Effect of increasing temperature on yield of some winter crops in northwest India

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The effect of increase in temperature on grain yield of some winter crops (wheat, mustard, barley and chickpea) in northwest India was evaluated on the basis of historic records and through a dynamic crop growth model, WTGROWS. The optimal date of sowing was also evaluated in view of the increase in seasonal temperature. The yield of these crops, especially wheat, already showing signs of stagnation in most places of northwest India, is most likely to be affected by temperature changes. The solar radiation–temperature interactions study in wheat reveals some interesting trends and is seen to vary from one location to another. Keeping in view the trends in global climate change, a shift in sowing time, as an adaptation strategy is recommended. The simple and empirical relations between yield and seasonal temperature change can be well used for a crude estimate of yield dependence of temperature rise of these winter crops.

Keywords: Radiation, simulation, sowing time, temperature change, winter crops, yield.

SEASONAL temperature is an important climatic factor which can have profound effects on the yield of crops. Changes in seasonal temperature affect the grain yield, mainly through phenological development processes. Winter crops are especially vulnerable to high temperature during reproductive stages and differential response of temperature change (rise) to various crops has been noticed under different production environments[1–4].

Climate change is a concern today, and researchers are engaged in understanding its impact on growth and yield of crops, and also identifying suitable management options to sustain the crops' productivity under the climate change scenarios. Crop growth models can simulate the growth and yield of crops under various biotic and abiotic stresses, and can be conveniently used for climate change studies[5,6]. However, the response of crops to the seasonal temperature and other weather variations needs to be studied in detail so that it can subsequently be used for evaluating the impact of climate-change by linking with the future climate change scenarios. At the same time, the altered agronomic management practices to help the crop adjust to the changed environment need to be identified as well[7,8].

Wheat (*Triticum* spp.) is the major rabi crop in India and is sensitive to various biotic and abiotic stresses like weather and inter-seasonal climatic variability (in terms of changes in temperature, rainfall, radiation), soil conditions and agricultural inputs like nitrogen, water and pesticides[9–13]. Wheat growth simulator, WTGROWS[14], has been developed and intensively tested for diverse agro-environments within the country. The present study aims to investigate the effect of increasing seasonal temperature on yield of four important winter crops of the north-western part of the country namely, wheat, mustard (*Brassica* sp.), barley (*Hordeum vulgare*) and chickpea (*Cicer arietinum*); evaluation of optimum sowing dates for exploring maximum yield potential of wheat and mustard crops, and to understand the variability of climate change on growth and yield of wheat in northwest India using the WTGROWS model.

Materials and methods

The normal weather data for wheat, mustard, barley and chickpea under different locations spread over four states in northwest India (Punjab, Haryana, Rajasthan and Uttar Pradesh (UP)) were compiled from published reports and papers. Average yields of 12 years (1986 onwards) pertaining to the winter crops under study along with the respective seasonal temperature and other meteorological parameters were collected and compiled from the reported literature, data from research experiments and farmers' field and agro-advisory units in India. WTGROWS was run for different dates of sowing under normal as well as elevated temperature (1–3°C rise) for Pantnagar and Saharanpur districts of North India. For working out the optimal sowing dates for the locations, the date of sowing was assumed between 280 and 360 Julian days, with 5-days increment level. Radiation and temperature change

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interactions on dry biomass and yield of wheat was evaluated using WTGROWS for Delhi and Patna environments with normal rainfall taking place in these locations and assuming agronomic inputs to be non-limiting. The data on mustard were collected and compiled from All India Coordinated Trials on Mustard through the ICAR network.

Results and discussion

Yield response of wheat

The optimal sowing dates in northwest India for winter crops, especially wheat, are relatively early compared to the eastern part of the country. The model output indicates that increase in temperature by 1–3°C is likely to advance the optimal sowing dates by 5–8 days per degree rise in temperature. However, this advancement is less in relatively cool regions.

