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ACKNOWLEDGEMENTS. We thank the Indian Council of Agricultural Research, New Delhi for providing the necessary financial assistance for this study.

Received 17 June 2017; revised accepted 6 June 2018

doi: 10.18520/cs/v115/i5/944-948

# Cotton crop in changing climate

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**Cotton is a major cash crop of global significance. It has a peculiar and inherent growth pattern with coinciding physiological growth stages. This study is based upon modelling and simulation for Hisar region. Stage-wise water stress has been quantified for three *Bt*-cotton cultivars with three sowing dates under both irrigated and non-irrigated (rainfed) conditions to assess the most sensitive stage. As per model output, it was observed that, at some stages stress value during excess years remains below 0.3 which is characterized as mild stress, in contrast with drought years where it is above 0.3, impacting potential crop productivity. Thus, rainfall impacts the productivity of cotton even in irrigated semi-arid region. Irrigation measures practiced, could partially alleviate influence of stress. Also, early sowing is found beneficial. The most water-sensitive period is ball formation and maturity stage followed by flowering stage.**

**Keywords:** Cotton, irrigation, temperature, water.

AGAINST the backdrop of reduced cotton production in recent years, there is an urge to study and mitigate the associated stresses. Cotton is a crop with an uncertain or ambiguous growth habit and has a dynamic growth response towards the environment and management practices. Site-specific management strategies considering the soil, weather, etc. need to be considered to optimize

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yield. Due to stress-dependent crop failure, farmers choose whether or not to cultivate cotton in field and how to achieve potential production. The cultivators are also baffled about its cost effectiveness. In India, cotton is grown in both irrigated and rainfed conditions.

Various studies are conducted on plant response to multiple environmental factors. For optimum growth, plants require a balance of all resources like water, energy, mineral nutrients, etc. where the balance varies with genetic make-up[1]. The nutritional hypothesis in combination with hormonal influences growth patterns during the cotton ontogeny, with a negative correlation between vegetative and reproductive growth[2]. Such growth could continue indefinitely under favourable conditions. However, due to demand on resource supply by reproductive organs of cotton, the vegetative growth ceases at the time called ‘cut-out’[3].

Water, being the major component, constitutes about 70–90% of plant fresh mass. Plant development and physiological processes are highly dependent on its availability and quality. The crucial role of water in plant physiology, viz. nutrient transportation, transpiration and chemical as well as enzymatic reactions suggests that water-stress can cause changes in the anatomy and morphology and alter the physio-biological processes[4]. Plant water stress is the condition under which water potential and turgor are reduced to the extent that leads to inhibition of normal plant function. The genotype, growth stage at which stress is introduced, as well as the magnitude and duration of stress defines the effects of water-stress[5].

Water stress has an adverse effect on plant development and yield. According to studies, it leads to a reduction in cell and leaf expansion, stem elongation, and changes in leaf area index. Moisture deficiency is one of the major abiotic factors limiting plant growth and crop productivity[5]. Reduction in leaf area expansion and stunted growth is observed in cotton owing to moisture deficit stress[6].

Seasonal variation is an important factor influencing the yield of different varieties of cotton[7]. Optimum time for sowing cotton to maximize yield is 5–20 May[7,8]. In Bahawalnagar (Punjab), sowing on 16 May gave the highest yield per hectare. Yield and its attributes in cotton plants are significantly higher in early sown[9] crop than in late sown crop conditions[9,10]. Based on two years’ mean early sowing of cotton on 15 May produced higher yield over other two dates 30 May and 15 June of sowing in Rajasthan[11]. Cotton leaf curl virus (CLCuV) limits the vegetative growth and productivity of cotton since it is one of the most destructive diseases. Yet no cotton genotype resistant to CLCuV is reported. So the only option left to minimize loss is management strategies like early sowing[10].

