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Do Farmers Adapt to Climate Change? A Macro Perspective

Shahzad Alvi [1,*], Faisal Jamil [1], Roberto Roson [2,3] and Martina Sartori [4]

1 School of Social Sciences and Humanities, National University of Sciences and Technology, Islamabad 44000, Pakistan; faisal.jamil@s3h.nust.edu.pk
2 Department of Economics, Ca' Foscari University of Venice, 30123 Venice, Italy; roson@unive.it
3 Department of Economics, Loyola Andalusia University, 41704 Seville, Spain
4 European Commission, Joint Research Centre, 41092 Seville, Spain; martina.sartori@ec.europa.eu
* Correspondence: shahzad.alvi@s3h.nust.edu.pk; Tel.: +92-3324223015

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Abstract: Greenhouse gas emissions cause climate change, and agriculture is the most vulnerable sector. Farmers do have some capability to adapt to changing weather and climate, but this capability is contingent on many factors, including geographical and socioeconomic conditions. Assessing the actual adaptation potential in the agricultural sector is therefore an empirical issue, to which this paper contributes by presenting a study examining the impacts of climate change on cereal yields in 55 developing and developed countries, using data from 1991 to 2015. The results indicate that cereal yields are affected in all regions by changes in temperature and precipitation, with significant differences in certain macro-regions in the world. In Southern Asia and Central Africa, farmers fail to adapt to climate change. The findings suggest that the world should focus more on enhancing adaptive capacity to moderate potential damage and on coping with the consequences of climate change.

Keywords: climate change; adaptations; cereal yields; emissions

1. Introduction

Climate change is considered to be an average change in weather patterns in the long-term sense, while climate variability refers to the fluctuations in weather patterns in the short term. Scientists and economists have come to a consensus opinion that agricultural production and crop yields are at risk due to variation and change in the climatic factors [1]. Crops are hit by droughts, floods, heavy or low levels of rainfall, humidity, decreasing water resources, and increasing windstorms. The climatic variability and change could create a shortage of food production in the future, especially in developing countries, which having fewer resources and are lagging far behind in terms of crop yields. It is expected that the world may face the severe problem of food scarcity in the coming years due to climate change. Climate change is becoming a threat to the Sustainable Development Goals (SDGs). The SDGs focus explicitly on food-related issues by seeking to end hunger, achieve food security by fighting against food scarcity and improving nutrition, and promote sustainable agriculture. SDGs also pay particular attention to poverty reduction, for which agriculture and food play a key role in developing countries [2].

A growing body of economic literature has focused on the impacts of climate change on the agriculture sector at a macro level [3–18]. The common finding of these studies is that climatic changes adversely affect crop yields. However, these studies ignore the farmers' long-term adapting behaviors, resulting in overestimations of the damages caused due to climate change. The adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to dampen potential damage, take advantage of opportunities, and cope with undesired negative consequences [1]. The adoption of new technologies, such as drought-tolerant seeds, and changing farm practices, such as sowing dates, are moderating the impacts of climate variability and change on crop yields [19–21]. However, this capability is contingent on many factors: the farmer's characteristics, the market structure, government policies, geographical and social conditions, education, etc. The farmers who have more access to credit facilities, for instance, can buy hybrid seeds and more advanced machinery [22]. A better level of education helps them to learn about the latest farming techniques; improved infrastructure gives them the advantage of easier access to markets; and an advanced technology and investment in research can mitigate the potential damages of climate change. The geographical conditions are also important because the cost of adaptation is too high for those countries that are already facing high temperatures or are more vulnerable to climate change.

There are numerous studies that have empirically investigated the impact of the farmers' adaptation at the micro or farm level [23–26]. This indicates that some farmers are adapting, while other's have failed to adapt to climate change, depending on the individual farmer's characteristics. However, little attention has been paid to macroeconomic policies and the social indicators of a country that provide support for adaptation, such as the government spending in the agriculture sector, research and development, education and training schemes, policy relevance to agriculture, information availability, and climate risk identification. Such macro-level factors that enable farmers to adapt to climate change are missing in the existing literature. Developed countries are providing such services to their farmers, to facilitate them to make adaptations to climate change; however, the developing countries are lagging far behind and it can be difficult for them to adapt [27–29].

