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AGRICULTURAL AND NATURAL RESOURCES ADAPTATIONS TO CLIMATE CHANGE

Adaptation to Climate Change in Rain-Fed Farming System in Punjab, Pakistan

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Farmers in the rain-fed agriculture in arid regions are highly exposed to the adverse effects of climate change due to complete reliance on frequency, intensity, and timing of the rainfall. Adaptation, in such condition, becomes crucial to remain in farming in climate change regime. In the rural settings of the less-developed areas, farm households mostly adapt to risks posed by climate change individually. However, the benefits of private adaptation can be private and public depending on the type of adaptation strategies. The present study investigates different adaptation strategies of farmers using cross-sectional data collected from semi-arid region of Punjab province of Pakistan. The study also examines the role of socioeconomic characteristics of farmers on adaptation to climate change. Private adaptations for private and public benefits are considered in the present study. Data is collected from 190 respondents through random sampling. Logit model is employed to find out determinants of adaptation strategies adopted by the farmers. Results indicate that education, farming experience, family size and tractor ownership are significantly related with adaptation to climate change. The study concludes that policymakers should consider the potential difference in private benefits and public benefits resulting from private adaptation to climate change in relation to human capital, family assets and farm machinery when designing policy interventions for climate adaptations. The public goods related private adaptations should be encouraged through appropriate policy interventions.

Keywords: Adaptation; rain-fed farming; climate change; public adaptation goods; private adaptation goods; arid environments; Pakistan

1. Introduction

Climate change has significant impacts on agriculture (Lobell et al., 2011) and has potential to further impact it through changing rainfall pattern, drought, floods, increase in average high temperature, etc. The negative effects of these changes are expected to be more common than positive effects. The intensity of negative effects on agriculture (Mendelsohn et al., 2006; Kok et al., 2016) and the poor (Schmidhuber and Tubiello, 2007) will be higher in developing countries due to high vulnerability and poor economic and technical capacity to respond the menace (Padgham, 2009). It is threatening small farmers' ability to remain in business in shifting conditions with poor resource base to adapt. This also has implications to increase poor and rich divide.

It is imperative to mention that climate change has detrimental effect on agriculture in the absence of adaptation strategies. However, a reduction in the effects is partly possible by adapting various measures at the farm level (Downing, 1991; Easterling III et al., 1993; Reilly and Schimmelpfennig, 1999; Smit and Skinner, 2002; Ali and Erenstein, 2017; Grost et al., 2018; Cholo et al., 2019). Gbetibouo (2009) argues that the adaptive capacity of the farmers is equally important in reducing the impact of climate change on agriculture. Soil biodiversity as adaptation to climate change (Pascual et al., 2015) contributes in increasing and stabilizing agriculture productivity in the rain-fed farming systems (Sidibé et al., 2018). However, inadequate technical knowledge, low financial resources and small farm size are important challenges in agricultural adaptation (Kichamu et al., 2018).

The literature on climate change adaptation has focused on quantification of impacts (Hansen et al., 2006; Stern, 2006) and assessment of the vulnerability of communities and ecosystems (Turner et al., 2003; Adger et al., 2007), division of adaptation efforts into structural, physical, institutional categories (Bastakoti et al., 2014), and identification of obstacles to adaptation (Burch, 2010).

1.1. Climate change adaptation in agriculture in Pakistan

Like other developing countries, the agriculture sector of Pakistan is highly vulnerable to climate change impacts. Many studies indicate that rising temperature is associated with a decline in agriculture productivity (Sultana and Ali, 2006; Aggarwal and Sivakumar, 2011; Mahmood et al., 2012; Ahmad et al., 2013; Tariq et al., 2014; Gorst et al., 2018). Siddiqui et al. (2012) estimated significant and negative impacts on widely-grown staple crops namely rice and wheat. These impacts on staple crops threaten food security in Pakistan because population heavily depends on wheat and rice for meeting food requirements.

Adaptation to climate change in agriculture is considered important for reducing the negative effects on the agriculture productivity. However, adaptation is not enough high in Pakistan mainly because of less knowledge of climate change (Abid et al., 2015, 2016; Rauf et al., 2017). Stocker et al. (2013) attributed the severe impacts of climate change on agriculture to poor infrastructure and low adaptive capacity in Pakistan. Literature on adaptation in agriculture in Pakistan is limited and only a few studies are available analyzing adaptation to climate change (Abid et al., 2015, 2016; Esham and Garforth, 2013; Ali and Erenstein, 2017; Gorst et al., 2018). Some important adaptation strategies reported in the literature on Pakistan include changing planting dates, crop varieties (Abid et al., 2016; Ali and Erenstein, 2017), fertilizer types, planting trees (Abid et al., 2015, 2016, 2016a) and shifting to new crops (Ali and Erenstein, 2017).

