Society for Advancement of Wheat Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Wheat Research

7(1):1-12

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Review Article

Management practices to mitigate the impact of high temperature on wheat

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Article history

Received: 21 February, 2015
Revised : 23 June, 2015
Accepted: 23 June, 2015

Citation

Kajla M, VK Yadav, RS Chhokar and RK Sharma. 2015. Management practices to mitigate the impact of high temperature on wheat. *Journal of Wheat Research* 7(1):1-12

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Abstract

The changing climate is one of the biggest threats to agriculture during the years ahead. According to estimates, on an average 50% yield losses in agricultural crops are due to different abiotic. The expected changes in the climate could strongly affect the wheat production worldwide. Among various factors affecting wheat productivity, the increase in atmospheric temperature has the most significant effect. The temperature above optimum shortens the vegetative and reproductive phases. Generally, the growing degree days (GDD) or heat unit requirement to produce a mature winter wheat crop is approximately 2200, using 4° Celsius as the base temperature. Exposure to heat stress accelerates the development stages in wheat crop which in turn leads to reduced grain yield as well as quality. The high temperature during vegetative stage reduces the number of effective tillers per unit area and during reproductive stages leads to reduced grain number as well as grain weight. The impact of high temperature on wheat productivity can be minimized by adoption of various agronomic management practices. Adjustment in sowing time is one of the most important agronomic strategies to counteract the adverse effect of temperature stress. In addition, tillage crop establishment methods, residue retention, selection of heat tolerant varieties, water management, and foliar spray of KNO_3, KCl, 1-Methylcyclopropene (1-MCP) and GA_3 can also help mitigating the temperature stress effects.

Keywords: Climate change, tillage methods, residue retention, water management, foliar spray, no-tillage.

1. Introduction

Wheat (*Triticum aestivum* L) is the second most important staple food crop of the world accounting nearly 30% of global cereal production covering an area of 218.5 million hectare with an average productivity of 3.26 tonnes ha^{-1} (FAO, 2014). In India , in the year 2013-14 the wheat production was recorded as 95.91 million tones from an area of 30 million hectare (DES, 2014). But with an evergrowing population, the country needs to produce 100 million tones of wheat by 2030 which is a major challenge under changing climatic scenario. According to world estimates, an average of 50% yield losses in agricultural crops is due to different abiotic stresses under these changing climatic conditions (Thilert, 2006). Therefore, concerted efforts are needed to intensify the research on enhancing the productivity in terms of per unit area on ecologically and economically sustained basis under this present situation.

Variability in climate is one of the biggest environmental threats to agriculture particularly wheat crop (Levitt *et al.*, 1980, Anonymous, 2010). So, the knowledge as how environment influences crop growth, development and yield is of great importance (Singh *et al.*, 2011). The growth and yield of wheat crop is adversely affected by environmental stresses such as high temperature, soil moisture deficit, low light intensity etc and among these stresses high temperature is the crucial one (Trnka *et al*, 2004, Modarresi *et al*, 2010, Joshi *et al*, 2007). As per estimates the global mean temperature is steadly rising which may result in significant decline in wheat yields in South Asia by 2050 (IFPRI, 2009).

2. Effect of high temperature on wheat crop

As detected by Lobell and field, 2007 between 1961 and 2002, it was found that rising temperature had a negative effect on wheat yields. High temperature particularly during November sowing accelerates its growth by making the crop to enter into jointing stage too early, thus reducing tillering period (Harrison *et al*, 2000). This results in reduced number of tillers, in turn reducing total crop yield. Likewise, high temperature at flowering and grain filling stage shortens the duration of grain filling resulting in early maturity, thus reducing the crop yield. Exposure to heat stress accelerates the development stages in wheat crop to such a degree which cannot be paced by necessary supply of environmental inputs (radiation, water and nutrient) (Tandon, 1985, Laghari *et al*, 2012, Blum *et al,* 2001). High temperature between flag leaf stage and flowering reduces sink period, reducing grain size (Sharma *et al*., 1997). An increase of 0.5^{0}C temperature resulted in decrease in duration of crop by seven days, reducing yield by 0.5 tha^{-1} in north India (Parry *et al*., 1992). High temperature after flowering hastens leaf senescence, thereby reduces grain filling stage and thus decreases grain yield (Ford *et al*., 1975). Ideally the best temperature regime for optimum growth and yield of wheat crop is: 20–22 ^{o}C at sowing, 16–22 ^{o}C at tillering to grain filling and slow rise of temperature to 40 ^{o}C at harvesting (Sharma, 2000). The temperature sensitivity with respect to developmental phases in wheat crop is depicted in the table as below:

Response of phasic development to temperature

Developmental phase	Temperature Sensitivity
Germination	strong
Canopy development	moderate /strong
Spikelet production	Slight/moderate
Spikelet development	moderate /strong
Grain development	Moderate/strong

Note: Source: Slafer and Rawson., 1994

The growth and yield of the crop are determined by calculating the thermal unit requirement of the crop. The thermal time required for crop production is determined by adding the daily heat units together for the period between planting and harvest. When the centigrade temperature scale is used, the heat units generated each day is determined by using the formulae:

Growing degree-days (GDD) $=\sum (T_{max}+T_{min})/2 - T_b$

where,Tmax and Tmin are the daily maximum and minimum temperature (°C), and Tb is the base temperature and for wheat it is 4^{o}C.

and, the other agrometerological indices which determine the growth and yield of the crop are calculated using the formulae:

Helio-thermal unit (HTU) = GDD × Duration of sunshine hour

Photo Thermal Unit (PTU)=∑GDD x Day length

Heat use efficiency (HUE) = Grain yield(kg/ha) ÷ GDD

Phenothermal index (PTI) = GDD ÷ Growth days.
(Gill et al ., 2014)

The heat unit requirement to produce a mature crop is approximately 2200 for winter wheat. Translated into calendar days, this means that it would take 147 (147 x 15 = 2205) days to produce a winter wheat crop if the average daily temperature was a constant 15°C, but there are large variations in temperature from day to day and growing season to growing season. With increase in temperature the heat requirement of the crop to reach to maturity will be fulfilled in less time-period thus reducing the maturity period of crop which in turn leads to decrease in no. of tillers, spikes/plant, grains /spike, size of grain etc, ultimately reducing the grain yield. Grain yield can be expressed as the product of three variables (yield components):

Grain yield = (number of ear heads) x (kernels per ear head) x (kernel weight).

A study was conducted at two different locations (LDH : Ludhiana, BTH: Bathinda) using two different varieties (PBW 343 and PBW 621) calculated various agrometrological indices (AGDD : Accumulated growing degree days, APTU: Accumulated photothermal units, APTI: Accumulated phenothermal index, AHTU: Accumulated heloithermal units) at different growth stages (Table:1) and found that the variety PBW 343 had longer phenophases, more GDD, PTU and HTU requirement for different phenol phases than PBW 621 irrespective of sowing time. Whereas, PBW 621 had high HUE and produced higher yield at both the locations (Gill *et al*., 2014).

Heat stress during the stem elongation and booting stages increase the rate of tiller mortality by placing added restrictions on resource availability. The effect of temperature on grains per unit area may be attributed to a decreased number of fertile spikes or to fewer grains per ear because during anthesis to maturity high temperature mainly affects assimilate availability, translocation of photo-synthates to the grain and starch synthesis and its deposition in the developing grain. So, the net result is a lower kernel weight. Ram *et al*., 2012b reported that in wheat crop, normal sowing crop requires higher GDD requirement than the later growing one. Late sowing decreased the duration of phenology as compared to normal sowing due to fluctuated un-favourable high temperature during the growth period.

