Pak. J. Bot., 49(2): 503-508, 2017.

THE EFFECTS OF HIGH TEMPERATURE STRESS ON SOME AGRONOMIC CHARACTERS IN COTTON

REMZI EKİNCİ[1], SEMA BASBAĞ[1], EMINE KARADEMIR[2] AND ÇETIN KARADEMIR[2]

[1]*Department of Field Crops, Faculty of Agriculture, University of Dicle, Diyarbakır, Turkey.*
[2]*Department of Field Crops, Faculty of Agriculture, University of Siirt, Siirt, Turkey.*
[*]*Corresponding author: sbasbag@dicle.edu.tr*

Abstract

High temperature is one of the abiotic stress causing morphological, physiological, biochemical and molecular changes on plant growth and productivity. One hundred and sixty cotton genotypes obtained from genetic stocks was evaluated for high temperature tolerance based on some agronomic characters under field and controlled conditions. Genotypes showed differences for all investigated characters. Plant height, node number and HNR ranged from 68.38-136.45 cm, 18.22-30.10 number.plant^{-1}, 2.89-6.31 (HNR) respectively. Maximum and minimum values in terms of number of sympodial branches, boll abscission at first position, number of seed and seed-cotton yield changed from 11.09-24.42 number.plant^{-1}; 4.17%-20.80%; 20.39-44.11 number.boll^{-1} and 5.74-60.30 gr.plant^{-1} respectively. Differences among genotypes were statistically significant for all characters under high temperature stress conditions. High temperature stress was declined the cotton plant development, the decline are important for cotton breeders and cotton breeding programs on the genotypes less affected from high temperature.

Key words: High temperature stress, Abiotic stress, Cotton.

Introduction

Plants are affected by many abiotic stress factors such as high temperature, drought, salinity and chemical toxicity during growth period. Temperature directly affects plants by causing chemical reactions, indirectly by causing genetic and environmental interactions (Hochachka & Somero, 1973). In the growth of cotton plant, the primary environmental factor influencing growth and maturity is temperature (Baker, 1965; Bibi *et al*., 2008). There are two different mechanisms of high temperature tolerance in plants, genetic and non-genetic (Klueva *et al*., 2001). The future cotton production is likely to occur under an increased prevalence of multiple abiotic stresses, including extreme and prolonged high temperature (Timothy & Michael, 2014). The temperature requirements of the cotton plant vary according to the phenological periods of the plant. This difference may vary not only to phenological periods, but also the time of occurrence of the temperature, the physio-morphological and genetic structure of the plant. There are many studies on optimum temperatures in cotton. The results of earlier studies show differences releated to temperature requirements of the cotton (Burke ve Wanjura, 2009). Cotton is a plant of warm climate origin, but it is damaged by extreme high temperatures (Oosterhuis, 2002). Cotton is a plant of warm climate origin and its maximum development is dry matter accumulation of during the flowering period at 30/20°C (day / night) (Reddy *et al*., 1991). The flowering time is the most sensitive period to high temperature on cotton plant. Daily maximum temperature should be for vegetative growth and during the flowering period 21-27°C and 27-32°C respectively (Waddle, 1984; Reddy, 1996). Stress conditions effect the plant height, number of internodes, number of sympodial branches, number of monopodial branches and number of seeds per boll on cotton depending on stress duration and intensity. High temperature due to shortening of the growth period negatively affects agronomical properties (Hodges *et al*., 1993, Khan *et al*., 2008) especially in early maturing genotypes (Lu & Zeiger, 1994). Cotton plant growth such as shoot development, flowering and fiber quality traits are influenced largely due to high temperature (Saifullah *et al*., 2015; Farooq *et al*., 2015; Noshair Khan *et al*., 2014). High temperature stress reduce plant height (Pace *et al*., 1999) and length of internodes (Quisenberry *et al*., 1981). High temperature stress negatively impacts seed properties (Rehman *et al*., 1993) and fruiting (Oosterhuis, 1999). Measurements of high temperature tolerance performances of plants can be evaluated separately from each other both in field and controlled conditions (Hall, 2001; Cottee *et al*., 2010). Some of researchers reported that high temperature tolerance have genotypic in cotton (Snider *et al*., 2010). This study was carried out to determine the effects of high temperature stress on some agronomic characters on cotton and to contribute to the use of genetically resistant cotton genotypes in future breeding programs.