Socioeconomic factors of farm and farmers are considered critical in agricultural adaptation to climate change. Education (Abid et al., 2016; Ali and Erenstein, 2017), farming experience (Abid et al., 2015, 2016), access to agricultural extension and credit (Abid et al., 2016; Ali and Erenstein, 2017; Gorst et al., 2018), institutional and informational constraints (Gorst et al., 2018), farm size and household size (Ali and Erenstein, 2017) are significant factors related with adaptation to climate change. Policies focusing on these factors can lead to an increase in agriculture adaptation in order to reduce risk in agriculture. This in effect is associated with food security of Pakistan.

1.2. Objectives and contribution of the study

It is equally important to understand local adaptation measures and constraints and understand nature of adaptation efforts at private and government level. The provision of adaptation goods is categorized into public or private (Tompkins and Eakin, 2012). The nature of adaptation goods provided by private and public institutions can be of public or private and that gives rise to free riding and under-provision. Similarly the non-targeted subsidies with benefits to small segment of well-off individuals may result in wastage of resources and trigger inequality.

The government's ability to support the farmers is limited due to resource constraints and extent of the issues in developing countries. The governments in developing countries have urban bias in public investment to support ever increasing urban population and industrial activities. The problem is further aggravated as major part of agricultural investment is allocated for irrigated agriculture due to high expected returns. This has left the rain-fed and other marginal farming with productivity deprived of public support (Zia et al., 1997). The water management, moisture conservation and nutritional management are major agricultural constraints of rain-fed farming and that puts higher reliance on natural forces. It is therefore pertinent to note that variation in rainfall pattern and heat stress due to climate change can heavily hit these areas. In contrast, irrigated agriculture has natural advantage to cope climatic variability.

Wani et al. (2009) find that globally 80% of the agricultural land area is rain-fed which generates 65% to 70% staple foods but 70% of the population inhabiting in these areas are poor due to low and variable productivity. About 69% of all cereal area is rain-fed, including 40% of rice, 66% of wheat, 82% of maize and 86% of other coarse grains (Rosegrant et al., 2002). Rain-fed agriculture can increase net returns per hectare substantially through crop improvement and natural resource management interventions (Harrisk and Orr, 2014). Siderius et al. (2016) argue that the rain-fed area of the Nile has the potential to meet above 75% of the needed increase in food production by 2025. This implies the importance of the rain-fed agriculture to meet the rising demand for food production in the future.

In Pakistan, the rain-fed areas contribute about 80% of livestock with modest share of 90% groundnut, 85% pulses, 77% gram, 69% sorghum, 53% barley, 27% maize, 25% rape and mustard, 21% millet and 12% wheat to agriculture sector (Zia et al., 1996). Punjab province of Pakistan is the major contributor of food production, in addition to the higher population concentration. Punjab province is divided into rain-fed and irrigated Punjab. Different technologies are used in adapting to climate change in the rain-fed Punjab. Some of those technologies include soil and water conservation (manure application, deep plowing, soil bund-making, etc.), changing sowing dates, crop diversification, crop rotation, water harvesting, income diversification and land renting out and these adaptation strategies are almost similar to those reported in other countries (Rurinda et al., 2014, Mugi-Ngenga et al., 2016). In the rain-fed region of the province, small landholders dominate the agrarian economy. A large number of factors influence adaptation strategies to climate variability. These include socioeconomic characteristics of farms and farmers. Further, these characteristics also vary across farms and farm households. It is therefore utmost important in understanding of how small landholders perceive climate variability and its impacts on their agricultural production and ongoing adaptation measures taken by the farmers. However, we find little evidence indicating the factors influencing adoption of technologies/practices as adaptation measures to climate variability in the rain-fed agriculture of Pakistan. Keeping in view the significance of adaptation to rain-fed farming in arid environment, the study is formalized to explore adaptation strategies by household and delineate the factors and barriers for adaptation of public and private nature goods by households and give policy recommendations to promote public goods adaptation in resource constraint rain-fed environment with high vulnerability to climate change.

