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Implications of Elevated Temperature due to Changing Climate on Cotton Crop

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***Abstract:** Due to anthropogenic forces which poses climate change the temperature is increasing as per IPCC reports (Newman, 2016). In general, temperature influences the duration of a crop's growing period. Therefore it may control the phenological development and water requirements indirectly. Increasing temperature also increases photosynthesis and other metabolic processes, until a crop type specific temperature optimum is reached. Cotton in its native state grows as a perennial shrub in a semi-arid habitat, and thus requires warm temperatures. Cotton despite being is a thermophilic plant and originating from hot does not necessarily yield higher at excessively high temperatures. Thus we can say it has a negative correlation between harvested yield and high temperature as observed in model studies. In this study effect of long-term averages of weather parameters such as temperature precipitation and sunshine i.e. the climatology of Hisar region on cotton crop is studied. For simulation of model three Bt-cotton crop varieties Pancham-541, RCH-791, SP-7007for three sowing dates have been selected. Further to examine the impact increase in temperature due to climate change 1ºC has been added at three time steps in the model upon the observed climatology of the study region. From the simulated output eight parameters has been taken to assess the impact. These parameters includes Anthesis date, Evapotranspiration (mm), Tops Nitrogen at Maturity (kg/ha), Days to harvest, Leaf Area Index (Maximum), Maturity date, Harvest index and Harvested yield (kg/ha). Model output depicts that Anthesis date, Evapotranspiration, Tops Nitrogen at Maturity (kg/ha), Leaf Area Index (Maximum), Maturity date and Days to harvest has increasing trend with increasing temperature. On the other hand Harvest index and Harvested yield (kg/ha) has decreasing trend with increasing temperature for all the cultivars. This shows that with increasing temperature if derived due to climate change the crop yield may decrease.*
***Keywords-** Temperature, Cotton crop, Modeling*

I. INTRODUCTION

Cotton is the principle cash crop grown worldwide chiefly for its fiber and seed. It is found growing almost on every continent except Antarctica. Accounting for about 26% of the world cotton production India is standing at the topmost position of the world in production. It also has the distinction of having the largest area under cotton cultivation in the world which is approx 38% to 41% of the world area under production (International Cotton Advisory Committee report, March 2017). It is primarily grown in tropical and subtropical climates. Plant growth and yield attributes are affected by genetic constitution of crop and weather that prevailed during the growing season. Temperature, solar radiation, rainfall (amount and temporal distribution), relative humidity are considered as significant meteorological parameters that influence the growth and development of the crop (Meena and Dahama, 2004; Reddy and Reddi, 2003).

Among major field crop, perhaps cotton plant has the most complex physiological structure of all (Oosterhuis, 1990). Its growth and development in a four-dimensional occupation of space and time have made it difficult analyze the effect of stress on its physiology (Mauney, 1986). Due to this complex growth habit it is very sensitive towards adverse environmental conditions. The transitions among the physiological growth stages are subtle and not always clearly distinguishable. Further, each stage may have different physiological processes operating with some specific requirements at the same time (Oosterhuis, 1990).

For successful cultivation of cotton, it requires a long frost-free period, plenty of sunshine, and moderate rainfall. Temperature plays the most significant role in cotton growth and production. Mauney in (1986) found that all processes such as square formation, blossom development and boll formation and maturation are temperature-dependent. An average annual temperature of over 16°C and rainfall of about 500 mm distributed throughout the growing season is required for its growth. An, increase in temperatures above optimum can decrease the yield of cotton due to smaller boll size and increased boll abscission (Reddy et al., 2005). During its germination, vegetative growth phase and fruiting period a daily minimum temperature of 15°C, 21-27°C and 27-32°C is required respectively (Reddy et al., 1992a; Pettigrew, 2004). Doorenbos et al., in (1984) also stated that it is essential for cotton to have degrees of rainfall and/or irrigation between 550 and 950 mm during its growing season. Specifically in cotton plants during photosynthesis the supply of photosynthate is reduced by external factors such as water deficits and high temperatures and this process may lead to increase in square and boll shed (Guinn, 1998).

During the growing season rate of development of the crop are related to air temperature which can be expressed as heat units accumulated or growing degree days (GDD). In the series of experiments meant for investigating interactive effects of vegetative growth due to light and temperature Roussoppoulos (1998) observed that leaf area of plants was larger with high temperature-low light intensity and least in low temperature–low light regime. The length of internode and number of nodes and were temperature-dependent rather than light. The floral production was favored by high light and high temperature. Finest quality of most uniform fibers was observed with high light combined with low temperature (Roussoppoulos et al., 1998).

Cotton is a C3 plant (Wong, 1979) and plants with C3 metabolism are favored by cool temperatures and on the other hand plants with C4 metabolism are favored by warm temperatures. But biological sciences is full of exceptions and cotton is one of them. Although having the C3 pathway of photosynthesis universally, yet it's temperature optimum exceeds many crop plants with C4 photosynthesis. (Bugbee, B., 2011). These characteristics of the plant can partly be explained by high transpiration rates of cotton and the associated evaporative cooling. This gives it a unique ability to cool itself on hot days. The canopy temperature can be found much lower than the surrounding air temperature.

Temperature plays a vital role during the germination and emergence of the crop. Further, it also has affects subsequent stand development, the fruiting patterns and finally yield (Arndt, 1945; Pearson et al., 1970). The number of vegetative and fruiting branches produced per plant were strongly influenced by temperature, with an increase in vegetative branches and a decrease in fruiting branches with high temperatures (Hodges et al., 1993). Reddy et al. (1996) also reported that young bolls shed when grown at average daily temperatures of 32°C or higher. Prior to flowering if there is hot temperature or after boll formation, the yield is often increased. Since, hot temperatures after boll formation hasten the opening of the bolls and its maturation. High night temperatures is also found detrimental to young bolls for its formation and maturation, and precipitation or irrigation could partially compensate for its reduction in yield. Khichar and Niwas (2006) also reported that temperature profile during noon hours were inverse i.e. rate of increase in temperature with crop height was less as compared to inversion rate of morning and evening profiles temperature profile in wheat crop under different sowing environments. Analysing the effect of sowing date, Jalsingh and Bishnoi (2000) reported that out of four dates of sowing from 22nd April to 6th June, early sowing of cotton has produced highest seed cotton yield over late sowing.

Long-term averages of weather parameters are defined as the climatology of those factors for a region. Considering the response of crop growth and meteorological conditions, it was hypothesized that climatology of a region has a major role to play in the present and future climate. The present investigation was conducted to find out the effect of an increase in temperature as predicted by IPCC.

II. Materials and Methods

Study area

The study area is Hisar, the westernmost district of Haryana. Situated between 74°24' to76°18'E longitude, 28°54' to 29°59'N latitude and at an elevation of 215.2 m. It lies in the sub-tropical region of India. With quite hot summers and fairly cool winters, they show an arid type of climate. Chief characteristics of this climate are dryness, extremes of temperature and scanty rainfall. The mean temperature is 40°C and 10°C in summer and winter, respectively. On an average, there are 24 rainy days in a year with average annual rainfall of 450 mm. Generally, light winds blow but there occur dust-storms in summer and thunderstorms in monsoon. Weak inversions are commonly observed in winter.

Model

Crop models which share a common input and output data format have been developed and embedded in a software package called Decision Support System for Agrotechnology Transfer (DSSAT). The DSSAT itself (Jones, 1993; IBSNAT, 1994 and Tsuji, et al., 1994) is a shell that allows the user to organize and manipulate crop, soil and weather data and to run crop models in various ways and analyze their outputs. The models running under DSSAT include the CERES–wheat, rice, maize, sorghum, pearl millet, and barley; the CROPGRO (CROP GROwth) for cotton, bean, peanut, and soybean.

Methodology

For simulation of model three Bt-cotton crop varieties Pancham-541, RCH-791, SP-7007 have been selected as it is cultivated generally in Hisar region of Haryana during the Kharif season. The genetic coefficient for this variety is already developed and reported by Dr. Ram Niwas (Swami et al., 2016). These cultivars were sown on 10th May, 21st May, and 06th June. To achieve this general objective, field experiment is conducted during Kharif season at Chaudhary Charan Singh Haryana Agricultural University popularly known as HAU, Hisar under the FASAL project of India Meteorological Department (IMD). In all 200 kg/ha of urea (NH2–CO–NH2) was applied in two equal doses (basal and vegetative growth stage). Irrigation is applied in equal amounts in six applications. Daily weather data for the parameters viz. maximum temperature, minimum temperature, hours of bright sunshine and rainfall has been taken from IMD for the location during the experimental period 1981-2015. Increase in temperature at three equal time steps to see the impact has been performed with the environment modification module facilitated under the model.

III. Results and Discussion

To examine the impact of an increase in temperature due to climate change 1ºC has been added at three-time steps in the model upon the observed climatology of the study region. From the simulated output, eight parameters have been taken to assess the impact. These parameters are the following

Anthesis date	Leaf Area Index (Maximum)
Evapotranspiration (mm)	Maturity date
Tops Nitrogen at Maturity (kg/ha)	Harvest index
Days to harvest	Harvested yield (kg/ha)

Graphs have been plotted from the simulated output as shown in figure 1 and 2.

In figure 1, mean and standard deviations of the variables are plotted for the three cultivars with three sowing dates.

Anthesis Date- In figure 1a, we can see that with increasing temperature anthesis date has increased in general for all the varieties as per model simulation. Maximum anthesis date is for the variety RCH-791 for all the three sowing dates. In figure 1b, the maximum standard deviation is in sowing date10th May and minimum in 06th June.

Tops Nitrogen at Maturity (kg/ha) - In figure 1c, we can see that with increasing temperature tops nitrogen at maturity has increased in general for 10th May and 21st May but decreased for 06th June as per model simulation. It is observed maximum for the variety Pancham-541 among all the varieties. It has been seen decreasing with delaying the three sowing dates. In figure 1d, we observe increasing deviation by delaying sowing dates.

Harvested yield (kg/ha) - In figure 1e, we can see that with increasing temperature harvested yield has decreased in general for all the varieties and planting dates as per model simulation. Maximum yield can be observed for the variety Pancham-541 for all the sowing dates. This has also been seen increasing in crop sown on 06th June. Again as per in figure 1f, the maximum standard deviation is observed for Pancham-541 for all sowing dates.

Days to harvest- In figure 1g, we can see that with increasing temperature days to harvest has increased in general for 10th May and 21st May but decreased for 06th June as per model simulation. Again as per in figure 1h, it is observed least for SP-7007among all the varieties.

Maturity date- In figure 1i, we can see that SP-7007 has the earliest maturity date and for all the cultivars planting date 06th June matures late comparatively. Also in figure 1j, we see maximum standard deviation is observed for sowing date 06th June.

Harvest index- In figure 1k, we can see that with increasing temperature harvested yield has decreased in general for all the varieties and planting dates as per model simulation. Maximum yield can be observed for the variety Pancham-541 for all the sowing dates. Again as per in figure 1l, the maximum standard deviation is observed for SP-7007 for 10th May and 21st May, and Pancham-541 for sowing date 06th June.

Leaf Area Index (Maximum) - In figure 1m, we can see that with increasing temperature Leaf Area Index has increased in general for all the varieties as per model simulation. And, it is found least for the cultivar SP-7007. It is observed maximum for sowing date 06th June for all the varieties. Again as per in figure 1n, the maximum standard deviation is observed for crops sown in June.

Evapotranspiration(mm) - In figure 1o, we can see that with increasing temperature Evapotranspiration has increased in general for all the varieties as per model simulation. And, it is found least for the cultivar SP-7007. Again as per in figure 1p, the maximum standard deviation is observed for crops sown in June.

