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Impact of climate change on wheat productivity in Central Asia

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ABSTRACT

Climate change (CC) may pose a challenge to agriculture and rural livelihoods in Central Asia, but in-depth studies are lacking. To address the issue, crop growth and yield of 14 wheat varieties grown on 18 sites in key agro-ecological zones of Kazakhstan, Kyrgyzstan, Uzbekistan and Tajikistan in response to CC were assessed. Three future periods affected by the two projections on CC (SRES A1B and A2) were considered and compared against historic (1961–1990) figures. The impact on wheat was simulated with the CropSyst model distinguishing three levels of agronomic management. Averaged across the two emission scenarios, three future periods and management scenarios, wheat yields increased by 12% in response to the projected CC on 14 of the 18 sites. However, wheat response to CC varied between sites, soils, varieties, agronomic management and futures, highlighting the need to consider all these factors in CC impact studies. The increase in temperature in response to CC was the most important factor that led to earlier and faster crop growth, and higher biomass accumulation and yield. The moderate projected increase in precipitation had only an insignificant positive effect on crop yields under rainfed conditions, because of the increasing evaporative demand of the crop under future higher temperatures. However, in combination with improved transpiration use efficiency in response to elevated atmospheric CO_2 concentrations, irrigation water requirements of wheat did not increase. Simulations show that in areas under rainfed spring wheat in the north and for some irrigated winter wheat areas in the south of Central Asia, CC will involve hotter temperatures during flowering and thus an increased risk of flower sterility and reduction in grain yield. Shallow groundwater and saline soils already nowadays influence crop production in many irrigated areas of Central Asia, and could offset productivity gains in response to more beneficial winter and spring temperatures under CC. Adaptive changes in sowing dates, cultivar traits and inputs, on the other hand, might lead to further yield increases.

1. Introduction

Global warming and related climate change (CC) may pose a major challenge to agriculture and rural livelihoods in Central Asia, with its five countries Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan and Turkmenistan. However, in view of the little hard data at hand, there is considerable uncertainty about the impact of CC, and the subregion is clearly in need of more climate change-related research (ADB and IFPRI, 2009).

Higher minimum as well as maximum air temperatures has been projected consequences of climate change for the late 21st century in Central Asia (IPCC, 2007). This would raise the water demand of rainfed and irrigated crops in general, but may also increase the risk of heat stress during flowering time of winter and spring crops (wheat, barley) grown in the region. On the other hand, higher temperatures during spring may boost early crop growth of winter crops, lower the risk of severe/late frost damage and thus lead to higher yields.

The projections by Global Climate models (GCMs) of the impact of climate change on precipitation, especially in the high mountain

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regions of the eastern part of Central Asia, are not clear-cut. There is some indication that the northern part of Central Asia (Kazakhstan) may receive more precipitation in the future, while the southern part (Uzbekistan, Turkmenistan) may receive less; the extent of both areas varying in (future) time and space depending on the underlying particular GCM. For certain areas in the center of Central Asia some GCMs project an increase in precipitation while others suggest the opposite. However, the overall changes in precipitation are projected to be rather small (IPCC, 2007). Lioubimtseva and Henebry (2009) reviewed the literature on the vulnerability of the Central Asian countries to climate change. Among others, they examined climate change as projected by IPCC GCMs and concluded that changes in precipitation are small and hardly discernible given the high temporal and spatial variability of precipitation, and that the changes in temperature will be the stronger factor affecting potential vulnerabilities across Central Asia. This is in line with the review of Singh et al. (2011), who estimated the reduction in precipitation for the whole Central Asia to be only about 3%.

Irrigated areas of Central Asia however do not depend so much on the annual precipitation as they depend on river water availability. Yet, snowfall projections and glacier and snow melt in the Pamir Mountains in response to CC are equivocal as well. Consequently, there is uncertainty about the impact of CC on river water availability and seasonality in Central Asia, as the Pamir is the spring of the two major Central Asian Rivers, the Amu Darya and Syr Darya. Up till recently, it was commonly assumed that total glacier ice mass in the Pamir Mountains is shrinking at fast rate. However, latest estimates seem to show that previous projections of glacier melt were too high (Jacob et al., 2012). Even if CC triggered a fast shrinkage of glaciers, the downstream short-term consequences would not be lower but higher water runoff, unless at the same time reduction in snowfall would counterbalance the surplus glacier water input. Nevertheless, CC may have an effect on the seasonality of stream flow. Siegfried et al. (2012), for instance, projected a shift in peak flows, due to earlier snow melt, towards spring and subsequently less water available in early summer in unregulated sub-catchments of the Syr Darya. Overall, however, their results did not point towards a notable change in total annual discharge rates for the coming 40 years. On the other hand, Krysanova et al. (2010) assessing the impact of CC, among others, on the Amu Darya watershed, predicted decreasing annual water availability and increasing frequency and intensity of droughts.

