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Research Article

POTENTIAL IMPACT OF CLIMATE-SMART AGRICULTURE (CSA) PRACTICES ON COTTON PRODUCTION AND REDUCTION IN GREENHOUSE GAS (GHG) EMISSIONS IN SOUTH PUNJAB, PAKISTAN

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ABSTRACT. Adopting Climate-Smart Agriculture (CSA) is an innovative approach compared to conventional resource-intensive farming. The current study aimed to investigate the impact of climate-smart practices in cotton production and the reduction potential of GHG emissions due to optimized use of farm inputs and conservative farm operations in the core cotton zone of Punjab (Khanewal and Bahawalpur). The adopters of CSA (n=200) and non-adopters of CSA (n=50) were randomly selected, and the data were collected using well-structured questionnaires in the cotton-growing season. CSA practices/technologies include using resilient cotton varieties, laser land leveling, sustainable farm operations, optimized fertilizer inputs, integrated pest management, and efficient irrigation. The analytical tools viz., descriptive statistics and a Tobit regression model were used to analyze the adoption impact of CSA interventions. In contrast, Cool Farm Tool (open-source software) estimated GHG emissions during cotton production. The statistical comparison analysis revealed that adopters of CSA were significantly ($p \leq 0.001$) far better than non-adopters of CSA in the efficient resource utilization and produced high cotton yield (887.90 kg acre^{-1}) with the maximum net return (21,017.99 PKR acre^{-1}) and good benefit-cost ratio (1.37). Our results also depicted that widespread adoption of CSA interventions has the potential to minimize GHG emissions by 25.87% (1258.11 kg CO_2 e acre^{-1}) as compared to the non-adopters of CSA (1697.14 kg CO_2 e acre^{-1}), thus helping in reducing climatic risks in agricultural production systems besides improving resource utilization, enhance crop productivity and farmers' income. The study's findings will help create an enabling policy environment to minimize farmers' financial load by adopting CSA practices and scaling up among the farming communities of the entire province and beyond.

Keywords: *Climate-smart agriculture, cotton production, economic analysis, greenhouse gas emissions, south Punjab, Tobit model*

INTRODUCTION

Agriculture is considered the backbone of Pakistan's economy and is prone to climate change and highly vulnerable to increasing threats of weather variability due to distinct geography, demographic trends, and socioeconomic factors [1, 2]. The situation is getting worse owing to a lack of adaptive capacities; thus, the accumulative vulnerability of the farming communities has become a significant threat to the efforts for poverty alleviation and ensuring food security in Pakistan [3]. The advent of the Green Revolution in resource-intensive crop production has given birth to increased environmental challenges, viz., climate change, habitat loss, soil degradation, and deterioration of water resources (quality and quantity) [4, 5, 6]. Hence, executing conservation-focused strategies and increasing ecosystem sustainability can aid in reducing and even counterpoise these challenges [7]. The Food and Agriculture Organization (FAO) has encouraged climate-smart agriculture (CSA), consisting of three main pillars (i.e., adaptation, food production, and mitigation measures) that maintain sustainability in the agricultural production system [8]. CSA is a reliable and sustainable approach to substitute conventional agriculture. It is intended to enhance the efficiency of natural assets, improve climate resilience, and mitigate greenhouse gasses (GHG) emissions in agriculture production [9, 10].

Pakistan is the 5th largest producer of cotton (*Gossypium hirsutum* L.); this cash crop is grown on a large scale and contributes 0.6 percent to the gross domestic product (GDP) and 3.1 percent of the agricultural sector's value-added. It is a significant crop in southern Punjab (cotton zone) after wheat in terms of cultivated area. Though Pakistan is the fourth-largest cotton producer, this crop is prone to climate variability and has been declining over time due to the conventional agriculture farming system [11]. Numerous studies revealed that climate change adversely affects cotton production, inefficient cotton management practices (i.e., excessive water irrigation and the intensive application of agrochemicals via fertilizer, pesticide, and herbicides), and market failures [12, 13, 14]. In Pakistan, most farmers still practice conventional farming approaches for cotton production, which have increasingly proven ineffective in combating challenging climatic variability and require farming practices to be modified under changing weather patterns [13, 15]. The adverse effects of climate change and variability on cotton production can be reduced by adopting climate-smart agricultural (CSA) practices/technologies at the farm and regional levels. Recent studies demonstrated that adopting CSA practices/technologies (individually or in combination) significantly reduces the negative impacts of climate change and enhances resource input efficiency, yield, and farm income sustainably [9, 16, 17]. Besides, the adaptability of CSA is considerably influenced by socio-economic features, economic profits, type of ownership, quality and scarcity of groundwater, credit access, and extension services [3, 16, 18, 19].