In figure 2 means are plotted for thirty-five years and increasing temperatures for the three cultivars with three sowing dates. For the three cultivars, graph are plotted with three different sowing dates with average baseline climatic conditions as observed and with model evaluated increase in temperatures. This is to study the effect climate change on cotton crop due to increasing temperature on different sowing dates for the three Bt-cotton cultivars.

In figure 2a we observe that with increasing temperature anthesis date has increased in general for all sowing dates as per model simulation. Maximum anthesis date is for the sowing date 06th June. Again, for evapotranspiration (mm) in figure 2b shows similar pattern as anthesis date depicting some relation with it. But as in case of anthesis date i.e. 06th June shows much variability with crops sown on May. So we can say that early sown crop enters into reproductive phase earlier than late sown ones. Also, evapotranspiration rates are high for late sown crop and can be seen increasing with increasing temperature. In figure 2c, tops Nitrogen at maturity (kg/ha) mean is plotted this pattern also coincides with the earlier ones i.e. Anthesis date and evapotranspiration rates and increases with increasing temperature and increasing sowing dates. In figure 2e and 2f we observe that Leaf Area Index (maximum) and maturity dates also follows the pattern of the top three variables anthesis date, evapotranspiration and tops Nitrogen at maturity of increasing with late sowing dates and temperature. Unlike the above three variables, days to harvest as seen in figure 2d has decreased with 1°C increase in temperature and then further increased with increasing temperature. This has difference in the present climate but with increasing the effect of sowing dates has been consolidated and the graph seems to be converged. So we can say that with increasing temperature no effect could be seen of sowing dates as per model output. In figure 2g and2h we can observe there a decreasing trend of harvest index and harvested yield with increasing temperature and sowing dates. Harvested yield for Pancham-541 is not much impacted due to sowing dates in present climatology as observed from simulation. With 1°C increase in temperature it has increased for all the sowing dates. Further with increase of 2°C difference in sowing dates has effect on harvest index of the crop as it is higher in May. And with increase in 3°C temperature May has higher yield than sown in June. On the other hand harvested yield in Kg per hectare showed a different picture which is not so precise taking the effect of increasing temperature so precisely. It is observed decreasing with increase in temperature and higher yield in crop sown in June.

In figure 2i- 2p, for RCH-791 all the seven variables shows similar pattern with Pancham-541 except for harvest index and much lower. The pattern is almost the same except that present climatology and with increase in 1°C has same mean but for 2°C and 3°C temperature May has higher yield than sown in June.

In figure 2q- 2x, for SP-7007 five variables followed the same pattern except for the days to harvest, harvest index and harvested yield. In figure 2t as observed for days to harvest with increase in temperature it increases but shows an opposite trend in case of sowing dates. The crop sown on May has higher values i.e. the crop sown in June are harvested first as per model output which is not in the case of previous two cultivars as observed. Again in case of harvest index and harvested yield it shows a different picture then the other two cultivars. In figure 2w we observe that harvest index for SP-7007 in the present climate is also affected by sowing dates. The crop sown in May has higher harvest index then the crop sown in June. Same is with 1ºC and 2ºC increase in temperature but with 3ºC increase in temperature harvest index of crop grown in June is higher. In figure 2x we observe the harvested yield (kg/ha) is higher for the crop sown in June then sown in May for the cultivar SP-7007. So we can say for this cultivar late sowing is preferable in the present climate as well as with increase of 1ºC and 2ºC. And it can be noted that the case is reversed in case of 3ºC rise in temperature.

IV. Conclusion

Above optimum temperature cotton is highly sensitive towards heat stress. The damage towards the crop depends upon the duration and intensity of stress (Reddy et al., 1996). An, increase in temperatures above optimum can decrease the yield of cotton due to smaller boll size and increased boll abscission (Reddy et al., 2005).He further elaborated this through experiments conducted for the future climates, the yield and quality of the fiber are observed to decrease if increasing CO_2 is associated with an increase in temperatures particularly in fields where present temperature are near to optimum for the crop. Considering this hypothesis an model simulation has been done for the observed climatology of 35 years and with increasing temperature of 1ºC at three-time steps. Eight physiological parameters have been plotted to see the effect of increasing temperature. This is done for three cultivars with three sowing dates. It is observed that with increasing temperature there is a decreasing trend in harvested yield and harvest index. In contrast to this observation, there is an increase in trend for Anthesis date Evapotranspiration tops nitrogen at maturity and leaf area index. Days to harvest and maturity does not show any significant difference but a slight increase i.e. the crop growth period is almost same in future climate too. This shows that for cotton with an increase in temperature in the future climate Evapotranspiration increases to keep the plant cool but the yield is reduced. Anthesis date is also found to be increased depicting that the simulated output shows that with an increase in temperature reproductive maturity or flowering is also delayed. Leaf area index is found to be increased with an increase in temperature. These model output also shows that crop is grown in May and that grown in June has different outputs. Evapotranspiration rates, Anthesis date, and harvested yield are higher for the crop grown in 06th June as per model output. This can be the result of the arrival of monsoon in JJAS in the semi-arid region of Hisar, which can compensate for the heat and water stress for the crop.

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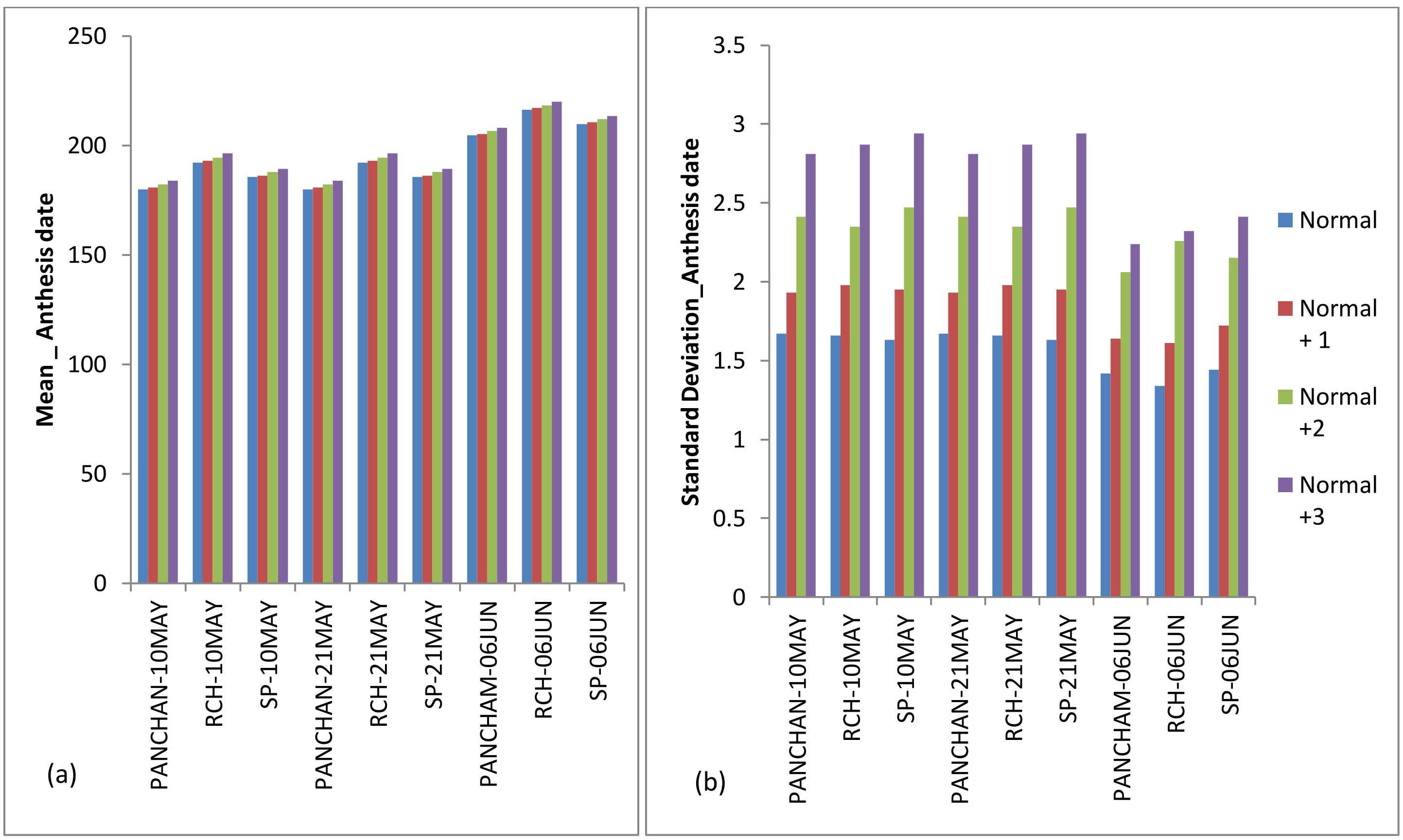

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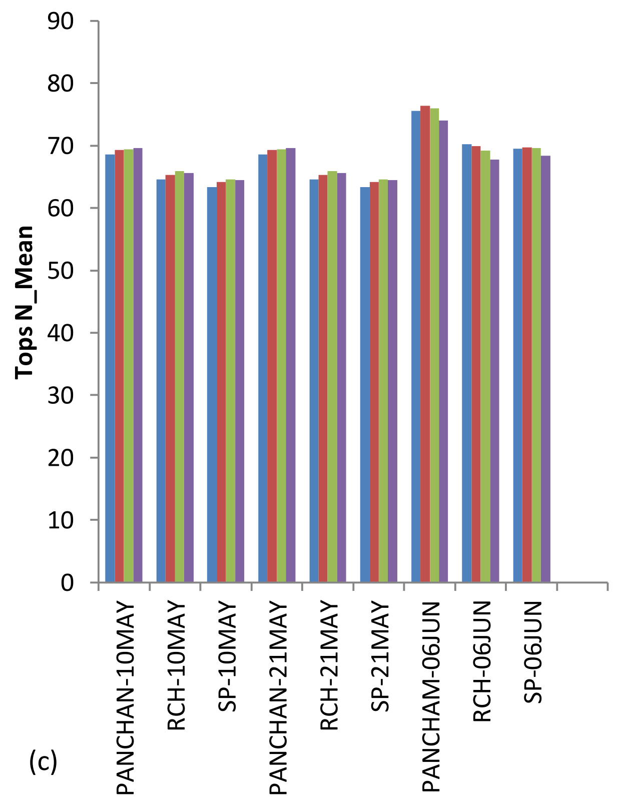

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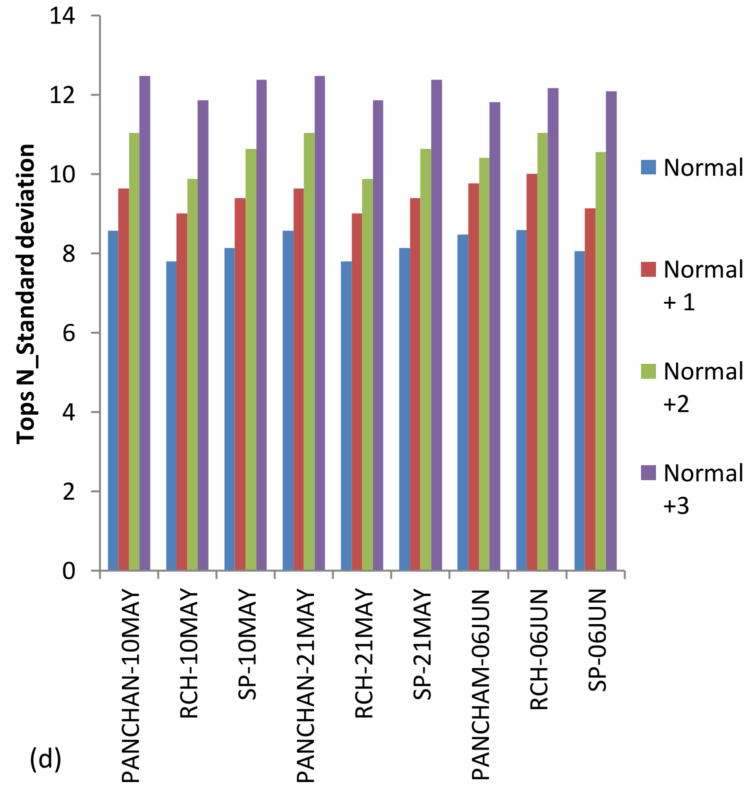