2. Data and Source

2.1. Study area

The Punjab province being the largest province in term of population is also the major contributor in agricultural production in Pakistan. Further, Punjab province is divided into rain-fed and irrigated Punjab on the basis of mode of irrigation. The northern part of Punjab province (aka Pothowar plateau) is comprised of rain-fed farming system (**Figure 1**). The climate of this region is predominantly semi-arid or *barani*. Rawalpindi division includes all rain-fed districts of the region, receiving annual rainfall below

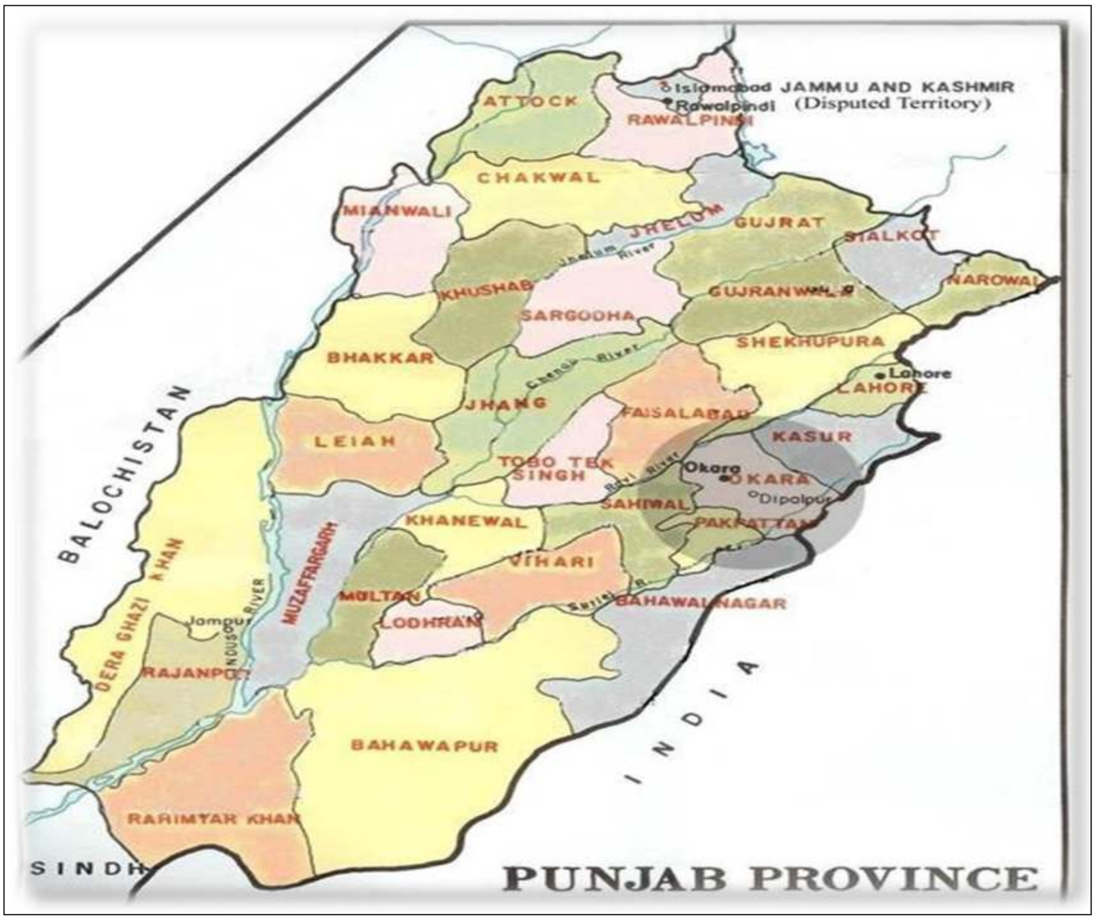

Figure 1: Map of the study area.

1000 mm from 2002 to 2016 with the exception of a few years (**Table 1**). The rainfall follows erratic pattern with most of the rainfall (about 70%) in months of June-September i.e. summer season while the winter season gets long spells of gentle showers. Considering temperature, mean of minimum and maximum temperature shows an increasing trend during the period of 2002 to 2016 (**Table 1**). Further, the area has generally slightly undulating slopes with low hill ranges. Arid region of the province is exposed to adverse effects of climate change.

Chakwal district was selected from the province as agriculture production in the district predominantly depends on rainfall. Two cropping seasons namely *rabi* (October–April) and *kharif* (May–September) seasons are traditionally followed keeping in consideration the rainfall probabilities and temperature for different crop growth stages. Wheat and peanuts are the important crops planted in the study area. This district is the most important area (occupies 27% of Rawalpindi division) for wheat production among rain-fed farming area of the Punjab. **Table 2** shows the importance of Chakwal district in Rawalpindi division, being the rain-fed division. Out of total cultivated area of Rawalpindi division, share of Chakwal district is amounted 32.19%. Further, this district has 33.29% share in the unirrigated[1] or rain-fed area of Rawalpindi division and it is therefore considered the most rain dependent district of the arid zone of the province.