Since the last decade extensive crop simulations along with field experiments were done in agricultural research. Several mechanistic simulations on the development and yield of cotton, spanning from sowing to maturity, in response to non-specific site environment were carried out. Model simulates growth, development and yield of cotton in correspondence to various factors like weather and soil conditions as well as management practices. It reduces the time, cost and human resources required for analysing the complexities and provides an alternative decision. This also helps determine if modifications are needed to improve yield[12,13].

Understanding the nature of irrigation response requires elaborate knowledge of cotton phenology and its response to varying types of moisture deficit stresses. This was antecedently done through various agronomic field experiments, but since the introduction of modelling, this mode of research is also utilized. The objective of this study is to quantify water stress at different growth stages of cotton crop and analysis crop sensitivity for water deficit stress using modelling efforts.

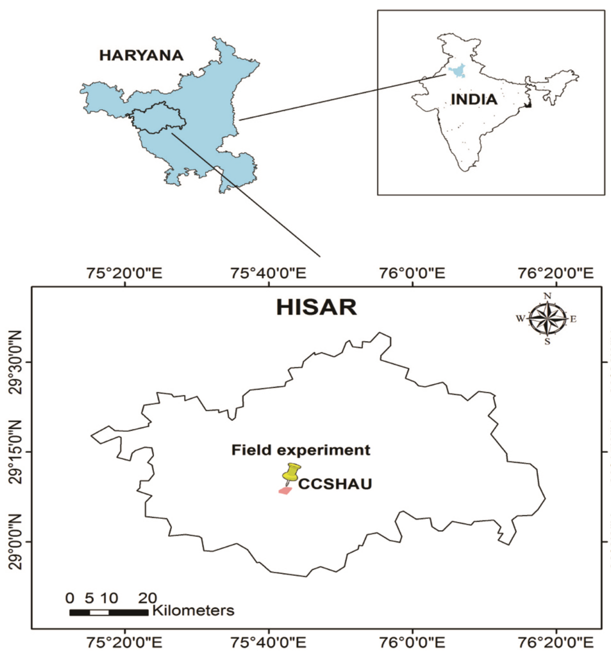


**Figure 1.** Study area in Hisar, Haryana.

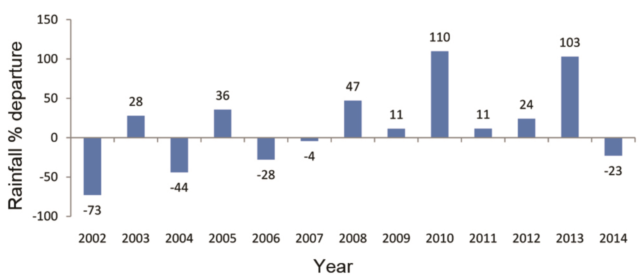


**Figure 2.** Rainfall % departure from normal during JJAS for the period 2002–2014.

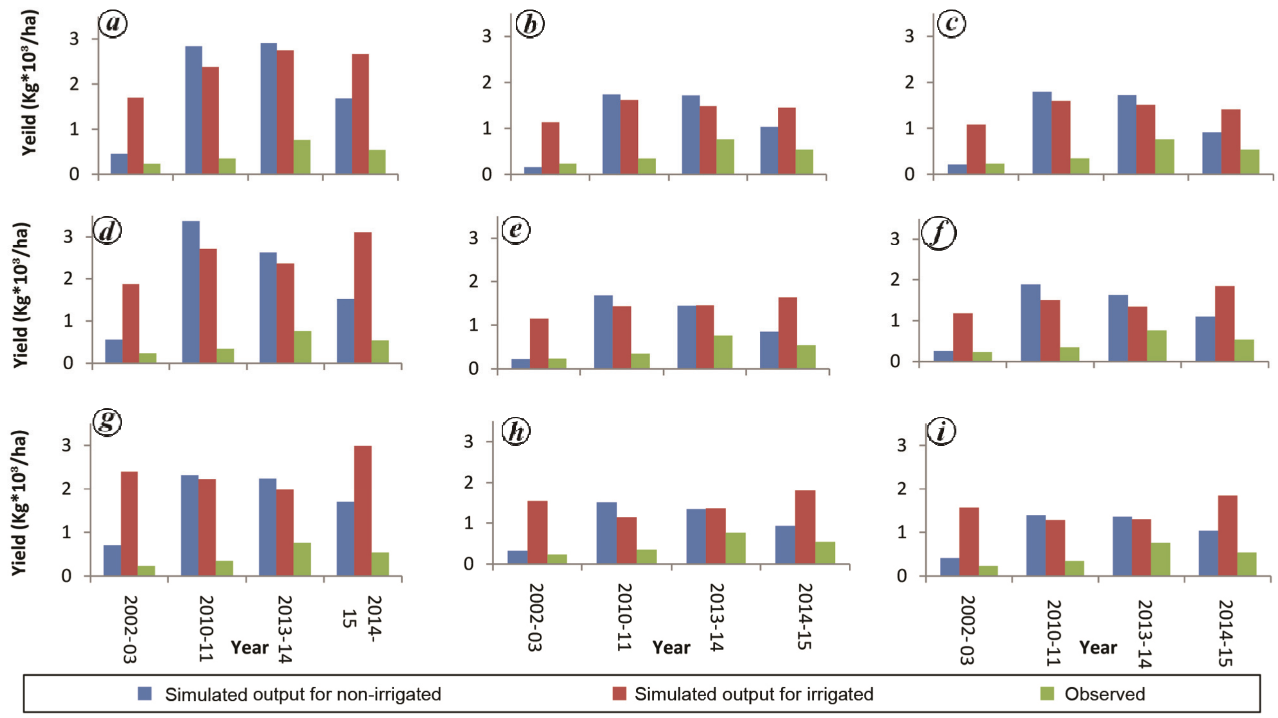


**Figure 3.** Yield of varieties sown during the selected year. ***a***, Pancham-541 on 10 May; ***b***, Pancham-541 on 21 May; ***c***, Pancham-541 on 6 June; ***d***, RCH-791 on 10 May; ***e***, RCH-791 on 21 May; ***f***, RCH-791 on 6 June; ***g***, SP 7007 on 10 May; ***h***, SP 7007 on 21 May; ***i***, SP 7007 on 6 June.

The study area of Hisar is shown in Figure 1. It is the western most district of Haryana in North and is a cotton growing region.