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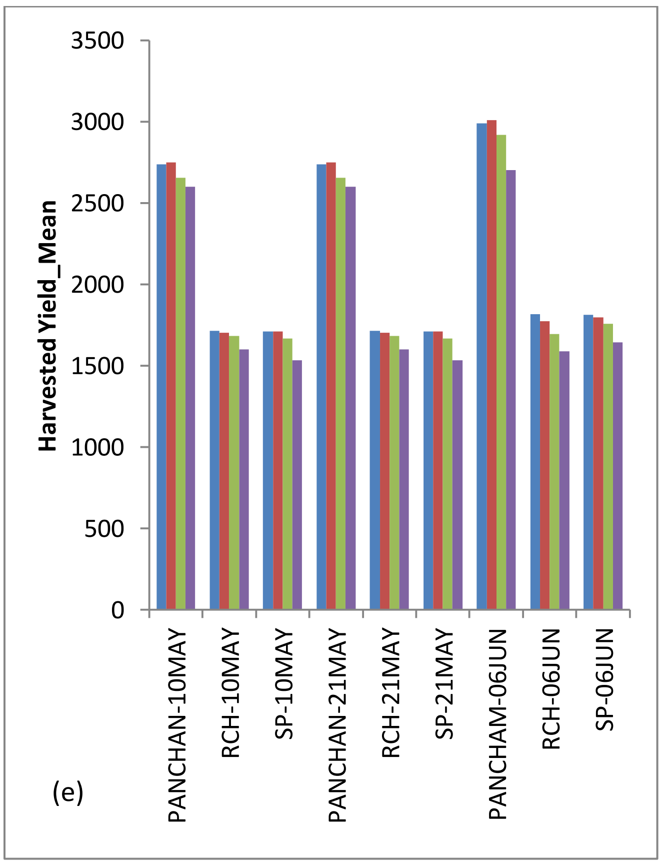
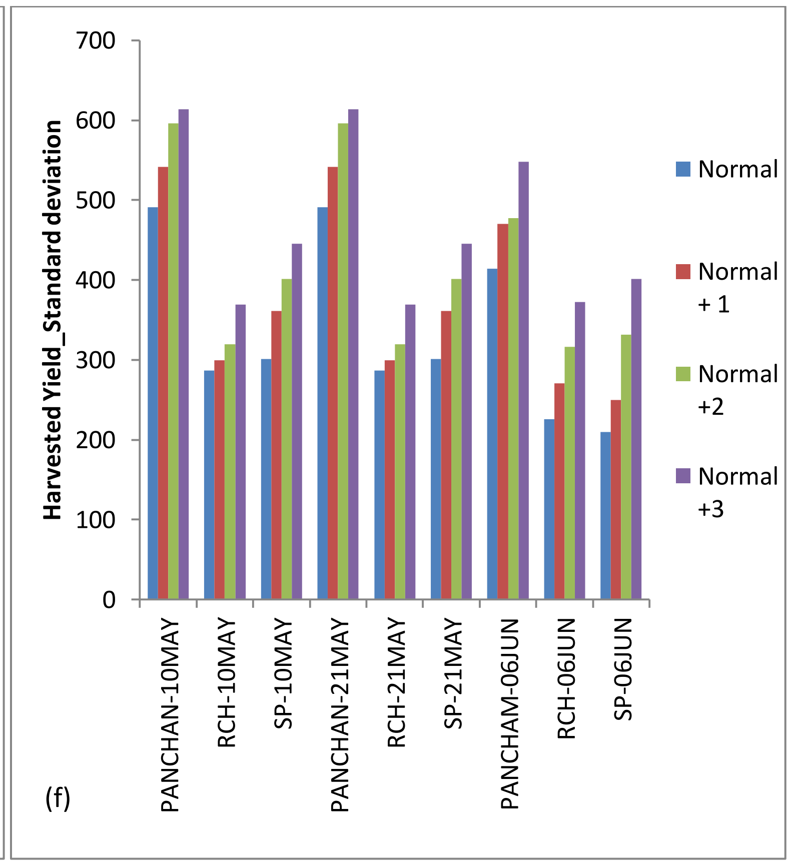

Harvested Yield_Mean
3500
3000
2500
2000
1500
1000
500
0
PANCHAN-10MAY
RCH-10MAY
SP-10MAY
PANCHAN-21MAY
RCH-21MAY
SP-21MAY
PANCHAM-06JUN
RCH-06JUN
SP-06JUN
(e)


Harvested Yield_Standard deviation
700
600
500
400
300
200
100
0
PANCHAN-10MAY
RCH-10MAY
SP-10MAY
PANCHAN-21MAY
RCH-21MAY
SP-21MAY
PANCHAM-06JUN
RCH-06JUN
SP-06JUN
Normal
Normal + 1
Normal +2
Normal +3
(f)

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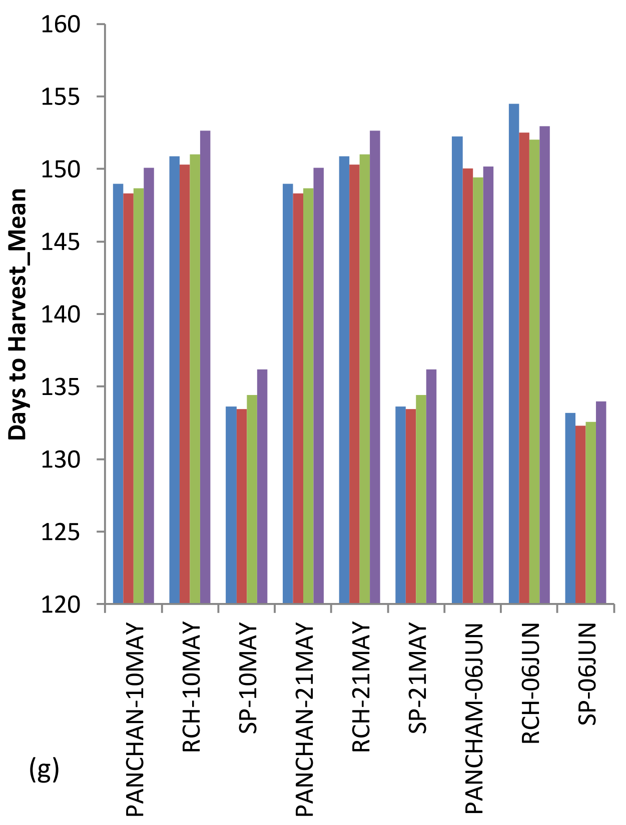

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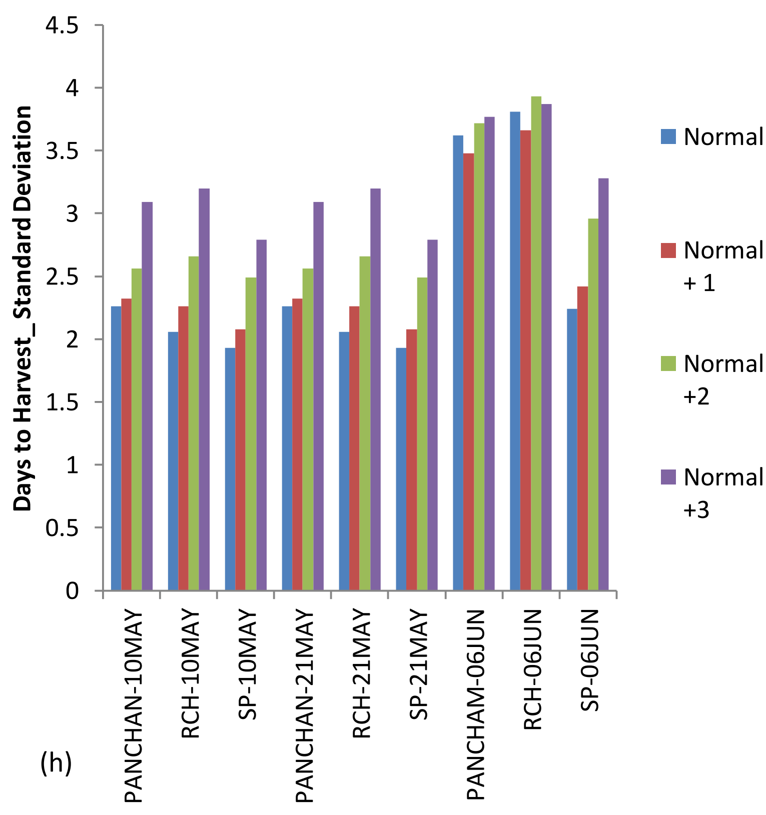

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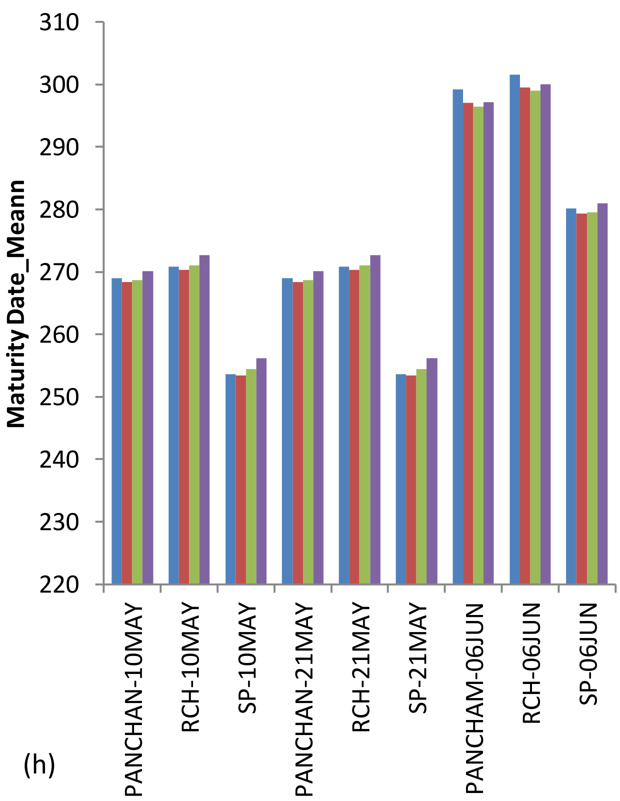

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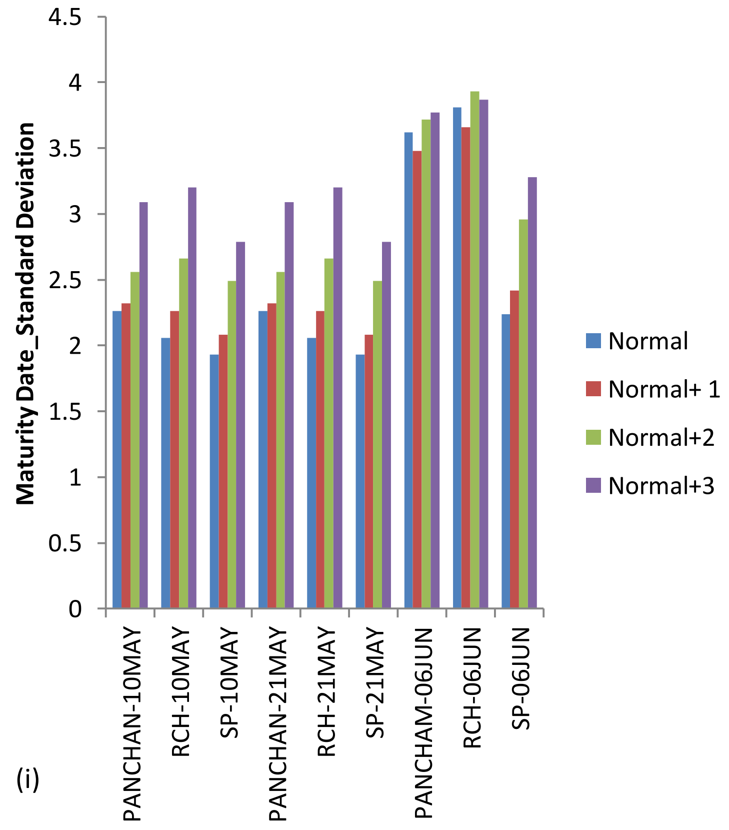