Greenhouse gas (GHG) emissions by agricultural production are the major contributor to global warming, with carbon dioxide (CO_2) emissions accounting for an estimated 77% of GHGs and thus having a massive impact on the ecosystem [20, 21]. Pakistan is acutely vulnerable to climate change and accounts for 0.8% of global emissions, estimated at 355 megatons of CO_2 equivalent [22]. Higher crop intensity, excessive chemical inputs (pesticides & synthetic fertilizers), and increasing dependence on mechanization lead to increased GHG emissions from farm operations, i.e., the application of agrochemicals and farm machinery using more fuel [23]. Likewise, cotton production requires significant energy resources for seed plantation, crop cultivation, irrigations, application of agrochemicals, harvest, and transport, resulting in more GHG emissions [9, 24]. Thus, various agriculture management practices/technologies related to CSA have been recognized as tools to minimize adverse environmental impacts, mitigate GHG emissions [25], and increase carbon sequestration [6, 26]. Similarly, some practices, viz., planting cover crops, extended crop rotations, reducing tillage intensity, water, and nutrient management (exact use of nitrogen fertilizers), can reduce GHG emissions (mainly carbon dioxide and nitrous oxide emissions) from agricultural cropping systems [27, 28, 29, 30]. Hence, we hypothesized that implementing various CSA interventions would reveal significant potential to enhance cotton production (yield) and reduce GHG emissions (on-farm). Such assessments would assist using low-cost inputs and low-tech approaches for climate change mitigation and adoption.

The current investigation aims to assess the impact of CSA interventions in cotton production under WWF-Pakistan's Climate Resilient Crop Production (CRCP) project. The study that was conducted in two regions of southern Punjab (Khanewal and Bahawalpur) provides rich information about the resource-use efficiency of cotton farmers (i.e., adopters and non-adopters of CSA), improved productivity, and the potential of GHG emissions reduction by the adoption of different CSA practices/technologies.

MATERIAL AND METHODS

Study Sites

This study is focused on the Punjab province due to its significant share in Pakistan's cotton production and GDP by 80% and 53%, respectively [9, 21]. The current study was carried out in two districts of southern Punjab viz., Khanewal (30° 17' 11.0940" N and 71° 55' 55.3080" E) and Bahawalpur (29° 25' 5.0448" N and 71° 40' 14.4660" E) in the cotton cropping season of Punjab (Fig. 1). It was piloted by WWF-Pakistan's Climate Resilient Crop Production (CRCP) project under the program of Food and Markets. Both districts were selected due to large areas under cotton cultivation and having a high agricultural vulnerability to climate variability [31]

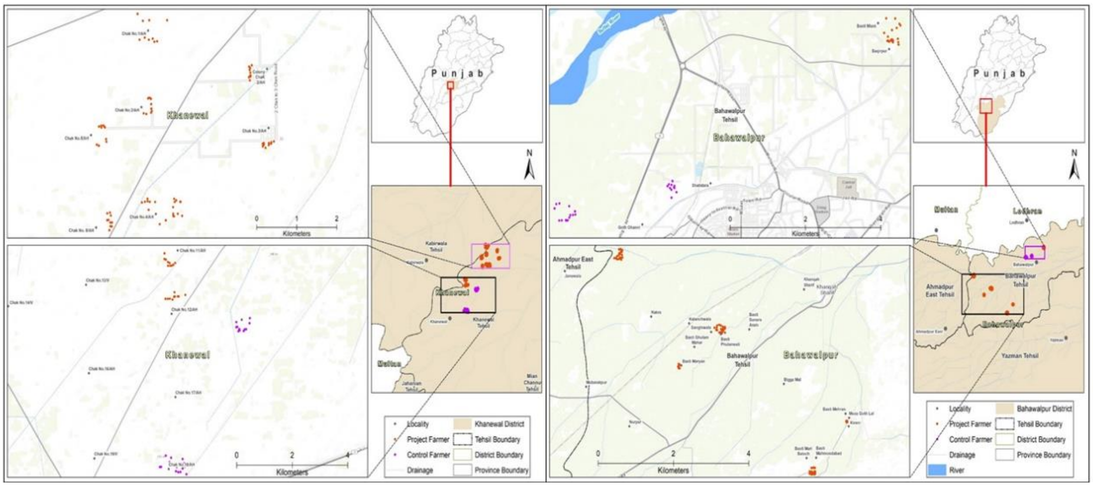

Fig. 1. *Selected regions of south Punjab (Khanewal and Bahawalpur) to conduct the study by WWF-Pakistan*

Selection of Farmers

The cotton farming communities in these two districts, i.e., Khanewal and Bahawalpur, are subjected to different environmental and socioeconomic issues under climate variability [32]. Hence, cotton-farming families were purposefully involved, and more than 4,000 cotton growers registered under the CRCP project from the selected regions. About 160 climate-smart groups (30-40 farmers per group) were organized from the selected farmers (4,000) according to availability in the same area. The field trainers (FTs) were trained to conduct the preliminary survey, and a planned questionnaire was used to gather the data on the farmers' adaptive practices for cotton cultivation.

Training of Farmers for the Adoption of CSA Practices

After the selection and grouping of cotton-growing farmers, the CRCP project team developed the training material based on the following CSA interventions:

Crop Production and Protection

Via seed selection (climate-smart cotton varieties: pest and disease-resistant varieties), seed treatment (seed dressing with fungicides and insecticide), a suitable time for planting (to manage pests and diseases), optimization of plant population per acre, use of bio-products to control pest, e.g., pheromones traps, judicious use of pesticides/herbicides based on regular pest monitoring data.