Materials and Methods

The study was conducted under controlled and field conditions (FC), daily (N) and high temperature stress (S). Field and greenhouse experiments were carried out in the GAP International Agricultural Research and Training Center GAPIARTC, in 2010 and 2011. One hundred sixty cotton genotypes from genetic stocks and six commercial varieties (Stoneville-474, Stoneville-468, Teks, Fantom, DP-90, Fibermax-832) were used. Experiments were arranged in augmented design with seven replications. Plots are 12 m length (field) and 2 m length (greenhouse), 2 rows with 70 cm interrow spacing; 20cm intrarow spacing. Field experiment was planting on April 9th and June 14th; and other experiment was planting on April 9th in greenhouse. Normal temperature (N) trial in 2010 (long term averages of hourly temperatures are parallel) and for high temperature stress (S) trial in 2011 (+5 °C higher than the long term average of the highest hourly temperature). To ensure CC, the greenhouse to be used was transformed into closed system temperature and moisture controlled one after air conditioning and automation works. Fertilize was applied with sowing, 70 kg.ha^{-1} N and 70 kg.ha^{-1} P, and 70 kg.ha^{-1} N at the first irrigation. Irrigation was applied 10 times with drip irrigation system.

Data of daily high temperature for FC and CC trials during cotton growing season given in Fig. 1a and Fig. 1b.

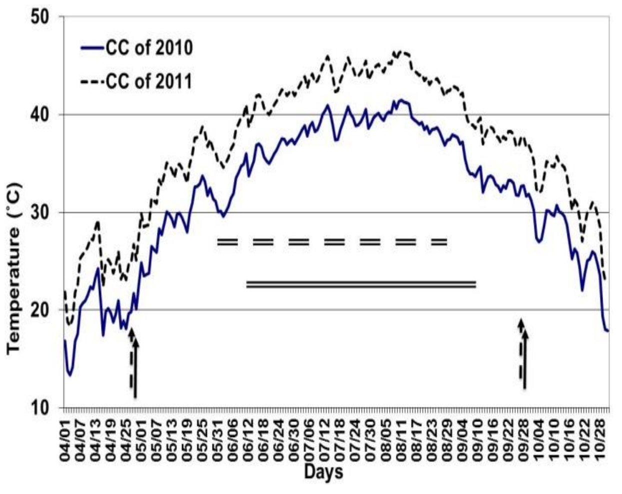

Fig. 1a. Daily max of the CC trials during cotton growing season of 2010 and 2011 at GAPIARTC, Diyarbakır, Turkey.

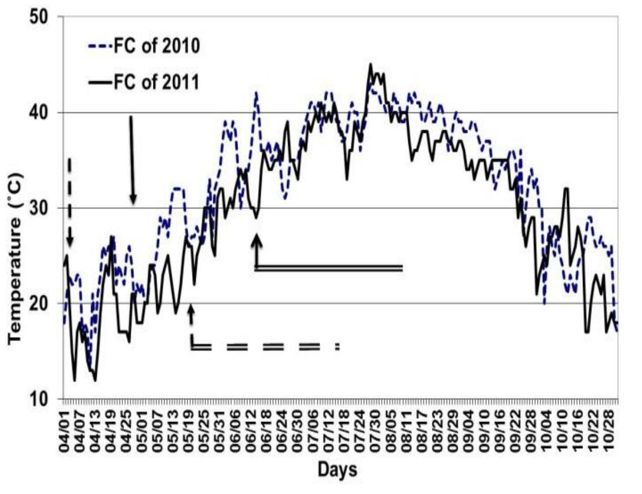

Fig. 1b. Daily max. of the FC trials during cotton growing season of 2010 and 2011 at GAPIARTC, Diyarbakır, Turkey.

Heat Stress Index was computed using the following for all the characters.

$$HSI = \frac{\frac{G_N - G_S}{G_N}}{\frac{M_N - M_S}{M_N}}$$

(HSI: Heat Stress Index; G: Genotype; M: Mean; N: Normal Condition; S: Stress Condition) (Fischer & Maurer, 1978). Genotypes were rated as follows; HSI≤0.50 high tolerant, HSI 0.5-1.0 middle tolerant; HSI>1.0 sensitive (Khanna & Viswanathan, 1999). Statistical analyses were performed using JMP 7.0.1 statistical software (Fig. 2).

