Irrigation and Nitrogen Management for Sustainable Potato Production under Climate Change Scenario: A Simulation Study

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Abstract: Potato growth and development is largely influenced by water and nutrient availability, light and temperature making it highly vulnerable to anticipated climate change. This study is undertaken to simulate the impact of climate change on potato production and to evaluate the various agro-adaptation strategies such as irrigation and fertilizer management. SUBSTOR- potato model was used to simulate the growth and development of potato crop. This study was carried out for Kharagpur conditions in India. Simulation results indicate that 140 kg N/ha applied in 3 split doses gives the highest sustainable yield for both automatic drip and conventional furrow irrigation schemes. Automatic drip irrigation gave 44 % higher yield than conventional furrow irrigation. The study has revealed yield reduction up to 27.81 % and 40.7 % for conventional furrow and automatic drip irrigation respectively in future climate scenario.

Keywords: Potato, climate change, simulation, agro-adaptations, planting date, SUBSTOR-model.

1 Introduction

Crop production under global climate change is one of the key challenges of modern agriculture. It affects agriculture in a number of ways, including a rise in temperature, high variability in precipitation, changes in atmospheric CO_2 and nutritional quality of some foods. Agriculture being very vulnerable to climate change, needs to be prepared in advance to combat the negative impacts of climate change and utilize the possible benefits of changed environmental conditions. Thus, adaptive strategies for different climate change scenarios (e.g. fertilizer and irrigation management, etc.) need to be evaluated to optimize the crop yield due to climate change.

Potato figures among the principal non-grain crops worldwide. The global potato production has shown a steady increase from 267 million metric ton in 1990 to 376.8 million metric ton in 2016 [FA18]. India is the second largest producer of potato. Together with China, India accounts for nearly 35 % of the world production. Potato is a cool climate crop and best suited to temperate regions. It is a weather sensitive crop and its growth and production is influenced by climate [Ko95] and numerous other factors

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like nutrition, irrigation, etc. Potato is the main source of food security and income in the developing world [LC09]. A growing population, along with climate change, will put additional pressure on potato food systems. Hence, integrating crop models when evaluating the impact of new technologies and strategies for adapting to climate change, is required. Thus, this study is aimed at evaluating the impact of climate change on potato yield using SUBSTOR- model and obtaining the sustainable fertilizer and irrigation management strategies to improve production.

2 Simulation Model

The SUBSTOR-potato model is embedded in the DSSAT-CSM (Decision Support Systems for Agro-technology Transfer-Crop Simulation Model) software. The model simulates growth and development of potato crop using daily weather data, soil, management and cultivar information. GBR93 and Ri95 have given an extensive description of this model. This model has four sub models simulating simultaneously which are phenological development, biomass formation and partitioning, soil water balances and soil nitrogen balances. The accumulation and partitioning of biomass in potato depends on intercepted radiation, temperature and photoperiodicity. The model uses a zero to one relative temperature function based on mean daily air temperature to simulate the response of different plant organs and processes over a wide temperature range. Five cultivar-specific parameters control crop development and growth. [GBR93]. The SUBSTOR- potato model has been successfully calibrated and validated under different environments in many countries to assess the yield responses to climatic conditions [Ra17]. The SUBSTOR-model has been validated for Kharagpur area in India for Kufri Jyoti cultivar. The validated genetic coefficients for Kufri Jyoti cultivar (G2-1100, G3-30, PD-0.8, P2-0.8 and TC-19) are taken from previous studies.

3 Evaluation of adaptation strategies

The adverse impacts of climate change can be reduced by using good management strategies. The SUBSTOR model was used to simulate the potato yield for 13 fertilizer treatments under two irrigation schemes in the data period of 2001-2010.

The recommended doses of P_2O_5 (100 kg/ha) and K_2O (120 kg/ha) were applied on the day of sowing. Four doses of nitrogen fertilizer (urea) with four split applications were selected (Tab. 1). The fertilizer doses applied on the day of sowing were broadcasted and incorporated into the soil while those applied later were simply broadcasted without incorporation.

The model was simulated for two irrigation schemes i.e. automatic drip irrigation and conventional furrow irrigation. Under automatic drip irrigation system, water was applied whenever the available water content dropped below 60 % while in furrow irrigation, 300 mm of water was applied in nine splits throughout the growing season.

