Managing impact of climatic vagaries on the productivity of wheat and mustard in India

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ABSTRACT. Wheat and mustard crop is highly vulnerable, particularly in the semi-arid and arid regions of India. The climate is warming through the processes such as CO₂ and changed pattern of temperature and precipitation resulting in heat and drought stresses, respectively. The effect of increasing temperature during grain filling stage of wheat causes
substantial reduction in grain yield. The effect of low temperature (frost) during podding and seed development stage in mustard causes freezing injury in seeds and sizable reduction in seed yield. In this review paper response of wheat and mustard crop to weather extremes and management practices such as time of sowing, selection of resistance cultivars, mulching, seed priming, foliar spray of salts, use of extra irrigation water, foliar spray of micronutrients, sprinkler, wind barrier etc. to mitigate the temperature and moisture stress effect on the productivity of wheat and mustard crop have been discussed. Above ground dry weight of wheat and its rate decreased with increasing water stress at each stage. The averaged values of damage threshold temperatures compiled from the literature were 31 °C for flowering and 35 °C for grain filling of wheat. Changes in average daily maximum temperature during flowering and grain filling had a negative effect on grain yield of 518 kg/ha and 1140 kg/ha, respectively for every 1 degree increase in average maximum temperature in South Australia. Temperature rise would be most harmful for the crop in eastern region, followed by central and northern India, where winter season temperature is comparatively higher than northern region. Rainfed mustard was less vulnerable to temperature rise in northern India as compared to other two central and eastern India. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of mustard crop. Seed yield reduction occurred by low water availability during stem elongation, flowering and pod development in mustard. Priming with moringa water extract and ascorbate substantially improved the tissue water status, membrane stability, gas exchange, water productivity of the plant. Late sown wheat crop faces high temperature stress during ripening phase. Delayed sowing reduces the tillering period and hot weather during critical period of grain filling lead to forced maturity thereby reduces the grain yield. Application of mulches in wheat produced higher grain yield over without much wheat. Organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield as compared to inorganic mulch. The foliar spray of KNO3 (0.5%) at 50 per cent flowering stage, 1.0 per cent KNO3 during anthesis stage, 2.5 mM of arginine, spray of zinc, extra irrigation water during grain filling stage increased the productivity of wheat under high temperature stress.

Light irrigation in mustard crop one day before frost occurrence protects from frost damage by improving heat transfer and heat capacity. Plastic mulch raises the surface temperature of the soil nearly 10 °C over bare soil. Smoke particles are usually less than 1 µm in size, reflect visible radiation but trap the long wave radiation and so are effective in preventing rapid cooling of surface near ground. Mixing air and liquid materials in the right proportion to create many small bubbles is the secret to generate foam with low thermal conductivity. Organic mulches (straw and saw dust) provided better soil water status over ash mulch.

Key words – High temperature, Frost, Water deficit, Seed priming, Mulching, Wheat, Mustard, Fogging, Smoke Insulation, Chemical spray, Extreme weather.

1. Introduction

Professor John Monteith considered the question of climatic variation and the growth of crops in his presidential address to the U K Royal Meteorological Society in 1980. This topic continues to capture the imagination of agricultural scientists and agrometeorologists. He concluded that the two largest climatic causes of variation in yield were temperature and rainfall and their independent effects were three to four times larger than caused by variation in how much light was incident on crops. Other causes of yield variation, notably management, contribute much more to yield variability than those factors beyond our control. However, increased variation and changes in mean temperature and precipitation are expected to dominate future changes in climate as they affect crop production. Therefore, it is certain that weather play a more determining role in global yield variability. The definition of what constitutes extreme weather differs for the properties of weather such as temperature, rainfall, wind speed etc. from crop to crop for a region. For example, temperature extremes (low temperature) abnormal for the mustard crop may be normal for wheat crop in North West India. Crop growth, development and yield are affected by climatic variability via linear and nonlinear responses to weather variables and the exceedance of well defined crop thresholds, particularly, temperature. Integrating the study of meteorological extremes and crop responses to weather thresholds, leads to an assessment of the possible impacts of changes in climatic variability on crop production and quality.