However, it is difficult to capture the concept of adaptations because it includes government policies and the behavior of farmers. Thus, assessing the actual adaptation potential at the macro level in the agricultural sector is an empirical issue. Thus, the objective of this study is to investigate whether farmers adapt to climate change or not. To achieve this, a panel data method with cross-country data is employed, with data ranging from 1991 to 2015, and including 55 developing and developed countries. Countries were grouped into eight regions; namely, Southern Europe, Central and West Europe, Northern Europe, Northern Africa, Central Africa, Southern Africa, Southern Asia, and Southeast Asia. The growing degree days and cumulative precipitation as climatic factors were used in the first difference estimation model to check the impact of climate change on cereal yields. Then, the lag effects of climatic variables were introduced to capture the adaptation to climatic change.

Several studies can be found in the literature which examine the impact of climate change on agriculture. All these studies use different models which have both advantages and disadvantages.

Most of the scholars analyzed, that the impact of climate change is solely on the production, and affects some major crops, i.e., cotton, maize, rice, and soybeans, which are termed "crop stimulation models." The analysis of these models is mostly limited to the crop physiology and its productivity when exposed to different climate conditions [30,31]. Due to the emphasis on the change in the physiology and ecosystem of the crop and soil, they are considered agriculturally oriented. In the crop stimulated model, the management of crops are considered fixed, and no attention is paid towards the farmer's behavior. These models are applicable for major crops at particular places, and their adjustment is limited to the grain crops [32].

Some scholars' work has indicated how climate change impacts the yields, and how yields of the crops are sensitive to the changes of climatic patterns; for this purpose most studies have used the production function approach [33–37]. The approach of this model is based on the fact that climate and soil are explanatory variables in the model, and that their role is assessed in the production function.

In the formulation of the production function approach, the economic benefits gained from the crops are not considered a priority; instead, they are given secondary consideration and treated in a simple way [38]. The economic consideration is discussed later in some studies, which have touched on the economic aspect in the production function [39,40]. The economic factor of climate change has also been found in the analysis given by agroeconomic models by applying mathematical programming [41,42].

The major drawback found in the production function approach is that it focuses only on crops and its site-oriented model. It has analyzed and formed the hypothesis of the uneducated farmers; in this model it does not consider that farmers believe in the adoption of the strategies which help them to cope with change in climate; i.e., farmers replace those crops with others which are more sensitive to the climate [43,44].

When this limitation of the production function approach could not comply, another model was formulated named the Ricardian model in 1994 by Mendelsohn; in this model the climate was considered the black box in the agriculture sector. This model is used to assess the relationship that exists between outcomes of the agricultural land which a farmer utilizes and climate, which includes cross sectional data, analyzed by repressors and control variables. This model is implicitly considered as the farmer's adaptation model [32].

The weakness of this model, as discussed above, is that the efforts of the farmer cannot be determined in this model, and to overcome this weakness the farmer's efforts are assessed by the mathematical programming developed in the same model [41,45,46]. The main focus was the irrigation of the land [47]. This specification of the models also has limitations, such as the fact that it only considers hypothesized and simulated strategies, which cannot be correct. The most recent application of this model is the addition of the positive mathematical programming method commonly known as positive mathematical programming [48,49].

In recent times many studies have been conducted that show how the limitation of the Ricardian model can be overcome by considering the survey from a farmer's point of view and by applying econometric models. This application of the model uses the adopted strategies of the farmer and its explanatory variables [20,24,50,51]. The adaptation to climate change was first considered in agriculture modeling in the pioneering works of [28,52–56] in terms of the decision to adapt and examine the impact of climate change in presence of adaptations.

The works of [57,58], empirical and theoretical, considered adaptation in the form of different types of technology adoptions and preventive measures. The technologies under consideration and preventive measures of adaptations are different across studies; therefore, the measures of the impact of adaptations are not comparable. A few comprehensive studies covering multiple regions show that the results of adaptation are considerably different in developed and developing countries, with little gain or net decline in the agricultural production in the developing countries, and net gain in the developed countries [27,28,55,58,59].

Climate changes are unevenly distributed throughout globally, penalizing some parts of the world more than others; some areas are getting benefits from changes in precipitation [3,56]. Undoubtedly, the adaptation practices are related to knowledge and perceptions about the climate change. There is a need for greater investment in research and implementing adaptation strategies to mitigate the risks of climate change [60,61].