Soil Health Improvement

Via soil conservation (minimum tillage practices), fertilizer calculation [using fertilizer calculation tool (UAF)] and application for the right amount and suitable source of nutrients based on soil test results, use of bio-fertilizers (i.e., bio-power and phosphorus pool), and application of liquid organic manures.

Water Conservation

Via on-farm water conservation practices, e.g., laser land leveling, smart-sowing techniques (multi-bed planter) to avoid water losses and improve water productivity, procurement of drought-resistant varieties, and management of soil organic matter.

Precision Agriculture

Via demonstration of climate-smart farm machinery, e.g., laser land leveler, multi-bed planter, and on-farm weather station (updating information about weather forecasts).

A training plan was designed, and FTs were trained in the aforementioned thematic areas. The training sessions were organized & conducted by FTs (two training events per month) to ensure the familiarity of farmers with climate-smart agricultural (CSA) practices/technologies. Consistent with the training plan, farmers were trained through establishing demonstration sites and implementing CSA practices according to the crop growth stage and requirement. Trial plots were established at each selected region (Khanewal and Bahawalpur). The following salient interventions were adopted such as soil analysis was done before cotton sowing, and the. Thedations for the application of plant nutrients [(urea, diammonium phosphate (DAP), calcium ammonium nitrate (CAN), nitrophos (NP), and gypsum)] were suggested accordingly (at different growth stages of the crop). Minimum tillage practices and laser land leveling were adopted to conserve soil and water. Adopters of CSA were also facilitated to use the seed of resilient cotton varieties developed by premier research institutions [i.e., Central Cotton Research Institute (CCRI), Multan] for cotton cultivation. Besides this, seeds were treated with fungicides (Oberon) and insecticide (Imidacloprid)] before sowing as a preventive measure to control diseases (fungal and insect attack). Likewise, almost 7-8 pheromone traps acre-1 were installed to control the pest along with the 5-6 sprays of different pesticides, and 1 spray of herbicides mixture (Pendimethyline and Acetochlor) was applied to manage cotton pests and weeds. For the improvement of soil health, seeds were treated with bacterial inoculum (biofertilizers: bio-power and phosphorus pool), and the rational amount of the fertilizers viz., urea, DAP, CAN, and NP were applied following the 4R model (right source, correct rate, corrective & right place proper, as well as a liquid organic manure fermenter was built at each farm site. Moreover, a weather station was installed to record weather updates to manage the plan of irrigation and tubewell) for cotton cultivation.

Data Collection

Adopters of CSA (n=200) and non-adopters of CSA (n=50) were randomly selected from the project working areas of Khanewal and Bahawalpur for cotton cultivation. The farmers were interviewed using a well-structured and comprehensive questionnaire at their farm sites,. The maximum information was acquired about cotton cultivation in the respective cotton-growing season. The data (viz., cotton cropping area, selected cotton varieties, land preparation/management practices, crop production & protection practices, irrigation, and yield) were collected from both groups of cotton farmers and compared to estimate the impact of various CSA interventions.

Cotton Crop Budget: Total Cost (TC)

Different types of inputs (fixed and variable) were involved in cotton production. To estimate the on-farm crop production budget, the total cost of cotton cultivation includes the cost of all inputs, viz., seed procurement and treatment, land preparation, seed sowing, intercultural operations, fertilizers, pesticides, herbicides, and irrigations (canal and tubewell) as well as labor cost.

Data Analysis

Economic Analysis

An economic analysis was also computed to assess the progressive effect of CSA interventions compared to the conventional system of cotton cultivation in both districts. The data relating to cotton yield and net returns after implementing particular CSA practices/interventions in cotton production were compared between adopters and non-adopters of CSA. The predictable total cost and benefit were used to analyze the financial performance of cotton growers (adopters and non-adopters of CSA). The total revenue (TR), total cost (TC), net return (NR), benefit-cost ratio (BCR) ratio, and productivity of cotton were calculated using the formula followed by the previous studies [9, 24, 33].

$$TR = Q \times P \ [Q = \text{yield (kg acre}^{-1}\text{)}, P = \text{price of yield (PKRs acre}^{-1}\text{)}] \quad (1)$$

$$TC = V \times X \ (\text{PKRs acre}^{-1}) \ [V = \text{input prices}, X = \text{input purchase quantity}] \quad (2)$$

$$NR = TR - TC \ (\text{PKRs acre}^{-1}) \quad (3)$$

$$BCR = TR/TC \quad (4)$$

$$\text{Productivity} = Q/TC \ [Q = \text{yield (kg acre}^{-1}\text{)}, TC = \text{Total cost (PKRs acre}^{-1}\text{)}] \quad (5)$$

Finally, the quantitative data were tabulated, summarized, and analyzed using Statistical Package of Social Science (SPSS) version 25. The input and output differences in cotton cultivation between both groups of cotton farmers (adopters of CSA and non-adopters of CSA) were assessed by an independent two-sample *t-test* assuming unequal variances for comparing the mean values [13, 34].