Table 1: Crop phenology, AGDD, APTU and AHTU for crop sown on 15 November in Ludhiana and Bathinda

Phenology	Phenology (DAS)				AGDD (ºC day)				APTU (ºC day hr)				APTI (ºC day)				AHTU (ºC day hr)	
	PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343	PBW 621
	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	LDH
Sowing	0	0	0	0	15.1	15.7	15.1	15.7	160.1	168.9	160.1	168.9	-	-	-	-	68.6	68.6
Emergence	4	5	4	5	75.1	95.0	75.1	95.0	792.1	1000.4	792.1	1000.4	15.0	15.9	15.0	15.9	437.3	437.3
Emergence complete	12	8	12	8	188.7	137.8	188.7	137.8	1976.6	1440.1	1976.6	1440.1	14.2	14.3	14.2	14.3	529.8	529.8
CRI	20	19	20	19	288.9	279.7	288.9	279.7	3007.9	2888.2	3007.9	2888.2	12.5	12.9	12.5	12.9	1256.3	1256.3
Tillering	31	28	31	28	405.1	377.0	405.1	377.0	4191.8	3875.5	4191.8	3875.5	10.6	10.8	10.6	10.8	1975.8	1975.8
Jointing	79	71	79	71	714.2	633.3	714.2	633.3	7384.5	6498.6	7384.5	6498.6	6.4	6.0	6.4	6.0	3769.3	3769.3
Flag leaf	96	86	93	84	840.8	731.1	818.3	721.1	8775.7	7563.3	8524.0	7453.3	7.4	6.5	7.4	6.8	4469.5	4316.7
Booting	103	93	100	91	907.2	785.6	883.2	773.4	9527.8	8166.1	9254.2	8030.5	9.5	7.8	9.3	7.5	4927.2	4695.0
Heading	110	101	108	99	986.9	861.9	959.1	846.0	10448.0	9020.0	10125.5	8841.1	11.4	9.5	9.5	9.1	5578.2	5428.1
Anthesis	119	108	117	106	1101.9	951.1	1073.1	921.8	11801.3	9933.9	11459.6	9657.4	12.8	12.7	12.7	10.8	6507.2	6228.3
Milking	129	114	126	112	1246.4	1021.5	1209.8	1003.4	13545.7	10632.6	13100.1	10448.6	14.5	11.7	15.2	13.6	7505.1	7217.7
Physiological maturity	142	129	140	127	1497.8	1239.0	1454.6	1205.9	16673.5	13107.3	16129.2	12699.9	19.3	14.5	17.5	13.5	9552.7	9075.4

Source: Gill et al ., 2014

An average temperature of 15^{0}C during grain filling stage is optimum for getting maximum grain yield (Chowdhary *et al.*, 1978). A high temperature after flowering i.e. during grain filling accelerates the rate of grain filling and shortened its duration (Dias and Lidon., 2009). Yin *et al.,* 2009 reported that a 5^{o}C increase in temperature above 20^{o}C increased the rate of grain filling and reduced the grain filling duration by 12 days in wheat crop. So, this paper discusses the effect of high temperature on grain yield of wheat and agronomic practices which can be used to mitigate its effect in wheat crop.

3. Management practices

3.1 Selection of varieties: Selection of appropriate variety with respect to date of sowing and expected temperature rise during the crop growth period is necessary to get an optimum yield under high temperature stress conditions in wheat crop. Varieties like PBW-343 and DBW-17 have flexibility, adaptability and are suited to different sowing times and also well suited to normal and early (October) sowing time. The variety PBW-343 was released for the northwestern India primarily because of its wider adaptability in terms of temperature and water stress tolerance. DBW-17, PBW-343 and PBW-502 have comparable yield results when sown under the late conditions. PBW-343 was the predominant in the rice-wheat growing areas, where sowing can often be delayed because of later harvest of second rice crop and/or managing stubble from the rice crop (Malik *et al.*, 2007). Under this situation zero till seeding of the wheat provides the opportunity for achieving an earlier sowing of the wheat crop.VarietyC-306 performed best when sown early, and gave poor yield under late sowing conditions, whereas early sowing of high yielding varieties that are suited across sowing time (like PBW-343 and PBW-502) allows longer maturation time and earlier anthesis, thus reduces high temperature exposure to wheat crop (Coventry *et al.*, 2011). On the other hand varieties like PBW-373 and kaushambi (HW 2045) possess terminal heat stress tolerance and Naina (K-9533) and Parbhani-51 are heat tolerant varieties which on adoption for sowing can overcome the adverse effect of high temperature on wheat crop(DWR Perspective Plan Vision 2025).