2.2. Data collection method

A total of 190 farmers were interviewed from Chakwal district. A multi-stage stratified cluster random sampling technique was followed as used by the Pakistan Bureau of Statistics. Within the selected districts, rural union councils were selected randomly. Villages (cluster) were then selected randomly with probability proportion to population. We stratified union councils with large (above 10) and small (below or equal to 10) number of villages and 10 to 15 villages were chosen. Households from the selected villages were stratified into small, medium and large farms based on the landholdings where households with below 12.5 acres were considered small, 12.5–<24 acres as medium and above 24 acres holding as large. A 95% confidence interval for the estimates was used to determine the appropriate sample size. This sampling approach produced a sample size that was representative for the rain-fed division of the

Table 1: Annual rainfall and temperature data for 2002–2016.

Year	Maximum Temperature (°C)	Rainfall (mm)
2002	30	931
2003	29	1247
2004	30	1027
2005	28	973
2006	29	1598
2007	29	1828
2008	29	1388
2009	30	607
2010	30	1018
2011	29	1018
2012	29	1023
2013	31	925
2014	28	1507
2015	28	1621
2016	30	1044

Source: Govt of Punjab (2016).

[1] Irrigated area is primarily irrigated through ground or surface water in the province whereas unirrigated area mainly depends on rainfall.

Table 2: Land utilization statistics of Chakwal district (thousand hectares).

Particulars	Rawalpindi division	Chakwal district
Cultivated area	991	319
Total cropped area	839	260
Unirrigated/rain-fed area	778	259
Kharif area	311	102
Rabi area	528	158
Wheat area	484	130

Source: Govt of Punjab (2017).

province for understanding adaptation to climate change in the rain-fed agriculture with the objective of informing policy makers.

A semi-structured, pre-tested questionnaire was used to gather information. The questionnaire included a number of closed-ended and open-ended questions on socioeconomic characteristics, adaptation to climate change, farm assets, etc. In addition, the respondents were asked to provide qualitative information on farmers' decision to carry activities or to invest in adaptation to climate change in response to the perceived, actual or potential changes resulting from climate change. This sort of information was sought to understand reasons for carrying out activities or investing in adaptation to climate change. We considered activity or investment as an adaptation strategy if it was taken as a conscious investment to solve climate change related problem. We found mainly six adaptation strategies to climate change recorded by the respondents. These included manure application, deep plowing, bund-making, income diversification, crop diversification and land renting-out. Services of four postgraduate students from rural background with primary degree in agricultural economics discipline were hired to collect data during 2013. This helped to get information in native language and translate local language and terminologies.

3. Empirical models

Based on the benefits and costs of adaptation to climate change, we followed classification of adaptations into two broad categories (following Tompkins and Eakin, 2012) of 'private adaptation for private benefits' and 'private adaptation for public benefits'. Private adaptations for private benefits are those adaptations where the actions are taken by individuals and all the benefits are accrued to the individuals (Tompkins and Eakin, 2012). Deep plowing and manure application are examples of adaptations with private benefits. On the other hand diversification of income and crops, bund-making, and renting-out land area are other private adaptations to climate change and the owners bear the costs of adaptation whereas such adaptation decisions create public goods. So these adaptations are called private adaptation for public benefits. Diversification of income and crops is linked with the increased economic activities in the rural areas. Similarly, decision on renting-out land creates public good as this decision provides benefits to tenants and landless farmers. Bund-making is used to avoid soil erosion. However, its benefits are availed by the neighboring farmers as well through declining soil erosion.

A number of farm, farmer and socio-economic characteristics affect the decision on adaptation to climate change. Gender, age, education and experience are important among the farmer characteristics (Knowler and Bradshaw, 2007; Vitale et al., 2011; Baumgart-Getz et al., 2012). D'Emden et al. (2008) and Gedikoglu and McCann (2012) find that farm size, location, proximity of market to house, access to irrigation and the agro-ecological and socio-economic conditions of the area are important determinants of adoption decisions. The economic theory explains that farmers decide to make investment in adaptation to climate change when the expected utility of adaptation (D_1^*) is greater than the utility of non-adaptation (D_0^*). Thus decision on adaptation is observable as a dichotomous choice i.e. $D_i = 1$ if $D_i^* > D_0^*$, otherwise $D_i = 0$. This can be modeled as:

$$D_i^* = Z_i\beta + \varepsilon_i \text{ with } D_i = 1 \text{ if } D_i^* > D_0^*, \text{ otherwise } D_i = 0 \quad (1)$$

where Z is a vector of the explanatory variables, β is a vector of parameters to be estimated and ε_i is the error term.