Econometric Model

The Tobit model is widely used to analyze the adaptation and awareness to climate variability [35, 36] in testing the farm practices/technology adoption decision logy hypothesis. The focal feature of the Tobit model is not only to measure the adoption decision but also the intensity of adoption [37]. As the cotton crop is drastically affected by climate change and farmers are sensitive regarding climatic uncertainties in Pakistan [38], in the present study, a Tobit model was used to analyze the adoption impact of climate-smart agriculture (CSA) through sustainable management practices for land preparation, fertilizers application, pest and weed protection, and irrigation for cotton production in two districts of south Punjab (Khanewal and Bahawalpur). Likewise, the data for this analysis were used to find the adoption impact on farm management practices and crop yield.

There were distinct dependent and independent observations regarding certain variables due to specifically recommended quantities for the stakeholders in training sessions [39, 40]. The current study's data collected from the adopters and non-adopters of CSA were bounded within a given range. Excessive zeroes complicate the use of linear econometric techniques for these datasets [4,1], and that’s why we use a Tobit regression model. The adaptation package improves the crop yield with rational resource allocation at the farm.

Ho = The proposed climate-smart interventions positively impact crop yields with resource conservation

H1 =The proposed climate-smart interventions have no positive impact on crop yields without resource conservation

For our data sets, we have two cotton farmer groups, i.e., adopters and non-adopters of CSA. We have all the information about CSA management practices with certainty for adopters, but we censored data for non-adopters. On-farm adaptation is of two types: one is planned, and the other is unplanned adaptation. So, the control group might adopt specific adaptations independently, but we consider them non-adopters [42]. In the Tobit model, the dependent variable is an adaptation, assigned the value of 0 for not adapting and 1 for adapting.

$$Yi = B1 + B2\,Xi + \mu i \quad if \qquad RHS > 0$$

Yi= 0 Otherwise

Yi =Farmers adoption status about CSA (Non adopters = 0 and adopters=1)

Xi= Impact of adoption on-farm management operations

GHG Emissions Calculation

The reduction in net greenhouse gas (GHG) emissions was analyzed between both groups of cotton farmers (adopters and non-adopters of CSA) in both regions of south Punjab (Khanewal and Bahawalpur). Elevation in GHG emissions in the agriculture production system is directly linked with the intensification of farming activities (i.e., residue management, fertilizer applications, crop protection, irrigation, on-farm/off-farm energy use, etc.) [43]. In the current study, on-farm GHG emissions were calculated using an open-source software online calculator, “Cool Farm Tool” (version CFT v0.11.35) [44]. The GHG emissions, such as total emissions per acre and emissions per kg of cotton yield, were figured by activity data input on soil, climate conditions, and farm management practices such as cotton-growing area & yield, soil properties (texture, moisture, pH, soil drainage capacity & organic matter), inputs (fertilizers, pesticides &

herbicides), fuel and energy (diesel used by all types of machinery), irrigation (occasions, water source, water used), and carbon sequestration [45]. The percent reduction in cumulative GHG emissions from both districts (Khanewal and Bahawalpur) was estimated using the following formula:

$$\text{Percent reduction GHG emission} = (G1 - G2)/G1 \times 100$$

Where G1 is GHG emissions accounted by non-adopters of CSA in cotton production and G2 is GHG emissions produced by adopters of CSA in cotton production

RESULTS AND DISCUSSION

Cotton Cultivation Area

The results showed that the average area under cotton cultivation was almost the same 6.30-6.85 acres between both groups of farmers (adopters and non-adopters of CSA). (Khanewal and Bahawalpur). Climate-smart cotton variety "IUB-13" was highly cultivated by adopters of CSA (20%) followed by Niab-Kiran (14%), BS-15, GH-UHAD, CIM-313, & Mubarak (12%), Deebal and Cyto-179 (9%) in both selected districts of Punjab (Khanewal and Bahawalpur). About 75% of the CSA adopters also cultivated two different cotton varieties on the same land. Nonadopters of CSA selected local cotton varieties (from 18 different varieties) for cultivation, and more than 75% of cotton farmers were reluctant to cultivate two cotton varieties simultaneously.

Inputs Used by Cotton Farmers (Adopters and Non-Adopters of CSA)

The level of inputs was considerably varied between adopters and non-adopters of CSA (Table 1). Adopters of CSA have used a significantly low level of inputs such as low rate of seed, fertilizers, sprays of pesticides and herbicides, less mechanical operations, less amount of water applied, and fewer labor hours compared to the non-adopters of CSA. The current findings of inputs used by adopters of CSA were coherent with Imran et al. [9].

Seed Rate

The average seed rate differed significantly in both farmer groups (Table 1). Adopters of CSA used a significantly low amount of average seed (7.93 kg acre^{-1}) as compared to the non-adopters of CSA (11.39 kg acre^{-1}) at $p \leq 0.001$. A similar difference was noticed in the previous studies reported by Imran et al. [9, 24].

Land Preparation

The data displayed that adopters of CSA from both districts (Khanewal & Bahawalpur) were done climate-smart interventions for land preparation and seed sowing practices. At the same time, non-adopters of CSA have opted for more numbers of cultural practices (Table 1) as they were committed to conventional agricultural management practices [46]. About 28% of adopters of CSA used deep ploughs, 12% used disc plough, and 100% of farmers used cultivators (n=2-times) and rotavators (n=1-time) for land preparation. In contrast, all non-adopters of CSA have not used deep plough, while 47% of farmers used disc plough, 100% used cultivator (n=3-4 times) and rotavator (n=1-2 times) operations for land preparation. Likewise, about 80% of adopters of CSA used multi-bed planters for seed sowing; the remaining were done by the drill (7%) and dibbling method (14%).