3.2 Sowing time: Time of sowing is one of the non-monetary inputs for getting optimum yield in wheat crop. Selecting optimum planting time, avoids high temperature stress during anthesis and grain filling. High temperature at that time shortens the season and reduces yield. Adjust sowing time so that crop escapes to hot and desiccating wind during grain filling period. The growth and development in wheat crop varies with date of sowing.

The optimum time of sowing for wheat crop in India is first fortnight of November. The delay in sowing of crop is mainly because of late harvest of paddy crop, delay in field operations, climate changes etc which results in sowing of crop upto first fortnight of January. Crop sown in mid November shows better growth and maximum plant height (84.3cm) than rest of sowing dates which is followed by late November sowing (78.6cm) as shown in table 2 (Mukherjee , 2012). Similar results were obtained by Singh *et al.*, 2008 and Singh *et al.*, 2000. The reason for this difference is the rise in temperature which makes the crop to enter into the next stage without much development required for the succeeding stage. Jat *et al.*, 2013 and Hussien *et al.*, 1990 showed that the crop sown on 20th November achieved maximum height, dry-matter accumulation plant^{-1} and number of tillers than rest of sowing dates. The reason for this is the maximum growing period length availability in 20 November sowing than other dates. However, Sardana *et al.*, 2002 and Sardana *et al.*, 2005 found that plant height is not significantly influenced by date of sowing.

The plant height and dry matter accumulation decreases with delay in sowing from timely (21 November) to very late (7 January) (Shivani*et al.*, 2003). This might be due to lowering of temperature which results in decrease in cell activity like cell division and expansion, which decides

Table 2. Effect of date of sowing on growth and yield attributing characters of wheat crop

Date of sowing	Plant height (cm)	Dry matter (g/plant)	Effective tillers/m^2 (no.)	Grain/ear (no.)	Ear length (cm)	Grain weight / spike(g)
Nov 1	77.6	4.64	258	35.6	8.7	1.32
Nov 15	89.4	6.92	301	49.6	8.9	1.81
Nov 30	81	4.94	286	48	9.8	1.59
Dec 15	78.3	2.62	256	39.4	8.2	1.22
Dec 30	55.6	2.31	214	38.9	7.6	1.28
CD(P=0.05)	2.2	2.0	30	4.9	1.3	0.36

Source: Mukherjee, 2012

the yield attributes like number of tillers, spikes, fertile spikelets etc reducing the ultimate yield of the crop. Also, LAI showed decreasing trend with delay in sowing (Ram *et al*., 2012a). At 50 and 90 DAS the LAI is significantly higher in 15 December sowing as compared to 1 January one. The reason for this is high temperatures causes considerable damages, including scorching of leaves and twigs, sunburns on leaves, branches and stems, leaf senescence and abscission.

Hence, there is remarkable reduction in growth parameters like plant height, dry matter accumulation, number of tillers and LAI with delay in sowing through reduction in maturity period. So sowing done in November produces maximum growth parameters as compared to December sowing which further reduces in January sowing, which is mainly due to change in temperature with the subsequent period of time.

Delay in sowing after the optimum date showed decreasing trend in the yield of the crop. The crop sown on 20 November showed maximum number of effective tillers and 1000-grain weight as compared to late sown one (Jat *et al*., 2013, Hussien *et al*., 1990 and Mukherjee , 2012). Both the yield attributes are highest under timely sowing as compared to late sowing conditions (Kumar *et al*., 1997, Kumar *et al*., 1994 and Bangarwa *et al*., 1996). The reason for this is that with increase in temperature there is reduction in the growth period which results in decrease in yield attributing characters, affecting finally the grain yield. Studies conducted in NW India showed that sowing with delays from a timely period (first fortnight of November) to a late period (first fortnight of December) resulted in reductions of grain yield @ 32.0 kg ha^{-1} day^{-1} (Table 3) (Tripathi *et al*., 2005, Shivani *et al*., 2003 and Ram *et al.,* 2012) and noticed that delay in sowing beyond normal sowing reduces grain yield by 16.2, 37.4 and 59.9 percent under moderately late (7 December), late (21 December) and very late (7 January) sown conditions, respectively.