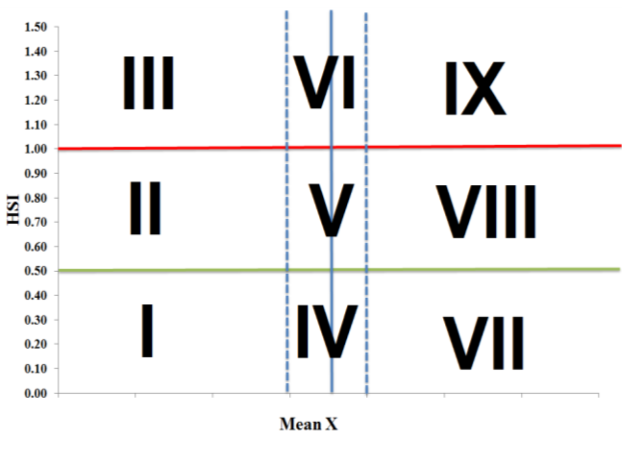

Fig. 2. The normal conditions mean values and HIS.
I. Region: X<Mean and HSI≤0.05; **II. Region:** X<Mean and 0.05<HSI≤1.00; **III. Region:** X<Mean and HSI>1.00; **IV Region:** X=Mean and HSI≤0.05; **V Region:** X=Mean and 0.05<HSI≤1.00; **VI Region:** X=Mean and HSI>1.00; **VII Region:** X>Mean and HSI≤0.05; **VIII Region:** X>Mean and 0.05<HSI≤1.00; **IX Region:** X>Mean and HSI>1.00

Results

Plant height (cm): The plant height ranged from 68.4 to 134.70 cm under FC_S conditions, from 69.43 to 134.70 cm under FC_N conditions; plant height varied between 68.38 and 104.47 cm under CC_S conditions, between 90.58 and 136.45 cm under CC_N conditions. The plant height values were determined to be 96.60±13.41 cm, 103.58±13.56 cm, 85.66±7.64 cm, 114.37±10.24 cm under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Eighty six genotypes were determined to be sensitive (22 in Region III, 47 in Region VI, 17 in Region IX), and seventy four genotypes medium tolerant (9 in Region II, 52 in Region V, 13 in Region VIII) (Fig. 3).

Number of nodes (number.plant^{-1}): The node number varied from 18.51 to 30.10 under FC_S conditions, from 18.99 to 30.10 under FC_N conditions; they changed in the ranges of 18.22-25.60 under CC_S conditions, 20.20-29.97 under CC_N conditions. The mean node number were to be 23.16±2.40, 24.03±2.50, 22.96±2.03, 25.05±2.41 under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Forty eight genotypes were determined to be sensitive (2 in Region III, 16 in Region VI, 30 in Region IX), and one hundred twelve genotypes were medium tolerant (28 in Region II, 79 in Region V, 5 in Region VIII) (Fig. 4).

Height to node ratio (HNR): Height to node ratio has changed from 2.98 to 5.84 under FC_S conditions, from 3.06 to 5.90 under FC_N conditions; they varied from 2.89 to 5.24 under CC_S conditions, from 3.51 to 6.31 under CC_N conditions. The mean height/node rates were determined to be 4.18±0.55; 4.33±0.56; 3.75±0.45; 4.59±0.53 under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Seventy three genotypes were determined to be sensitive (15 in Region III, 50 in Region VI, 8 in Region IX), and eighty seven genotypes were medium tolerant (10 in Region II, 60 in Region V, 17 in Region VIII) (Fig. 5).

Number of monopodial branches (number.plant^{-1}): The number of monopodial branches varied from.28 to 5.99 under FC_S conditions, 0.32-6.00 under FC_N conditions; they changed from 0.58 to 5.28 under CC_S conditions, from 0.65 to 6.00 under CC_N conditions. The mean number of monopodial branches were determined to be 3.87±0.98, 4.03±1.02, 3.60±0.86, 4.11±1.09 under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Seventy one genotypes were determined to be sensitive (5 in Region III, 43 in Region VI, 23 in Region IX), and eighty nine genotypes were medium tolerant (26 in Region II, 62 in Region V, 1 in Region VIII) (Fig. 6).

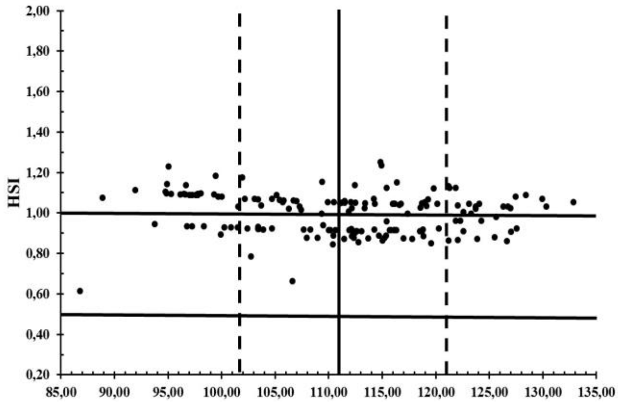

Fig. 3. The plant height (cm)