While non-adopters of CSA used two methods of seed sowing viz., drill and dibbling, by 65% and 35%, respectively.

Lase Land Leveling

Laser land leveling (LLL) is one of the important interventions under CSA practices/technologies, it increases input cost but assists water conservation as well. Moreover, LLL helped to reduce GHG emissions by significantly reducing the demand for tubewell irrigated water by 38% ($p \leq 0.01$) between the adopters of CSA (2739 m^3) and non-adopters of CSA (4434 m^3) (Table 1). Likewise, Abdullaev et al. [47] reported that laser land leveling reduced the demand for water irrigation which resulted in less runoff (24%) and deep percolation (8%) as relevant to the non-leveled field. Furthermore, this technology saved a considerable amount of energy and operating time (about 15%) during on-farm agricultural operations (Aryal *et al.*, 2015). Our results were coherent with the previous outcomes of Ali et al. [19] and Ahmad et al. [48] in terms of water conservation and productivity.

Nutrient Management

Adopters and non-adopters of CSA used considerably varied amounts (kg) of inorganic fertilizers (Table 1). Our results showed that adopters of CSA have used significantly lower inputs of fertilizers i.e., urea ($p \leq 0.05$), DAP ($p \leq 0.01$), and NP ($p \leq 0.001$) than non-adopters of CSA. While 100% of non-adopters of CSA were using the highest amount of inorganic fertilizers especially the application of NP was 70% more than adopters of CSA, this result is consistent with a previous study by Imran et al. (2018). This indicates that non-adopters of CSA had a higher dependency on fertilizers. Additionally, adopters of CSA considerably used biofertilizers ($p \leq 0.001$), liquid organic manure (via installed on-farm fermenter), and gypsum fertilizer (to improve groundwater quality) as compared to the non-adopters of CSA. The findings of Zulfiqar and Thapa [13], Khatri-Chhetri et al. [16], and Hussain [49] related to nutrient management are consistent with our results.

Pest Management (Herbicides & Pesticides)

Plant protection was started with the sowing of crop seed, and a significant variation ($p \leq 0.001$) was observed in the frequencies of synthetic herbicides and pesticide applications between two groups of cotton farmers (Table 1). Adopters of CSA have sprayed a mixture of herbicides (Pendimethyline and Acetochlor) just once (n=1) while 70% of the non-adopters of CSA were sprayed with the same herbicides 2-times (n=2). Likewise, adopters of CSA were used significantly ($p \leq 0.001$) fewer numbers of pesticide applications (n=5). In contrast, 73% of the non-adopters of CSA were sprayed with different pesticides almost 8 times (n=8). Khan and Damalas [50, 51] also reported that less than 50% of conventional cotton farmers disclosed an affinity toward the overuse of pesticides by spraying higher applications of pesticides.

Table 1. *Level of inputs (acre^{-1}) by cotton farmers in South Punjab (Khanewal and Bahawalpur)*

Practices (acre^{-1})	**Unit**	**Adopters of CSA (N=200)**	**non-Adopters of CSA (N=50)**
Land Preparation			
Deep ploughing	f	0.28***	0.00
Cultivator	f	2.00	3.32***
Rotavator	f	1.00	1.75***
Disc plough	f	0.12	0.57***
Seed, treatment and sowing			
Seed rate	kg	7.93	11.39***
Seed treatment	f	2.00***	0.00
Seed sowing operations	f	2.17	3.33***
Pest Protection			
Installed pheromone traps	f	7.39***	0.00
Pesticide spray	l	4.38	7.49***
Herbicide spray	l	1.00	1.74***
Nutrient Management			
Urea	kg	104.39	109.59 *
Diammonium phosphate	kg	67.71	75.88**
Gypsum	kg	18.25***	0.00
Nitrophos	kg	21.18	71.09***
Calcium ammonium nitrate	kg	35.39 ^{ns}	30.26
Biofertilizers	kg	2.00***	0.00
Water management			
No. of canal irrigation	f	4.49 ^{ns}	4.31
Canal irrigation	m^3	113.41	128.50 ^{ns}
No. of tubewell irrigation	f	12.27	14.66**
Tubewell irrigation	m^3	2739	4434**

Note: The significance values * at $p \leq 0.05$; ** at $p \leq 0.01$; *** at $p \leq 0.001$; $^{\mathbf{ns}}$ at the non-significant level for two-group mean comparison t-test assuming unequal variances.

CSA: Climate-Smart Agriculture; **f**: frequency; **kg**: kilogram; **l**: liter; **m^3**: cubic meter

Water Management

Both adopters and non-adopters of CSA from both districts applied an almost equal number of canal irrigations (n=4-5 times) and the volume of water irrigated by the canal system (each time) was estimated approximately 120 m^3 acre^{-1} which was not significantly different between adopters and non-adopters of CSA (Table 1). However, the rate of tubewell irrigation was found to be significantly different at $p \leq 0.01$ by the adopters of CSA (n=12 times) as compared to the non-adopters of CSA (n=14-15 times) in both districts [49]. Hence, a significantly high volume of water (4,434 m^3 at $p \leq 0.001$) was utilized by non-adopters of CSA to irrigate an acre of cotton-cultivated land as compared to the adopters of CSA (2,739 m^3 acre^{-1}) (Table 1).