Summing it up in a nutshell, just as the impacts of climate change vary from one region to another, the adaptation and its consequences also vary depending on the factors ranging from farmer's characteristics to socioeconomic factors. These factors either limit or improve the farmer's capability to move towards adaptations in order to avoid negative impacts or benefits from climate change. The farmer's decision to move towards adaptations hinges on the perceptions of climate change and the benefits of using new technology, inputs, or techniques requiring investment. The developed countries generally have developed markets for agricultural inputs, including dissemination of information which helps farmers to move towards adaptions and invest in new technology. On the other hand, in developing countries, markets are not developed for the agricultural inputs and the farmers are relatively unaware of the available technologies to avoid the negative impacts of climate change.

The study proceeds as follows. Section 2 presents the material and methods. Section 3 is about results and discussion, and the final section concludes the study.

2. Materials and Methods

2.1. Climate Change

We used the production function approach to check the impacts of climate change and adaptations on cereal yields. The cereal yields (kg/ha) are related to climatic and non-climatic input variables.

The vector of climatic variables is characterized here by temperature and precipitation (we also used the humidity as a climatic variable, but due to the problem of multicollinearity, we dropped it), while the non-climatic vector is related to capital stock and labor force. The use of capital stock is important in agricultural production, especially in case of the developing countries. The regression is as follows:

$$y_{it} = \beta_1(GDD_{it}) + \gamma_1(Pr_{it}) + \Pi_1(K_{it}) + \Pi_2(LF_{it}) + \beta_i + \alpha_t + \varepsilon_{it}, \quad (1)$$

where y is cereal yields, GDD is growing degree days, Pr is precipitation, K is capital stock, LF is the labor force in the agriculture sector, β_i is the time-invariant and individual fixed effects, and α_t is the time-fixed effect.

When investigating the impact of change, it makes sense to look at the first-order differences [62]. A panel first difference estimation model has been employed that incorporates a set of climatic and non-climatic inputs. This regression method has three advantages. First, it allows us to capture the oscillations in weather patterns; second, it easily addresses the problem of omitted variables in the panel data [63]; and third, it eliminates the time-invariant term and individual country fixed effects. The impact of climate change on cereal yield is therefore estimated as follows:

$$\Delta y_{it} = \beta_1(\Delta GDD_{it}) + \gamma_1(\Delta Pr_{it}) + \Pi_1(\Delta K_{it}) + \Pi_2(\Delta LF_{it}) + \alpha_t + \varepsilon_{it}, \quad (2)$$

where Δ indicates the first difference, i index stands for country and t for year, α_t is the time dummy variable, and ε is the residual term. (The country's dummy variable is not included in the regression, as it is a first-difference estimator. Inter-country differences cancel out).

2.2. Adaptation to Climate Change

The concept of modelling adaptation is not new in the literature. Helson was among one of those who developed a quantitative model of adaptations [64]. More recently, Menz and Korhonen et al. [65,66] investigated the income adaptation by including lagged income into the life satisfaction equation. To check the impact of growing degree days and precipitation on cereal yield, it is important to understand that both the indicators of climate change are noticeable, gradually. Therefore, it is obvious to include the lags of climate change indicators; otherwise, their impacts will remain overestimated. Thus, the current study critically attempts to include lagged or past values of growing degree days and precipitation so that the truly representative impacts of climate change adaptation may be revealed. By doing so, the model of oscillations in weather patterns is granted. This modelling approach makes this study unique in the literature of climate change adaptation in the agriculture sector because no other method can appropriately estimate the impact.

To investigate whether farmers adapt to climate change or not, we include the lag of growing degree days and precipitation in the difference equation by following the Menz [65] and Korhonen et al. [66]. The model is as follows:

$$\Delta y_{it} = \sum_{l=0}^{n} \beta_{i,t-l}(\Delta GDD_{i,t-l}) + \sum_{k=0}^{n} \gamma_{i,t-l}\left(\Delta Pr_{i,t-l}\right) + \Pi_1(\Delta K_{it}) + \Pi_2(\Delta LF_{it}) + \alpha_t + \varepsilon_{it} \quad (3)$$

where l is the lag length of climatic variables, and the $\beta_{i,t}$ and $\gamma_{i,t}$ coefficients represent the first-year effects of growing degree days and precipitation on cereal yields, respectively. The sum of the coefficients of growing degree days, $\beta_{i,t} + \beta_{i,t-1} + \beta_{i,t-2} + \cdots + \beta_{i,t-n}$, gives the full effect of growing degree days. Similarly, $\gamma_{i,t} + \gamma_{i,t-1} + \gamma_{i,t-2} + \cdots + \gamma_{i,t-n}$ gives the full effect of precipitation. We set the null hypothesis of lag-independent climatic variables, $\beta_{i,t-1} + \beta_{i,t-2} + \cdots + \beta_{i,t-n} = 0$ and $\gamma_{i,t-1} + \gamma_{i,t-2} + \cdots + \gamma_{i,t-n} = 0$. If the null hypotheses are accepted, then the cereal yield is affected by neither changing the growing degree days nor the precipitation, and resultantly, the farmers are adapting to climate change. This could be interpreted as the result of adaptive behavior, making the output level immune to meteorological contingencies.