Decision Support System for Agro technology Transfer (DSSAT) Cropping System Model (CSM) is an assemblage of various models including CROPGRO for cotton crop[13,14]. DSSAT-CSM Version 4.6 model was used to assess crop growth pattern and the associated stage-wise stress.

For simulation, three *Bt*-cotton crop varieties Pancham-541, RCH-791, SP-7007 were selected as they are cultivated in Hisar during the *Kharif* season. The genetic coefficient for these variety was developed and reported earlier[15,16]. District level yield data of the state was extracted from the Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi (Source: www.eands.dacnet.nic.in). These cultivars were sown on 10 May, 21 May and 6 June. To achieve the objective, field experiment was conducted during *Kharif* season at CCSHAU, Hisar under the FASAL project of India Meteorological Department (IMD). Daily weather data of Hisar was taken from IMD during the experimental period.

For calibration and validation, model outputs were compared with actual data. Rainfall % departure for 2002–2014 during June, July, August and September (JJAS) is shown in Figure 2. Based on the rainfall % departure for four years, two excess years, i.e. 2010 and 2013 and two drought years, i.e. 2002 and 2014, were selected for the study.

Water stress for irrigated and non-irrigated/rainfed conditions was calculated to quantify the most sensitive crop stage in drought and excess years. This was done for three sowing dates for Pancham-541. Both irrigated and non-irrigated conditions were assessed for stress values at different stages. Dry yield output was taken as parameter for the study.

Stage-wise sensitivity of water stress was analysed by reducing the amount of irrigation as well as rainfall at 10%. This was done for Pancham-541 with sowing date 10 May.