Cost of Production

The average cost of production for cotton cultivation in both regions of Punjab (Khanewal and Bahawalpur) has been shown in Table 2, including the costs of land preparation, seed, seed treatment, seed sowing, pest management, nutrient management, and irrigation. The total production cost of cotton cultivation by the non-adopters of CSA was significantly higher than that of adopters of CSA (Table 2), which was attributed to the application of higher amounts of inorganic fertilizers/chemicals and excessive use of water (especially via tubewell) (Table 1). The results showed that non-adopters of CSA attained significantly higher costs in average seed rate ($p \leq 0.001$), inorganic fertilizers ($p \leq 0.01$), pest control ($p \leq 0.001$), and irrigation ($p \leq 0.001$) than adopters of CSA (Table

3). Although non-adopters of CSA showed significantly higher levels ($p \leq 0.001$) of cultural practices/operations for land cultivation as compared to adopters of CSA, even an average cost of land preparation was significantly higher (6,051 PKR acre^{-1} at $p \leq 0.05$) by the adopters of CSA than non-adopters of CSA (5,527 PKR acre^{-1}) in both districts (Table 2), These results are in line with the other studies [13, 18, 51, 52].

Table 2. *Cotton production summary (acre^{-1}) in south Punjab (Khanewal and Bahawalpur)*

Practices	Adopters of CSA (N=200)	non-Adopters of CSA (N=50)
Land Preparation	**Average cost: PKR acre^{-1}**	
Cost of deep ploughing	341.23***	0.00
Cost of cultivator	1699.00	2775.49***
Cost of rotavator	1175.00	2027.45***
Cost of disc ploughing	109.50	555.90***
Cost of land cultivation	3324.00	5357.84***
Cost of land leveling	2727.13***	156.86
Seed, treatment and sowing		
Cost of cottonseed (average of V1 & V2)	2008.54	2973.63***
Cost of seed treatment	782.00***	0.00
Cost of seed after treatment	2790.54	2973.63**
Cost of seed sowing	2853.25*	2746.08
Pest Management		
Cost of installation of pheromone traps	833.60***	0.00
Cost of all pesticides	3108.90	3942.84***
Cost of pesticide application	1731.50	2882.35***
Weed Management		
Cost of all herbicides	945.50	1674.88***
Cost of herbicide application	947.25	1658.96***
Nutrient Management		
Cost of urea application	3757.87	3944.47 *
Cost of DAP application	4875.44	5476.24**
Cost of gypsum application	438***	0.00
Cost of nitrophos application	1143.45	3832.94***
Cost of CAN application	1273.86^{ns}	1083.53
Cost of biofertilizers	380.00***	0.00
Cost of broadcasting of fertilizers	723.50	1249.50***
Irrigation		
Cost of tubewell irrigation	610.63	762.52**
Cost of total irrigations (canal+tubewell)	13588.43	18220.22***

Note: The significance values * at $p \leq 0.05$; ** at $p \leq 0.01$; *** at $p \leq 0.001$; ^{ns} at the non-significant level for two-group mean comparison t-test assuming unequal variances.

CSA: Climate-Smart Agriculture; **PKR**: Pakistani rupee

This study uses the average exchange rate for the year 2019 (1 PKR = 0.0064 USD) when the survey was carried out.

Economic Analysis

The economic analysis was estimated using the benefit-cost ratio (B:C) in cotton production by both groups of cotton farmers (adopters and non-adopters of CSA). The results showed that there is a significant difference in the costs of inputs and outputs (benefits) between both groups of cotton farmers (Table 3). The cotton yield (kg acre^{-1}) and net crop were found to be significantly higher in the case of adopters than non-adopters of CSA (Table 3). The average cotton yield harvested by the adopters of CSA and non-adopters of CSA was 887.90 kg acre^{-1} (22.19 maund acre^{-1}) and 726.35 kg acre^{-1} (18.18 maund acre^{-1}), respectively. Notably, despite the relatively low level of inputs viz., inorganic fertilizers, pesticides, herbicides, and irrigation (Table 1), the harvested yield by adopters of CSA was significantly higher by 22% at $p \leq 0.001$ than that of non-adopters of CSA in both regions of south Punjab (Khanewal and Bahawalpur). The current results indicated that farmers who adopted CSA interventions attained the maximum cotton yield (kg acre^{-1}) and net income level (PKR acre^{-1}) than non-adopters of CSA likewise reported in previous studies [53, 54, 55, 56].

Additionally, our results revealed that the net return (profit) of adopters of CSA was found to be significantly several times higher (21,018 PKR acre^{-1} at p≤0.001) than that of non-adopters of CSA (2,468 PKR acre^{-1}) (Table 3). This is because, the conventional agricultural system uses extensive resources and practices (i.e., excessive use of chemicals, land cultivation operations, and water applications) that not only reduce yield and net return but also threaten future food production by limiting biodiversity, degrading the environment, and changing climate as reported in previous literature (Zulfiqar and Thapa, 2016, 2018). Likewise, the financial return per unit of input cost was analyzed and the results displayed that adopters of CSA showed a significantly good B-C ratio by 1.38 at p≤0.001 as compared to non-adopters of CSA (1.04) (Table 3). Likewise, adopters of CSA were far better in terms of cotton productivity by 38% as compared to non-adopters of CSA. The current results indicated that the cotton yield harvested by adopters of CSA was financially superior over non-adopters of CSA. The findings of our study are in line with the findings of other studies conducted in a similar context [18, 57, 58, 59].