Logit model is used to estimate equation 1 as the dependent variable is the dummy of adaptation to climate change i.e. farmers that adapt to climate change and those that don't adapt to climate change. Six separate logit models for six adaptation practices are estimated using maximum likelihood as these models cannot be consistently estimated using ordinary least square because of the dummy dependent variable in all the six logit models. The logit model is defined as follows:

$$P(D=1)=\frac{\exp(Z_i\beta)}{1+exp(Z_i\beta)} \tag{2}$$

$$P(D=0)=\frac{1}{1+exp(Z_i\beta)} \tag{3}$$

Where D takes the value 1 if the farmer adapts to climate change and 0 otherwise. Z is the row vector of independent variables and β is the corresponding parameter vector to be estimated. Details of dependent variables and explanatory variables used in the above models are presented in **Table 3**.

In order to estimate the effect of private adaptation on wheat yield, we employ log-linear production function in the present study. We used different forms of production function, log-linear production function is selected based on signs and significance of the variables and values of R^2. Wheat yield in log is considered as dependent variable. All six adaptation practices are taken as explanatory variables. Age, farming experience, family size, males and females above 15 years are also considered as independent variables. However, the results of this regression are interpreted with caution as physical quantities of farm inputs namely fertilizer, seed, labor, etc. are not included due to non-availability of the data. However, variables namely family size, males and females above 15 years are proxy of labor used in wheat production. Deep ploughing used for conserving rainwater and moisture is taken as proxy of irrigation water whereas dummy for manure applied is considered as the representative of fertilizer use.

Table 3: Socioeconomic characteristics and adaptation.

Characteristics	Unit	Mean	Standard deviation
Socioeconomic characteristics			
Age	Years	50.55	11.99
Education	Schooling years	7.72	3.65
Farming experience	Years	21.36	12.93
Family size	Numbers	8.21	2.84
Males above 15 years	Numbers	2.28	1.14
Females above 15 years	Numbers	1.87	0.95
Land area	Acres	7.75	15.29
Livestock	Animal units	3.02	3.43
Tractor	Yes = 1	0.33	0.47
Rotavator	Yes = 1	0.04	0.18
Distance from city	Km	9.98	7.75
Private adaptation for private benefits			
Deep plowing	Yes = 1	0.38	0.48
Manure application	Yes = 1	0.62	0.49
Private adaptation for public benefits			
Bund making	Yes = 1	0.54	0.50
Income diversification	Yes = 1	0.73	0.44
Crop diversification	Yes = 1	0.30	0.46
Land rented out	Yes = 1	0.82	0.38

4. Results

4.1. Socioeconomic characteristics

Considering manure application and deep plowing as adaptation to climate change, 62% and 38% respondents are found adaptors whereas 54% respondents are found using bund-making as adaptation to climate change. The respondents reporting income diversification are 73% and only 30% farmers are found diversifying crops. The most common adaptation to climate change is land renting out (82%) to fellow farmers (**Table 3**).

Descriptive statistics in **Table 3** show that the respondents are around 51 years old with average education of approximately 8 schooling years. The respondents reported farming experience of 21 years on average, indicating that the respondents have substantial experience in farming and they have learnt better farm practices through experience and observations. Pakistan is among the densely populated countries in the world and the present study depicts that the respondents have large family size i.e. 8 family members and mostly family size comprises children as evident from small number of males and females above 15 years of age. Small farms dominate in the study area as indicated by 7.75 acres land area owned by the respondents. Further, small landholding induces farmers to diversify income so the study finds average 3 livestock heads. Ownership of farm machinery is considered an important asset in adaptation to climate change. We find that 33% farmers possess tractor whereas rotavator is found with 4% farmers only. Distance of the farm from the city is important for having access to information and markets and the mean distance is found to be approximately 10 km that is quiet long distance.

4.2. Model results of private adaptation for private benefits

The empirical results obtained from logit models of private adaptation for private benefits are given in **Table 4**. It is evident from the results of both models that most of the exogenous variables are significantly related with adaptation to climate change i.e. manure application and deep plowing. Livestock is important in explaining the adoption of manure application as more livestock heads will result in higher probability of applying manure at the farm. The farmers having tractor are more likely to apply manure at their farms, since tractor is used for transportation of manure, although tractor is also used for other farm practices. Two variables namely farming experience and the distance from the city/market have significant negative relationship with the adoption of manure application.