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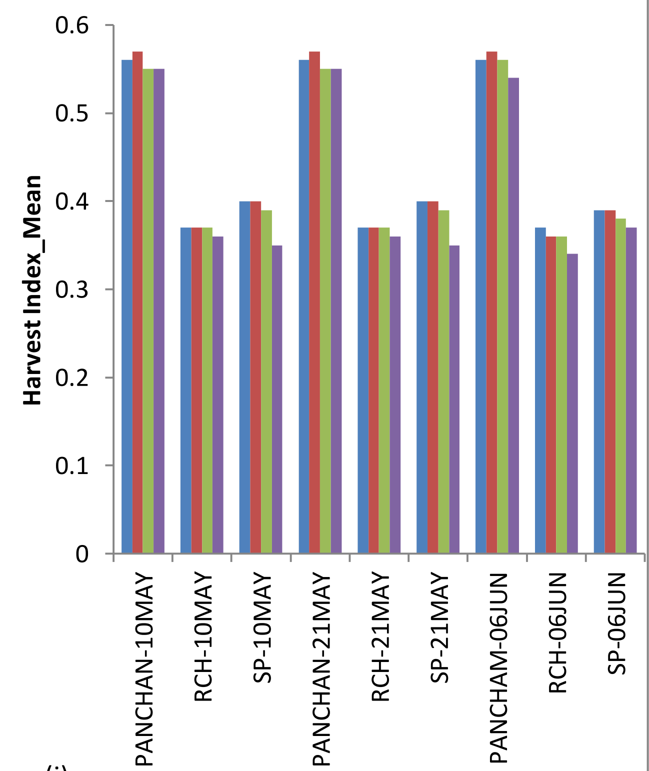

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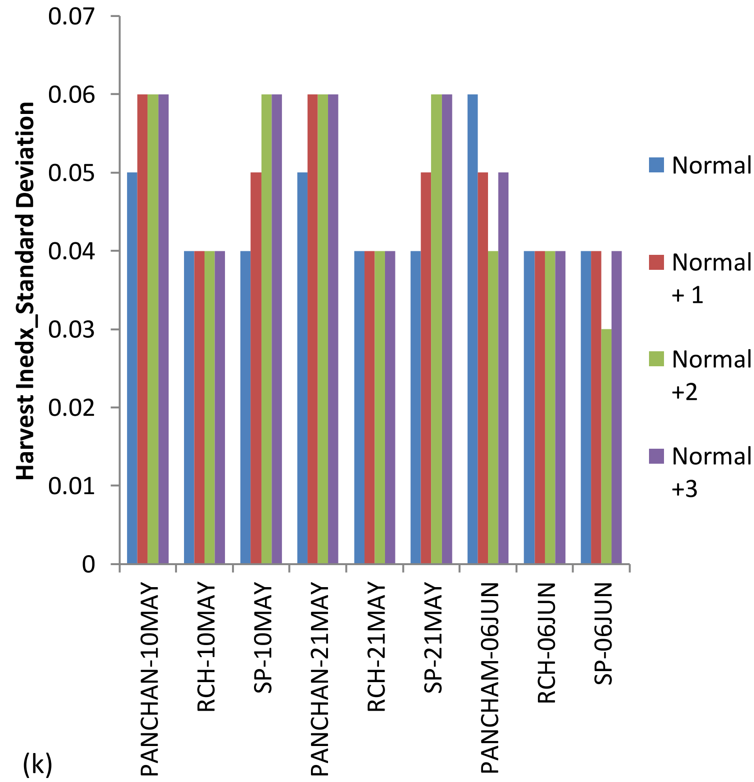

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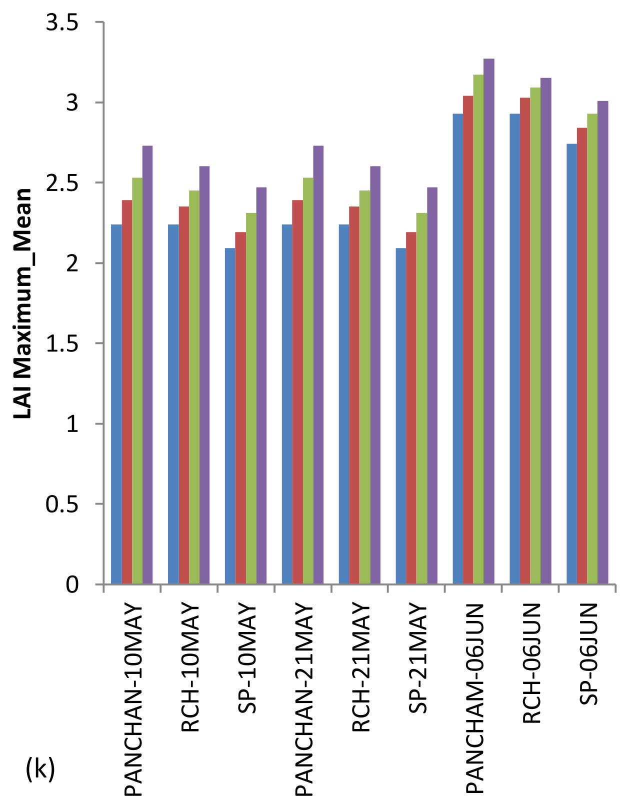

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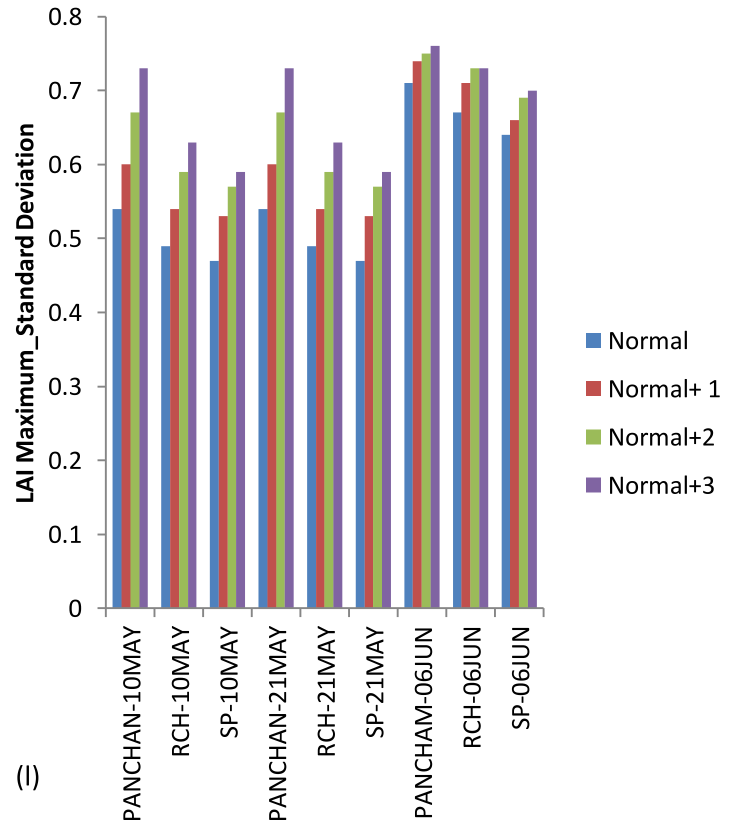

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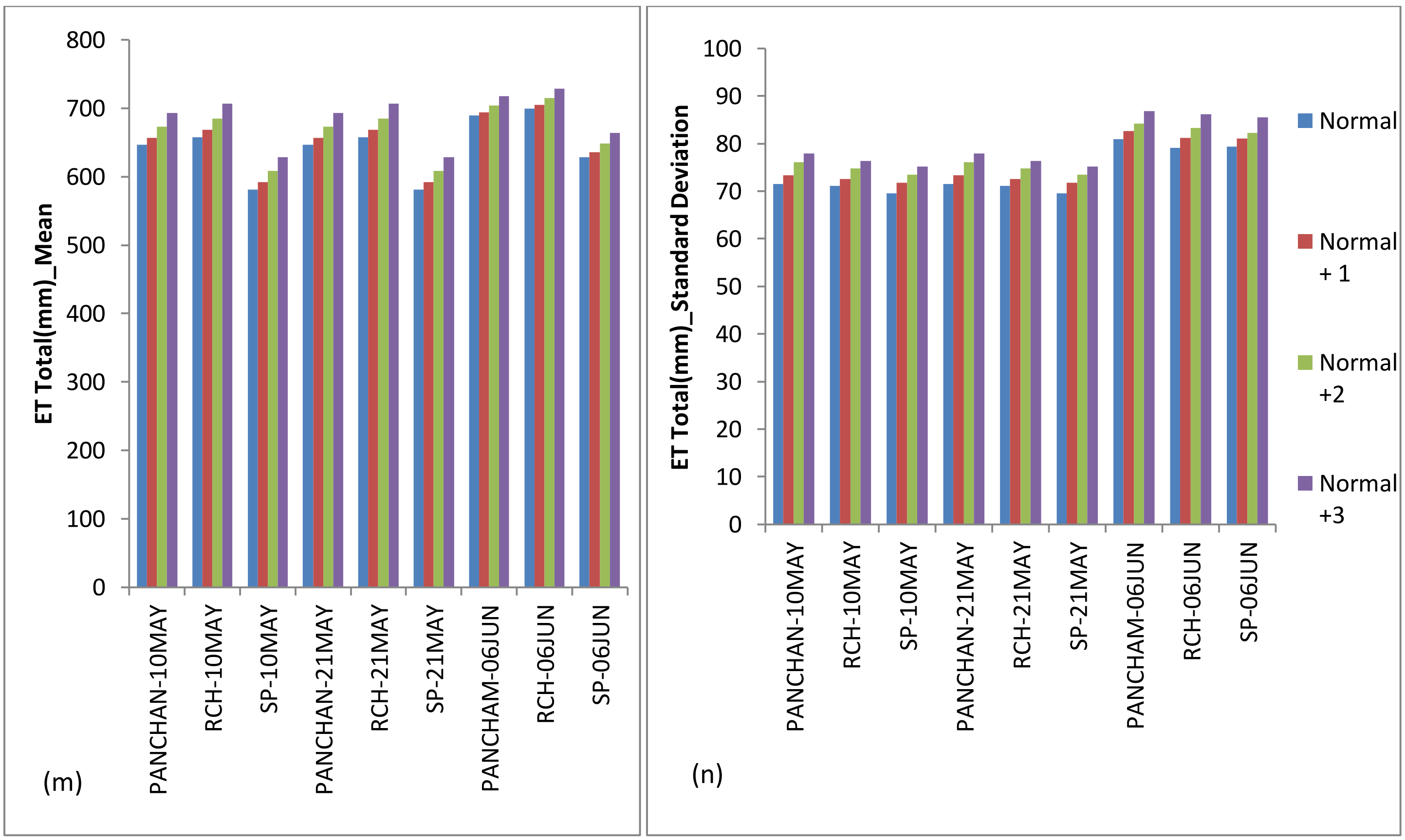

