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Prospects for wheat production under changing climate in mountain areas of Pakistan – An econometric analysis

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Abstract

We assess potential future impacts of climate change on wheat yields in Swat and Chitral districts of Pakistan, mountainous areas with average altitudes of 960 and 1500 m above sea level, respectively. Using past climate data (1976–2000) to track temperature trends in both study districts, we find that increased temperatures correspond to an increase in Growing Degree Days (GDDs) and a decrease in Growing Season Length (GSL). Chitral district shows a stronger decline in season length than Swat district. Compared with the estimated optimum level of 157 days, the 25 year average GSL for the dominant varieties is estimated to be 156 days in Swat district and 195 days in Chitral district. Future increases in temperature of 1.5 and 3 °C are likely to cause wheat yields to decline (by 7% and 24% respectively) in Swat district and increase (by 14% and 23% respectively) in Chitral district. Future increases in precipitation of 5–15% during the growing season show a negligible impact on wheat yield.

Development and dissemination of short duration varieties, which can withstand the climatic anomalies expected in the future, should be given priority in the mountain region. More recent High Yielding Varieties (HYV) of the warmer plain areas should also be tested and introduced in the mountain areas because the expected future increases in temperatures caused by global warming would render these varieties suitable for the mountain areas.

Keywords: Climate change impact; Wheat yield; Mountain areas; Growing season length; Transcendental model; Chitral; Swat; Pakistan

1. Introduction

Research conducted over the last decade by the Intergovernmental Panel on Climate Change (IPCC) has found that average global temperatures have increased by about 0.6 °C since the industrial revolution, mainly as a result of an increase in concentration of Green House Gases (GHGs) in the atmosphere. These results have been confirmed in a recent study by Brohan et al. (2006), showing that 20th century was the warmest century, 1990s the warmest decade of the millennium, and ten of the eleven warmest years in the series have now occurred in the past 11 years (1995–2005). Future changes in global average temperatures are expected to be between 1.4 °C and 5.8 °C over the 21st century (IPCC, 2001). In spite of this overall increase in average global temperatures, IPCC research predicts that large changes (both increases and decreases) in temperature and precipitation will occur in different world regions with considerable direct and indirect impacts (both positive and negative) on various socio-economic sectors, such as water, agriculture, health, forestry, and biodiversity. [Current global model simulations however show that most regional land areas would warm more than the global average (Giorgi and Bi, 2005).]

In some regions climate change may lead to prolonged dry spells or more intensified heat waves, seriously impairing agricultural productivity by causing moisture or thermal stress, particularly during critical stages of crop growth (Rounsevell et al., 1999 in the IPCC, 2001). Dry land areas,

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including arid and semi-arid regions in South Asia, are most vulnerable to these climatic changes, especially given their existing water shortages and the high temperatures that already approach tolerance limits (CGIAR, 2004–2005; Parry et al., 1988b). Land degradation and limited water supplies restrict present agricultural productivity and threaten the food security of most of the countries in this region.

There are few projections of the impacts of climate change on agriculture production for the region. The average change in wheat yields in South Asia may range between +4% and −34% by the mid-21st century under current projections of global mean temperatures rising 3–4 °C above the pre industrial period (ECF, 2004). In general, wheat production in Pakistan would decline under selected scenarios of climate change (GOP/UNEP, 1998; Hussain et al., 2005a; Watson et al., 1997). The decline in irrigated wheat yield in semi-arid areas of Pakistan is expected to be in the range of 9–30% for temperature increases of 1–4 °C (Malik et al., 2005).

Whereas many regions are likely to experience adverse effects of climate change, some effects of climate change are likely to be beneficial. In middle to high latitudes and at high altitudes there may be an increase in agricultural productivity, depending on crop type, growing season, changes in temperature regimes, and the seasonality of precipitation (FAO, 2004; Parry, 1990; Watson et al., 1997). In these areas, temperature increases can enhance crop growth by allowing earlier planting of crops in the spring, faster maturation and earlier harvesting (Rosenzweig and Hillel, 1995).

In this paper, we argue that agricultural productivity in the mountainous Himalayas and Hindukush regions are currently limited by temperature and that an increase in average temperatures due to climate change would accelerate the development and growth of winter crops, thus, reducing the growing period required by crops for maturation (hereinafter referred as Growing Season Length) and increasing yields. The paper assesses climate change impacts on agriculture in the mountain areas of Pakistan by focusing on the effect of increases in temperature on wheat cultivation. Specific objectives of the paper are to analyze the effect of temperature on Growing Season Length (GSL) of wheat, and assess the impact of temperature increases on wheat yield.

2. Study area

The study covered two districts, Chitral and Swat, parts of the HinduKush mountain ranges in northern Pakistan. Chitral district has an altitude of 1500 meters above sea level (in the valley bottom) with a latitude and longitude of approximately 35° 51′ N and 71° 50′ E, respectively. Swat district lies at 960 m on average with a latitude and longitude of approximately 34° 44′ N and 72° 21′ E, respectively. The two districts have separate and distinct weather systems. The weather system in Chitral is dominated by a winter weather pattern, with rains caused by western disturbances that occur in the period of December–March. The weather system in Swat, however, is dominated by monsoon patterns, influenced by monsoon lows and depressions in the Arabian Sea and the Bay of Bengal.

In Chitral district, the mean annual temperature is 16 °C. The district receives an annual total rainfall of 451 mm, more than 60% of which occurs during the wheat growing season (October–April). In Swat district, the mean annual temperature is 19 °C. It receives a total annual rainfall of 966 mm, 41% of which occurs during the wheat growing season (October–March).

Around 60% of household income in the districts depends directly on agriculture, with a per capita income of US$ 100–150 (Munir, 2003). Another major source of income is off-farm labour. Agricultural systems are subsistence-based, land holdings are small, and crop-livestock interactions dominate the farming system in the area. Wheat and maize are the main food crops grown in Rabi (winter) and Kharif (summer) seasons respectively and both are grown predominantly under irrigated conditions. Other crops grown in the two districts include beans, rice, barley, fruits and vegetables. Double cropping is widespread in most areas of Swat district, whereas in Chitral district farmers tend to plant only one crop per year on almost half of the arable land due to low temperatures (IUCN, 2004).

These two districts were chosen to allow an analysis of the differential impacts of climate change on wheat production that may occur at different altitudes and in distinct weather systems. In general, wheat grown in the mountains and foothills is used for food as well as for fodder. Up to an altitude of slightly over 1500 m wheat is grown for food. Above this level, however, wheat is used as fodder because lower temperatures prevent the crop from maturing into edible grain (Heisey et al., 1992; Hussain, 2003).

3. Methods

Two broad classes of models for examining the response of agricultural crops to climatic variation can be identified. Crop simulation models are based on biophysical processes (photosynthesis, transpiration, nutrients and moisture flow) and involve dynamic relationship between the crop growth, environment and management interactions – climate, soils and cultivation practices (Rosenzweig and Iglesias, 1998). These models have a variety of applications such as problem diagnosis or yield gap analysis, precision agriculture, and adaptive management, and they have also been widely used in various national climate change impact assessment studies completed in the United States, Canada, Australia, UK and New Zealand (Rosenzweig and Iglesias, 1998) and in some regional studies including the high latitude and semiarid agriculture areas (Parry et al., 1988a,b). More recently, some studies have used outputs from simulation models as input to economic models for integrated ecosystem assessment (Antle et al., 2005). Crop simulation models and integrated Biophysical–Economic models require recorded measurement of crop growth and yields for calibration and validation, as well as information on