The diverse nature of extreme events leads to variable effects on different aspects of the crop growth cycle and associated field management. Extreme weather events can in fact impact crops both via negative impacts on plant physiological processes and direct physical damage, as well as by affecting the timing and conditions of field operations. For instance, above-threshold temperatures and precipitation leading to heat and drought stress, can negatively affect crop photosynthesis and transpiration (Wolf et al., 1996 and Porter and Semenov, 2005; Gerber, 1979), as well as increased pest and disease incidence. Extreme temperature events may also hinder fruit setting and development, critically lowering yield potential (Tubiello et al., 2007). On the other hand, heavy rain, hail storms and flooding lead to crop failures by physically damaging crop canopies, or via anoxic soil conditions limiting root and plant function. Extremely wet conditions can also delay key field operations such as planting and harvesting. Importantly, the same extreme events can have very different outcomes depending on the time of the year and the crop development stage. Understanding of how extreme events modify processes and interactions in agricultural production systems is
therefore essential to devise appropriate management responses under currently and future climate regimes.

Indeed, future climate change conditions are likely to be characterized by increased frequency of extreme events and thus larger negative impacts on crop yields (Easterling et al., 2007). They analyzed modeling results and found that in low-latitude regions, a temperature increase of 1-2 °C is likely to have negative yield impacts for major cereals. The IPCC has projected a temperature increase of 0.5-1.2 °C by 2020, 0.88-3.16 °C by 2050 and 1.56-5.44 °C by 2080 for the Indian region, depending on the scenario of future development (IPCC, 2007). Himalayan glaciers and snow cover are projected to contract leading to much higher variability in irrigation water supplies. It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. Overall, the temperature increases are likely to be much higher in winter season when crops such as mustard are grown. In this season, precipitation is also likely to decrease. There is a probability of 10–40% loss in crop production in India with increase in temperature by 2080-2100 (Fischer et al., 2007; Parry et al., 2004; IPCC, 2007).

There are a few Indian studies (Saseendran et al., 2000 and Aggarwal, 2008) which also confirm decline in the agricultural production with climate change. Winter crops are especially vulnerable to high temperature during reproductive stages. Mall et al. (2004) reported that crop production in winter season might become comparatively more vulnerable due to larger increase in temperature and higher uncertainties in rainfall.

Wheat is the main cereal crop in India. The total area under the crop is about 29.8 million hectares in the country. The production of wheat in the country has increased significantly from 75.81 million MT in 2006-07 to an all time record of 94.88 million MT in 2011-12 and productivity increased from 26.0 to 31.4 q/ha. India is among the top few vegetable oil economies of the world. Here, oilseeds are an important component of the agricultural economy, next to food grains, in terms of area, production and value. But still India is a net importer of vegetable oils and almost 40% of its annual edible oil needs are met by importation. In future, the demand for oilseeds production is likely to go up significantly due to increase in population and income. Finally, there is a consideration of how crops might be managed or be bred to adapt to variable conditions to minimize their effects.

2. Crop response to extreme weather

Abiotic stress includes any environmental conditions or combination of them that negatively affect the expression of genetic potential for growth, development and reproduction. Drought stress and heat stress frequently occur simultaneously, exacerbating one another. They are often accompanied by high solar irradiance and high winds. Under drought stress, the crop’s stomata close, reducing transpiration and, consequently, raising plant temperatures. Flowering, pollination, and grain-filling of most grain crops are especially sensitive to water stress. The extent of crop damage depends on the duration of stress and crop developmental stage. Crop yields are most likely to suffer if the adverse weather conditions, especially high temperature and excess or deficit precipitation during critical developmental stages such as the early stages of plant reproduction (Miroslav Trnka et al., 2014).

2.1. Wheat

In India both temperature stress and moisture stress are important and affect the wheat productivity. Terminal stress (temperature and moisture) badly affects the wheat productivity especially in late sown wheat, which is a common practice in rice-wheat or cotton-wheat cropping system etc due to delayed maturity of rice and cotton crop.