Doses of Nitrogen	Split Applications
T1: 0 kg/ha	SA1: 50% at Basal+25% at 30 DAP+25% at 45 DAP
T2: 100 kg/ha	SA2: 25% at Basal+50% at 30 DAP+25% at 45 DAP
T3: 140 kg/ha	SA3: 25% at Basal+25% at 30 DAP+50% at 45 DAP
T4: 200 kg/ha	SA4: 50% at Basal+50% at 30 DAP

Tab. 1: Nitrogen application (DAP stands for days after planting)

Changing the planting dates in future scenario affects the potato yield significantly as manipulation of light and temperature can be done to a certain extent by altering the planting dates. This use of planting dates as adaptation strategy is another part of this research, not included in this paper.

The other growing conditions were assumed to be standard and no stresses other than N and water were assumed. Potato yield was simulated for all of the above management practices for the data period of 2001-2010. The practice giving the highest sustainable yield was obtained and then was used for future climate scenario.

4 Climate change scenario

The global simulations from Max Planck Institute for Meteorology-Earth System Model (MPI-ESM) was downscaled using REMO over CORDEX domain for South Asia. The MPI-ESM model consists of the general circulation model for the atmosphere ECHAM6 coupled to the MPI Ocean Model (MPI-OM) whereas, REMO is a 3D atmospheric circulation model based on Europa-model and ECHAM4 over limited area [GJA09]. The data were downloaded from Indian Institute of Tropical Meteorology, Pune website. The data was extracted for the location in eastern India. Climate change experiments were performed for three future periods i.e. 2011-2040, 2041-2070 and 2071-2100 with the representative concentration pathway (RCP 4.5). The RCP scenarios are based on total radiative forcings (W/m^2). In RCP 4.5, radiative forcings are expected 4.5 W/m^2 without overshoot and to be stabilized by 2100 as result of improved technologies and reduced greenhouse gas emissions. This represents medium concentration of greenhouse gases, aerosols, ozone and anthropogenic land use scenarios [Mo10]. The future climate change scenarios were applied to current potato cropping systems and the yield trend was obtained for the future period. Average values of all the climatic parameters were obtained for data periods 1971-2000, 2001-2010, 2011-2040, 2041-2070 and 2071-2100. These values were then compared to get the climate change trend in the future years (Fig. 1).

All four climatic parameters show different trends in future years (Fig. 1). Tmax and Tmin shows an increasing trend whereas SRAD increases until data period 2041-2070 and then reduces in 2071-2100. Rainfall shows a very uneven trend. It increases in data period 2001-2010 then decreases till 2041-2070 and then again increases in 2071-2100. [Ho18] justifies this unexpected increase in rainfall in data period 2071-2100.

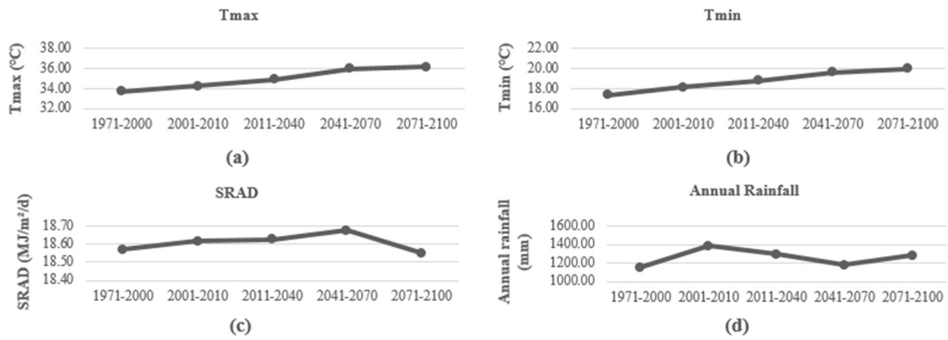

Fig. 1: Predicted change in (a) Tmax, (b) Tmin, (c) SRAD and (d) Rainfall in future scenario

5 Results and discussions

The output from crop modelling in terms of best treatment and yield trend in future climate scenario are summarised and then discussed below.