Maximum positive deviation in rainfall % departure was seen in 2010 (110% departure) and maximum negative deviation in 2002 (–73% departure). IMD classifies >19% departure as excess year and <19% departure as drought year. So, 2002, 2004, 2006, 2014 are drought years and 2003, 2005, 2008, 2010, 2012, 2013 are excess years. Of these four years selected for the present study, two were excess years, i.e. 2010 and 2013 and two were drought years, i.e. 2002 and 2014.

A large difference between simulated and observed yield was noticed (Figure 3). Also, simulated irrigated output was higher than non-irrigated in drought years but vice-versa simulated irrigated output was lower than non-irrigated in excess years. The simulated irrigated conditions gave higher yield for all three sowing dates.

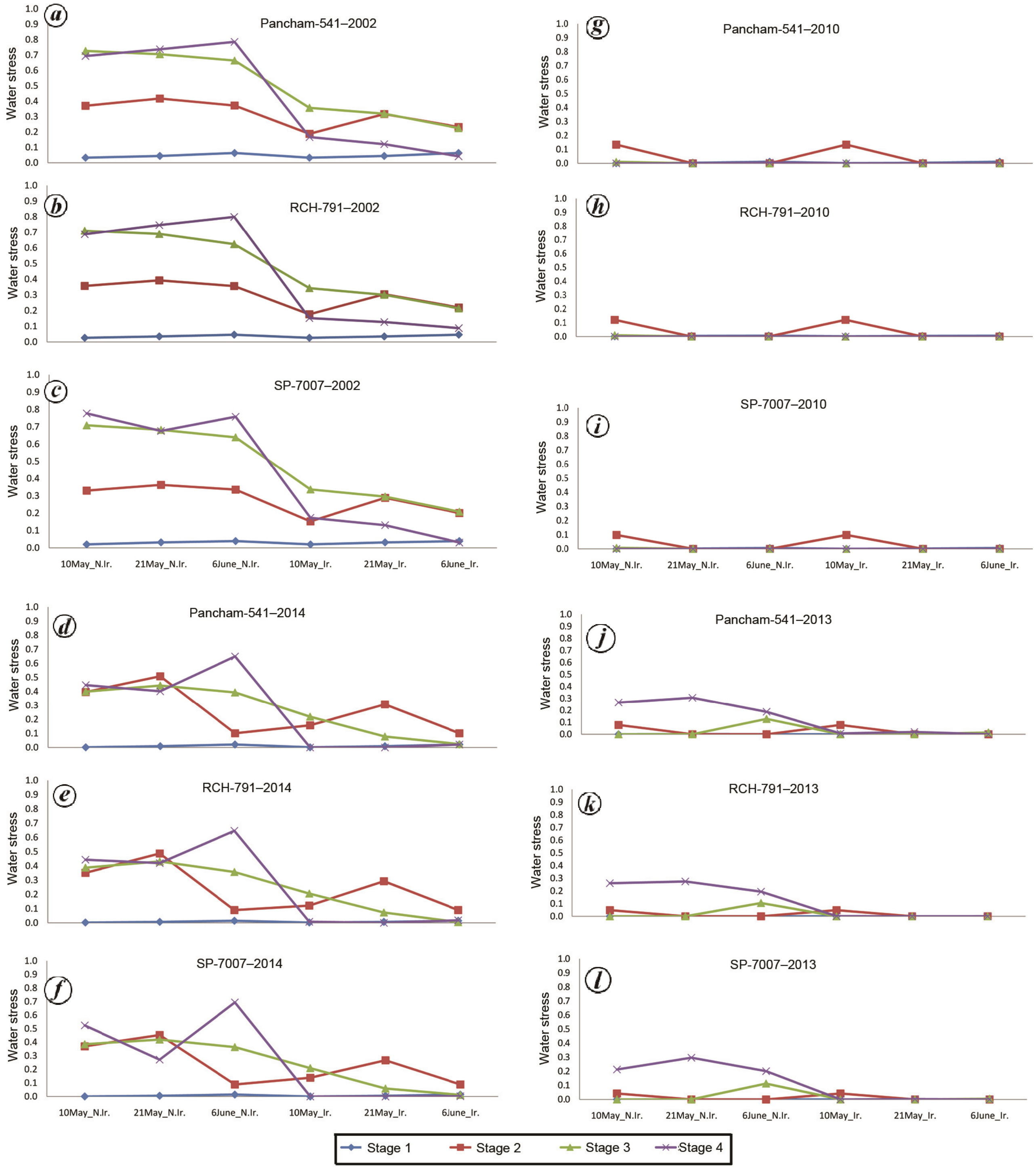


**Figure 4.** Stage-wise water stress quantification for cultivars sown on three dates under irrigated and non-irrigated conditions. ***a***, Pancham-541 for 2002; ***b***, RCH-791 for 2002; ***c***, SP-7007 for 2002; ***d***, Pancham-541 for 2014; ***e***, RCH-791 for 2014; ***f***, SP-7007 for 2014; ***g***, Pancham-541 for 2010; ***h***, RCH-791 for 2010; ***i***, SP-7007 for 2010; ***j***, Pancham-541 for 2013; ***k***, RCH-791 for 2013; ***l***, SP-7007 for 2013.

However, for excess years the non-irrigated simulated output also gave higher yield. These values vary as cotton crop simulation model has certain limitations not discussed here as it is outside the present objective. The simulated yield for variety RCH-791 was closer to the actual yield. The maximum simulated yield was found for the sowing date 10 May. As per studies early sowing gives better yield and cotton grown in May has higher yield than June.

Availability of water is one of the primary edaphic factors influencing the production of potential fruiting