Figure 1: Mean and standard deviation of the various simulated outputs for three cotton cultivars Pancham-541, RCH-791 and SP-7007 for three sowing dates 10th May, 21st May and 06th June.(N=taken as normal year for climate data between 1981 to 2015), (N+1 = N year with environment modification as +1 ºC) , (N+2 = N year with environment modification as +2 ºC)

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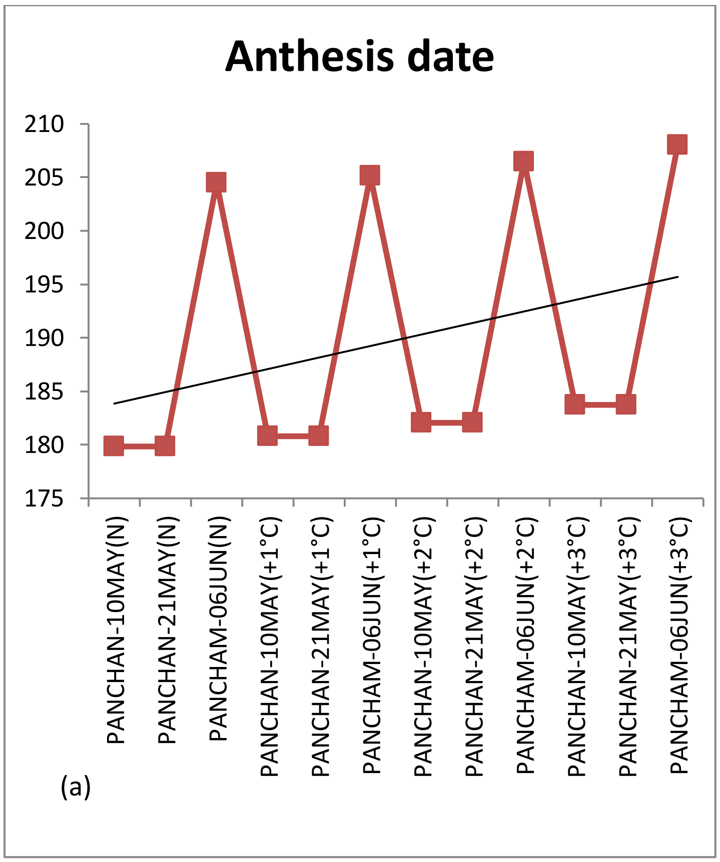

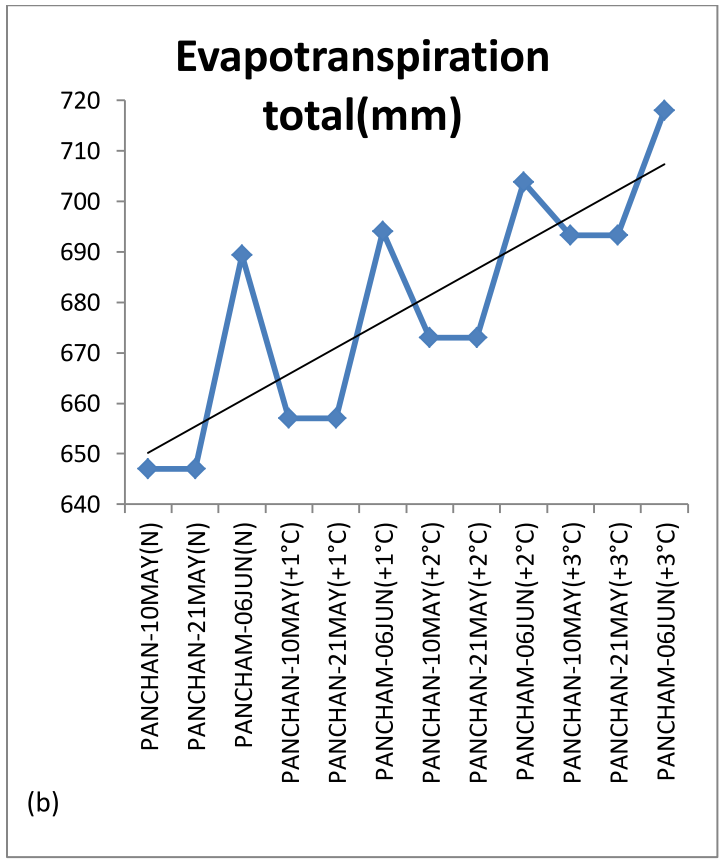

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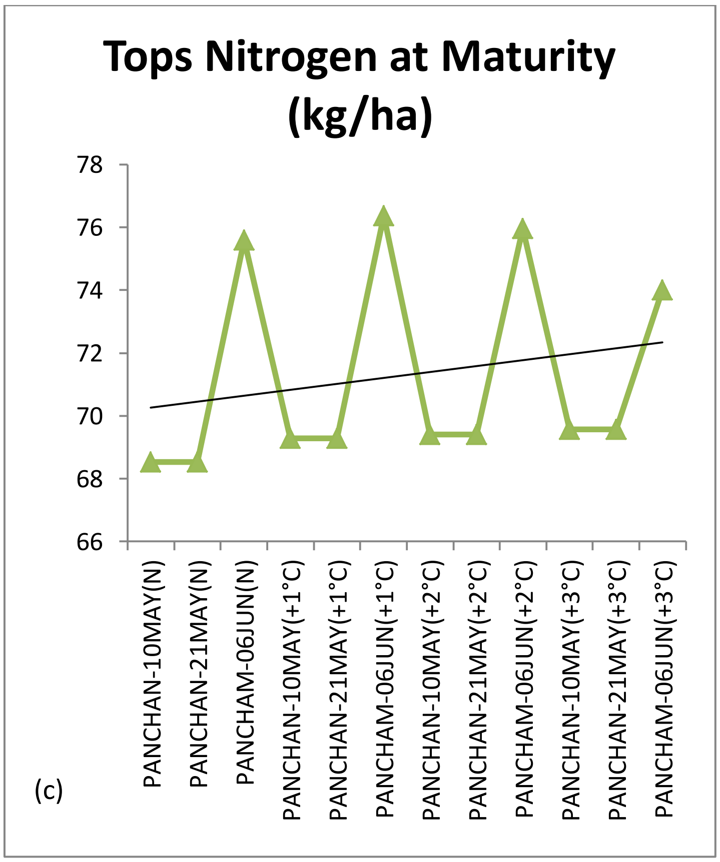

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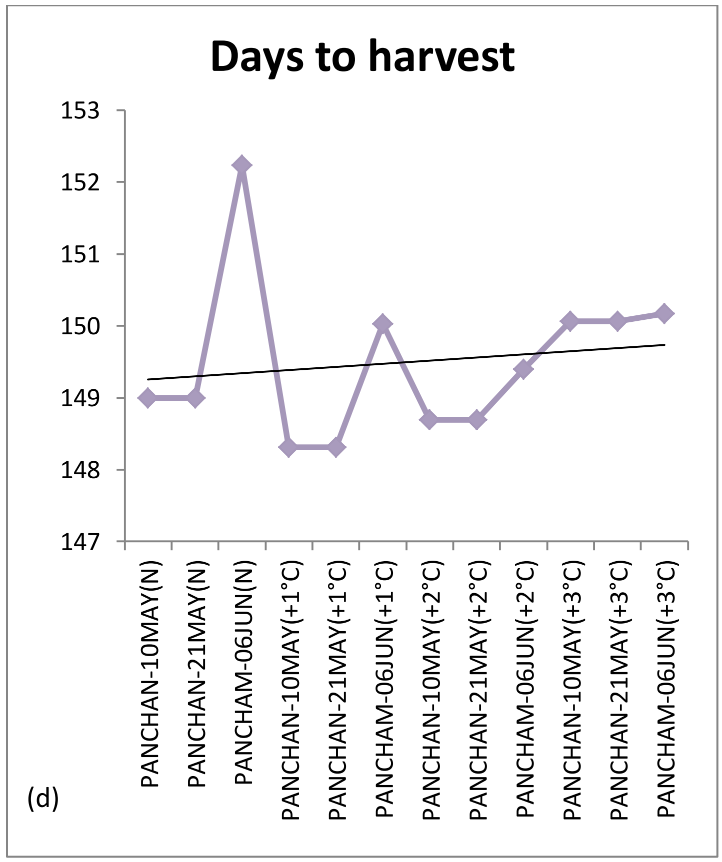

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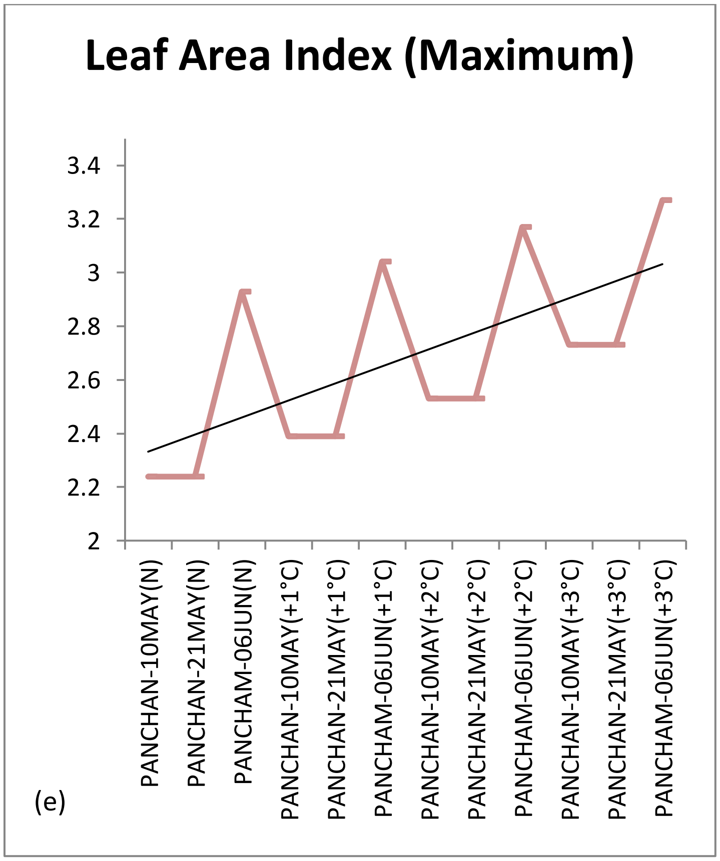