2.1.1. Temperature stress

Extreme low temperature viz., frost, particularly damages wheat crop between flag leaf emergence and ten days after anthesis. The damage appears as an erratic occurrence of aborted spikelets at the base, centre or tip of the spikes. It is also manifested as sterile florets in parts of the entire spike. This is due to an initial supercooling of plant tissues and a later erratic spread of the freezing front through stems and ears. The damage during this period occurs at minimum temperature below 0 °C and tissue temperature of around -4 °C (Harding, et al., 1990) and is associated with radiative cooling in calm clear nights. The lethal low temperature reported for wheat is -17.2 °C (±1.2 °C) (Porter and Gawith, 1999) and must be considered together in the presence or absence of a snow cover layer. Gusta and Fowler, 1976 reported that minimum temperatures below -2 °C after the main growing stage dehardened the crop with reduction in the yield substantially. However wheat crop escapes from frost damage in India because the sensible stage (grain filling) occurs mainly in second week of February, during this period frost is uncommon. Sometime early maturing wheat varieties are damaged if grain filling coincides with frost in last week of January.

Changes in average daily maximum temperature during flowering and grain filling had a negative effect on grain yield of 518 kg/ha and 1140 kg/ha, respectively for every 1 degree increase in average maximum temperature
in South Australia (Table 1). During grain filling in particular, this accounted for a large component of the variation within the data set (98%). Interestingly this is larger than the variation accounted for by growing season rainfall (84%) (Huang et al., 2005).

A significant negative impact of heat stress on wheat grain yield in South Australia was reported by Telfer et al., 2013. They also reported that growth stage 45 or booting showed the greatest decline in fertility compared to the control (Fig. 1).

Stress at this time corresponds to the formation of the pollen within the plant, which is very sensitive to stress, with the size of the effects decreasing as stress occurs later in the plant’s development (Flowering is also known to be sensitive to abiotic stress, with the pollen aborting or having reduced viability when subjected to stress). However, the opposite effect was observed on leaf, with less leaf damage observed at the earlier growth stages, while the rate of leaf senescence was increased if heat stress occurred post flowering and during early grain filling.

Heat stress during anthesis increases floret abortion (Wardlaw and Wrigley, 1994). They also reported that heat stress during the reproductive phase between anthesis to grain maturity, caused reduction in grain yield (Fig. 2).

![Fig. 1.](image)  
**Fig. 1.** Treatment mean responses for fertility (grains set per spike), and change in visual score 3 and 10 days after stressing (visual leaf score, based on the proportion of leaf area remaining viable) [Plants were placed in the chamber in growing environment with temperatures of 36 °C and 40 km/hr winds, for three consecutive eight hour days, 10 days after the main tiller had finished flowering (GS72), booting (GS45), three quarters head emergence (GS57), start of flowering (GS62) and the end of flowering (GS69)] (Source: Telfer et al., 2013)

TABLE 1

| Site           | Grain yield (kg/ha) | Sowing date | Average maximum temperature (°C) during flowering | Average maximum temperature (°C) during grain fill |
|----------------|---------------------|-------------|--------------------------------------------------|--------------------------------------------------|
| Angas Valley   | 1789                | 23 May      | 26.0                                             | 27.7                                             |
| Booleroo       | 3119                | 17 May      | 24.7                                             | 26.3                                             |
| Minnipa        | 2295                | 15 May      | 23.2                                             | 27.3                                             |
| Pinnaroo       | 2318                | 28 May      | 24.1                                             | 27.4                                             |
| Roseworthy     | 3489                | 17 May      | 21.9                                             | 26.3                                             |
| Winulta        | 5222                | 10 May      | 20.2                                             | 24.8                                             |

| Significance (p Value) | 0.022 | <0.001 |
| Percent variation accounted for | 77 | 98 |
| Effect (kg/ha)         | -518  | -1140  |