Since crop production on the farms located in the rain-fed region depends on precipitation, conservation of moisture through deep plowing during the rainy season[2] is the utmost important farming practice and it has become critical in the presence of climate change. Education of the respondents is significant at 1% level of significance and it has positive impact on adaptation of deep plowing, implying that increase in schooling years by 1%, increases probability of adapting deep plowing by 0.25%. Family size is positively related to adapting deep plowing and this variable is statistically different from zero at 1% level of significance. Number of males above 15 years age is negatively related with deep plowing. A positive and significant coefficient of tractor ownership ($p < 0.01$) implies that the respondents having tractors are highly likely in adapting deep plowing. The result was expected because tractor ownership makes it convenient for farmers to go for deep plowing.

4.3. Model results of private adaptation for public benefits

The results of the logit models for private adaptation for public benefits are given in **Table 5**. The coefficients of education, farming experience, family size and farm owned area are positive and statistically different from zero for bund-making adaptation. These results indicate a strong association between exposure to technology and adaptation. In case of income diversification, significant variables are age of the respondents, farming experience and livestock heads. Education, family size, number of adults, tractor and distance from the city are significantly associated with crop diversification. Land renting-out is another private adaptation for public benefits as this adaptation results not only in benefits to the owners of the farm but it also provides benefits to others having no and or a few acres of land. Owned land area, tractor and number of male above 15 years are significantly related with this adaptation measure to climate change. Variables namely tractor ownership and owned land area are negatively associated with land renting-out whereas number of males in the family has positive effect on land renting-out.

[2] It is also important that deep plowing during dry season can cause evapotranspiration. We ensure that farmers follow deep plowing practice during the rainy season only to conserve moisture.

Table 4: Private adaptation for private benefits and determinants.

Variables	Manure applied	Deep plowing
Age	0.04*	–0.03
	(0.02)	(0.02)
Education	–0.01	0.25***
	(0.05)	(0.06)
Farming experience	–0.08***	0.04*
	(0.02)	(0.02)
Family size	0.04	0.26***
	(0.08)	(0.07)
Males above 15 years	–0.03	–0.49***
	(0.18)	(0.19)
Female above 15 years	–0.22	–0.35
	(0.23)	(0.22)
Owned land area	–0.02	0.00
	(0.02)	(0.01)
Livestock heads	0.23***	–0.03
	(0.07)	(0.05)
Tractor ownership	2.03***	0.94**
	(0.45)	(0.37)
Rotavator ownership	0.85	
	(1.17)	
Distance from city	–0.05**	–0.04
	(0.02)	(0.02)
Constant	–0.12	–2.10*
	(1.15)	(1.19)
LR Chi^2	62.67***	47.81***
Observations	198	191

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4. Effect of adaptation practices on wheat productivity

Results of multiple regression given in **Table 6** show the effects of private adaptation on wheat productivity in the rain-fed district. Out of all adaptation practices in the present study, we find that renting out, deep ploughing, crop diversification and income diversification are statistically different from zero. Income diversification and land renting out are negatively related with wheat productivity. As expected, deep ploughing and crop diversification are found positively affecting wheat yield. In addition to adaptation practices, family size is significant and negatively associated with wheat yield. Males and females above 15 years significantly positively affect wheat yield.

5. Discussion

Technology adoption for adaptation is taken by farmers to reduce the risk of climate change (Di Falco et al., 2011). Soil bunds, tree planting, water harvesting, contour plowing and cultivation of hedges are the most common adaptation strategies in the dry and rain-fed regions (Di Falco and Bulte, 2013). Income diversification is another risk mitigating adaptation strategy in the developing world (Eliss, 2000; Chavas

Table 5: Determinants of Private adaptation for public benefits.

Variables	Bund-making	Income diversification	Crop diversification	Land renting out
Age	0.02	0.06**	0.04	–0.02
	(0.02)	(0.03)	(0.03)	(0.03)
Education	0.29***	0.13	0.15*	–0.08
	(0.06)	(0.08)	(0.08)	(0.08)
Farming experience	0.05**	–0.05*	0.02	0.00
	(0.02)	(0.03)	(0.03)	(0.03)
Family size	0.39***	–0.04	0.16*	–0.07
	(0.09)	(0.11)	(0.09)	(0.09)
Males above 15 years	0.33	0.27	0.73**	0.54*
	(0.20)	(0.25)	(0.28)	(0.31)
Female above 15 years	–0.13	0.28	0.56*	0.52
	(0.24)	(0.32)	(0.31)	(0.35)
Owned land area	0.09**	–0.00	0.00	–0.34***
	(0.04)	(0.06)	(0.02)	(0.07)
Livestock heads	0.04	1.82***	–0.04	0.13
	(0.06)	(0.30)	(0.08)	(0.08)
Tractor ownership	0.68	–1.01	4.98***	–1.18**
	(0.42)	(0.65)	(0.70)	(0.58)
Rotavator ownership	–1.27	–0.90	–1.67	0.17
	(1.07)	(1.18)	(1.56)	(1.46)
Distance from city	–0.01	0.00	0.06*	0.01
	(0.02)	(0.04)	(0.03)	(0.03)
Constant	–8.68***	–4.79***	–8.74***	4.59***
	(1.59)	(1.68)	(2.14)	(1.71)
LR chi^2	84.65***	123.69***	136.34***	82.93***
Observations	198	198	198	198

