Climate change affects agricultural productivity by altering biophysical relationships such as changing growing periods of crops, altered scheduling of cropping seasons, changing irrigation water requirements, altering soil characteristics and increasing the risk of pests and diseases (Nelson et al. 2014; Tripathi et al. 2016; Schönhart et al. 2016). Higher temperatures during different crops growth stages can considerably affect the process of photosynthesis, flowering, grain filling and crop yields which could further lead to decreasing farm incomes and accelerating food insecurity (Battisti & Naylor 2009; Naylor et al. 2007). These negative repercussions of climate change could further worsen the already miserable conditions of smallholders and subsistence farming communities in the developing nations - Pakistan is one of them (Morton 2007).

1.1.1 Climate Change and farming in Pakistan

Pakistan has a total area of 796,095 square kilometres. It is located between the latitudes of 24° and 37° north and longitudes of 61° to 75° east, stretching over 1600 kilometres from north to south and 885 kilometres from east to west. It has diverse agro-ecological zones (AEZs) with the climatic classification ranging from subtropical to arid and semi-arid. The annual rainfall in the country ranges from 100 mm to 125 mm in the extreme southern plains, 500 mm to 900 mm in the sub-mountainous plains while from 760 mm to 2000 mm in mountainous and extreme northern plains. About 70 percent of the total rainfall occurs as heavy rainstorms in summer season between July to September, mainly instigating from the summer monsoons, and 30 percent of rainfall transpires in winter. The months of summer season, except in the mountainous areas are very hot with a maximum temperature range of 40°C to 46°C, while the minimum temperature in winter goes a few degrees below freezing point in northern Himalayan mountainous areas (PMD 2009; Chaudhry et al. 2009).

In general, past and present climate trends and variability in Pakistan can be characterized by increasing air temperatures, unpredictable precipitation patterns, and an increasing trend in the frequency and severity of extreme events such as floods and droughts (FFC 2014; Chaudhry et al. 2009). Temperature projection for Pakistan in the 21st century warrants a significant rise over that observed in the last century (IPCC 2014). In addition, an increase in occurrence of extreme weather events has also been projected in the country including heat waves and fluctuating rainfall patterns such as increase in the

inter-annual and seasonal variability of daily precipitation (FFC 2014; Chaudhry et al. 2009).

Agriculture sector contributes 20.9 percent in the Gross Domestic Product (GDP) of Pakistan (GOP 2016). It provides a source of livelihood to 70 percent of the rural population directly or indirectly. As farming is the major economic contributor to the health of Pakistan's economy, any negative effect on farming sector would directly influence not only the food production, food security and livelihoods of farming communities but overall rural development in the country. Farming sector is experiencing decline in production and a downward trend in contribution to real GDP and export earnings during the last decade (FAOSTAT 2014; GOP 2016). The decline in farm production is mainly attributed to the variations in climatic parameters within the country and it is expected to further exacerbate in the future due to predicted climate scenarios (Chaudhry et al. 2009; GOP 2016). Efficient farm production and enhancing crop yield therefore is essential in order to maintain and boost the food security level and livelihoods of rural farming communities by continuously providing climate resilient adaptation strategies which make the farming systems less vulnerable to climate change. Climate smart farming would subsequently lead to sustain and trigger economic growth, reduce rural poverty and mount rural development in the country (GOP 2016).

Rice and wheat are two major staple food crops for millions of people in Pakistan, which are rotated in sequence across AEZs in the country. Productivity of this cropping sequence plays a key role in Pakistani farming, as rice and wheat contribute 50-60 percent and 5-10 percent, respectively, of the average daily per capita calorific intake (WFP 2010). The negative effect of terminal heat stress on wheat crop productivity in neighbouring South Asian countries has already been reported (Krupnik et al. 2015a; Krupnik et al. 2015b). Given the importance of wheat and rice as the two principal grain crops determining food and livelihood security in Pakistan (a country of 82.6 million food-insecure people, WFP 2010), it is important to quantify the effects of climate variability and heat stress on the average yields, yield variability and economic efficiency of farmers that produce these crops, under their own field management conditions in order to develop robust adaptation strategies that account for both agronomic and economic concerns. Country specific impact assessment studies help reduce the uncertainties in describing how climate change and variability would affect agricultural

productivity and aid in designing appropriate adaptation strategies and agricultural development policy (Asseng et al. 2013). In addition, an improved understanding of the farmers' perception to climate change, adaptation behaviour and intended future adaptation practices to cope with climate change could help this process.