*Source: (Telfer et al., 2013)*
TABLE 2

Response of wheat to temperature stress at different phenophases

| S. No. | Weather extremes       | Effect on wheat                                                                 | Weather extreme description – situation must occur at least once per season to be counted |
|--------|------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| 1.     | Late frost             | Its occurrence after loss of the winter-hardiness leads to leaf chlorosis,       | Event is triggered when the minimum temperature is equal to or below -2 °C after the start   |
|        |                        | burning of leaf tips, floret sterility, damage to lower stem and consequently   | of the following window, determined as the period when the mean air temperature is           |
|        |                        | medium to severe yield losses                                                  | continuously 10 °C (for at least five days) and does not drop below 10 °C for               |
|        |                        |                                                                                | more than two days in a row                                                                |
| 2.     | Heat stress during     | Causes partial or complete sterility of the florets with a severe effect on    | Event is triggered when the $T_{\text{max}}$ is above +31 °C for at least two days during   |
|        | anthesis               | yield                                                                            | the period ± 5 days around anthesis.                                                       |
| 3.     | Heat stress during     | Speeds up development and decreases yield until the growth stops, resulting in  | Event is triggered when the $T_{\text{max}3}$ is above +35°C for at least three days       |
|        | grain-filling          | a substantial yield reduction                                                   | during the period from five days after anthesis to maturity.                                |

Source: Ruiz-Ramos, et al., 2011

It is attributed to reduced time by heat stress to capture the resources. Isolated periods of extremely high temperatures around sensitive crop developmental stages such as flowering could reduce the grain yield considerably, and a continuous period of extreme high temperature can result in an almost total yield loss (Porter and Semenov, 2005).

The wheat yield could be limited by the low grain number, which is established to a large extent during the period around anthesis (flowering), which is known to be sensitive to high temperature stress (Ferris et al., 1998). If the crop is unstressed, it establishes the grain number and its potential size at sufficiently large values to accommodate the biomass that is produced during grain filling. Grain number and grain size can be substantially reduced if a heat-sensitive cultivar is exposed to a short period of high temperature around flowering, limiting the capacity of the grains to store newly produced biomass. Wheeler et al., 1996 a&b reported that temperatures between 27 °C to 31 °C or even higher (before and during anthesis resulted a high number of sterile grains and considerable yield losses.

Temperatures above 31 °C shortly after anthesis and during grain filling were shown to reduce the net assimilation, thus causing the production of smaller grains (Tashiro and Wardlaw, 1989) and increasing leaf senescence (Asseng et al., 2011). Although the rate of grain growth increases with temperature increase and an increase in the grain-filling rate compensates for the shorter grain-filling period, but this compensation does not occur at temperatures above 30 °C due to limited assimilated translocation from flag leaf to grain (Stone et al., 1995; Wardlaw et al., 1980). The averaged values of damage thresholds that were compiled from the literature by Porter and Gawith (1999) were 31 °C for flowering and 35 °C for grain filling and Ruiz-Ramos et al., 2011 have used these values to define temperature as an indicator to evaluate stress during flowering (anthesis) and grain filling (Table 2). Yield penalties are associated chronically with both high temperatures as well as heat shocks, at temperature greater than 32.0 °C during mid or late reproductive stages including grain filling (Wardlaw and Wrigley, 1994). High respiration rates especially during night due to high temperature can increase reactive oxygen species, leading to cell damage affecting pollen viability (Prasad et al., 1999).
### TABLE 3
Grain filling duration and final grain weight of wheat grown at four temperatures

| S. No. | Crop growth mean temperature (°C) | Grainfilling mean temperature (°C) | Grainfilling durationa (days) | Final grain weighta (mg) | Grain filling per day (mg/kernel) |
|--------|-----------------------------------|-----------------------------------|------------------------------|--------------------------|---------------------------------|
| 1.     | 12.2                              | 17.0                              | 28.5a                        | 39.5a                    | 1.39                            |
| 2.     | 20.7                              | 24.0                              | 29.4a                        | 28.9b                    | 0.98                            |
| 3.     | 23.9                              | 25.6                              | 26.5a                        | 30.5b                    | 1.15                            |
| 4.     | 27.5                              | 24.4                              | 30.5a                        | 27.6c                    | 0.91                            |

*aMean of 24 genotypes.

*Numbers followed by a different letter differ at P = 0.05.

Source: Acevedo et al., 1991b.