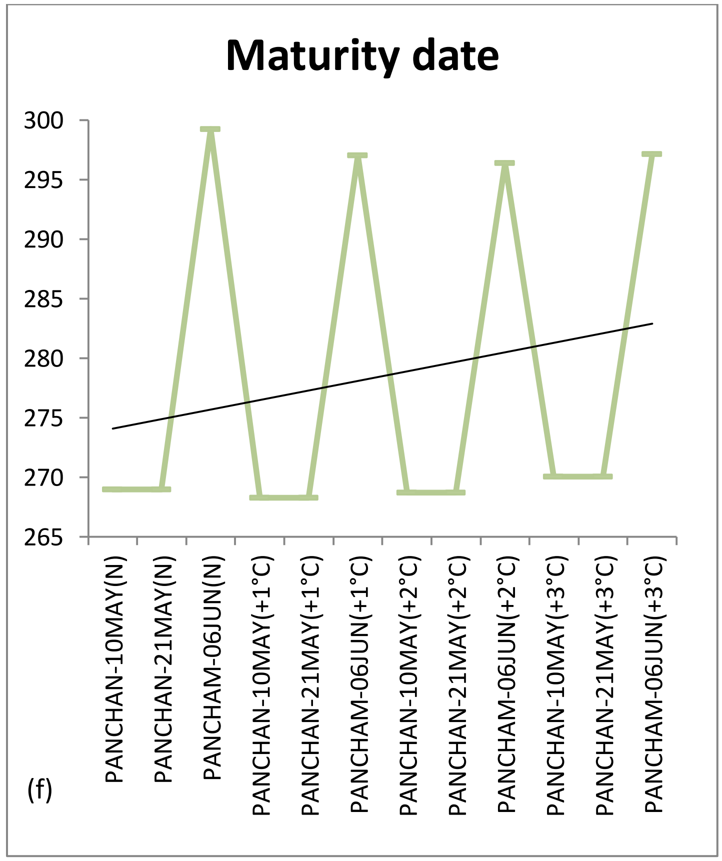

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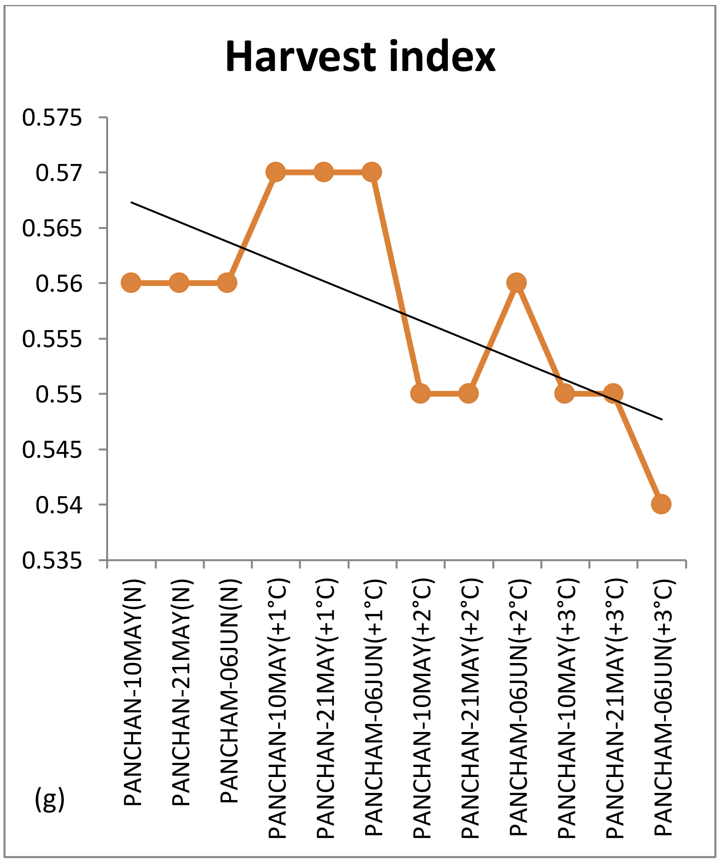

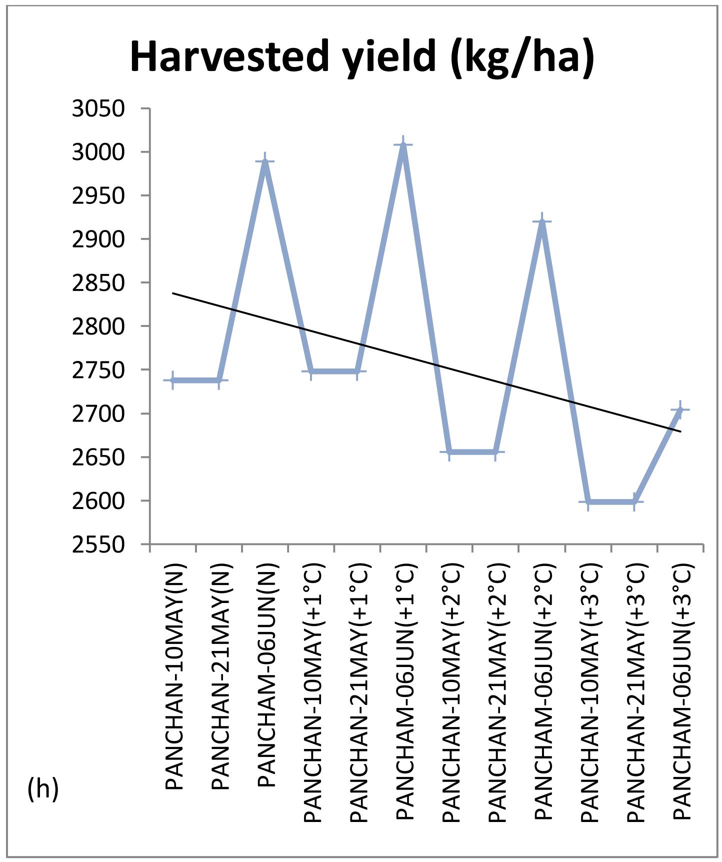

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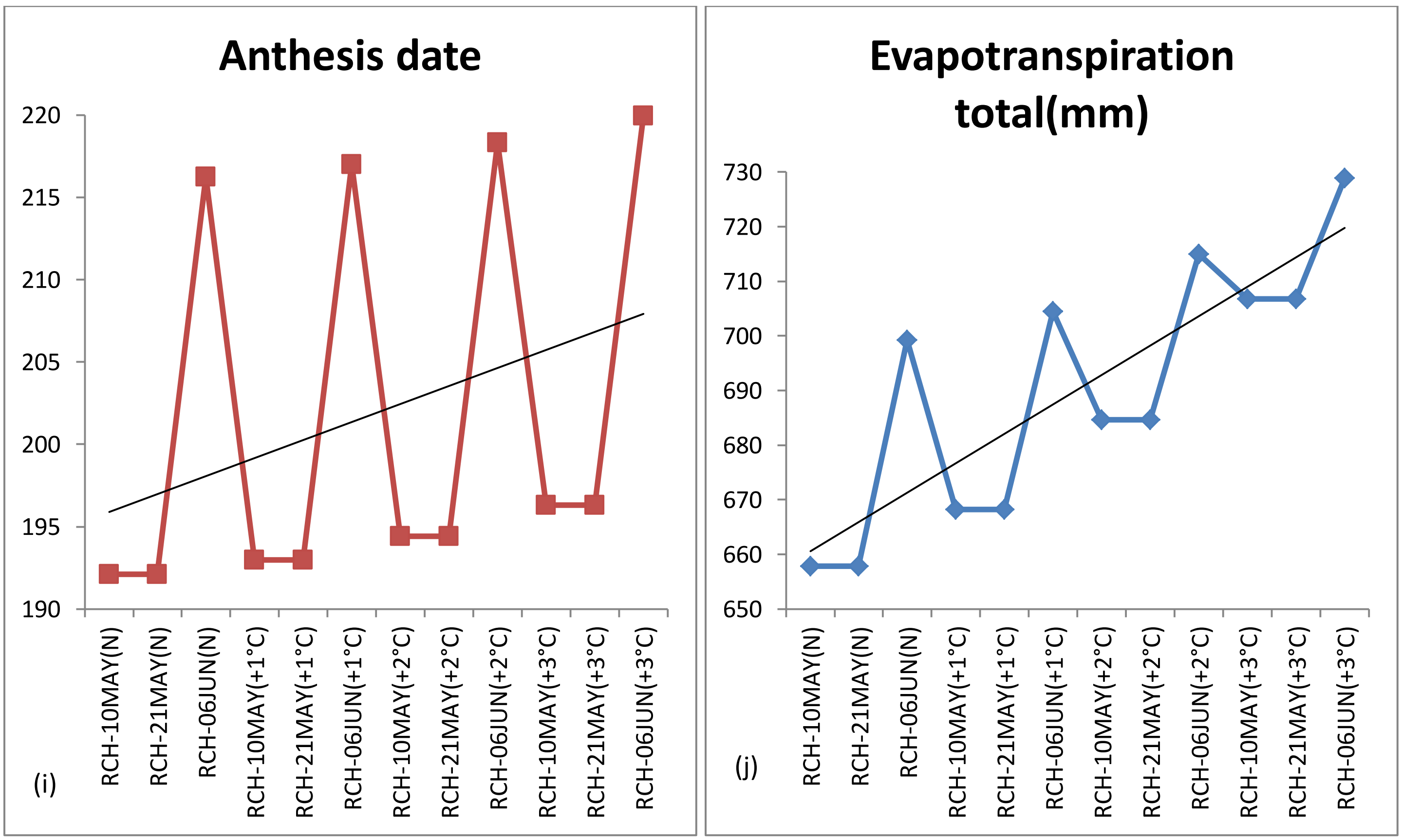

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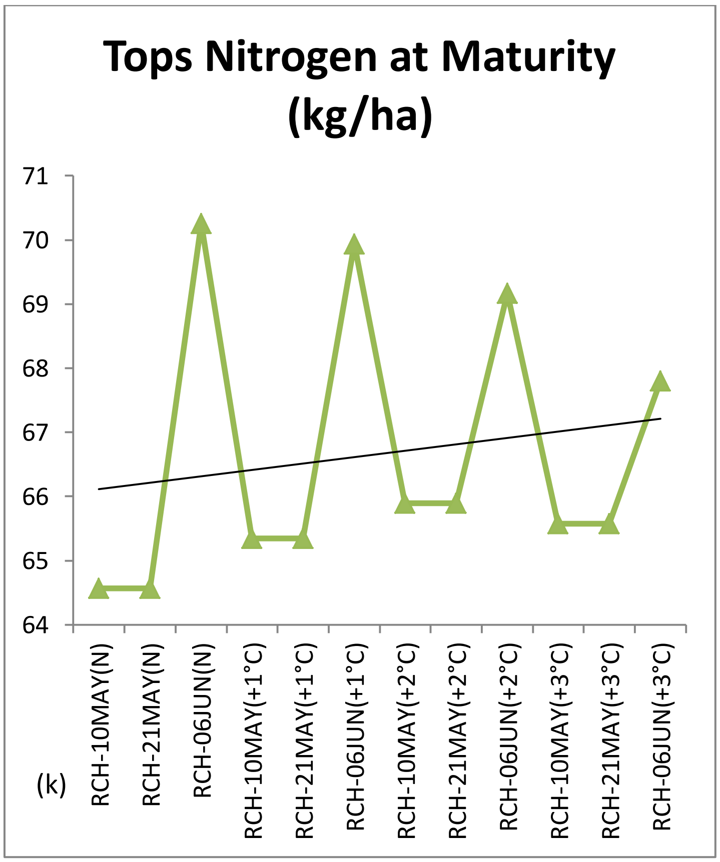

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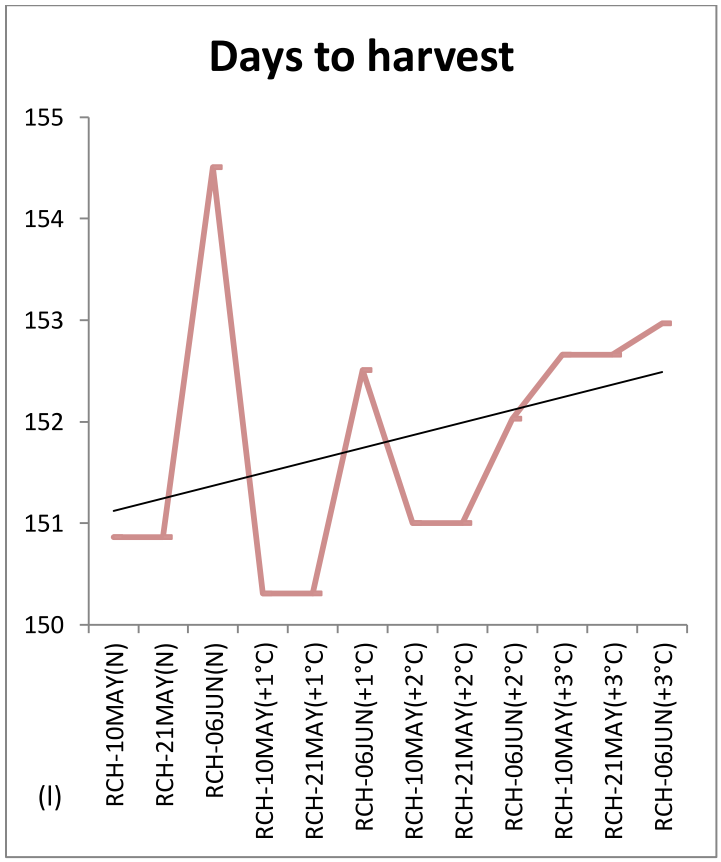