Table 3: Effect of date of sowing in different zones of Indiain wheat crop

Zones	Average of timely sown varieties				Average of late sown varieties		
	Mean yield (q/ha)			Decline inyield	Mean yield (q/ha)		Decline in yield
	Early	Normal	Late	(kg/ha/day)	Late	Very late	(kg/ha/day)
NHZ	35.3	34.8	32.1	15.5	-	-	-
NWPZ	41.9	45.3	37.0	32.0	38.6	39.8	42.7
NEPZ	36.6	37.7	31.1	27.6	34.2	34.9	44.8
CZ	40.0	44.0	36.3	32.9	38.0	26.3	51.6
PZ	35.4	35.2	30.2	21.8	33.9	25.3	37.8

Source:Tripathi et al., 2005

In another date of sowing experiments, it was reported that after the optimum sowing date, there was a 0.8, 0.7 and 0.7% day– yield reduction for PBW 34, PBW 154 and PBW 226, respectively (Oritz-Monasterio *et al*., 1994). Also, it was suggested that high temperature decreased grain numbers (by 56 % averaged across both experiments) and individual grain weight (by 25 %) (Prasad *et al*., 2011).

So, it is clear that there is substantial decrease in biological and economic yield of wheat crop under late sowing. It is because of prevalence of high temperature during reproductive stage and low temperature during germination. In late sown conditions, the duration of crop growth decreased because of forced maturity due to higher mean temperature coupled with low relative humidity.

Extreme heat episodes after anthesis increase development of the crop, shorten the grain filling period, and may result in reduction of kernel weight and of grain quality parameters (starch). Heat stress during post-anthesis increases the proportion of gliadins to glutenins and decrease the proportion of large polymer in flour, hampering the flour quality of wheat (Ashraf, 2014). There are two types of proteins present in the grain which decides its quality, one is the structural protein (albumins – globulins and amphiphils) accumulated in the grain mainly during the cell- division stage, and the other is storage protein (gladins and gluteins) accumulated mainly during the grain filling period (Triboi *et al*, 2003). In timely sowing crop there is low temperature after flowering stage as compared to late sown one, so there is reduction in accumulation of structural protein due to reduction in cell division at low temperature and also there in increase in filling period which leads to accumulation of more starch and less storage protein in the grain, as protein is inversely related to carbohydrate accumulation (Torbica *et al*., 2008).

Normal and early sown crop has less protein, starch content as compared to late sown one (Kumar *et al* ,1997, Kumar *et al.*, 1994 and Bangarwa *et al.*, 1996).The final stage of wheat crop is the grain filling stage. High temperature during this period reduces the yield which is because of reduction in starch accumulation (65% of grain dry weight is due to starch content of that grain). The effect of temperature on protein content of wheat is unclear and varies with type of genotype (Beata *et al.*, 2008).

3.3 Tillage practices: Type of tillage options and planting methods exhibits an important role in better emergence and subsequent crop growth. Sowing of wheat crop using different tillage options depends upon type of soil, sowing time and irrigation water availability. In no-till and zero tillage system there is minimum disturbance to soil regime and maintenance of plant residues. The presence of mulch/ crop residues protect seedlings from high temperature during its initial growth period and keeps soil temperature down during the day and reduces cooling at night and also helps in conserving moisture(Geiger et al, 1992). This helps the plant to carry out its metabolic activity with the same pace as required for its optimum growth i.e. without reducing its growth period. Also the transpiration process get increased with increase in soil temperature , which in turn reduces the canopy temperature and thus helps in overcoming the terminal heat stress in plant. As the time period to maturity is delayed, so the senescence in plant.