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

and Di Falco, 2012, Wuepper et al., 2018). In the present study, we find that the most common adaptation strategy is land renting-out being the private adaptation for public benefits. Applying manure to conserve soil fertility is the most common private adaptation for private benefits. The least adapted strategy is crop diversification among all adaptation strategies. Many of the reported adaptation strategies in the present study are similar to those of Di Falco and Bulte (2013). Income diversification is the tool used by 73% farmers to reduce the risks posed by climate change. Farmers living in the rural areas of Pakistan have no or little access to credit and capital. These factors induce farmers to diversify in order to make more income security (Reardon et al., 2006; Ellis, 2004; Lanjouw & Lanjouw, 2001). Deininger & Olinto (2001) find that farm households choose to diversify into non-farm economic activities to reduce risk. Farmers of the study area are characterized with small landholding, lack of access to credit and capital. These characteristics may enforce rural households and their members to diversify farm activities.

Human capital such as education, farming experience and family size is important determinant of deep plowing for moisture conservation, soil bund-making and income diversification. With high schooling years, the farmers have access to information relating to the best adaptation strategies. Significant coefficient

Table 6: Estimates of adaptation practices on wheat yield.

Variables	Coefficients	Standard error
Constant	7.00	0.22
Age	0.01	0.00
Farming experience	–0.01	0.00
Family size	–0.05**	0.02
Male above 15 years	0.06*	0.03
Female above 15 years	0.06*	0.04
Renting out	–0.24***	0.09
Bund making	0.11	0.08
Manure application	0.04	0.08
Deep ploughing	0.07*	0.04
Crop diversification	0.25***	0.08
Income diversification	–0.08*	0.04
R^2	0.15	
Adjusted R^2	0.13	
F-test	3.79***	
Observations	198	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

of education variable implies its important role in adaptation to climate change. This is in line with Pali et al. (2002) and Mugi-Ngena et al. (2016) who found a positive influence of education on the soil water conservations and soil fertility management. Skoufias, Bandyopadhyay and Olivieri (2015) argue that education is strongly related with diversification in agriculture-related activities in India.

Farming experience learnt over the years enables farmers in making decisions in the right direction to reduce the ever increasing risk to their farms. Soil bund-making adaptation strategy is one such practice taken by the farmers to conserve their farms. This corroborates Mugi-Ngena et al. (2016) who observed that farming experience was significant in explaining farmers' adaptation to climate variability in regard to water harvesting strategy. Maddison (2006) argues that less experienced farmers have less knowledge and information to climate change and adaptation strategies to be taken in order to reduce the effects of climate change. Although soil bund-making, being an adaptation strategy is private in nature, it results in public benefits as the neighboring farmers with relatively low lying farms also avail advantages.[3] The reason lies in the fact that flow of water and soil erosion intensity will decline due to soil bund-making done by the former farmers. On the other hand, negative association of farming experience with income diversification is due to the reason that experienced farmers stick to their age-old reliance on agriculture production and they are reluctant to take risk in diversifying sources of income. Farming experience is also related with manure application. Farmers mostly obtain manure from livestock farming which is labor intensive and highly risky farming activity. Since experienced farmers have mostly risk averse behavior and therefore rarely invest in livestock farming. With no or little livestock heads, such farmers may have no manure and thus may not be able to apply manure at their farms. However, farming experience is positively associated with deep plowing adaptation strategy. Moisture or water conservation through deep plowing is totally private adaptation with private benefits and the experienced farmers are in a better position to invest in this type of adaptation strategy because of their knowledge and expertise of previous years in conserving rainwater through deep plowing. These results can be supported by Maddison (2006) and Mugi-Ngena et al. (2016) who found the important role of farming experience in adaptation to climate variability.

Farm mechanization is very low in Pakistan and it is particularly evident in the rain-fed areas of Punjab province where farmers have very small landholdings and their farm production depends on precipitation.

[3] Public benefits of private adaptation are not given in the present study. However, future study should consider these benefits.