2.3. Data

Data on the climatic variables (growing degree days (GDD) and cumulative precipitation (pr) were obtained from the World Bank Climate Knowledge Portal [67], for the period of 1991–2015, of 55 countries (The World Bank Climate Knowledge portal provide data at the country level with global coverage). GDD is the sum of heat that a crop receives over the growing period above the lower threshold. The crop-specific upper and lower thresholds are still in debate. Following [16,18,68], the study used 8 °C as the lower threshold. The growing degree days are calculated from the average monthly temperature as follows:

$$g(T) = \begin{cases} 0 & if\ T \leq 8 \\ T - 8 & if\ T > 8 \end{cases} \quad (4)$$

Data on the cereal yields by country, on capital stock in agriculture and on labor force were retrieved from the Food and Agriculture Organization [69] database for the same time period. Several summary statistics for each country are reported in Appendix A Table A1.

3. Results and Discussion

3.1. Impacts of Climate Change on Cereal Yields

The results indicate that climate variability strongly affects the cereal yields. An increase in the growing degree days is negatively correlated with the cereal yields in all regions, except for Southeast Asia (Table 1). The largest impact is estimated for Southern Europe and Central Africa, at 0.74 and 0.73, respectively, followed by Northern Africa (0.55). As expected, an increase in precipitation has a positive effect on the cereal yields only in Southern Europe, Northern Africa, Central Africa, Southern Africa, and Southeast Asia. However, the impact of increasing precipitation is significantly negative in the Central, Western, and Northern European regions because the above-average rain causes an excess of moisture in the soil which decreases the cereal yield in these regions. The major cereal crop in these regions is wheat which requires less water. The impact of an increase in precipitation is also found to be negative in the Southern Asia region. The reason for the negative impact is a lack of water infrastructure, which results in the flooding of the river basins, especially when there is more rain, particularly in Bangladesh, India, and Pakistan, due to rivers flowing from the top of the Himalayas down to plain irrigated land. The cereal yields are also positively affected by changes in non-climatic explanatory variables that include labor force and capital stock, which are significant in some regions.

Table 1. Impacts of climate change on cereal yields.

Variable	Southern Europe	Central &Western Europe	Northern Europe	Northern Africa	Central Africa	Southern Africa	Southern Asia	Southeast Asia
ΔGDD	−0.741 ***	−0.236 ***	0.145 ***	−0.553 **	−0.737 *	−0.463 **	−0.340 **	−0.226 **
	(0.000)	(0.000)	(0.001)	(0.033)	(0.089)	(0.033)	(0.011)	(0.018)
ΔPr	0.162 ***	−0.236 ***	−0.232 ***	0.155 ***	0.236 ***	0.677 ***	−0.050 ***	0.037 **
	(0.009)	(0.000)	(0.000)	(0.009)	(0.000)	(0.000)	(0.001)	(0.017)
ΔK	0.233 **	−0.043	−0.007	0.706 ***	0.070 ***	0.088 **	0.097 ***	0.102 ***
	(0.023)	(0.383)	(0.894)	(0.000)	(0.006)	(0.012)	(0.003)	(0.000)
ΔLF	0.023	0.053	0.212 *	0.309 ***	−0.103	0.024	0.119	−0.059
	(0.908)	(0.616)	(0.097)	(0.009)	(0.665)	(0.877)	(0.173)	(0.203)
N	120	144	96	120	408	168	96	168
R-squared	0.52	0.51	0.74	0.61	0.45	0.26	0.67	0.43
F-stats	3.69	4.63	7.13	5.41	3.40	14.64	5.10	9.52

Notes: ***, ** and * denote significance at the level of 1, 5 and 10% respectively. Source: Author's own calculations.