Attainable yield of wheat is also subject to decrease with similar degree of increase in temperature. Yield–temperature response curves show that there is a decrease in grain yield of wheat in all the four states studied (Figure 1), with maximum decrease in Haryana (4.29 q per ha) followed by Rajasthan (2.49 q per ha) per degree rise in seasonal temperature. For rest of the locations, small decline of 0.62 (Punjab) and 0.56 q per ha (UP) in grain yield per degree rise in temperature was observed.

The local climate and associated micrometeorological variations are key factors in deciding the optimum date of sowings in a particular location, and this varies from one location to another. Using WTGROWS, the optimal sowing 'window' for wheat in five meteorological subdivisions in north and northwest India, viz. eastern and western UP, Punjab, Haryana and Rajasthan was evaluated and extent of reduction in yield associated with the delay was also quantified (Figure 2). The optimum date of sowing of wheat for all locations was around 320 Julian days and variation in yield reduction due to shifting of sowing 'window' was evident. For Punjab and Haryana, due to assured irrigation and improved input management practices, the yield reduction seems to be less compared to eastern and western UP and Rajasthan. Thus, in view of recent trends in temperature rise as a part of global climate change, the optimal sowing time as prevalent today may need to be modified so as to accommodate the crop for getting its maximum yield potential. The model output indicates the need of advancing the date of sowing by 6 days per degree rise in temperature for the northwest India condition.

WTGROWS was run for Pantnagar (eastern UP) and Saharanpur (Punjab) locations, with normal weather and

