SIMULATING THE EFFECT OF TEMPERATURE ON GROWTH AND YIELD OF BT COTTON UNDER SEMI-ARID CONDITIONS OF PUNJAB, INDIA

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ABSTRACT:

Cotton cultivation in semi-arid region of Indian Punjab provides the full potential to offer livelihood security to millions of marginal and small farmers. But the farmers consider it most risky crop as its yield varies with season and prices fluctuate in the market largely. Temporally, its production has increased from 176 lakh bales in 1996-97 and an all time record of 280 lakh bales during 2006-07. This record production became possible only due to the good weather and introduction of *Bt* cotton hybrids. The unpredictability of cotton yield is a great concern to the cotton industry. Many factors, such as length of the growing season, climate (including solar radiation, temperature, light, wind, rainfall, and dew), cultivar, availability of nutrients and soil moisture, pests, and cultural practices affect cotton growth. Of these, it is thought that environmental factors exert the major influence on yield development during each season. Temperature is considered to be one of the main environmental factors contributing to variable yields in cotton. Till now limited information exists on the effects of temperature on Bt cotton growth and yield in this region. To generate such information CropSyst model was used rather than field experimentation as the later is not feasible due to difficulty in controlling/ creating variability in weather parameters. The model was customized using the data of crop, soil and weather for an experiment conducted on *Bt* cotton hybrid RCH 134 during 2005 at Bathinda and simulations were made for 15 years 1991-2005. From the simulated results, relationships between temperature and duration of total crop growth period as well as of phenophases (sowing to flowering, flowering to boll formation and boll formation and maturity) and subsequently between duration of phenophases and cotton seed yields were developed. The results indicated that by the increase in temperature from 28 to 32 ^oC cotton seed yield decreased from 4700 to 2300 kg ha^{-1} following a linear relation with high coefficient of determination (0.97) and the reduction was more during sowing to flowering stage than others. Regarding water relationships, real crop water productivity was more (10.2 kg mm^{-1}) than apparent (8.8 kg mm^{-1}).

1. INTRODUCTION

In Cotton, the king of fibers, is one of the most important commercial cash crops of semi-arid region of Indian Punjab. Its cultivation in this region provides the full potential to offer livelihood security to millions of farmers. It is considered as most risky crop as its yield varies with the season. Temporally, its production has increased from a merge 28 lakh bales (170 kg lint/bale) in 1947-48 to a high of 176 lakh bales in 1996-97 and an all time record of 280 lakh bales during 2006-07. This record production became possible only due to the favourable weather conditions and introduction of *Bt* cotton hybrids. In future, due to global warming temperatures are likely to be increased and may influence the cotton seed yield and crop water productivity. At present, no study is available that shows the effect of increased temperature on phenol- phases and yield of the Bt cotton in this region. Generation of such information through field experimentation is possible only under controlled environmental conditions, which are very expensive. Alternately simulation models are the most power tool for such studies to have the conclusive results (Jalota et al, 2006). Therefore, the present simulation study using CropSyst model was undertaken with the objectives to quantify (i) duration of phenol-phases in relation to temperature, (ii) yield in relation to duration of phenol-phases and (iii) evapotranspiration (ET) and crop water productivity.

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2. METHODOLOGY

2.1 Site Characteristics

Field experiments were conducted during *kharif*, 2005 on Entisols, low in organic carbon (0.21%) and nitrogen (41 kg ha^{-1}), medium in available phosphorus (13.9 kg ha^{-1}) and high in potassium (431 kg ha^{-1}) at PAU Regional Station, Bathinda (Figure 1). Soil physical (texture, bulk density and hydraulic conductivity) and chemical (pH, EC, OC, ammonical nitrogen and nitrate nitrogen) properties of experimental field were determined up to 1.8 m with 0.15 m soil depth interval following the standard procedures. Physical properties of the soil profile showed that below 90 cm there is sharp increase in bulk density and decrease in hydraulic conductivity in soil layers. The soil texture was loamy sand to sand for 0-45 cm of soil depth and thereafter texture changed to silt loam up to 165 cm of soil depth of the soil profile. The ground water at the experimental site was more than 10 m deep. Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall during the crop growth period were recorded at meteorological laboratory, situated at the experimental site.