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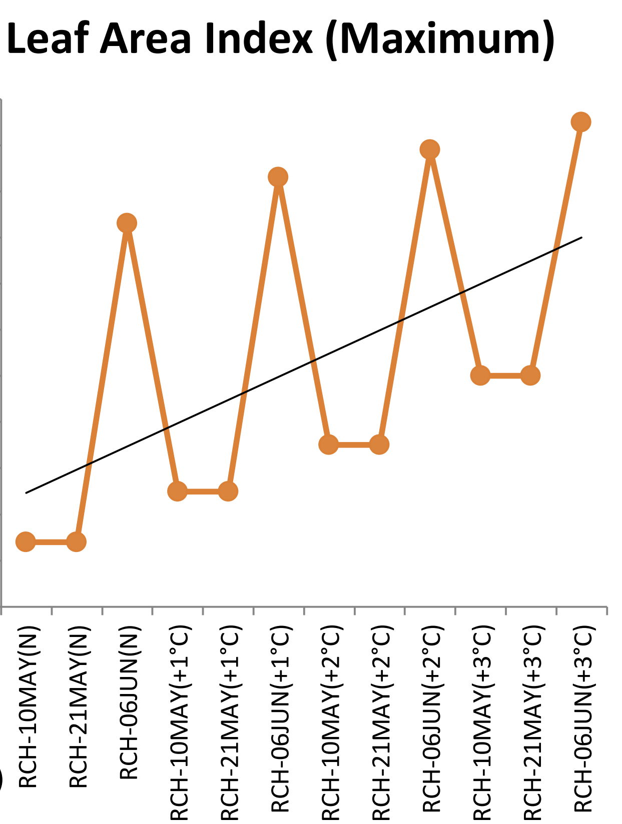

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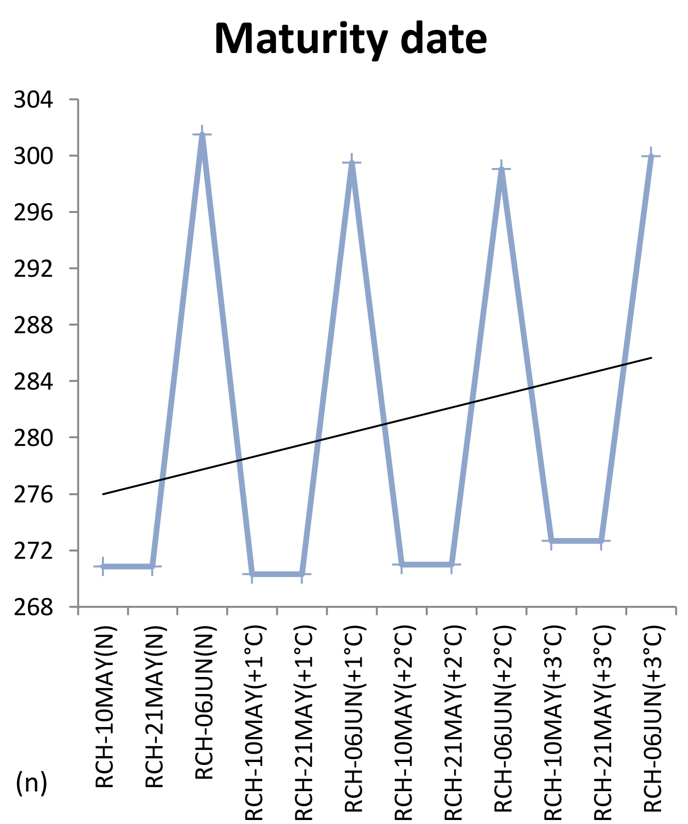

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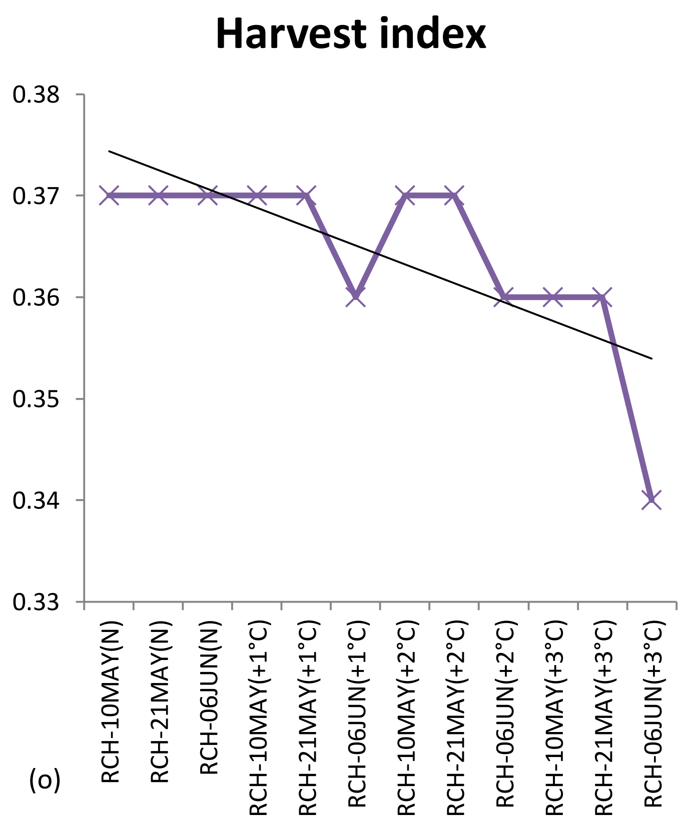

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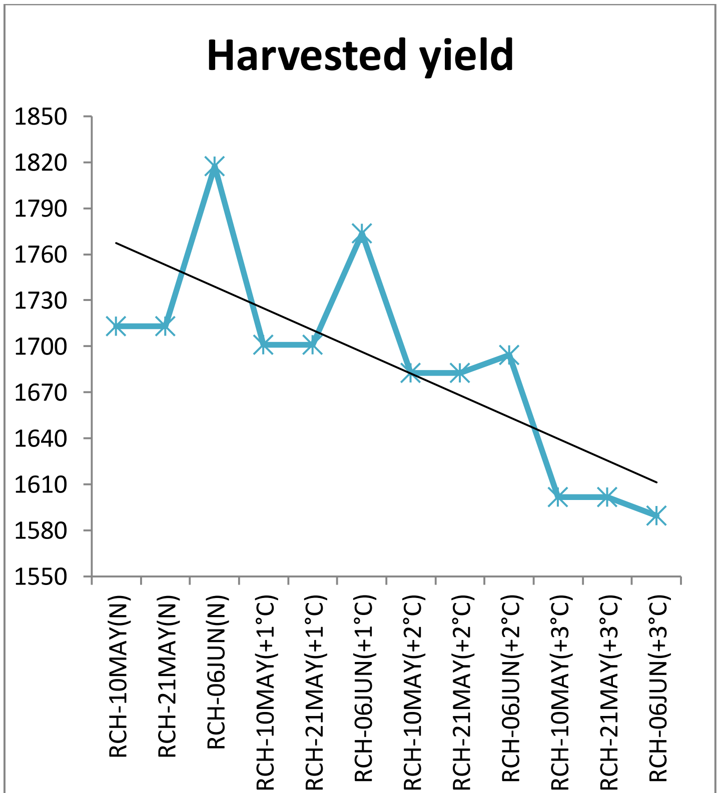

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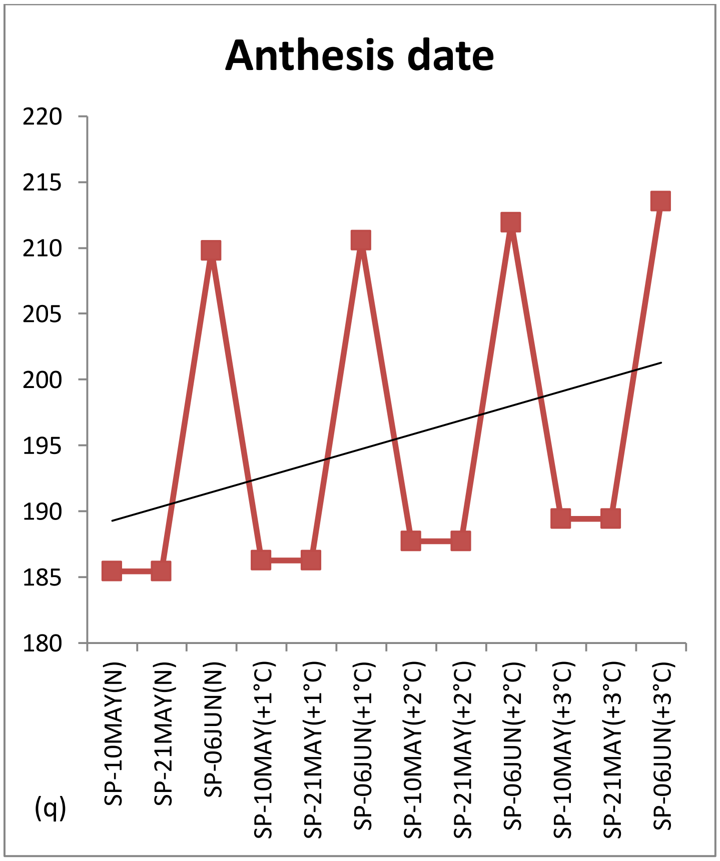

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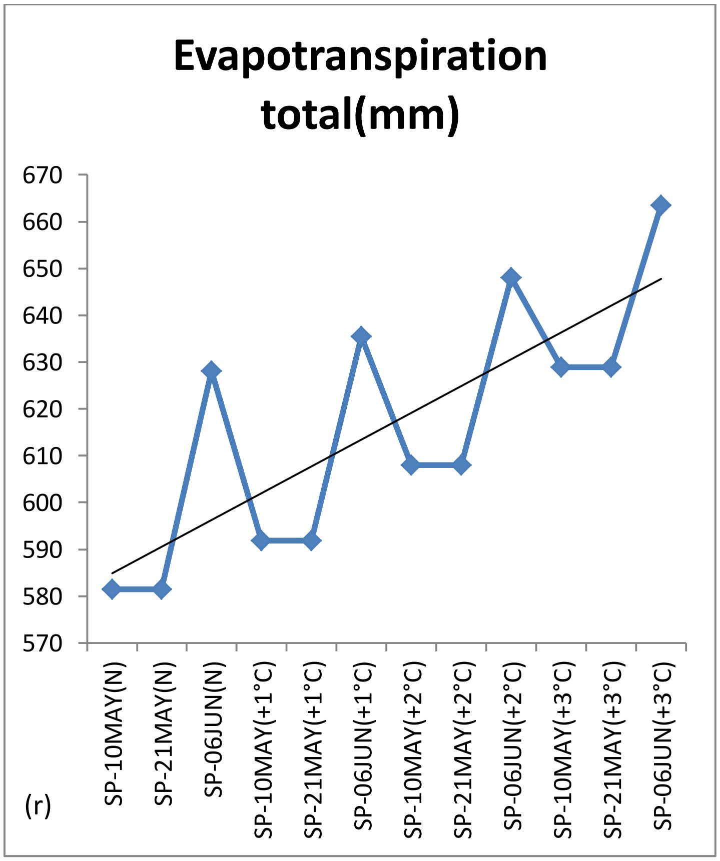