Zero tillage led to an improvement in yield attributes, viz. plant height, effective tillers/m, grains per ear as compared to conventional tillage (Mishra *et al.*, 2011). Also, among all tillage practices Zero tillage gave maximum plant height (103.48 cm) as compared to other tillage practices (Imran *et al.*, 2013).Dry mass was also highest under reduced tillage as compared to conventional and no-till systems (Akbarian *et al.*, 2011).

Furrow irrigated raised bed sowing (FIRBS) results in decreased LAI as compared to conventional flat sowing (Khichar *et al.*, 2007).The reason might be the increase in temperature in FIRB as compared to conventional one. Also, the plant height was maximum in bed planted wheat as compared to conventionally sown crop (Jakhar *et al.*, 2005). This might be due to increase in vegetative phase of the crop under bed planting.

Sowing of wheat done by Chinese seeder gave significantly higher growth parameters followed by Pantnagar Zero till drill and lowest in conventional tillage (Halvorson *et al.*, 1994). The presence of high rice residue load hinders in the use of zero-till seed drills due to clogging of the machinery with loose straw. Therefore, zero-till sowing of wheat in rice fields is possible only after complete or partial removal of residue (Singh *et al.*, 2008).

Higher (7.7%) yield of wheat was obtained under zero tillage in comparison to conventional tillage, which is due to increase in growth period of the crop, leading to increase in number of effective tillers, grains ear^{-1} and 1000-grain weight (Mishra *et al.*, 2011,Sardana*et al.*, 2002, Tripathi *et al.*, 1999, Martens *et al.*, 1992,Yadav *et al.*, 2005and Imran *et al.*, 2013). Beside tillage options the grain yield depends on the climate conditions prevailing in the area. When the water stress index was high, grain yield was greater with conservative tillage techniques (like residue retention and no tillage) than with conventional tillage, whereas the opposite was true when the water stress index (- a measure of the relative transpiration rate occurring from a plant at the time of measurement using a measure of plant temperature and the vapor pressure deficit which is a measurement of the dryness of the air) was low; no significant differences in grain yield were observed among the three tillage techniques in medium water stress conditions (Gaetano *et al.*, 2013).Also, the straw mulching treatments, created a better soil water holding capacity mitigating the reduction of 1000-grains weight due to high temperatures at the late grain filling stage, especially in conventional tillage (Tang *et al.*, 2013). In another study it was noticed that grain yield of wheat is higher under mulches, because of longer rooting and higher moisture content in the upper soil layers (Bisen *et al.*, 2002). Hossain *et al., 2006* reported that bed planting produced more number of plants and spikes per square meter, longer spike length and maximum grain weight than conventional methods. Grain yield and straw yield also showed highest in bed planting due to higher yield attributes.

Rawson, 1998 observed that under rice–wheat cropping system wheat yield were increased by 10% in no-tillage as compared to conventional tillage, which is due to better establishment, increase in number of tillers and lesser weed population. Singh *et al.*, 2009 reported that the effects of straw and tillage management on wheat yield depends on soil type. The yield under straw burnt-ZT was lowest on sandy loam whereas straw incorporation-CT performed poor on silt loam as shown in table 4. Also, wheat yield was lower in 2005–2006 as compared to other years on both soils and the reason for this was unusual warm temperature in February 2006 coinciding with grain filling stage.

So, the zero tillage, bed planting and conventional tillage with mulching produced higher grain yield and are helpful in mitigating adverse effects of high temperature during growth period of wheat crop.

The wheat grain protein content was lower with no-tillage (NT) than with conventional tillage (CT). This may be due to the reduction in availability of plant nitrogen with NT as compared to CT Also, there is increase in nitrogen losses from the system (NH_3 volatilization) in no tillage technique as compared to CT (Gaetano *et al.*, 2013).

Table 4: Effect of rice straw management, tillage system and N fertilizer on grain yield (t/ha) of wheat on two soils.