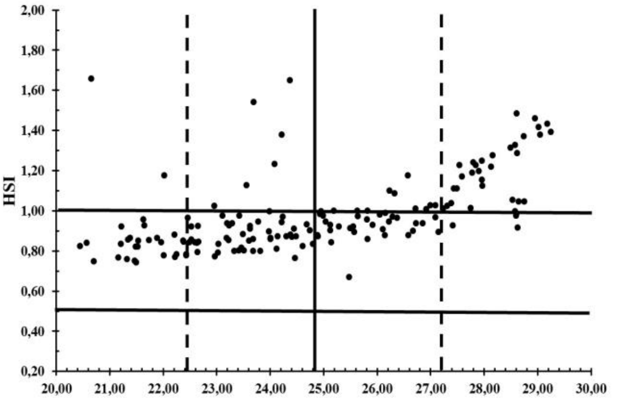

Fig. 4. Number of nodes per plant (number.plant^{-1}).

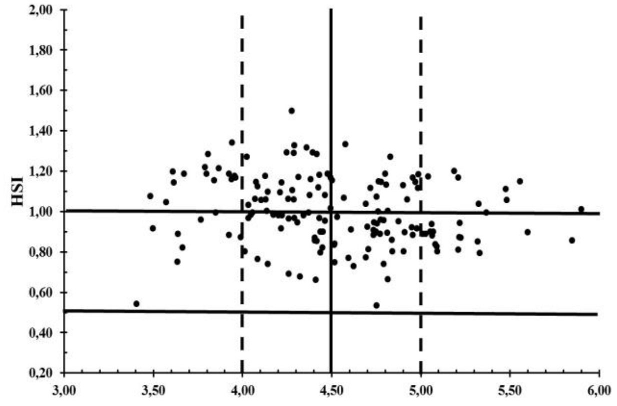

Fig. 5. Height to node ratio (HNR).

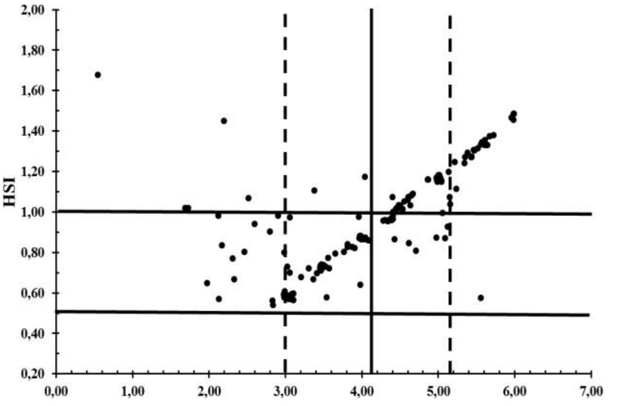

Fig. 6. Number of monopodial branches (number.plant^{-1}).

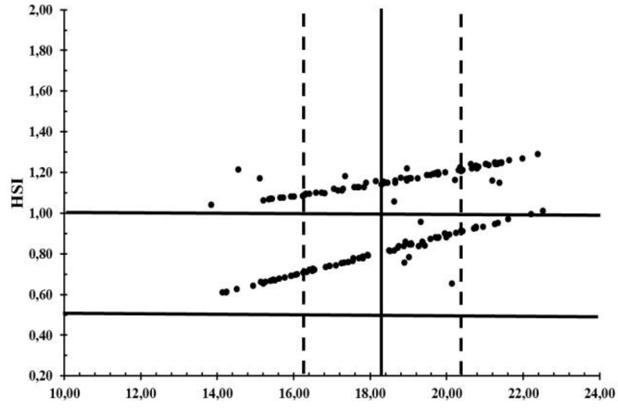

Fig. 7. Number of sympodial branches (number.plant^{-1}).

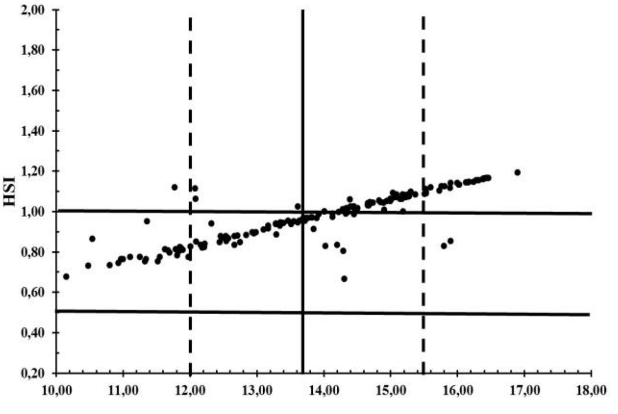

Fig. 8. Boll abscission at first position (%).