3.2. Adaptation to Climate Change

The lags of the first differences are introduced in the model to check whether farmers adapt to climate change (Equation (3)). The results indicate that the current impacts of changes in growing degree days are significantly negative in all regions except Northern Europe (Table 2). The lag effect of growing degree days is insignificant in Southern Europe, Central and Western Europe, Northern Africa, South Africa, and Southeast Asia.

Table 2. Climate change and adaptation.

Variable	Southern Europe	Central & Western Europe	Northern Europe	Northern Africa	Central Africa	Southern Africa	Southern Asia	Southeast Asia
ΔGDD_t	−0.762 *** (0.0008)	−0.272 *** (0.003)	0.157 *** (0.001)	−0.114 * (0.089)	−0.984 * (0.069)	−0.013 * (0.098)	−0.685 *** (0.000)	−0.168 (0.442)
ΔGDD_{t-1}	0.273 (0.270)	−0.041 (0.693)	0.141 *** (0.000)	0.113 (0.944)	−1.220 ** (0.050)	0.684 (0.278)	−0.367 *** (0.050)	−0.019 (0.929)
ΔGDD_{t-2}	0.219 (0.303)	0.013 (0.884)	−0.026 ** (0.529)	0.875 (0.545)	−0.451 (0.389)	−0.357 (0.590)	−0.008 (0.730)	−0.005 (0.978)
ΔPr	0.175 ** (0.022)	−0.264 *** (0.000)	−0.223 *** (0.000)	0.235 * (0.099)	0.222 *** (0.000)	0.278 * (0.058)	0.044 ** (0.027)	0.046 ** (0.056)
ΔPr_{t-1}	0.085 (0.320)	−0.058 (0.466)	0.063 (0.1850)	0.174 (0.278)	−0.056 * (0.418)	0.090 (0.557)	0.092 ** (0.012)	0.060 ** (0.017)
ΔPr_{t-2}	−0.156 ** (0.049)	0.049 (0.520)	−0.109 *** (0.009)	0.082 (0.553)	−0.145 ** (0.016)	−0.362 *** (0.009)	0.009 (0.712)	0.028 (0.248)
ΔK	0.261 ** (0.014)	−0.034 (0.521)	0.027 (0.664)	0.690 *** (0.000)	0.073 *** (0.005)	−0.067 (0.151)	0.092 *** (0.004)	0.140 *** (0.000)
ΔLF	−0.215 (0.395)	0.084 (0.486)	0.053 (0.650)	0.394 * (0.096)	0.009 (0.968)	−0.159 *** (0.004)	0.247 *** (0.008)	0.053 (0.446)
N	110	132	88	110	374	154	92	154
R-squared	0.59	0.538	0.90	0.45	0.51	0.478	0.77	0.44
F-stats	4.00	4.102	19.06	2.327	3.28	2.60	6.81	3.68
$\sum\Delta GDD$	−0.268	−0.301	0.272	0.874	-2.652	0.313	−1.060	−0.193
F-stats	0.250	1.652	12.79 *	0.053	3.178 *	0.055	6.912 **	0.128
(p-value)	(0.618)	(0.201)	(0.000)	(0.817)	(0.075)	(0.814)	(0.011)	(0.720)
$\sum\Delta GDD$ (lags)	0.493	−0.028	0.115	0.988	−1.667	0.327	−0.375	−0.025
F-stats (lags)	1.518	0.027	7.561 ***	0.131	2.752 *	0.102	4.093 **	0.004
(p-value)	(0.221)	(0.869)	(0.008)	(0.716)	(0.098)	(0.784)	(0.048)	(0.946)
Adapt to GDD	Yes	Yes	-	Yes	**No**	Yes	**No**	Yes
$\sum\Delta CPr$	0.104	−0.273	−0.268	0.493	0.020	0.006	0.146	0.136
F-Stats	0.267	2.133	5.535 **	2.018	0.018	0.0003	4.068 **	6.652 ***
(p-value)	(0.606)	(0.147)	(0.022)	(0.159)	(0.89)	(0.984)	(0.048)	(0.010)
$\sum\Delta Pr$ (lags)	−0.071	−008	−0.453	0.257	0.202	−0.272	0.102	0.088
F-Stats (lags)	0.250	0.004	0.296	0.964	3.178 *	1.114	3.004 *	4.723 **
(p-value)	(0.618)	(0.947)	(0.588)	(0.329)	(0.075)	(0.293)	(0.089)	0.031
Adapt to Pr	Yes	Yes	Yes	Yes	**No**	Yes	**No**	**No**

Notes: ***, ** and * denote significance at the level of 1, 5 and 10% respectively. Source: Author's own calculation.