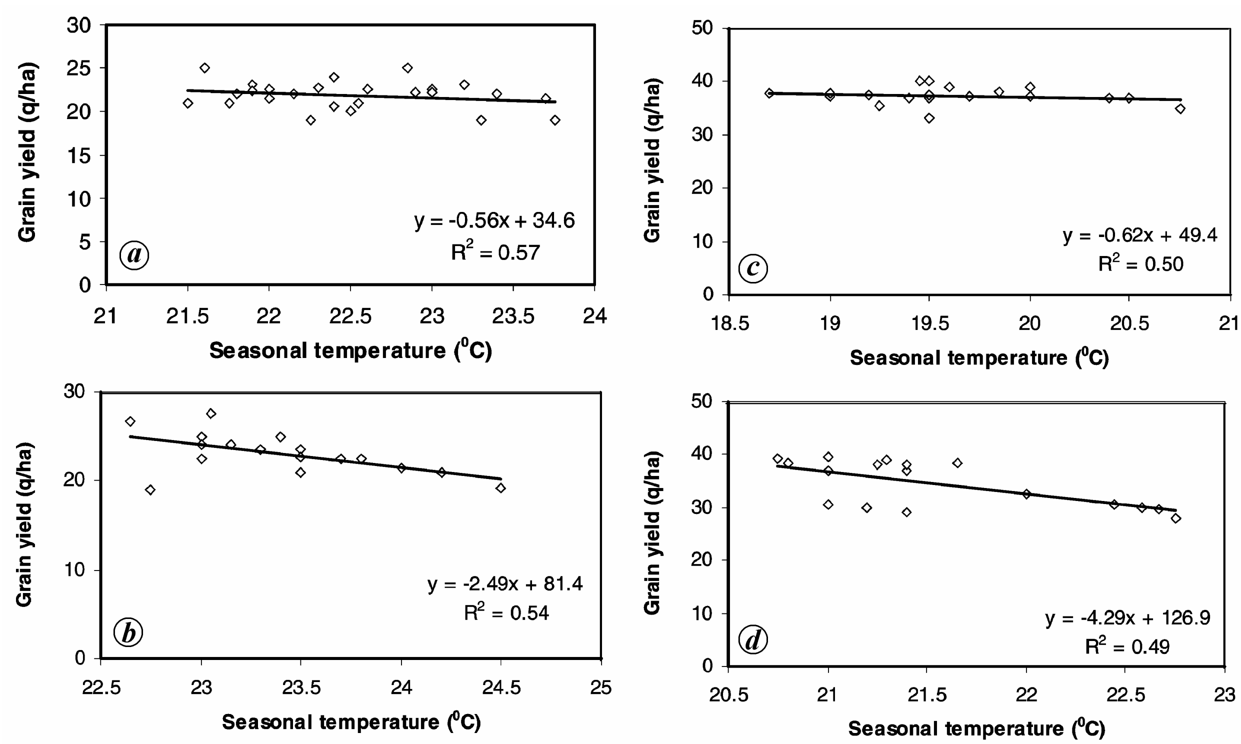

Figure 1. Effect of seasonal temperature change on yield of wheat in four northwestern states in India: ***a***, Uttar Pradesh; ***b***, Rajasthan; ***c***, Punjab and ***d***, Haryana.

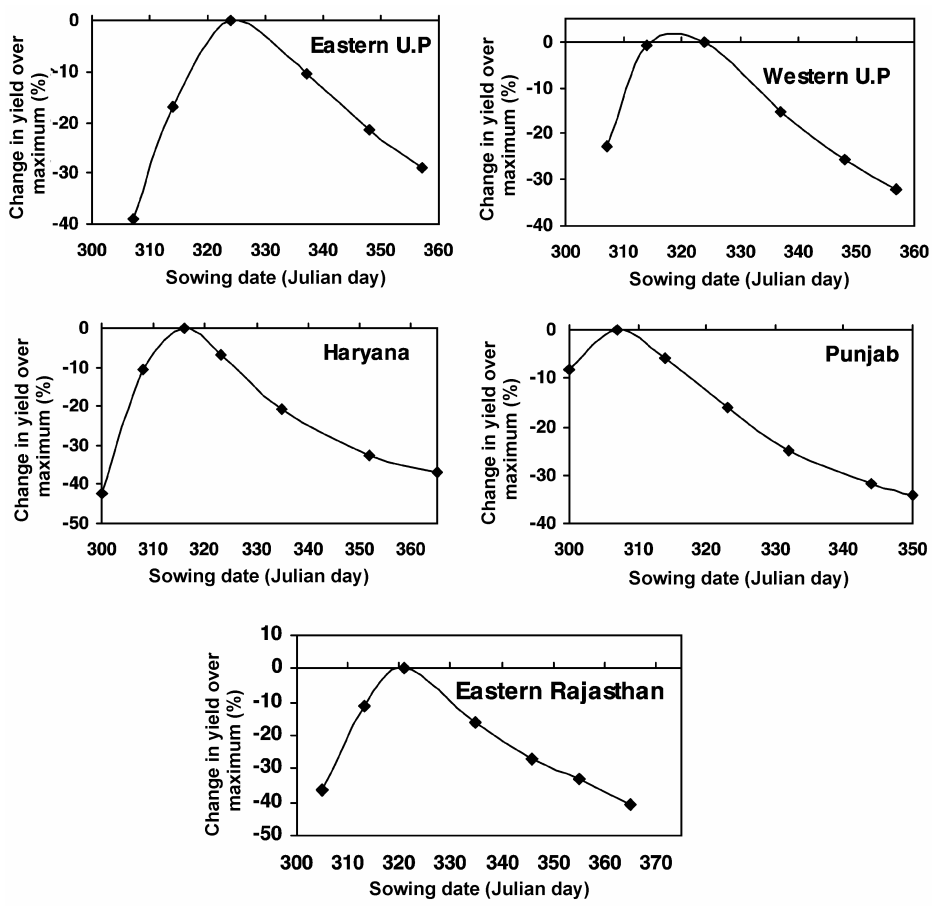

Figure 2. Effect of date of sowing on wheat yield under different meteorological sub-divisions in north and northwest India.