Table 3. *Cost and benefit analysis of cotton production (PKR acre^{-1}) in south Punjab (Khanewal and Bahawalpur)*

Cost and Benefit	**Adopters of CSA (N=200)**	**non-Adopters of CSA (N=50)**
Inputs Cost (PKR acre^{-1})		
Land preparation cost	6051.13*	5526.73
Average seed	2008.54	2973.63***
Seed sowing	2853.25*	2746.08
Pheromone traps	833.60***	0.00
Pesticides	3108.90	3942.84***
Herbicides	945.50	1674.88***
Fertilizers	11489.61	14337.18**
Biofertilizers	380.00***	0.00
Irrigation	13588.43	18220.22***
Cotton picking cost (PKR/kg)	9.79	9.82^{ns}
Picking cost (PKR/net yield)	8694.00**	7133.72
Labor cost	16362.28	17416.00**
Total expenses per acre	55940.36	63339.82***
Outputs/Benefit (PKR acre^{-1})		
Total cotton picked (kg)	887.90***	726.35
Total cotton picked (maund)	22.19***	18.18
Price of cotton (PKR kg^{-1})	86.73	90.58***
Price of cotton (PKR maund^{-1})	3469.00	3623.53***
Total Revenue	76958.25***	65805.31
Net Return	21017.99***	2465.71
Productivity	0.016***	0.011
BCR	1.38***	1.04

Note: The significance values * at p≤0.05; ** at p≤0.01; *** at p≤0.001; ^{ns} at the non-significant level for two-group mean comparison *t-test* assuming unequal variances.
CSA: Climate-Smart agriculture; **PKR**: Pakistani rupee; **kg**: kilogram; **BCR**: Benefit-cost ratio

Econometric Analysis

The impact of CSA interventions on cotton production in the regions of southern Punjab (Khanewal and Bahawalpur) was analyzed by using a Tobit regression model (Table 4). According to our results, the cotton farmers of the studied area were very interested in the proposed adaptation of CSA practices and training activities. About 75% of farmers (adopters of CSA) opted for the proposed adaptations and 25% of farmers (non-adopters of CSA) claimed that the proposed adaptations were not adopted. At first, we utilized the data for the calculation of the cost and returns of the cotton crop between both groups of farmers (adopters and non-adopters of CSA). The proposed adaptations were statistically significant and had positive impacts on cotton crop yield. The adoption rate is increased by the increase in farm area under cotton crop cultivation, water availability at the farm, and soil fertility. The adopters of CSA utilized a comparatively larger amount of biofertilizers (bio-power & phosphorus pool) and gypsum and decreased the use of DAP and NP as compared to non-adopters of CSA (Table 4). The fuel cost of adopters was less than that of non-adopters due to the rational use of resources at the farm. The fuel consumption used in the analysis as soil management operations displayed that better cultivation practices resulted in better crop yields and soil health [60]. The other way we can say, farmers from both regions adopted CSA practices but the adaptability rate in the Bahawalpur regions was relatively high. So, the farmers of the Bahawalpur district were significantly more adaptable as compared to the district of Khanewal. It is an evident phenomenon that resource conservation practices and efficient use of the resources at the farm also increase the crop yield, and farmers manage climate variations indirectly through improved farming management practices.

Table 4. *Econometric analysis to assess the impact of Climate-Smart Agriculture (CSA) practices and farm management practices*

Dependent variable: Adoption of Climate-Smart Agricultural (CSA) Practices (Adopters = 1, Non- Adopters = 0)			
Variable	**Description**	**Coefficient**	**Significance**
Yield of cotton	kg	0.015*	0.000
Farm area	acre	0.090*	0.003
Pesticide use	l	-0.103*	0.000
Biofertilizers application	kg	0.009	0.059
DAP application	kg	-0.005*	0.000
NP application	kg	-0.004*	0.000
Gypsum application	kg	0.001	0.94
Total irrigation water	m^3	-0.223*	0.000
Total fuel consumption	l	-0.018*	0.000
Soil organic matter	%	0.309	0.313
Location	BWP=1 KWL=0	0.036*	0.013
Constant		1.24*	0.000

Note: *at 1 percent level of significance (p > 0.01); Log-likelihood value = 166.24
Number of observations = 250; LR chi2 = 748.79; Probability of chi 2 = 0.000
KWL: Khanewal; **BWP**: Bahawalpur; **DAP**: diammonium phosphate; **NP**: nitrophos; **kg**: kilogram; **l**: liter; **m³**: cubic meter; **%**: percentage