Thus, the null hypothesis, $\gamma_{i,t-1} + \gamma_{i,t-2} = 0$, cannot be rejected. This indicates that farmers are taking adaptation measures to change the number of growing degree days. However, Southern Asia and Central Africa are failing to adapt because of the lag effect on growing degree days is significantly negative in these regions. Thus, we reject the null hypothesis of adaptation. Notwithstanding, in Northern Europe, the absolute value of second and third-year lag coefficients of growing degree days (0.11) is statistically significant, positive, and different from zero. This indicates that the Northern European farmers are benefiting from an increase in the growing degree days. The reasons for improvements in the Northern Europe are mainly related to prolonged growing seasons, higher minimum winter temperatures, and an extension of the frost-free period [70].

The first-year impact of precipitation is positive in all the regions except for the Northern, Central, and Western Europe. However, the lag effect of precipitation is significant in the Central Africa, Southern Asia, and Southeast Asia regions, which indicates that these countries have failed to adapt to changes in the precipitation patterns. This is mainly due to their geographical location and dependency on precipitation. Furthermore, they belong to the developing world and it is difficult for them to cope with the changing precipitation patterns due to lack of famers' training, social and human capital, and credit facility [29].

The developed countries are adapting to climate change because in these countries' the government is paying attention to the agriculture sector, such as spending on research and development, education and training, policy relevance to agriculture, information availability, and climate risk identification. The adaptation and its consequences also depend on the factors ranging from farmer characteristics to socioeconomic factors. These factors improve the farmer's capability to move towards adaptations in order to avoid negative impacts; meanwhile, developing countries are lagging far behind in providing such levels of services to their farmers, so it is difficult for them to adapt. South Asia and Southern Africa are two regions highly sensitive to climate changes, and hence demand more adaptation practices.

4. Conclusions

Given the importance of climate change and farmers' adaptation, the present study examines the impact of climate change on the cereal yields for 55 developing and developed countries. The present study divides the selected countries into eight regions. The estimated results indicate that the cereal yields are affected in all regions by the change in the growing degree days and precipitation. The adaptation regression model has been used. This approach considers the lag effects of the climatic factors. It is found that the farmers of the South Asian and Central African countries are failing to adapt to the changes in growing degree days and precipitation. Moreover, the Southeast Asian countries are sensitive to the change in precipitation. The Central and Western European, Southern European, Northern European, North African, and South African countries are adapting to climate change. However, the Northern European countries are growing more crops due to the increase in growing degree days. Improvements in Northern Europe are mainly related to prolonged growing seasons, higher minimum winter temperatures, and an extension of the frost-free period. The results of this study also indicate that regions of high social and economic status, and the ones that are less vulnerable to climate change, are adapting to climate change. Countries that are developing and vulnerable to climate change are failing to adapt.

This study suggests that the world should focus on adaptive capacity to moderate potential damage and cope with the consequences of climate change and variability in the agriculture sector. The adoption of new technology and improved seeds, cultivating more land, relaxing trade barriers, and changing farms' practices could be useful for mitigating the negative impacts of climate change and variability.

Notwithstanding, the developing countries need to take urgent adaptation measures to minimize the losses associated with climate change and to feed the growing population, especially in Central Africa and South Asia. In particular, there is a need to improve the water infrastructure and storage capacity in South Asia. Moreover, there is a global need to decrease the GHG emissions immediately.

Further, to achieve the SDGs, countries and communities need to develop adaptation solutions and implement actions to respond to the impacts of climate change that are already happening, as well as prepare for future impacts. Successful adaptation not only depends on the governments but also on the active and sustained engagement of stakeholders, including national, regional, multilateral, and international organizations; the public and private sectors; civil society; and other relevant stakeholders, and on effective management of knowledge.

One caveat of this study is that we have used only two climatic variables, precipitation and temperature, while ignoring the other variables due to non-availability of data at the country level, such as wind speed and humidity. Thus, the model may underpredict the situation. It is important to examine farmers' adaptation strategies and their impacts on each crop's yield at a country level. However, this topic is left for future research.

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Appendix A

Table A1. Summary statistics.