### TABLE 4
Effect of moisture stress on wheat crop

| S. No. | Moisture stress                      | Effect on wheat                                    | Moisture stress description – situation must occur at least once per season to be counted |
|--------|--------------------------------------|---------------------------------------------------|----------------------------------------------------------------------------------------|
| 1.     | Extremely wet early season           | Restricts growth and reduces yield through the occurrence of diseases, nitrogen leaching, logging and root anoxia | Event is triggered if the soil moisture is at or above the field capacity for more than 60 days from sowing to anthesis. Days with a mean temperature below 3°C are not counted |
| 2.     | Severe drought (sowing - anthesis)   | Causes a severe reduction of growth or crop die back | Event is triggered if ETa/ETr is less than 0.15 for at least ten consecutive days between sowing and anthesis; the days with a mean temperature below 3°C are not considered |
| 3.     | Severe drought (anthesis-maturity)   | Causes a severe reduction of growth or crop die back | Event is triggered if ETa/ETr is less than 0.15 for at least ten consecutive days between anthesis and maturity |
| 4.     | Severe dry season (sowing-maturity)  | Causes severe reduction of growth or crop die back | Event is triggered if ETa/ETr is less than 0.15 for at least 21 days during the period from sowing to maturity; the days with a mean temperature below 3°C are not considered |
| 5.     | Adverse conditions at harvest        | Restricts the ability to harvest at the most appropriate time | Event is triggered when soil moisture in the top layer below 85% and rain on the given day is below 0.5 mm and not more than 5 mm on the preceding day |

ETa and ETr are the actual and reference evapotranspirations

Source: Trnka, et al., 2014 et al., 2003

In hot environments, however, the maximum soil temperature in the top centimeters soil may exceed maximum air temperature by 10 °C to 15 °C if the soil surface is bare and dry and radiation intensity is high. Under such conditions, maximum soil temperature may reach 40 °C to 45 °C with serious effects on seedling emergence. The initial plant population may fall below 100 plants/m considered to be deleterious to crop yield (Acevedo et al., 1991b). They also reported a mean reduction of 4 percent in grain weight per degree increase in mean temperature during grain filling (Table 3). Crop growth mean temperature increase from 12.2 °C to 27.5 °C caused 34.5 per cent reduction in grain filling in wheat crop.

2.1.2. Moisture stress

Water excess (logging) and deficit are both detrimental to wheat crop. The occurrence of water logging due to exceedingly wet conditions between sowing and the end of tillering can reduce the number of kernels per head, the number of tillers per plant, plant height and finally grain yield. The risk of unusually wet conditions during the period from sowing to anthesis was based on number of days with the soil water content in the top soil layer at field capacity. The risk of dry conditions during the period from sowing to maturity was based on number of days with the top soil layer unable to meet crop water demand (Table 4). Grain yield and its attributes were reduced significantly under water stress conditions. The percent reduction in grain yield was 23.8 and 57.6 over non stress in mild (two irrigation) and severe stress (no irrigation) conditions, respectively (Sharma et al., 2003).

Rong-hua et al., 2006 reported that the values of chlorophyll content in drought tolerance genotypes of barley were significantly higher than those in drought sensitive genotypes under moisture stress. Although stress depresses grain yield (Hsiao, 1973) and it can elevate the
**TABLE 5**

Above ground matter dry weight of winter wheat under water stress condition

| Irrigation levels | Precipitation (mm) | Irrigation (mm) | Jointing stage (g/plant) | Heading stage (g/plant) | Mature Stage (g/plant) | Jointing to heading stage (g/plant) | The percent of decrease in comparison with control (%) | Decreasing percentage of in comparison with control (%) |
|-------------------|-------------------|-----------------|------------------------|------------------------|----------------------|----------------------------|------------------------------------------------|------------------------------------------------|
| 1                 | 66.70             | 300.00          | 0.15                   | 0.72                   | 2.84                 | 0.57                      | 1                                            | 2.12                                        |
| 2                 | 66.70             | 262.52          | 0.14                   | 0.57                   | 1.64                 | 0.43                      | 24.84                                       | 1.07                                       | 49.51                                      |
| 3                 | 66.70             | 225.04          | 0.16                   | 0.62                   | 1.64                 | 0.45                      | 21.00                                       | 1.02                                       | 51.74                                      |
| 4                 | 66.70             | 187.48          | 0.13                   | 0.44                   | 1.21                 | 0.31                      | 45.59                                       | 0.77                                       | 63.60                                      |
| 5                 | 66.70             | 150.00          | 0.14                   | 0.58                   | 1.10                 | 0.44                      | 23.68                                       | 0.52                                       | 75.4                                       |