5.1 Impact of different nitrogen and irrigation management on potato yield for data period (2001-2010)

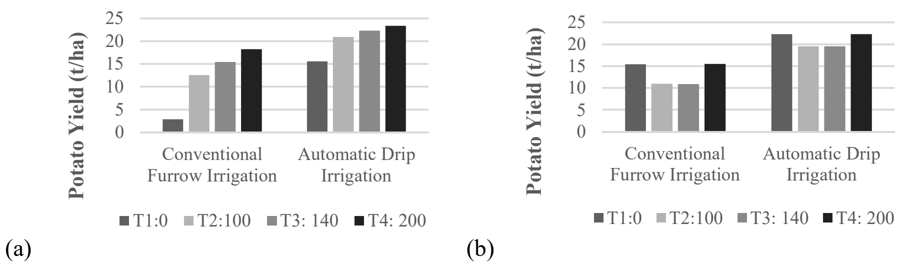

Fig. 2: Impact on potato yield of different (a) nitrogen doses and (b) split applications (SA)

In conventional furrow irrigation system, a small increase in fertilizer dose (about 50 kg/ha) increases the yield significantly by about 20 % whereas in automatic drip irrigation systems, such an increase in fertilizer dose increases yield by only about 6 % (Fig. 2(a)). Therefore, a general recommendation of 140 kg N/ha is suitable for both irrigation systems for the selected region [Tr08]. It is clear from Fig. 2(b) that the SA1 and SA4 gives good yield. Considering nitrate leaching losses, SA1 is better than SA4, as N is applied in three splits in SA1. Therefore, applying 140 kg N/ha in three split doses (2:1:1) gives best yield and thus this treatment should be used for future climate scenario. Moreover, for the best treatment, automatic drip irrigation gave 44 % more yield as compared to conventional furrow irrigation (Fig. 2). The reason for this increase is the good water use efficiency of drip irrigation, as water is applied directly in root zone of the crop and there are no conveyance, evaporation and percolation losses [Ta12]. Also, since drip irrigation is applied automatically, less water stress is experienced by the crop.

5.2 Impact of climate change on potato yield

The yield gap due to climate change is obtained by getting the difference between historic and future yields. The yields for three data periods ranging from 2011 to 2100 were simulated taking data period 1971-2000 as base dataset (Fig. 3).

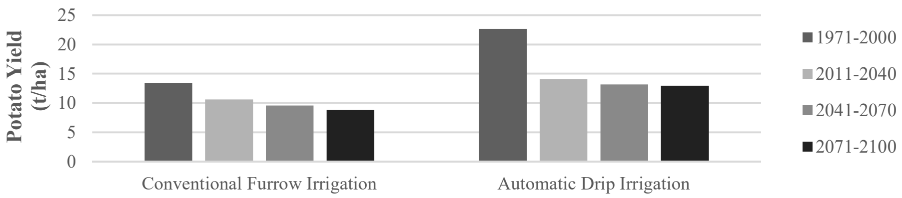

Fig. 3: Yield trend for RCP 4.5

For conventional furrow irrigation, the average historical yield was 13.42 t/ha (Fig. 3). In future scenario, the yield reduced. However, no linear trend was observed. The yield reduction from historical yield in data periods 2011-2040, 2041-2070 and 2071-2100 was 20.71 %, 28.53 % and 34.2 %, respectively (Fig. 3). A similar trend was observed in both irrigation schemes. The average historical yield for automatic drip irrigation was 22.64 t/ha. The yield reduction from historical yield in data periods 2011-2040, 2041-2070 and 2071-2100 was 37.8 %, 41.7 % and 42.7 % respectively (Fig. 3). Potato is a cool season crop and develops best at about 20°C. Overnight temperatures above 22°C severely hamper tuber development and may lead to drastic reduction in yield. Potato productivity is significantly reduced at temperature higher than optimum [Ry15]. Moreover, variety Kufri Jyoti is quite sensitive to temperature [PG13].

6 Conclusions

The SUBSTOR-potato model was used to simulate the effect of various nitrogen application and irrigation management schemes on potato yield. Simulation results imply that 140 kg N/ha applied in three split doses i.e. 2:1:1 at 0, 30 and 45 DAP gives the best yield for both irrigation schemes. Automatic drip irrigation gave 44 % higher yield as compared to conventional furrow irrigation. The comparative analysis of potato yield in changing climate showed that there is an overall decrease in future yield as compared to historical yield. As a result of climate change, on average 27.81 % and 40.73 % yield reduction is predicted in conventional furrow and automatic drip irrigation respectively. Further outputs of the model, not shown in detail, indicate, that the most crucial agro adaptation strategy is planting time. However, further study on adaptation alternatives like climate change resilient varieties, planting time combined with the occurrence of rainfall and optimum fertility level needs to be carried out.

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