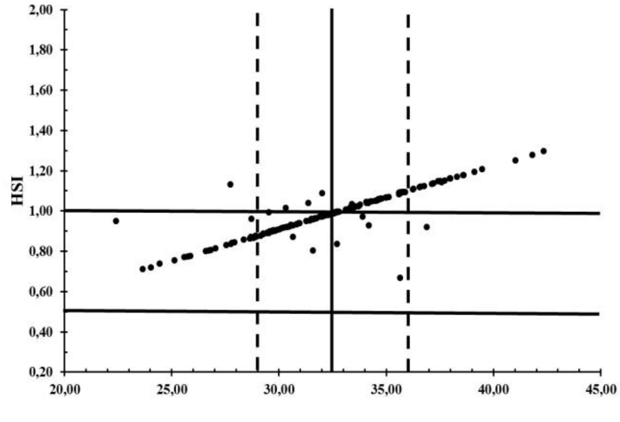

Fig. 9. Number of seed per boll (number.boll^{-1})

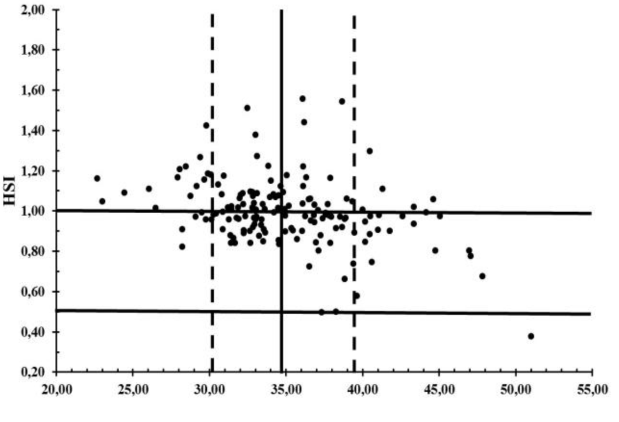

Fig. 10. Seed cotton yield (gr.plant^{-1})

Table 1. Minimum, maximum, and mean values of the investigated characters.

Characters	Cond.		Min.	Max.	Means	S.E.	Characters	Cond.		Min.	Max.	Means	S.E.
Plant height (cm)	FC	S	68.40	134.70	96.60	13.41	Number of sympodial branches (number.plant^{-1})	FC	S	11.09	24.42	16.16	2.47
		N	69.43	134.70	103.58	13.56			N	11.28	24.42	17.28	2.66
	CC	S	68.38	104.47	85.66	7.64		CC	S	12.08	19.16	15.81	1.49
		N	90.58	136.45	114.37	10.24			N	14.22	21.95	18.25	1.83
Number of nodes (number.plant^{-1})	FC	S	18.51	30.10	23.16	2.40	Boll abscission at first position (%)	FC	S	13.23	20.80	17.52	1.54
		N	18.99	30.10	24.03	2.50			N	5.25	14.10	9.99	1.97
	CC	S	18.22	25.60	22.96	2.03		CC	S	5.86	15.10	11.30	2.20
		N	20.20	29.97	25.05	2.41			N	4.17	7.53	5.62	0.53
Height to node ratio (HNR)	FC	S	2.98	5.84	4.18	0.55	Number of seed (number.boll^{-1})	FC	S	20.82	41.62	30.52	3.47
		N	3.06	5.90	4.33	0.56			N	21.34	41.62	31.25	3.58
	CC	S	2.89	5.24	3.75	0.45		CC	S	20.39	33.19	27.33	2.29
		N	3.51	6.31	4.59	0.53			N	23.40	44.11	33.76	3.70
Number of monopodial branches (number.plant^{-1})	FC	S	0.28	5.99	3.87	0.98	Seed-cotton yield (gr.plant^{-1})	FC	S	12.49	58.34	27.93	7.90
		N	0.32	6.00	4.03	1.02			N	14.59	60.30	32.54	8.74
	CC	S	0.58	5.28	3.60	0.86		CC	S	5.74	19.13	9.87	2.06
		N	0.65	6.00	4.11	1.09			N	23.33	40.88	30.82	3.10

FC, field condition; CC, controlled condition; S, high temperature stress condition; N, normal temperature condition

Number of sympodial branches (number.plant^{-1}): The number of sympodial branches have varied from 11.09 to 24.42 under FC_S conditions, from 11.28 to 24.42 under FC_N conditions; they changed in the ranges of 12.08-19.16 under CC_S conditions, 14.22-21.95 under CC_N conditions. The mean number of sympodial branches values were determined to be 16.16±2.47, 17.28±2.66, 15.81±1.49, 18.25±1.83 under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). eighty three genotypes were determined to be sensitive (14 in Region III, 49 in Region VI, 20 in Region IX), and seventy seven genotypes were medium tolerant (18 in Region II, 51 in Region V, 8 in Region VIII) (Fig. 7).