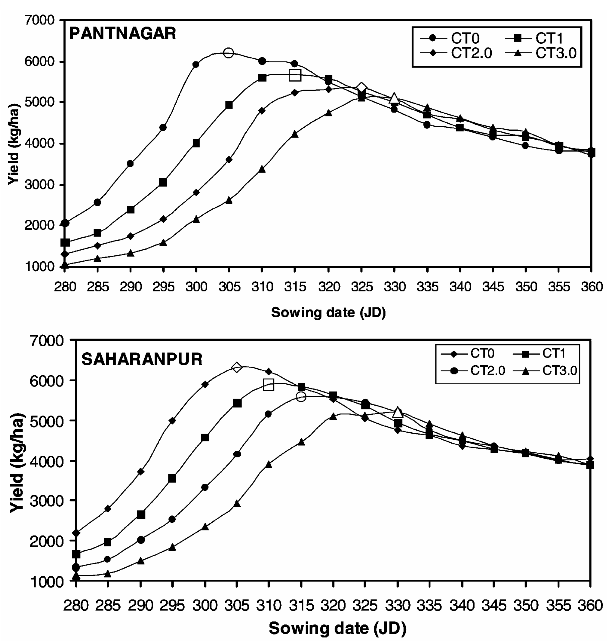

Figure 3. Effect of sowing date and temperature rise on attainable yield of wheat in Pantnagar and Saharanpur districts of North India.

adequate inputs, and with different dates of sowing under normal and temperature-rise scenarios. The results clearly indicate the delay in sowing under temperature-rise situations for achieving maximum benefits (Figure 3). This may be one of the adaptation strategies to sustain the yield under climate-change situation. The simulation was run for attainable yields under irrigated and non-limited production environment, and the results might be slightly different under limited irrigation and rainfed situations.

It is a well-known fact that solar radiation is the only source of energy either directly or indirectly for the ecosystem in the universe. It has been noticed recently, that the interception of solar radiation on the earth surface has been disturbed due to gases and particulate matter (aerosols) emitted in the atmosphere by anthropogenic activities[15–18]. WTGROWS was used to evaluate the interaction of radiation with temperature for wheat in the northwest India environment (data not presented here). The degree of reduction in yields associated with reduction in radiation amounts is not large till around 20% of the radiation is decreased from the normal values. Simulation results clearly indicate the significant interaction of radiation with temperature as far as growth and yield of crops are

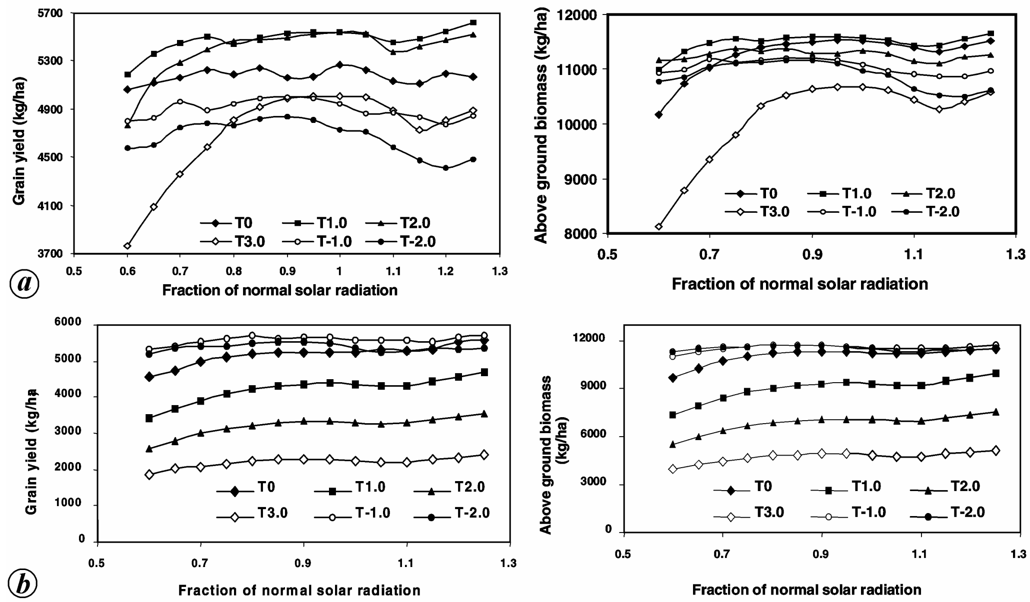

Figure 4. Radiation and temperature change interaction on growth and yield of wheat at (***a***) Delhi and (***b***) Patna environment.