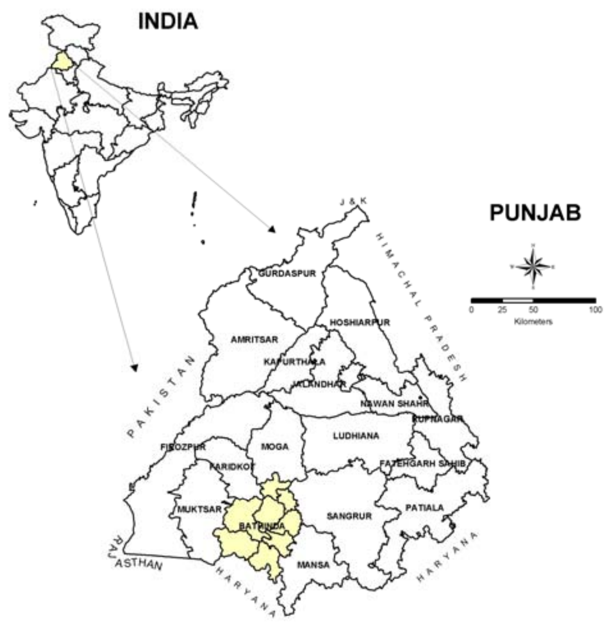

Fig: 1 Study Area

2.2 Field Experiment

A pre-sowing irrigation of 100mm was applied on 18April, 2005. when water content in surface soil dried to field capacity field was prepared with two discing followed by two plankings and plots of size m^2(m x m) were made. Earthen dikes of 30cm height surrounding all plots were made to check run off/gain by irrigation or rainwater. *Bt* cotton (*Gossypium hirsutum* L.) hybrid RCH 134 was sown on 23 April, 2005. The crop was sown at a spacing of 67.5 cm x 90 cm distance. Nitrogen @ 150 kg ha^{-1} and P_2O_5 @ 30 kg ha^{-1} were applied to the crop. All the phosphorus was applied at the time of sowing of the crop, whereas half the nitrogen was applied at the time of first irrigation (June 4) and remaining half at flowering stage of the crop (September 9). Weeds were controlled with pre-emergence application of stomp 30 EC (pendimeethalin) @ 2.5 l ha^{-1}. Two sprays of imidachlorpid @ 100 ml ha^{-1} were applied for controlling of sucking pests. Four irrigations of 75mm each on June 4, July 18, September 19 and September 30, 2005 were applied. Plant phenological stages and climatic factors were recorded during the crop season. The crop was harvested on Nov 11, 2005.

2.3 Simulation Study

2.3.1 Description of the CropSyst model: CropSyst model was chosen as it is a process based, simple, multi-year, multi-crop, daily time step cropping system simulation model and also has already been calibrated for periodic biomass, leaf area index and seed cotton yield (Figure 2).

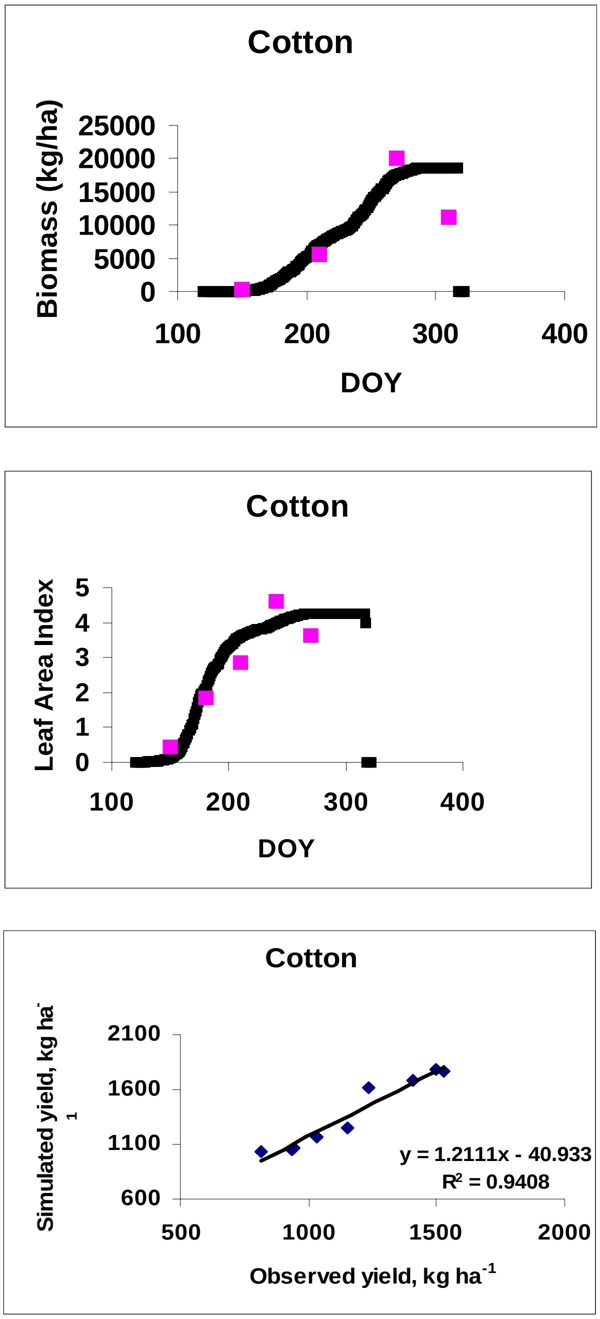

Figure 2. Comparison of Observed and CropSyst Model Simulated Biomass, LAI and Seed Cotton Yield