1.2 Research agenda

1.2.1 Problem statement

Ensuring food and livelihood security for the world's ever-growing population is one of the major global challenges of 21st century (FAO 2016). Evidence suggests that temperature rise will continue more severely in the tropics and sub tropics than in temperate regions (Mendelsohn et al. 2006; IPCC 2014). Enduring scientific research efforts are therefore much needed in order to maintain and boost the productivity of farming systems in tropical environments. A recent study by Mueller et al. 2014 reports that heat stress in Southern Pakistan consistently surges the long-term rural-urban migration of men because of continuously declining farm and off-farm income levels. Agricultural activities, specifically crop production mainly depends on seasonal weather conditions in Pakistan, crop production and food availability therefore are strongly affected by fluctuations in weather parameters during cropping seasons (GOP 2016). In addition, as the population of undernourished people in Pakistan shows an increasing trend in the recent years (FAOSTAT 2015), meeting the food needs of growing population in the country is of major concern.

Pakistan has been facing rising temperatures and strong heat waves over the last decade (IPCC 2014; FFC 2014), which necessitates investigating the impacts of climate variability and heat stress on farming systems and subsequently suggesting adaptation policy agenda to cope with the negative effects. Like other countries in South Asia, Bangladesh for example, farming communities in Pakistan will have to face variability in agricultural production in the future due to extreme weather evets (Immerzeel et al. 2010) and hence there is also a need to explore reliable non-structural risk reducing mechanisms in order to cope with such events. This will help ensure the food, income and livelihood securities of farming communities in general and subsistence farmers relying solely on agricultural activities for living - in particular.

Wheat being the primary food grain crop of Pakistan occupies the largest area under cultivation in the country. It contributes 10 percent to agricultural value addition and 2.1 percent to national GDP. Area under wheat cultivation decreased from 9199 to 9180 thousand hectares in the last two years indicating a decrease of 0.2 percent. Wheat production in Pakistan during 2014-15 was recorded 25.478 million tonnes, showing a decrease of 1.9 percent over the production of 25.979 million tonnes in the preceding year. The decline in wheat production was mainly due to prolonged winter season and unprecedented rains during the months of April & May which caused damages to grain during harvesting time. Rice is the second major staple food crop; it accounts for 3.2 percent in agricultural value addition and 0.7 percent for national GDP. Rice contributes in country's foreign exchange earnings as well (GOP 2016).

Under the changing climatic conditions holistic and interdisciplinary approaches need to be followed by the researchers to study the impacts not exclusively but collectively taking into consideration the crop physiological, biophysical, farm and socio-economic indicators. Building on the outcomes of scientific efforts, suggesting supplementary farm management measures and designing immediate adaptation actions along with identifying weaknesses in the existing farm management practices is highly imperative. As each crop is characterized by a specific phenological cycle; detailed analyses of the impacts of cropping-season specific and growth-stage specific climatic variability and weather parameters particularly heat stress, under farmers' field conditions is of utmost importance. From the farm-field to country level, there are many studies which show that besides the climatic parameters physiological, biophysical, farm and socio-economic factors are the drivers of changes in crop yields as well (Ray et al. 2012).