Country	Cereal Yields (Kg per Hector)			Growing Degree Days (Celsius)			Precipitation (Millimeters)		
	Mean	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
South Europe									
Greece	3956	4516	3553	2540	2905	2203	635	869	398
Italy	5063	5709	4307	2007	2293	1760	635	869	397
Portugal	3006	4606	1805	2687	2907	2328	841	1374	528
Spain	3041	4047	1729	2301	2547	1943	594	797	437
Turkey	2483	3307	1922	2086	2369	1811	570	686	437
Central-West Europe									
Austria	5881	7056	5088	989	1214	751	1172	1346	927
France	6985	7570	6125	1690	1996	1363	840	982	677
Germany	6573	8050	5335	1362	1585	1063	722	894	561
The Netherlands	7919	9073	7063	1345	1639	1095	806	1058	564
Switzerland	6268	7045	5086	901	1331	613	1523	1881	1159
United Kingdom	6918	7980	6215	910	1111	674	1248	1422	967
North Europe									
Denmark	6023	6884	4314	1109	1414	835	740	914	501
Finland	3351	3760	2402	611	820	423	560	679	473
Norway	3830	4801	2810	305	463	164	1083	1233	885
Sweden	4718	6053	3359	488	686	282	670	845	572
North Africa									
Algeria	1223	1813	741	5651	5905	5233	83	106	55
Egypt	6915	7556	5613	5511	6142	4991	30	45	20
Libya	666	836	621	5400	5882	4964	40	60	29
Morocco	1195	2140	266	3674	3985	3248	304	530	195
Tunisia	1394	1877	893	4560	4753	4072	266	415	181
Central Africa									
Angola	579	981	268	5056	5369	4929	981	1111	837
Cameroon	1521	1893	959	6177	6362	5936	1561	1764	1338
Central African Rep.	1043	1674	869	6288	6596	5584	1358	1470	1232
Chad	702	934	501	7059	7483	6416	339	415	259
Congo	779	811	765	6018	6218	5786	1473	1639	1309
Cote d'Ivoire	1665	2270	1050	6795	6985	6658	1350	1737	1113
Ghana	1439	1830	1042	7152	7322	6982	1149	1318	939
Guinea	1401	1514	1151	6624	6808	6409	1688	1975	1474
Kenya	1597	1918	1242	6222	6428	5995	670	1018	448
Mali	1154	1800	738	7633	7940	7317	319	398	256
Mauritania	907	1678	637	7475	7799	7182	97	136	69
Niger	390	551	267	7254	7569	6869	176	227	134
Nigeria	1311	1598	1094	7013	7234	6755	1139	1341	919
Senegal	947	1376	651	7532	7734	7294	716	921	502
Somalia	600	1190	410	6952	7140	6824	276	374	224
Tanzania	1401	2043	858	5476	5637	5271	974	1173	788
Uganda	1664	2056	1204	5685	6105	5283	1248	1461	951

Table A1. *Cont.*

Country	Cereal Yields (Kg per Hector)			Growing Degree Days (Celsius)			Precipitation (Millimeters)		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
South Africa									
Madagascar	2500	3772	1875	5709	6549	5308	1421	1709	1250
Malawi	1493	2467	481	5246	5459	5066	1007	1173	733
Mozambique	721	1191	177	5799	5822	6087	3016	3033	2853
Namibia	381	620	159	4630	4874	4473	269	420	130
South Africa	2963	4894	944	3702	3899	3407	462	605	312
Zambia	1911	3007	763	5205	5581	5013	953	1107	759
Zimbabwe	858	1502	309	5063	5507	4866	633	891	421
South Asia									
Bangladesh	3509	4617	2475	6311	6618	6101	2240	2900	1787
India	2433	2969	1926	6041	6279	5839	1018	1160	835
Pakistan	2417	3001	1805	4582	4809	4228	313	427	192
Sri Lanka	3414	3974	2902	7009	7199	6870	1715	2097	1397
Southeast Asia									
Cambodia	2299	3377	1301	7126	7320	6929	1887	2671	1446
Indonesia	4348	5306	3816	6627	6793	6522	2868	3605	2195
Malaysia	3271	3948	2787	6484	6658	6379	3104	3795	2426
Myanmar	3248	3798	2658	5561	5819	5359	1566	2288	953
Philippines	2839	3637	2042	6530	6714	6429	2535	3253	1894
Thailand	2815	3259	2119	6817	7070	6592	1542	1859	1326
Vietnam	4428	5601	3006	6057	6333	5801	1862	2243	1600

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