Boll Abscission at first position (%): The boll abscission at first position has changed from 13.23% to 20.80% under FC_S conditions, from 5.25% to 14.10% under FC_N conditions; they varied from 5.86% to 15.10% under CC_S conditions, from 4.17% to 7.53% under CC_N conditions. The mean of boll abscission at first position values were determined to be 17.52±1.54%, 9.99±1.97%, 11.30±2.20%, 5.62±0.53% under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Seventy seven of the genotypes were determined to be sensitive (3 in Region III, 50 in Region VI, 24 in Region IX), and eighty three medium tolerant (30 in Region II, 51 in Region V, 2 in Region VIII) (Fig. 8).

Number of seeds (number.boll^{-1}): The number of seeds per boll ranged from 20.82 to 41.62 under FC_S conditions, from 21.34 to 41.62 under FC_N conditions; they changed from of 20.39 to 33.19 under CC_S conditions, from 23.40 to 44.11 under CC_N conditions. The mean number of seeds per boll were determined to be 30.52±3.47, 31.25±3.58, 27.33±2.29, 33.76±3.70 under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). Sixty seven genotypes were determined to be sensitive (1 in Region III, 43 in Region VI, 23 in Region IX), and ninety three genotypes were medium tolerant (20 in Region II, 72 in Region V, 1 in Region VIII) (Fig. 9).

Seed cotton yield (gr.plant^{-1}): The seed cotton yield has changed from 12.49 to 58.34 gr plant^{-1} under FC_S conditions, from14.59 to 60.30 gr plant^{-1} under FC_N conditions; they varied from 5.74-19.13 gr plant^{-1} under CC_S conditions, from 23.33 to 40.88 gr plant^{-1} under CC_N conditions. The mean seed cotton yield was determined to be 27.93±7.90 gr.plant^{-1}, 32.54±8.74 gr.plant^{-1}, 9.87±2.06 gr.plant^{-1}, 30.82±3.10 gr.plant^{-1} under FC_S, FC_N, CC_S, CC_N, respectively (Table 1). three genotypes were determined to be tolerant (In Region IV: Primera, SJU-86; in Region VII: Fantom), and eighty two genotypes were medium tolerant (6 in Region II, 59 in Region V, 17 in Region VIII), and seventy five genotypes were sensitive (15 in Region III, 55 in Region VI, 5 in Region IX) (Fig. 10).

Discussion

The study was conducted under controlled and field conditions (FC), daily (N) and high temperature stress (S). Hall, (2001); Cottee *et al*. (2010) have reported that measurements of high temperature tolerance performances of plants can be evaluated separately from each other both in field and controlled conditions Some of researchers reported that high temperature tolerance have genotypic in cotton (Snider *et al*., 2010). Differences among genotypes were statistically significant for all characters under high temperature stress conditions. Our findings supported by Akhtar *et al*. (2013) and Zeeshan *et al*. (2010) plant height, number of sympodial branches; boll retention at the first position were decrease under both field and controlled conditions due to high temperature stress.