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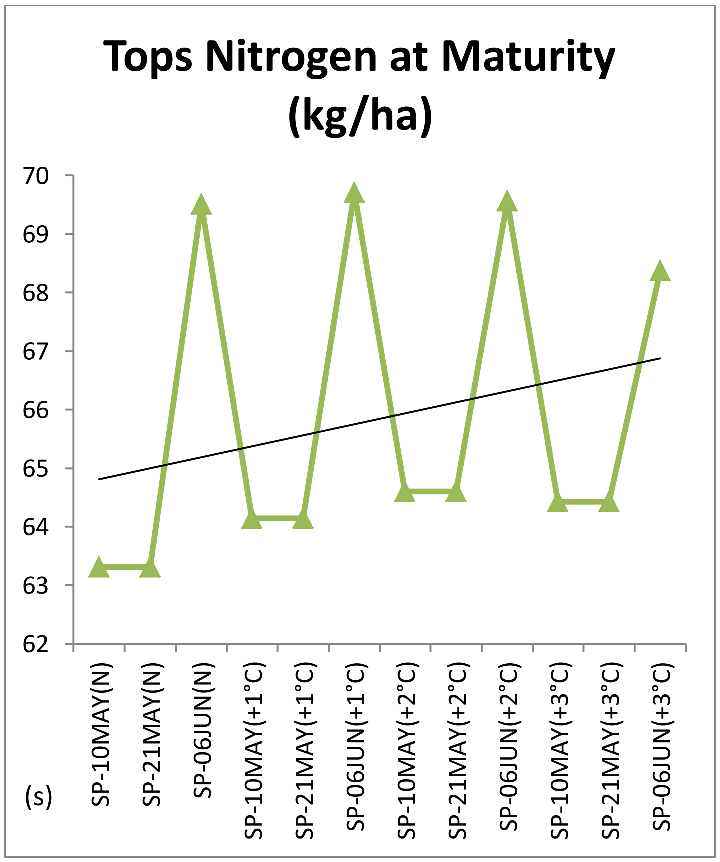

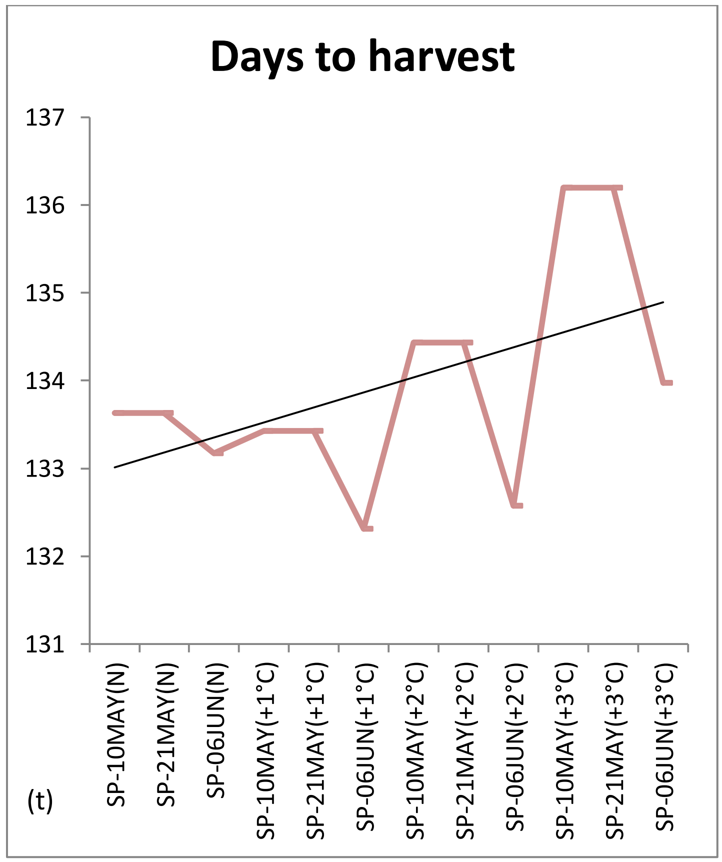

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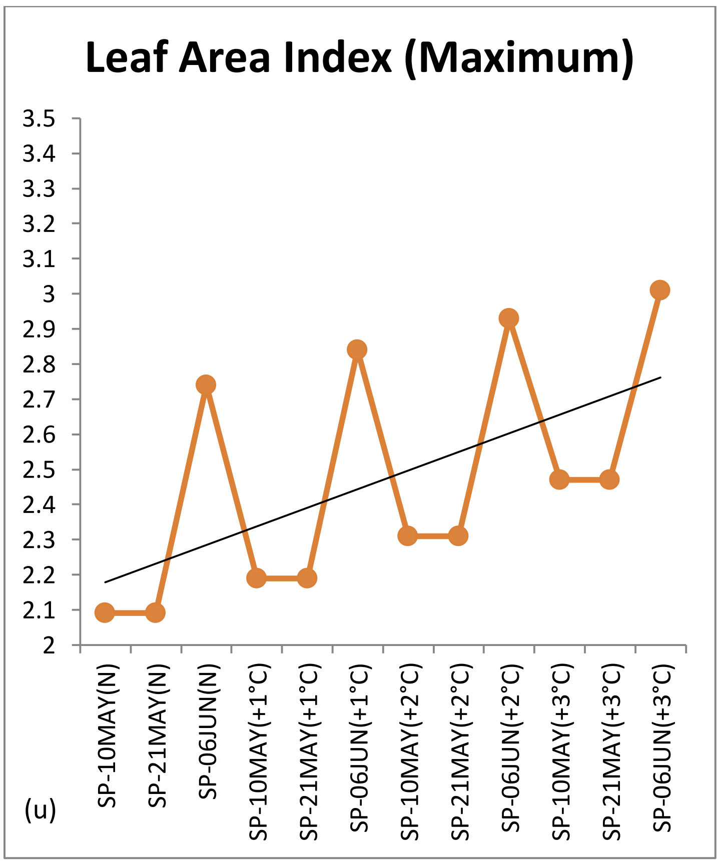

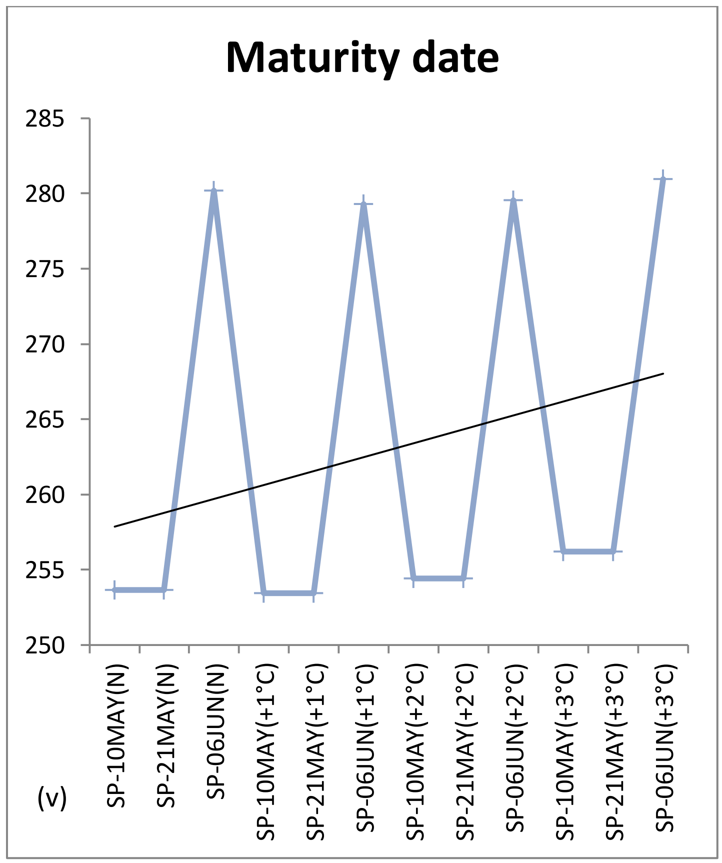

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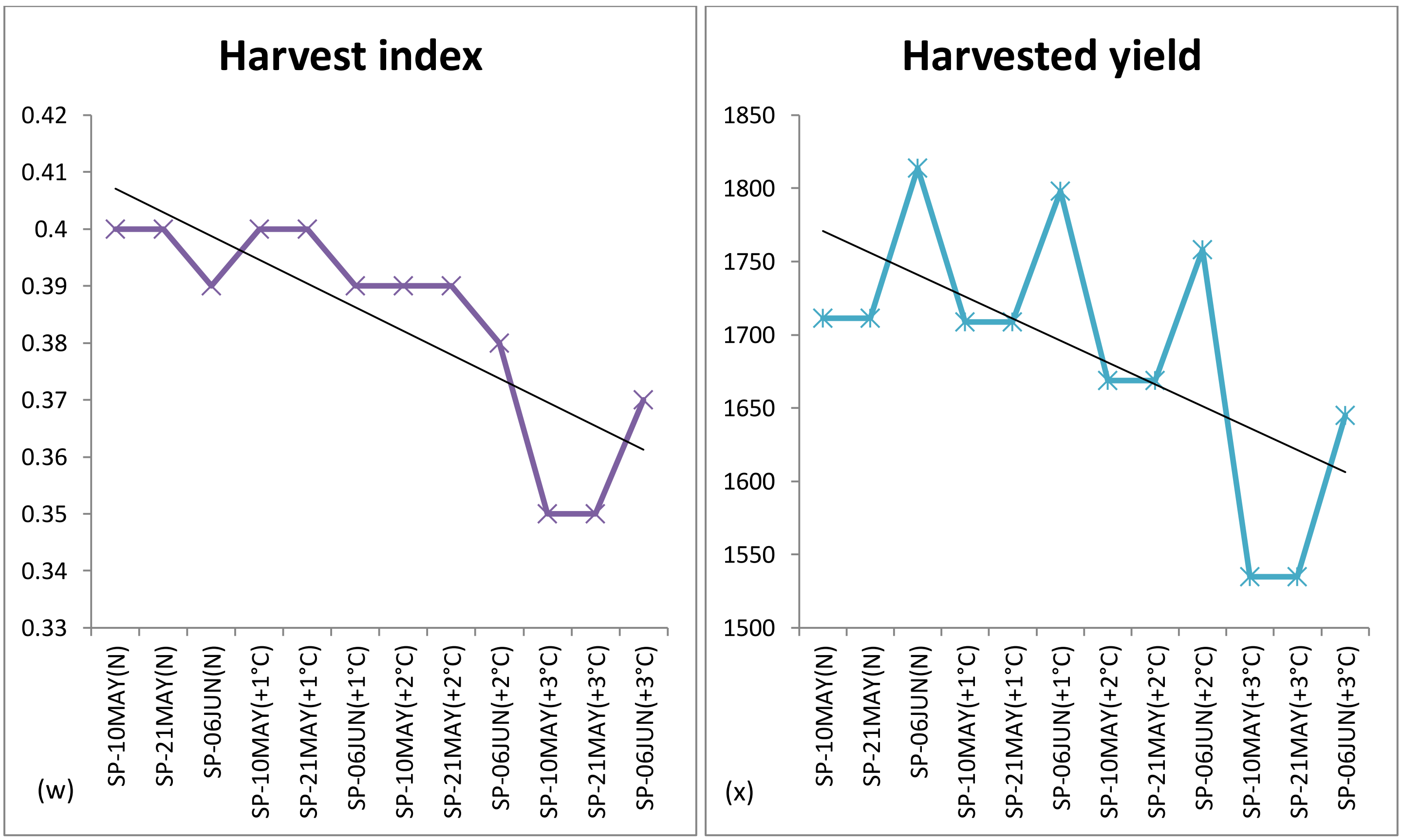

Figure 2 : Mean plots of the various simulated outputs for three cotton cultivars Pancham-541, RCH-791 and SP-7007 for three sowing dates 10th May, 21st May and 06th June.(N=taken as normal year for climate data between 1981 to 2015), (N+1 = N year with environment modification as +1 ºC) , (N+2 = N year with environment modification as +2 ºC)

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