduced temperature	16	Yield decreases due to lodging	41	Change the seeding and harvesting date	7

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