The model is designed to study the effect of soil, climate and crop/cropping system management on crop productivity and water balance (Stockle et al., 1994; Stockle and Nelson, 1999). Simulations were made by selecting a location and soil, and building crop rotations with management schedule. The location parameters included longitude, latitude, weather files and ET models. The soil parameters included specification of soil layers, thickness, texture, bulk density, cation exchange capacity, pH, volumetric water content at water potentials of - 30 kPa (Field Capacity) and -1500 kPa (Wilting Point). The management options in the model included cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations and residue management. The crop file comprised of common set of parameters related to classification, growth, morphology and phenology of the crop to represent different crops and crop cultivars. Model outputs taken were duration of different phenol phases, daily evapotranspiration (ET) and seed cotton yield at the end.

Simulations: Simulations were run for 15 years using the weather data of Ludhiana from 1991-2005 to assess the effects temperature on phenology, evapotranspiration, yield and crop water productivity. Real crop water productivity (RCWP) and apparent crop water productivity (ACWP), as reported in the literature (Jalota et al., 2006), were estimated as

RCWP = marketable seed cotton yield/ evapotranspiration, kg m^{-3} (1)

ACWP = marketable seed cotton yield/ Irrigation water applied, kg m^{-3} (2)

3. RESULTS

The yields of five varieties (RCH 134, RCH 317, MRC 6301, MRCH 6304, Ankur 651 and Ankur 2534) were simulated with the Cropsyst model by inputting the observed data on duration of different phenol-phases (Buttar et al, 2007) and harvest index (Buttar personal communication) during the year 2005 under field conditions. The simulated yield for varying duration of phenol-phases for these varieties was closer to the observed seed cotton yield .The RMSE was only 3.6 per cent., which gave a confidence that the model can be used for simulating the effects of temperature on duration of phenological phases and cotton seed yield.

3.1 Relationship Between Duration of Phenophases and Temperature

The simulated results were analyzed for developing quantitative relationships between temperature, different phenol-phases and cotton seed yield. Cotton is considered as warm season crop and optimum temperature for vegetative growth is 21-27°C. The simulation results showed that increased temperature beyond 27°C decreased the duration of sowing to flowering. For example, the duration was of 90 days at 30°C and that was reduced to 66 days at 36°C temperatures (Figure 3). With every in increase in temperature from 30 to 36°C, the decrease in duration of vegetative phase was 3.2days °C^{-1}. Though temperature of 25°C stimulate flowering (Mauney, 1966) but during flowering to fruiting stage of this crop, optimum temperature is 27-32°C (Lenka, 1998). The simulation study showed that duration of flowering to boll formation stage started decreasing with increase in temperature from 29 to33°C. In this temperature range the decrease in duration was of 12 days (from 67 to 55 days) indicating decrease in duration 3 days °C^{-1}. With the increase in temperature during boll formation to physiological maturity by just 8°C (from 23 to31°C) the decrease in the period was 22 days (from 45 to 22 days) indicating decrease in duration 2.9 days °C^{-1}. For cotton crop overall total duration is160-170 days but it decreased from 195 days at 28 °C to 152 days at 32 °C. This indicates that in the range of temperature from 28 to 32°C, the decrease in crop duration was 10.7 days °C^{-1}. Abrol and Ingram (2006) also reported relatively small change in annual temperature in semi-arid regions could markedly decrease in yield by reducing dry matter accumulation because of increased respiration, reduced photosynthesis and cellular energy.

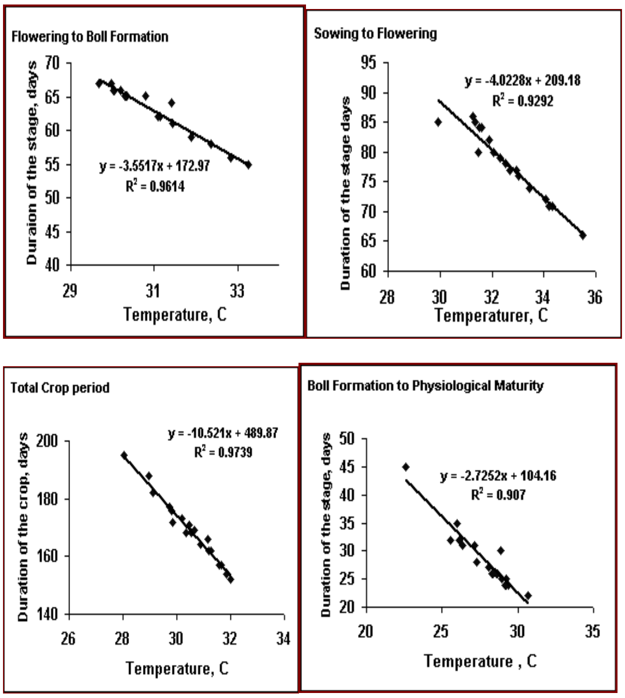

Figure 3. Simulated Effects of Temperatures on Duration of Different Phenophases of Bt Cotton