Treatment Straw management	Sandy loam			Silt loam		
	2004–2005	2005–2006	2006–2007	2004–2005	2005–2006	2006–2007
	Grain yield (t ha $^{-1}$)					
Straw burned-CT	4.09	4.14	3.96	3.63	3.45	3.16
Straw burned-ZT	4.08	3.87	3.64	3.33	3.36	3.25
Straw incorporated-CT	4.03	4.11	3.66	3.12	3.33	3.15
Straw mulch-ZT	4.15	4.40	3.83	3.32	3.59	3.11
LSD (0.05)	NS	0.26	0.21	0.20	0.11	NS

Source: Singh et al., 2009

3.4 Water management: High temperature damage is commonly associated with water stress so water management is critical. As long as plants can transpire freely they cope with high temperature. Field crops provided with sufficient water can withstand air temperatures to 40°C. But if water is limiting, 40°C will kill leaves. The reason for this is that water-stressed plants attempt to conserve water by closing their stomata, as a consequence evaporative cooling diminishes and, without that cooling, leaf temperatures might approach 50°C and at that temperature plant processes break down(wheatdoctor.org/high-temperature). So, irrigation methods based on soil type and availability of irrigation water and scheduling irrigation according to growth stages of crop are taken in account for good water management.

Seedlings grown in very hot dry soils can readily reach the critical temperature. The use of sprinkler irrigation under such conditions helps in reducing high soil temperature by irrigating at that time and irrigating the crop during evening time helps the crop to recover from day heat stress, thus reducing heat losses and increases the yield of the crop. To minimize the effect of high temperature at other stages of crop one should ensure that the crop is not water stressed. Tolk *et al.*, 1995 found that vapor pressure deficit (VPD) and canopy temperature decreased significantly during and following sprinkler irrigation. The canopy temperature in the irrigated area was decreased quickly with 4–7°C lower than that outside the irrigated area in the first 10 min after the start of sprinkler irrigation (Thompson *et al.*, 1993b). Another method i.e. drip irrigation also maintains adequate soil moisture thereby reduces soil temperature and helps plant to carry out transpiration process which in turn helps plant to reduce its canopy temperature. The grain yield obtained with drip irrigation was 24% higher than full irrigation treatment and 59% higher than the existing rule treatment (Kharrou *et al.*, 2011).

Scheduling irrigation according to critical stages, soil type, environmental conditions, quantity of water available for irrigation, helps in getting maximum growth parameters and in turn helps in mitigating high temperature stress in crop. The responses of dwarf wheat to three levels of water stress at three growth stages planting to jointing, jointing to flowering and flowering to maturity was studied under field conditions over two seasons and a maximum grain yield of 5.20 tonnes ha^{-1} was recorded with no water stress treatment. It was found that all levels of water stress except –0.5 MPa during flowering to maturity decreased the grain yield as compared to the no stress treatment and the results indicate that, the wheat crop should be irrigated at 50% depletion of available soil water (*ASW*) (Singh *et al.*, 1983). So, when water resources are limited, crop should be irrigated at a IW/CPE ratio of 0.75 and with an unlimited water supply the ratio may be increased to 1.2 at maximum tillering to flowering to maximise the yield (Chaudhary *et al.*, 1980). The irrigation control system (ICS) which works on manually calculated value of crop evapotranspiration to schedule irrigation had a clear impact on the plant height, Spike length, grain yield and biological yield as compared to the intelligent irrigation system (IIS) which uses digitally controlled evapotranspiration module that senses local climatic conditions via different sensors that measures wind speed, rainfall, solar radiation, air temperature and relative humidity, and calculates automatically crop evapotranspiration based on modified penman equation to schedule irrigation (Al-Ghobari *et al.*,2013). The highest plant height, spike m^{-2}, spikelet spike^{-1}, grains spike^{-1} and 1000-grain weight were obtained at full irrigation (control WS) and skipping during dough and ripening stages as compared to skipping during seedling, tillering and booting (Tahar *et al.*, 2011).

Considering climatic conditions, Zhang *et al.*, 2002 showed simulated results with single irrigation in wet years with an average rainfall of 154mm during season, two irrigations in normal years with an average rainfall of 105mm during season and three in dry years with an average rainfall of 59.6mm during season produced maximum profits. And considering stages, the irrigation should be scheduled: at jointing to booting for the single irrigation, at jointing and heading to milking for the two irrigations; and before over wintering, jointing, and heading to milking for the three irrigations to get maximum profits.