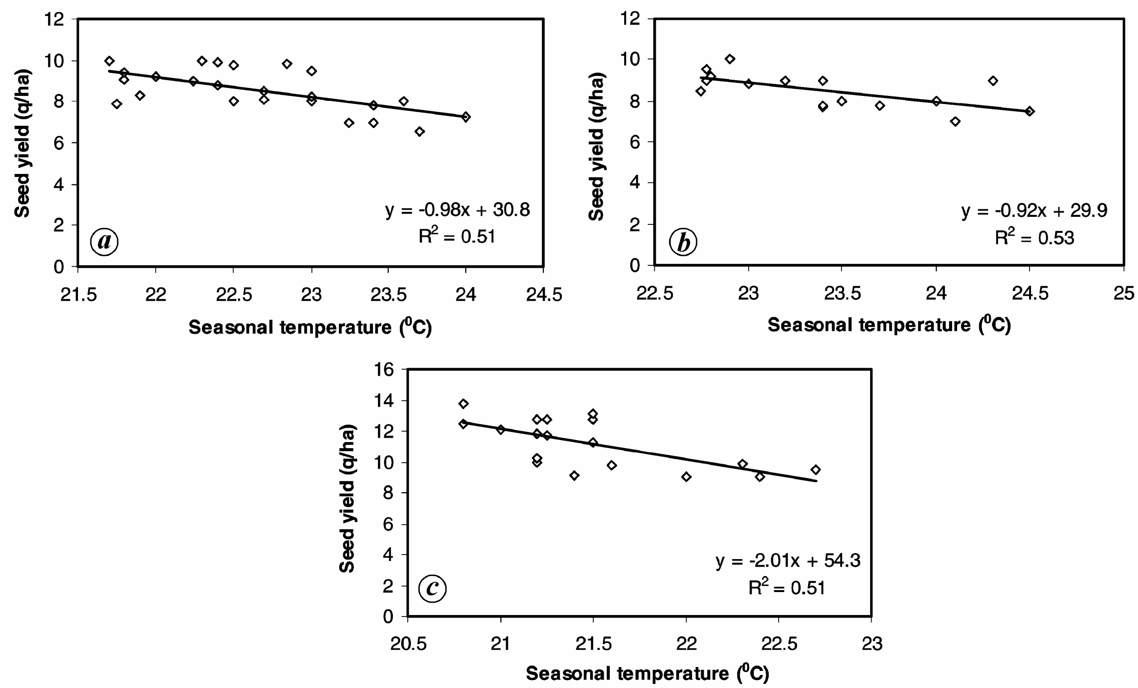

Figure 5. Effect of seasonal temperature change on yield of mustard in (***a***) Uttar Pradesh, (***b***) Rajasthan and (***c***) Haryana.

concerned. Behaviour of biomass seems to be more conservative (especially under Delhi environment), while the effect is pronounced for yield of wheat.