However, a significant decrease is not observed for number of nodes, HNR, number of sympodial branches and number of seeds per boll due to high temperature stress under field conditions, only a limited decrease was determined for these characters under controlled conditions. High temperatures decrease carbohydrate, and reduce boll size by decreasing the number of seeds per boll and the number of fibers per seed. High temperatures can affect pollination (Burke *et al*., 2004) and subsequent fertilization resulting in fewer seeds per boll (Snider *et al*., 2009, 2010). Oosterhuis (1999), (2002) has reported a negative correlation between yield and high temperature during boll development with high temperatures being associated with low yield. For plant height and HNR, our findings showed similarity with findings of Hodges *et al*. (1993), Khan *et al*. (2008) that high temperature due to shortening of the growth period negatively affects agronomical properties. Number of seeds, boll rate at the first position (Reddy, 2000), fruiting rate and number of seeds (Brown *et al*., 1995; Brown & Zeiher, 1997), number of nodes and boll set rate at the first position (Akhtar *et al*., 2013) were decreased due to high temperature. It was determined that genotypes of the high HSI value were high number of nodes, number of monopodial branches, number of sympodial branches, boll retention at the first position, number of seeds per boll and seed-cotton yield under normal conditions, thus these traits were much more sensitive to high temperature. Bibi *et al*. (2008) reported that the optimum temperature for the photosynthetic carbon fixation cotton is about 33ºC and photosynthesis decreased significantly at temperatures of 36ºC and above. Our findings are smilarity to results of Redy *et al*. (1992) who has reported the high temperature are frequently associated with infertility and cotton-boll retention problem and number of productive bolls, bolls retention is progressively reduced. Low seed yield with insufficient carbohydrate production due to high temperature was determined. Our results were different from findings of Oosterhuis (1999) and Onder *et al*. (2009) stated that highest number of opened boll and maximum lint percent resulted from plots under stress condition. Reduction in number of sympodial plant due to heat stress also reported in earlier studies (Saifullah *et al*., 2015; Farooq *et al*., 2015; Noshair Khan *et al*., 2014) who stated that high temperature can be attributed to a decrease such as shoot development and flowering.

Conclusion

A wide variation among genotypes was determined for high temperature stress tolerance. High temperature stress was declined the cotton plant development, the decline are important for cotton breeders and cotton breeding programs on the genotypes less affected from high temperature. Number of monopodial branches, number of sympodial branches, boll abscission at the first position, number of seeds per boll and per plant seed cotton yield could be used as selection for the tolerance to high temperature in the breeding programme.

Acknowledgements

This work was supported by the Scientific and Technical Research Council of Turkey (TUBITAK) under Grant No. TOVAG-109O339. We wish to thank TUBITAK for financial support.

References

Akhtar, N., G. Abbas, K. Hussain, N. Ahmad and S. Rashid, 2013. Impact of heat induced sterility on some genotypes of upland cotton under field conditions. *Int. J. Agric. Appl. Sci*., 5: 2-4

Baker, D.N. 1965. The effects of certain environmental factors on net assimilationin cotton. *Crop. Sci*., 5: 53-56.

Bibi, A.C., D.M. Oosterhuis and E.D. Gonias. 2008. Photosynthesis, quantum yield of photosystem II and membrane leakage as affected by high temperatures in cotton genotypes. *J. Cotton Sci*., 12: 150-159.

Brown, P.W. and C.A. Zeiher. 1997. *Cotton heat stress.* In: *Cotton: A College of Agriculture Report.* Series P-108. College of Agriculture, Univ. of Arizona, Tucson, AZ. P. 41-48.

Brown, P.W., C.A. Zeiher and J. Silvertooth. 1995. Response of upland cotton to elevated night temperature. In: *Proceedings of 1995 Beltwide Cotton Conferences,* 4-7 Jan. 1995, San Antonio, TX. National Cotton Council, Memphis, TN. Vol. 2: 1129.

Burke, J.J. and D.F. Wanjura. 2009. Plant responses to temperature extremes. pp. 123-128. In: (Eds.): Stewart, J.M., D.M. Oosterhuis, J.J. Heitholt and J.R. Mauney. *Physiology of Cotton*. Springer, New York.

Cottee, N.S., D.K.Y. Tan, M.P. Bange, J.T. Cothren and L.C. Campbell. 2010. Multi- level determination of heat tolerance in cotton (*Gossypium hirsutum* L.) under field conditions. *Crop Sci*., 50: 2553-2564.

Farooq, J., M. Khalid, W.A. Muhammad, R.M. Atiq, J. Imran, P.M.I. Valentin and N. Nawaz. 2015. High temperature stress in cotton *Gossypium hirsutum* L. *ELBA Bioflux,* 7(1): 34-44.

Fischer, R.A. and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield response. *Aust. J. Agric. Res*., 29: 897-907.

Hall, A.E. 2001. *Crop Responses to Environment*. CRC Press, Boca Raton, Fla. pp. 232.

Hochachka, P.W. and G.N. Somero. 1973. *Strategies of Biological Adaptation*, pp: 179-270. Philadelphia: W. Saunders.

Hodges, H.F., K.R. Reddy, J.M. McKinnon and V.R. Reddy. 1993. *Temperature Effects on Cotton*. Mississippi Agri. & Forestry Exp. Sta., Mississippi State University, Miss.