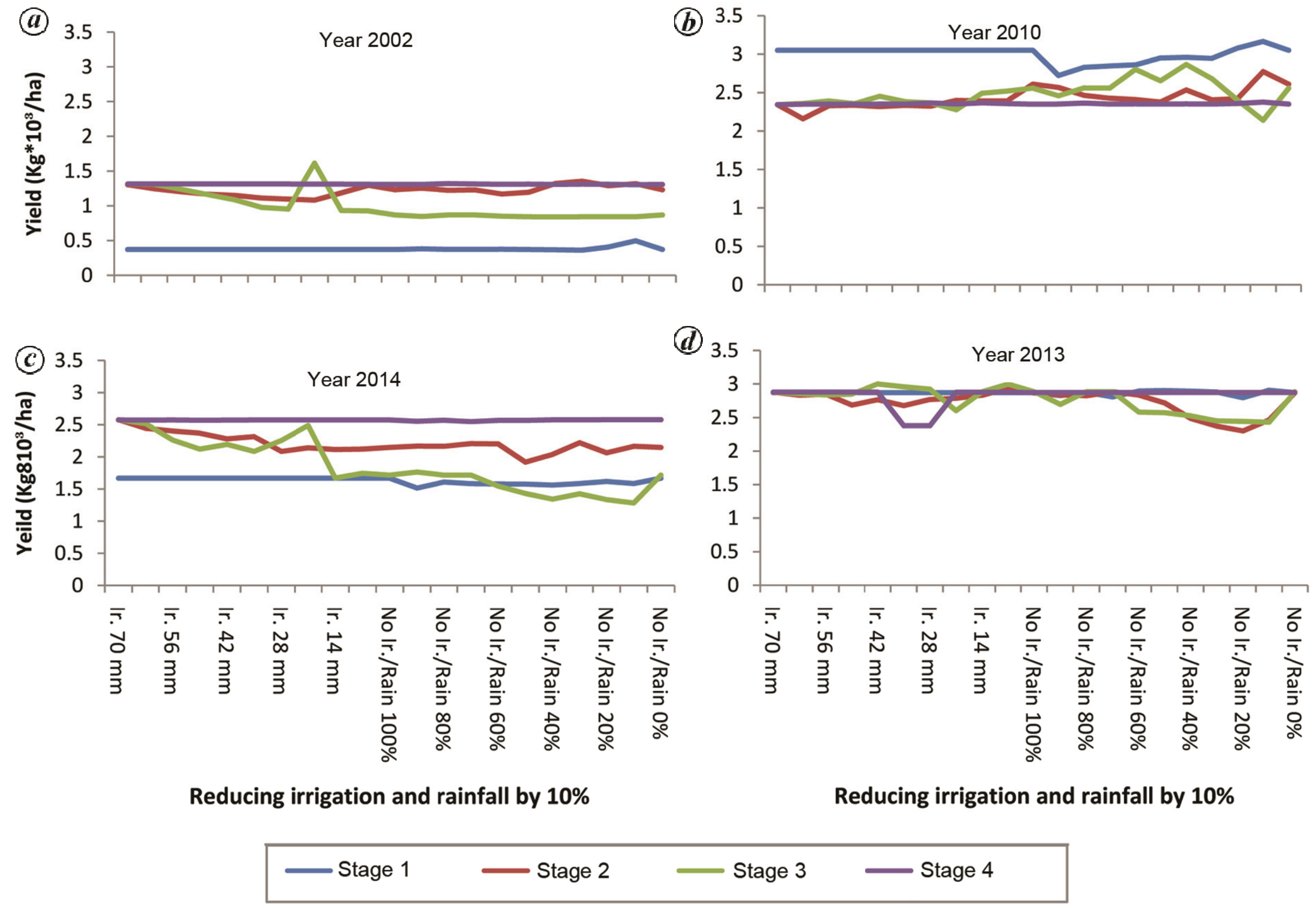


**Figure 5.** Stage-wise water stress analysis for Pancham-541 during (***a***) 2002, (***b***) 2014, (***c***) 2010 and (***d***) 2013. Ir, Irrigation (mm), N.Ir., No Irrigation.

bodies, the retention of squares and balls and yield attributes of cotton crop. Characteristics of plant water deficit situations, as in irrigated cotton, are usually quite different from those of non-irrigated cotton.

The graphs shown in Figure 4 indicate significant alleviation of stress after irrigation in all simulated experiments. During drought years maximum stress was observed for 6 June sowing. The output also certifies that early sowing dates of May show lesser stress for all the phenological stages. After irrigation, stress values reduced by a greater extent for all sowing dates in all stages. On the contrary, for excess years sowing date 6 June has minimum stress due to the effect of monsoon until this date. In general, the values for water stress are lesser during excess years than those during drought years for all stages as per model studies. In 2010 water stress did not exceed 0.14 and for 2013, it did not exceed 0.3 which is categorized as mild stress.

In stage 1 (7–47) days, i.e. emergence to flowering, not much of stress can be seen as per model studies in all three cultivars. Non-irrigated was provided as per normal package practices during this stage.

In stage 2 (47–66) days, i.e. first flower to first seed, more stress was seen as compared to stage 1. Irrigation was provided on the 60th day as per normal package practices and as input for the model, which was almost at the end of this stage. The stress was below 0.30 for all sowing dates during excess years and below 0.15 after providing irrigation. In drought years during non-irrigated condition generally the stress varied from 0.33 to 0.50 except sown on 6 June of 2014 for all the cultivars. It depicts that some stress impacts the crop in non-irrigated condition during the drought year.

In stage 3 (66–101) days, i.e. first seed to ball formation, ample stress was noticed during drought years as per model studies. During the drought year, on an average, maximum stress was noticed at this stage ranging up to 0.62 to 0.72, depending upon cultivar and sowing date in non-irrigated conditions. After irrigation stress was reduced to mild levels. Irrigation is provided on the 80th and 100th day as per normal package practices during this stage. On the other hand, during excess year whether it is irrigated or non-irrigated condition the stress remained below 0.3 which is categorized as mild stress.