Central Asia comprises a wide range of soils (Sommer and De Pauw, 2011) and agro-ecological zones (De Pauw, 2010). This is not surprising given the dimensions of Central Asia measuring about 2000 km north-south (35 N to 55°N) and almost 2900 km east-west (46°E to 87°E). Coverage of a wide range of altitudes (50–7500 m above sea level) adds to the complex set of agro-ecological zones. Furthermore, the regional differences in terms of dependency on irrigation water for agriculture are large. About 22% (85 Mha) of the total geographic area of Central Asia is under cultivation, whereas roughly 30% of this cultivated land is under irrigation (Celis et al., 2007). Uzbekistan almost fully relies on irrigated agriculture (>80% of the cultivated land), while percent-wise, Kazakhstan has the smallest share of the five countries (<13%). Furthermore, especially Uzbekistan, but also partly the other four Central Asian countries, suffer from land degradation by secondary soil salinization in response to suboptimal irrigation/drainage management and shallow, saline groundwater levels.

Wheat is by far the most important stable crop in Central Asia. An approximate 8.5 Million ha are under wheat in Kazakhstan alone. The Kazak wheat production amounted to 17.1 Mt in 2009 which represents about 2.5% of world total production. The four other Central Asia countries add another 11.5 Mt of wheat annually (FAOSTAT, 2011). Yet, surprisingly little is known about the impact of CC on wheat growth and productivity in Central Asia. Such assessments are often pursued using biophysical simulation tools, such as crop models. White et al. (2011) screened related literature of the past decades and identified 221 peer-reviewed papers that used crop simulation models to examine diverse aspects of how climate change might affect agricultural systems. They could not find a single related paper considering at least one of the five Central Asian countries. Likewise, the reviews of Lioubimtseva and Henebry (2009) and Singh et al. (2011) did not consider studies that dealt with the impact of climate change by means of biophysical (crop) models. Some limited information about the impact of CC on wheat production in Central Asia can be deducted from studies that cover the entire globe. Arnell et al. (2002) studied the consequences of three different climate change scenarios – unconstrained CO_2 emission, stabilization at 750 ppm by 2230, and at 550 ppm by 2170 – on various ecological and economic aspects at global scale. Among others, they used a “suite of dynamic crop growth models” (without detailing further) to simulate the effects of climate change and increasing CO_2 concentrations on the potential yield of major cereal crops. CO_2 levels according to their unconstrained emission scenario would reach around 700 ppm by the year 2100, i.e. similar to the IPCC SRES A1B (IPCC, 2007). In response, estimated changes in national potential long-term mean grain yield by the 2080s were predicted to be in the range of −2.5% to 0% for the whole of Central Asia.

Parry et al. (2004) assessed the effects of climate change on global food production by means of bio-economic modeling. They applied projections of CC of the HadCM3 GCM based on the IPCC SRESs A1FI, A2, B1, and B2. The biophysical impact (temperature, water, CO_2) of CC on the major crops wheat, rice, maize, and soybean was estimated with yield transfer functions based on earlier crop simulation studies (Rosenzweig et al., 1993) with the CERES models for wheat, maize, and rice and the SOYGRO model for soybean. In response to CC, cereal yields of Central Asia – unfortunately lumped together with Russia – were estimated to drop by between 2.5% and 10% (SRES B2a, 2050s: 10–30%) as compared to historic (1990) conditions. The SRES scenarios and the considered future time periods (2020s, 2050s and 2080s) had only a marginal additional distinct impact. Regional variations within countries were not given in the maps published in the study, nor were differences between crops. Iglesias and Rosenzweig (2009) provided the results of a major update of the above-mentioned Parry et al. (2004) study. Country level results are available for download from the internet. Wheat production in Kyrgyzstan, Tajikistan and Uzbekistan was projected to change by +3.6%, +6.9% and +9.9% (same figures for all three countries) in the 2020s, 2050s and 2080s, respectively, under emission scenario A2. For Kazakhstan the changes would be −2.6%, +0.02% and +10.0% for the same periods. The report is inconclusive about how many agro-ecological zones and wheat varieties were considered in Central Asia, but the fact that for Kyrgyzstan, Tajikistan and Uzbekistan exactly the same changes in wheat yields were projected, provides evidence that (at least) for these countries only one ‘case’ was simulated, probably using identical CC projections.

The International Food Policy Research Institute, IFPRI, made an attempt to simulate the biophysical and economic impacts of climate change at global (0.5° resolution) scale (Nelson et al., 2009). They used the IPCC SRES A2 climate change projections for the year 2050 of the two GCMs NCAR and CSIRO. Year 2000 served as baseline. Biophysical simulations were carried out with the DSSAT modeling suite (Jones et al., 2003). No details about crop model setup, calibration or validation are provided in the report. Furthermore, crop model results for the five crops wheat, rice, maize, soybean and groundnut were either only provides as global averages, or, if disentangle by regions (sub-contents), only for simulations in which the carbon fertilization effect of an elevated atmospheric CO_2 concentration was not considered. The latter seems hardly useful, as there is little doubt about such positive effect; at least for the five