Even tractors and basic implements are not sufficient to perform traditional farm practices. Statistics show that there are only 6315 tractors for 166 thousands rural households in Chakwal district (Government of Punjab, 2016), depicting that mostly farmers depend on their fellow farmers for tractor and other machinery services. Tractor ownership has strong role in adaptation to climate change as its ownership is positively related with deep plowing, manure application and crop diversification. All these strategies involve high use of farm machinery and farmers having tractor and other machinery. However, this variable is negatively related with land renting-out adaptation strategy. It is not economical for farmers having tractor and other farm machinery to rent out their farm area, as operating tractor and other machinery on the remaining farm area will not be economical. Owned land area variable has negative coefficient on renting-out adaptation. Negative relationship indicates that such farmers face greater difficulty in renting-out farm area as their staple food (wheat) heavily depends on farm production and they may not take risk of relying on staple food obtained from the fellow farmers, since the first priority for the small landholders is the staple food. Owned land area and soil bund-making are positively associated and this relation implying that farmers prefer to make investment in adaptation to climate change at their own land. Increasing owned land area by 1% will increase the probability of soil bund-making by 0.09%. This result is also in line with Anley et al. (2007) and Mugi-Ngena et al. (2016) that farmers with large farm size were found in investing water and soil conservation technologies.

Number of household members were significant in explaining the influence on deep plowing, soil bund-making and crop diversification. This shows that the farm households with large number of household members are more likely to have adaptation strategies in regard to the use of deep plowing, soil bund-making and crop diversification. These adaptation strategies are labor intensive practices and households with large family size can manage labor force requirement through their family members. This corroborates Dolisca et al. (2006), Anley et al. (2007), Nyangena (2007) and Mugi-Ngena et al. (2016) in that large family size enables farmers to take decision in favor of labor intensive adaptation strategies to climate variability.

Farmers make investment in adaptation practices with the goals of increasing productivity, income and overall welfare. The present study finds the relation between adaptation to climate change and wheat productivity. We find that adaptation practices namely land renting-out, crop diversification, income diversification and deep plowing are important contributors of wheat productivity. Negative sign of land renting out indicates that such farmers prefer to land renting-out instead of investing more in increasing wheat productivity. Crop diversification is another adaptation strategy showing a positive effect on wheat productivity. Farmers diversifying crops are inclined to allocate more resources in agriculture resulting in higher crop productivity whereas those diversifying income are more likely to divert their intension to other sources of earnings thus it may have negative impact on crop productivity. Since wheat productivity highly depends on rainfall and moisture available in the soil, deep plowing during the rainy season is critical in conserving soil moisture. Farmers following deep plowing receive higher wheat yield compared to their counterparts. Our results are in line with Akhter and Erenstein (2017) and Gorst et al. (2018) who find that adaptation to climate change is highly related with crop productivity in Pakistan.

6. Conclusions and policy implications

Adaptation to climate change is practiced by the farmers to mitigate the climate related risks. Adaptation through technology adoption can be based on decisions made by individual (private), community and public sector organizations. Private adaptation further can have benefits for individuals and public. The rain-fed agriculture in the north of Punjab is characterized with small landholdings, low farm mechanization, high dependence on precipitation, semi-hilly topography, and pre-dominant traditional farm practices.

Results of the study indicated that a host of socioeconomic factors of rural households in the rain-fed agriculture dictated farmers' response to climate variability, studying the role of these factors is inevitable for designing solid policy interventions for adaptation to climate variability. Results of the study imply that the policy-makers, researchers and regional planners can build on this work by undertaking more interdisciplinary research approach to find the most suitable adaptation strategies at individual and community levels. This becomes vital for heterogeneous rural households because some households have better capacity in adapting to climate variability compared to their fellow farmers. This necessitates to tailor adaptation policies while considering different biophysical and socioeconomic circumstances.

Education and farming experience, being the significant factors influencing the use of adaptation strategies imply that awareness about adaptation strategies is important area to be focused in policy interventions for adaptation to climate variability. Education and training programs are already organized for the farmers by the Department of Agriculture, Government of Punjab.

Mostly adaptation strategies are labor intensive farm practices such as crop diversification and soil bund-making. Presently, farm machineries available in the market are particularly designed for large landholders. Small landholders are not able to afford and operate optimally considering few hectares of landholdings. Thus, there is a need to invest in farm machineries suited to small landholders. The policy makers should give due focus to public sector interventions in the form of research and development to help these resource scarce rain-fed farming communities and also find ways to support the private adaptations providing public goods for benefit of environment and the society at large. Future research should consider the nature of public sector adaptation efforts and the related distributional issues among community members. Moreover, the village commons are facing additional threats and demand for ever bigger contribution for sustainability. The future research should address climate change related additional costs and resultant benefits and their distribution to members to develop a multidimensional understanding about adaptation to climate change.

Competing Interests

The authors have no competing interests to declare.

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