Hence, scheduling irrigation according to growth stages of crop, use of efficient irrigation methods, providing extra irrigation if available and irrigation based on moisture status of soil results in higher grain yield by alleviating the effect of high temperature in wheat crop.

3.5 Foliar spray: Foliar spray of potassium fertilizer increases the photosynthetates production in plant and thus increases the translocation of dry matter to the grain, which ultimately increases the total grain weight and yield. Also, potassium contributes in carbohydrate formation, maintaining water balance in leaves and regulates stomata closing, all these have a direct effect on stress resistance of the plant and its water use efficiency, resulted in producing maximum yield attributes ultimately maximum grain yield (Meshah *et al.*, 2009). The highest grain yield was obtained with foliar urea application of 32 kg ha^{-1} at booting stage (Eman *et al.*, 2000). Khan *et al.*, 2006 observed highest grain yield was obtained in KCl + Urea, followed by sole KCl treatment. The KNO_3 application increased yield but the magnitude of response was lower compared to KCl + Urea treatment. Dean *et al, 2008* reported that application of GA (Giberellic Acid) increased dry matter production of the winter wheat cultivar. The total DM production over time, however, was greater in GA treated plants compared with the control as shown in table 5.

Table 5. Dry matter production (DM) and plant height wheat following application of different rates of GA

GA (g ha^{-1})	DM (t ha^{-1})				Plant height
	109 DAS	116 DAS	123 DAS	130 DAS	(cm)
0	0.50	0.80	1.24	1.26	96.6
4	-	0.88	-	1.59	95.8
8	0.59	0.92	1.54	1.65	93.4
16	0.66	1.08	1.62	1.68	92.9
lsd (P=0.05)	0.10	0.19	0.22	0.22	2.5

Source: Dean et al., 2008

Under stress conditions, ethylene has been shown to regulate crop growth during the vegetative stages by reducing photosynthetic efficiency, reducing leaf area index, reducing plant stature, and accelerating leaf senescence. Suppressing the action of stress-induced ethylene with sprayable formulations of 1-MCP (1-Methylcyclopropene a growth regulator) has shown clear benefits in minimizing these negative effects of ethylene in agronomic crops (Malefyt *et al.*, 2010). So, use of 1-MCP spay improves stress tolerance, increases kernel weight and number in wheat crop.

Also, spray of Zn resulted in increase in growth parameters and yield of crop under high temperature stress conditions as it has the potential to provide thermotolerance to the photosynthetic apparatus of wheat (Graham and Donald, 2001).

Foliar application of thiourea under high temperature can effectively promote root growth possibly by enhancing assimilate partitioning to root at seedling and pre-anthesis growth stages resulting in increase in number of grains per spike and 100 grain weight (Anjum *et al.*, 2011). Eman *et al., 2000* reported that foliar urea spraying in Marvdasht cultivar at all N levels significantly increased the grain yield over the control plots, whereas in Phalat cultivar significant increase in grain yield was observed only with 16 kg N ha^{-1} treatment. The increase in grain yield with foliar urea application was due to increased number of grains ear^{-1} in both cultivars. The response of foliar spray was better in improving grain yield, when applied at booting or flowering stage compared to milk stage.Therefore, foliar sprays of potassium fertilizer, urea, Zinc, 1-MCP and GA_3 can help in increasing grain yield of crop by alleviating the effect of high temperature.

4. Conclusion

From the findings of various researchers, it can be concluded that high temperature adverrcy affects to wheat crop by reducy yield & qualiy Adoption of agronomic management practices such as timely sowing, tillage options like Zero tillage and No-till with residue retention, irrigation scheduling with respect to growth stages and availability of water, different irrigation methods and foliar spray of osmoregulators can help in mitigating or alleviating the adverse effect of high temperature and thus helps in maintaining the productivity level of wheat crop.

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