WTGROWS was used to evaluate the maximum possible effect of radiation change with the interaction of projected temperature change on wheat yield by undertaking daily change in radiation from (–) 40% to (+) 25% at 5% interval for New Delhi (northwest India) and Patna (northeast India) locations (Figure 4). The management practices were assumed to be optimum in achieving the maximum possible yield under the conditions. The range of variations among treatments for above-ground biomass exists in narrow range, except for temperature rise to the tune of 3°C. But the differences are wider in case of grain yield, where the interaction effect is more pronounced. Though the above-ground biomass and grain yield reduced gradually with reduction in radiation from the normal value, the trend was more consistent for the Patna environment in comparison to the New Delhi environment. Temperature rise of 1°C had relatively positive effects compared to the control (no temperature rise) both for above-ground biomass and grain yield at the New Delhi environment. Subsequent rise in temperature reduced the biomass and yield over the ambient condition and the extent of reduction was quite large for 3°C rise in temperature. Reduction in temperature by 1–2°C enhanced the yield and biomass under the Patna environment, possibly due to relatively higher temperature during growth of wheat crops under normal conditions. The degree of reduction in yields associated with reduction in radiation is not large till around 20% of the radiation decreases from the normal values. Thus, simulation results clearly indicate the significant interaction of radiation with temperature as far as growth and yield of crops are concerned.

Yield response of mustard

The response of mustard, the second important winter crop in North India only after wheat, is different to the rising seasonal temperature and varies depending upon the locations. The maximum decrease in grain yield was noticed in Haryana where the grain yield decreased by 2.01 q per ha per degree rise in seasonal temperature, whereas decrease of 0.98 and 0.92 q per ha in grain yield was observed in UP and Rajasthan respectively (Figure 5).

The effect of delay in sowing on yield of mustard is depicted in Figure 6, where zero on the *X*-axis refers to the optimum date of sowing for mustard under the North Indian climate. Twenty days delay may reduce the yield to half of the attainable yield and there will be a further drastic reduction in yield after one month delay in sowing from the optimum date. Optimum yield of mustard is expected when the average seasonal (winter) temperature stands between 17°C and 22°C, and the days to maturity are affected by increase in temperature as shown in Figure 7. The forced maturity (rate of hastening of maturity is 1.72 days per degree rise in temperature) might reduce the yield significantly. This kind of quantified relation would help in deciding the shifting of optimal date of sowing as well as the best agronomic management options in view of change and aberrations in winter climate.

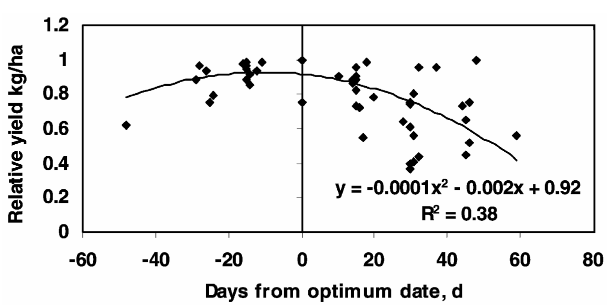

Figure 6. Effect of date of sowing on seed yield of mustard (zero day refers to the optimum date of sowing).

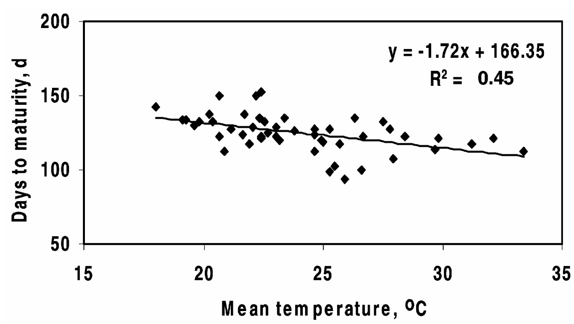

Figure 7. Duration of mustard crop growth as related to seasonal mean temperature.

Response of barley and chickpea

Similar decreasing trend in yield like that of wheat was also noticed in case of barley (Figure 8). The maximum decrease here also was observed in Haryana, where grain yield decreased by about 5.01 q per ha per degree rise in seasonal temperature. The grain yield decreased by 2.71, 1.94 and 1.64 q per ha per degree rise in temperature, in Punjab, Rajasthan and UP respectively. The yield of chickpea similarly decreased in all the four states with rise in seasonal temperature (Figure 9). Here also, maximum decrease of 3.01 q per ha in grain yield was observed in Haryana, whereas a minimum decrease of 0.53 q per ha was observed in UP per degree rise in seasonal temperature. Grain yield decreased by 1.81 and 1.27 q per ha in Punjab and Rajasthan respectively, with 1°C rise in seasonal temperature.