Khan, A.I., I.A. Khan and H.A. Sadaqat. 2008. Heat tolerance is varıable in cotton (*Gossypium hirsutum* L.) and can be exploited for breeding of better yieldıng cultivars under high temperature regimes. *Pak. J. Bot.,* 40(5): 2053-2058.

Khanna, C.R. and C. Viswanathan. 1999. Evaluation of heat stress tolerance in irrigated environment of *T. aestivum* and related species. I. stability in yield and yield components. *Euphytica*, 106: 169-180.

Klueva, N., E. Maestri, N. Marmiroli and H. Nguyen. 2001. Mechanism of thermotolerance in crops. In: *Crops Responses and Adaptations to Temperature Stress*. (Ed.): Basra, A., Food Products Press, Binghamton, N.Y. 177-218.

Lu, Z.M. and E. Zeiger. 1994. Selection for higher yields and heat resistance in pima cotton has caused genetically determined changes in stomatal conductances. *Phyiol. Plant*., 92: 273-278.

Noshair Khan, M.A. Faqir, A.A. Khan and A. Rashid. 2014.Measurement of canopy temperature for heat tolerance in upland cotton: variability and its genetic basis. *Pak. J. Agri.Sci*., 51(2): 359-365.

Oosterhuis, D.M. 1999. *Yield response to environmental extremes in cotton.* In: *Proc. Cotton Research Meeting Summary Cotton Research in Progress*. (Ed.): Oosterhuis D.M. Report 193. Arkansas Agric. Exp. Stn., Fayetteville, AR. pp. 30-38.

Oosterhuis, D.M. 2002. Day or night high temperature: A major cause of yield variability. *Cotton Grower*, 46(9): 8-9.

Pace, P.F., H.T. Cralle, S.H.M., El-Halawany, J.T. Cothren and S.A. Senseman. 1999. Drought-induced changes in shoot and root growth of young cotton plants. *J. Cotton Sci.*, 3(4): 183-187.

Quisenberry, J.E., W.R. Jordan, B.A. Roark and D.W. Fryrear. 1981. Exotic cottons as genetic sources for drought resistance. *Crop Sci*., 21: 889-895.

Reddy, K.N. 2000. Factors affecting toxicity, absorption, and translocation of glyphosate in redvine (*Brunnichia ovata*). *Weed Technol*., 14: 457-462.

Reddy, K.R., H.F. Hodges and V.R. Reddy. 1992. Temperature effects on cotton fruit retention. *Agron. J*., 84: 26-30.

Reddy, R.K. 1996. Weather and Cotton Growth, Present and Future. Vol. 1061, Office of Agricultural Communications, Division of Agriculture, Forestry and Veterinary Medicine, Mississippi State University, USA., Pages: 23.

Reddy, V.R., D.N. Baker and H.F. Hodges. 1991. Temperature effect on cotton canopy growth, photosynthesis and respiration. *Agron. J*., 83: 699-704.

Rehman, H., A. Rehman, W.S. Khan and N. Murtaza. 1993. Genotype-environment interaction and stability of seed quality traits In *Gossypium hirsutum* L. Cultivars. *The Pak. Cottons*, 37: 21-27.

Saifullah, A., M.T. Rajput, M.A. Khan, M.A. Sial and S.S. Tahir. 2015. Screening of Cotton (*Gossypium hirsutum* L.) genotypes for heat tolerance. *Pak. J. Bot*., 47(6): 2085-2091.

Snider, J.L., D.M. Oosterhuis and E.M. Kawakami. 2010. Genotypic differences in thermo tolerance are dependent upon pre-stress capacity for antioxidant protection of the photosynthetic apparatus in *Gossypium hirsutum* L. *Physiol. Plant*., 138: 268-277.

Timothy, A. and A. Michael. 2014. Challenges and perspectives on improving heat and drought stress resilience in cotton. *The Journal of Cotton Science*, 18: 393-409.

Waddle, B.A. 1984. Crop Growing Practices. In: Cotton, Waddle, B.A. (Ed.). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, USA.

Zeeshan, A., T.M. Khan and I.R. Noorka. 2010. Diallel analysis to determine gene action for lint percentage and fibre traits in upland cotton. *Int. J. Agric. Appl. Sci.,* 2(1): 11-14.

Zeiher, C.A., N. Matumba, P. Brown and J. Silvertooth. 1995. Response of upland cotton to elevated night temperature II. In: *Proceedings of 1995 Beltwide Cotton Conferences*, 4-7 Jan. 1995, San Antonio, TX. National Cotton Council, Memphis, TN. 2: 1129.

(Received for publication 3 February 2016)