1.2.2 Overall objectives and contribution to the exiting literature

This thesis aims to provide a comprehensive assessment of the impacts of climate variability and heat stress on Pakistani farming in various perspectives. Based on an extensive review of literature on the impacts of climate change on farming, the analyses done in this thesis investigate the effects of climate variability and heat stress on observed rice-wheat yields, yield risk, economic efficiency of crop production and farmland values by employing sophisticated econometric techniques. In addition, farmers' willingness to pay for crop insurance against floods and droughts are elicited separately, and a

comprehensive picture of farmers' perception of climate change and adaptation behaviour across the studied AEZs in Pakistan is presented.

This thesis contributes to the literature on climate change impacts in a number of ways. A large body of literature investigates the impacts of climate change on agricultural production at farm, country, regional and global level. However, there is a dearth of scientific literature on the impact assessments focusing on Pakistan's farming systems. This thesis fills that gap by mainly focusing on rice and wheat crops, the two major food crops cultivated in Pakistan with broader implications in South Asian region. Importantly, the modelling efforts done in this thesis offer novel and modified approaches to examine the effects of important climatic parameters on farming in an interdisciplinary way as opposed to the ones used in the state of the art impact assessment methods applied in previous economic and agronomic literature.

The analyses generally cover all the AEZs of Pakistan, but a special focus has been given to rice-wheat producing zones as rice and wheat are two principle staple crops providing food to millions of people in the country. The outcomes of the studies conducted in this thesis and subsequent policy recommendations are generally applicable to other South Asian countries as well, given the somewhat similar climatic conditions, monsoon seasons, socio-economic and farm characteristics of rural farming communities in South Asia. Nonetheless, as the empirical findings stem from the data collected from Pakistan, the resulting policy suggestions imply mainly for Pakistani farming. Specifically, following research questions have been addressed in this thesis:

- Do medium-term climate variability and heat stress affect the rice-wheat yield and yield variability (indicative of risk) in Pakistan? (Paper 1).
- Do medium-term climate variability and heat stress affect the economic efficiency of rice-wheat producing farmers in Pakistan? (Paper 2).
- Does medium-term climate variability affect the farmland values in Pakistan? (Paper 3)
- What are the farmers' perceptions to climate change and their adaptation behaviour in Pakistan? (Paper 3).
- Is there a potential for crop insurance market against extreme weather events (floods and droughts) in rural Pakistan? (Paper 4)

- What are the factors that drive farmers' willingness to pay insurance premiums in rural Pakistan? (Paper 4).

Given the focus of this thesis, above described pressing research questions are framed in multidimensional and multidisciplinary contexts. Each research question potentially covers the economic, agronomic, and physiological aspects of the effects of climate change and variability on farming systems in Pakistan. All the research questions are strongly embedded within the context of economic, agronomic and physiological variables. To address each research question state of the art econometric methods are utilized with significant modifications in modelling the all-important climatic, socio-economic, physiological, and agronomic and farm data. The thesis also describes farmers' perception to climate change, their adaptation behaviour and intended adaptation options based on the information reported by the farmers employing descriptive statistics. The findings of the analyses lead to infer important policy implications that may help adapt the farmers to climatic variability and trigger the agricultural and rural development in Pakistan and more broadly in South Asian region.

1.2.3 Methodological approaches

A large number of studies in climate change impact assessment literature investigate the impacts on agriculture in various perspectives. There is also a large heterogeneity in the use of methods and the results across studies, depending upon the geographical regions, farming systems and climate change scenarios. This thesis follows an amalgamation of quantitative approaches to address various objectives of the study. **In the first paper**, the effects of climatic variability and heat stress on yield and yield risks of rice and wheat were estimated employing the Just and Pope stochastic production functions (Just and Pope 1978). The J-P function captures both the effects of explanatory variables on the probability distribution of crop yields and variation in yields (yield variance), and is therefore useful to estimate the yield risk. The first step of analysis investigated whether any significant yield risk (non-constant variance) was observable in the dataset. The Breusch-Pagan (1980) test was therefore applied to the null hypotheses that the models hold homoscedasticity (constant variance) such that no yield risk is present. The presence of heteroscedasticity (non-constant variance - Indicative of yield risk) was revealed and the null hypothesis was rejected because of insignificant P value. In the second step on

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