3.2 Duration of Crop Growth Stages and Cotton Seed Yield

The effect of duration of crop stages and cotton seed yield is presented in Figure 4. With decrease in duration during sowing to flowering by 14 days (86-72), flowering to boll formation by 9 days (66-57), boll formation to maturity by 21 days (45-24) and sowing to maturity by 45 days (198-153) the cotton seed yield was reduced by 236, 140, 116 and 75kg ha^{-1} day^{-1}, respectively. These results are in line with the results of Rosenzweig and Hillel (1998), which indicate that with increase in temperature, crop productivity is decreased owing to shortened duration of different growth stages and subsequently crop growth period

3.3 Temperature and Crop Water Productivity

With increase in temperature evaporative demand is increased due to increased vapour pressure gradient (Goyal, 2004). But actual ET may decrease due to decreased duration of the crop. In the present study with increase in temperature from 28 to 31.8, duration was reduced to 43 days and relative ET was reduced to 0.78 (Figure 5). Corresponding to the same temperature range relative yield was reduced to 0.43. This indicates that both the components of crop water productivity are decreased with temperature, but relative reduction was more yield component that caused reduction in crop water productivity.

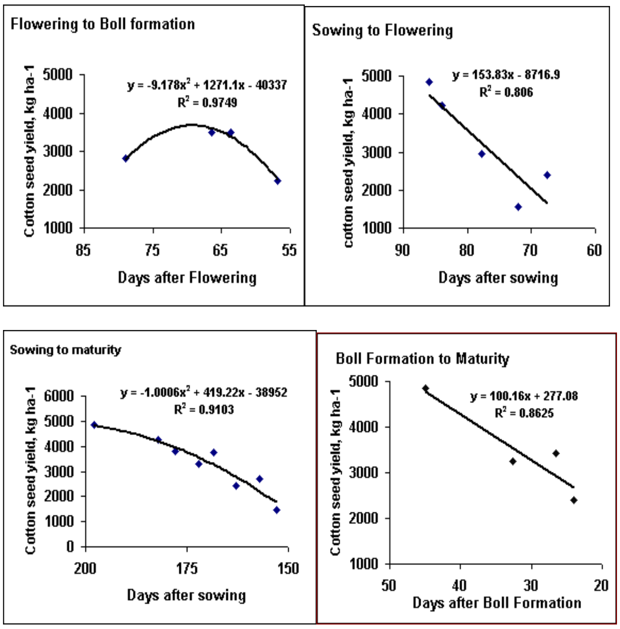

Figure 4. Simulated Effects of Duration of Different Phenophases on Seed Cotton Yield of Bt Cotton

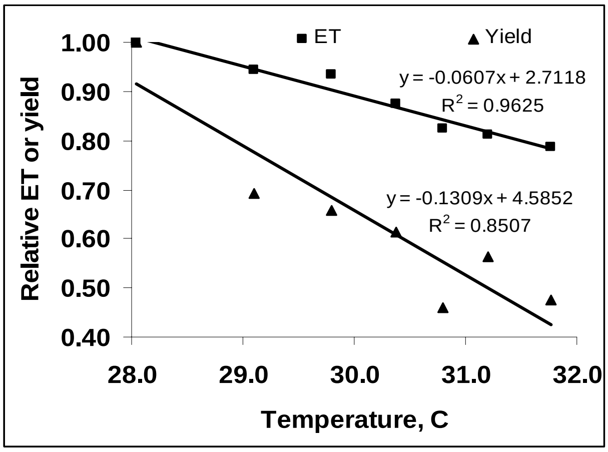

Figure 5. Evapotranspiration and Yield of Cotton as Influenced by Temperature

The RCWP and ACWP were 0.362 ±0.129 and 0.485±0.120 kg m^{-3}. These values are of the same range as indicated by Jalota et al (2006) and Zwart et al (2004). Water productivity based on total water supply was 0.120+ 0.049 kg m^{-3}.

CONCLUSION

The results of the present study suggest that CropSyst model can be used for assessing the effect of cultivars and temperature on duration of phenophases and subsequent yield of cotton crop. Crop yield decreased with temperature due to decrease in duration of pheno-phases and total growth period of the crops. Crop water productivity decreased with temperature and the effect is mainly through its effect on yield.

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