Estimation of GHG Emissions

The estimation of greenhouse gas (GHG) emissions was used as an indicator of detrimental output. In the current study, GHG emissions associated with on-farm management practices by adopters and non-adopters of CSA were estimated through CFT. The main source of GHG emissions is specifically due to (1) soil-derived nitrous oxide (N_2O) from the usage of nitrogen fertilizers; (2) usage of agrochemicals (pesticides and herbicides); (3) production and combustion of fossil fuels used in cotton farm operations and (4) energy/electricity used in cotton irrigation. About two greenhouse gasses (i.e., CO_2 and N_2O) were accounted and the value of GHG emissions is represented in kg of carbon dioxide equivalents (kg CO_2 e) per acre and per kg of seed cotton. Table 5 presented a quantitative analysis of average GHG emissions over various on-farm operations (e.g., fertilizer production, soil nutrients/fertilizers, crop protection practices, and on-farm energy use) in cotton cultivation by adopters and non-adopters of CSA in both regions (Khanewal and Bahawalpur) of Punjab.

Table 5. *Estimation of on-farm greenhouse gas (GHG) emissions in cotton production influenced by various farm management practices in Khanewal and Bahawalpur*

Sources	**Adopters of CSA**	**non-Adopters of CSA**	**Adopters of CSA**	**non-Adopters of CSA**
	Emissions of CO_2 (kg)		**Emissions of N_2O (kg)**	
Fertilizer production	243.19	304.35	0.00	0.00
Soil/fertilizer	31.87	32.52	0.75	0.82
Crop protection	58.07	74.66	0.00	0.00
Energy use (on-farm)	702.93	1040.00	0.00	0.00

CSA: Climate-Smart Agriculture

Results showed that adopters of CSA were responsible for an average of 1258.11 kg CO_2 e acre^{-1} of GHG emissions in both districts and the emissions value was considerably reduced by 25.87% as compared to the non-adopters of CSA (1697.14 kg CO_2e acre^{-1}) (Fig 2A). Likewise, overall emissions per kg of cotton yield were significantly reduced by 39.6% by CSA adopters (1.41 kg CO_2 e) when compared with non-adopters of CSA (2.33 kg CO_2 e) in cotton production (Fig 2B). Higher extents of the total GHG emissions by non-adopters of CSA in cotton cultivation attributed to an increased amount of farm inputs such as excessive use of fertilizers (especially nitrophos), agrochemicals (pesticides & herbicides), and demand for energy (diesel & electricity) for on-farm activities viz., land cultivation and irrigation. The results are supported by Lata et al. [61] as elevating input of the nitrogen-based fertilizers added to soil resulted in increased emissions of N_2O. Maraseni et al. [62] reported that the elevation in GHG emissions in cotton production is directly related to the increasing farm inputs. Likewise, Ziaei et al. [63] also reported that the highest energy consumption was attributed to the use of chemical fertilizers, irrigated water, and diesel fuel with the implementation of on-farm machinery in cotton production.

Our results showed that the potential adoption of CSA practices leads to reduced GHG emissions per unit (as kg CO_2 e) through fertilizers production (20.1%) & application (8.7%), crop protection (22.2%), and on-farm activities (32.4%) as compared to the non-adopters of CSA. Hence, the adoption of CSA practices/technologies is an innovative approach that may provide a viable means of lowering and offsetting GHG emissions along with the enhancement in cotton production and good economic returns on a sustainable basis. Various studies support similar findings that climate change in agriculture can be significantly reduced or minimized with the implementation of CSA practices/technologies [16, 17, 24, 55, 64, 65].

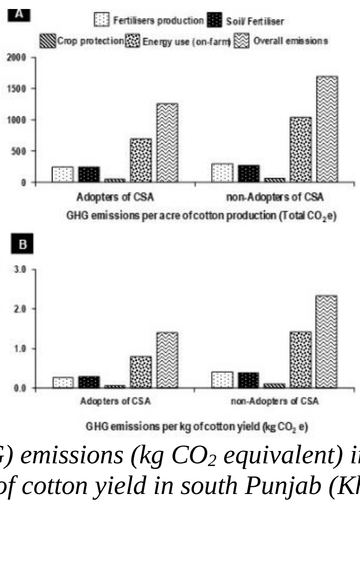

Fig. 2. *On-farm greenhouse gas (GHG) emissions (kg CO_2 equivalent) in cotton production* ***(A):*** *per acre of cotton yield and* ***(B):*** *per kg of cotton yield in south Punjab (Khanewal and Bahawalpur)*

CONCLUSIONS

It is concluded that the applicable management practices such as land management, selection of appropriate cotton variety, application of the rational amount of fertilizers, effective pests/disease control approaches and efficient use of water for irrigation are the most important factors responsible for enduring sustainability in cotton production. It has been found that adopters of CSA enhanced input resource efficiency by 30% and improved output by 22% with good profitability (1.37) as well and a substantial reduction in GHG emissions by 26% was estimated as compared to non-adopters of CSA for cotton production. Overall, the study confirms and quantifies that cotton farmers can efficiently use inputs by adopting CSA interventions in the cotton-growing areas of southern Punjab and elsewhere in Pakistan.

The findings suggested that intensive and adequate extension and research services should be pursued to create awareness and financial support for the cotton farmers to accelerate the adoption of CSA interventions in the cotton-growing areas of Punjab. This can enhance resource use efficiency, net farm income, and the livelihood of rural masses.

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