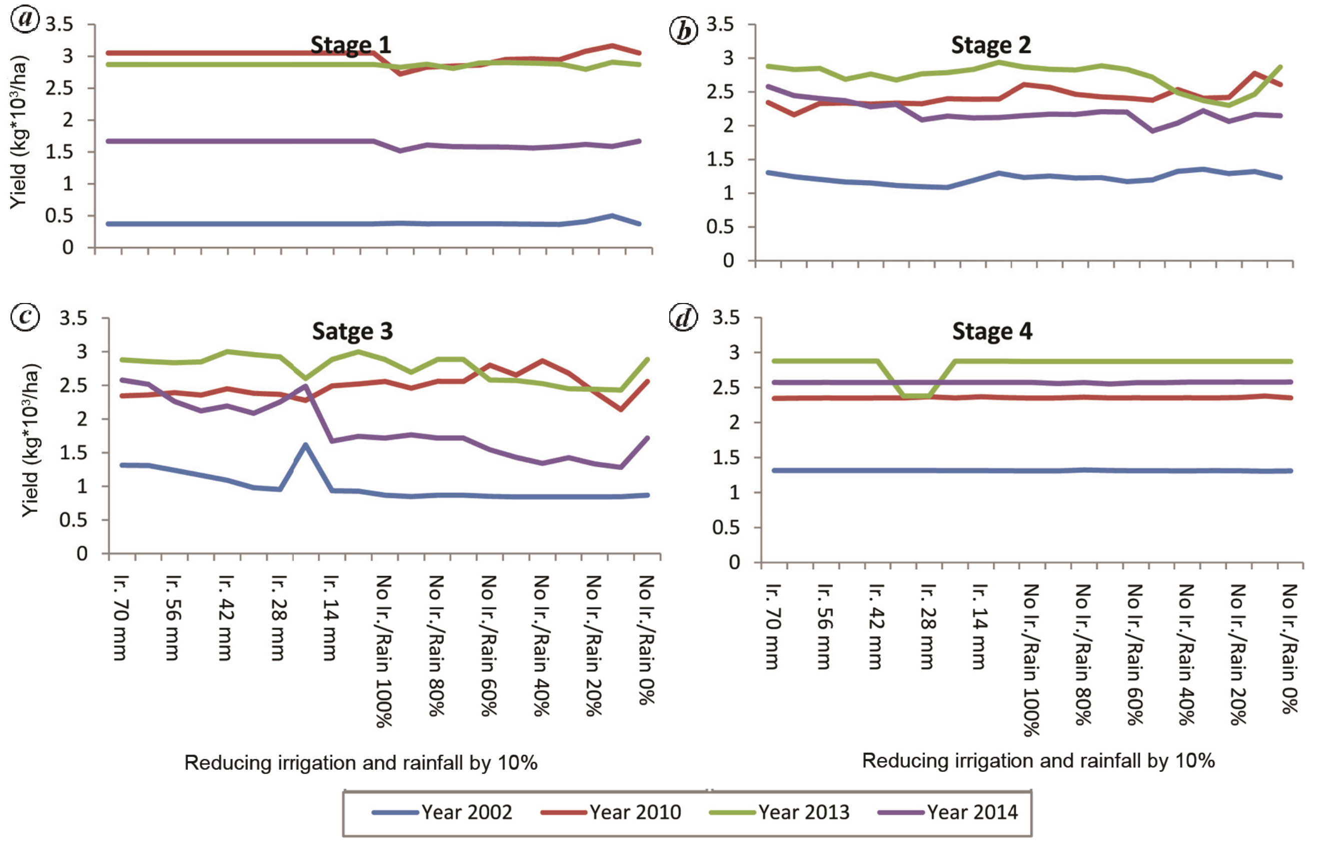


**Figure 6.** Water stress during (***a***) Stage 1 (7 to 47 days), i.e. emergence to flowering, (***b***) stage 2 (47 to 66 days), i.e. first flower to first seed, (***c***) stage 3 (66 to 101 days), i.e. first seed to ball formation, (***d***) stage 4 (101 to 135 days), i.e. ball formation to ball maturity for the selected year. Ir., Irrigation (mm), N. Ir., No irrigation.