Per cent variability in yield of these crops from the technology trend line (indicative of the trend in integrated input management factors) was plotted with the per cent variability in seasonal temperature from the normal value, but no significant relationship could be obtained (data not shown).

Conclusion

The study clearly indicates that the yield of wheat, mustard, barley and chickpea show sign of stagnation or decrease following rise in temperature at all the four northern states. However, the extent of decrease was different for crops as well as their locations. As a result of temperature rise as a part of the global climate change, shifts in optimal

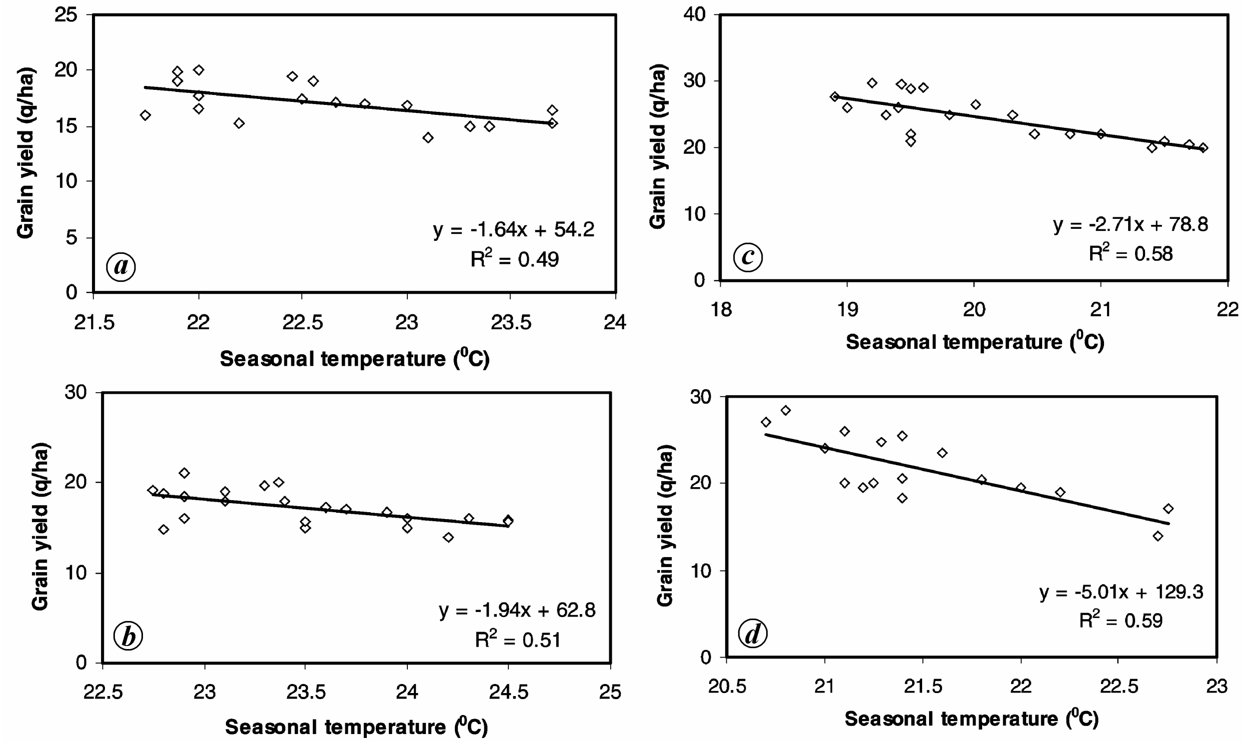

Figure 8. Effect of seasonal temperature change on yield of barley in (***a***) Uttar Pradesh, (***b***) Rajasthan, (***c***) Punjab and (***d***) Haryana.