In stage 4 (101–135) days, i.e. ball formation to ball maturity, maximum water stress was seen for non-irrigated condition during drought years. Maximum stress was noticed in the crop sown on 6 June, whereas it was minimum on 21 May in the non-irrigated conditions in all cultivars during drought year. On the other hand, mild stress (<0.20) was noticed in irrigated conditions. This stage was irrigated on the 120th and 135th day as per normal package practices and as model input.

In this study, stage-wise water-sensitivity as parameter for growth and development was studied to assess the impact of irrigation and rainfall. Figures 5 and 6 show significant yield reductions under water stress. Enormous difference was observed between drought and excess years.

Drought year 2002 had the lowest yield and excess year 2013 had highest impact on yield. In stage 1, linear line in the graph corresponds to reducing irrigation. Further slight reduction with reducing rainfall were seen as no irrigation was provided during this stage. Stage 3 was the most sensitive as per model studies, i.e. ball formation was the most sensitive stage.

There is debate regarding the most water-sensitive period during development in terms of cotton yield. Water sensitivity during flowering and ball development has already been well established[6]. Lint yield was limited due to reduced ball production. This was due to stress, extreme in magnitude and occurring during reproductive growth leading to enhanced ball abortions, and also as a result of fewer flowers[6,17]. Some studies found early flowering period to be the most sensitive while others have reported that water stress during peak flowering impacts cotton yield[18,19]. These outcomes depended on the variety and sowing dates in different regions[20].

Perennial irrigation during growing season is not beneficial in terms of economic returns. This study discusses the effect of water stress on cotton during different growth stages of the plant and the advantage of irrigation for alleviating stress. Irrigation extenuates the detrimental impact of soil water deficit on the diverse physiological plant processes. Irrigation management is aimed at reducing the water stress at critical stages of growth, so that the plants can initiate, retain, and mature balls to maximize yield. Much impact could be seen due to weather conditions on the yield. In drought years, yield is comparatively less than excess years for both irrigated and non-irrigated conditions.

Cotton crop is unique and has innate growth patterns, which makes it challenging to understand and demarcate the physiological stages. However, it has somewhat predictable pattern of its physiological stages with complexities and overlapping of stages. In this study it was observed that during excess years, stress values remained below mild levels and during drought years, stress values remained high thus affecting crop productivity. This shows that changing climate and erratic rainfall could affect the productivity of cotton. In the sensitivity analysis, it was observed that moisture stress varied greatly for drought years in comparison to excess years. Modelling studies show that this also varies with phenological stages and sowing dates. As per the simulated output, moisture deficit stress is more prominent due to rainfall departure rather than the variety of cotton crop. For all varieties is the third stage, i.e. the ball formation stage the most sensitive stage followed by the fourth stage, i.e. ball maturity stage. Water stress has detrimental effect both on vegetative phase and ball growth. Under the overlying debate of most water-sensitive period different cultivars have different outcomes.

Significant alleviation of stress can be observed in irrigated conditions in comparison to non-irrigated conditions for drought year. Yet in irrigated area rainfall plays an important role for yield appreciation or reduction. The characteristics of moisture deficit conditions, which develop in irrigated crop, are usually quite different from those of the non-irrigated crop. Crops have to be supported with irrigation to alleviate the negative influence of moisture deficit stress, which impacts its productivity. Also, cotton grown in May has higher yield than June inferring that the second fortnight of May is the best planting period under the prevalent conditions.


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Received 24 October 2017; revised accepted 13 May 2018

doi: 10.18520/cs/v115/i5/948-954