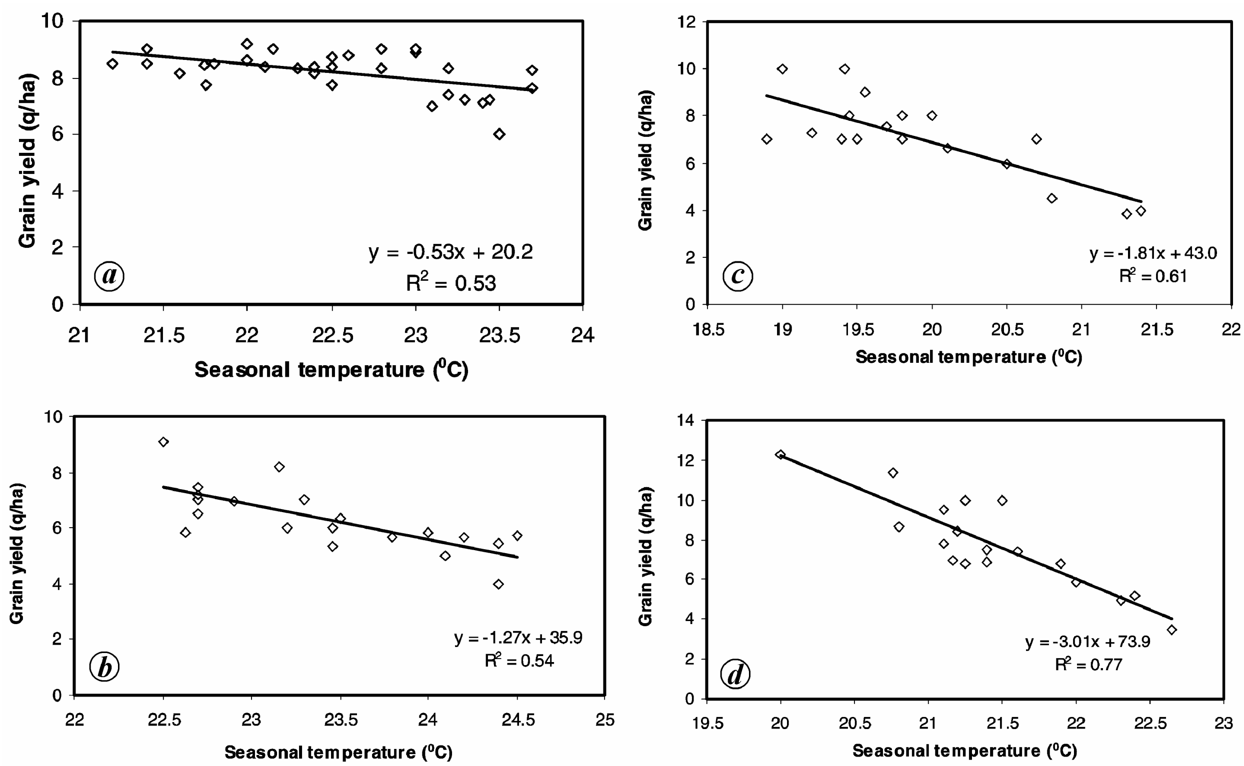

Figure 9. Effect of seasonal temperature change on yield of chickpea in (***a***) Uttar Pradesh, (***b***) Rajasthan, (***c***) Punjab and (***d***) Haryana.

window of sowing of the crops for sustaining the yields have to take place. There is a growing need to quantify the effects of rising temperature on yield of crops in different agroecologies and agri-production environments. Similarly, various climate-change scenarios need to be evaluated for these regions and the specific adoption strategies be evolved. Simulation models may help a long way in linking other bio-physical and socio-economic drivers of agri-production with climate change. The present study is just the beginning, which clearly demonstrates the utility in understanding and generating the simple coefficients of yield–response behaviour relationship, which can subsequently be employed for working out the impact of climate change on crops in future at regional scales.

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Received 22 February 2007; accepted 23 October 2007