(Source: Zhao, et al. 2009)

value of other components of the economic yield, such as quality of grain (Gutierrez *et al.*, 2000). Siddique *et al.*, 2000 reported a reverse relationship of photosynthetic rate with leaf water potential of wheat plants, which decreases with water stress (Fig. 3).

Above ground dry weight of single plant decreased at each stage and the increment of biomass reduced under the increasing water stress (Zhao *et al.*, 2009). Furthermore, the cumulative biomass in later stage was more than the earlier stage (Table 5). The increment of biomass of the 2nd to 5th irrigation plans in later stage reduced by 41.9%, 15.4%, 31.5% and 38.6% compared with the first irrigation plan, respectively. This indicates that spike growth was affected seriously by water stress. The wheat product decreased obviously under high water stress in later stage, whereas, the yield under slight water stress in jointing stage was more than other irrigation levels.

Drought stress reduced the number of days to heading, grain filling, and maturity, plant height, number of spike per m², peduncle length, spike length, number of grains per spike, 1000 grain weight of genotypes while it increased the chlorophyll content and grain protein content. Spikelets per spike were not affected by drought stress (Kılıç and Yaşbagaslanlar, 2010; Paknejad *et al.*, 2007). Kılıç *et al.* (1999) has reported that the number of days to heading, number of spike per m², 1000 grain weight and grain yield of durum wheat is reduced in the drought and terminal heat stress conditions. Severe water stress from the seedling stage to maturity reportedly reduced all grain yield components, particularly the number of fertile ears per unit area by 60% and grain number per head by 48% (Giuanta *et al.*, 1993).

2.2. **Mustard**

Mustard is much sensitive to climatic variables and hence weather extremes could have significant effect on its production. Apart of the decline and/or stagnation in mustard yields negative growth rate in India from 1997 was observed possibly due to unfavorable monsoon which created moisture stress (drought and excess rainfall) and temperature increase (Kumar, 2005). High temperature during mustard crop establishment (mid September to early November), cold spell, fog and intermittent rains during crop growth also affect the crop adversely and causes considerable yield losses. Frost is the most important weather extreme for mustard cultivation as it causes a great loss to seed yield through direct injury to seed during seed development phase.

2.2.1. **Temperature stress**

Increasing temperatures reduce days to flowering and maturity, which in turn reduces total crop duration. In plants, warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Rawson, 1992).
temperature rise in eastern India with yield loss of 78.4% crop, rainfed mustard would be most affected by higher than northern region (Table 6). Similar to irrigated India, where winter season temperature is comparatively harmful for the crop in eastern region, followed by central yield loss was observed. Temperature rise would be most was also vulnerable to temperature rise, where substantial CO2. Increase in CO2 Concentration at same temperature respectively. In north India, temperature rise by 5 °C, with 31.4 – 71.7

**TABLE 6**

Impact of current and adaptation measures on percentage yield gain loss of irrigated mustard in different climate change scenarios

|       | 2020 | 2050 | 2080 |
|-------|------|------|------|
| **Northern** |      |      |      |
| Current | -3.2 | -6.6 | -15.7 |
| S1     | 1.0  | -0.4 | -9.4  |
| S2     | -3.0 | -2.6 | -8.6  |
| **Central** |      |      |      |
| Current | -1.4 | -2.1 | -16.5 |
| S1     | -0.5 | -1.9 | -7.7  |
| S2     | -1.1 | -2.1 | -6.9  |
| **Eastern** |      |      |      |
| Current | -9.9 | -37.4 | -63.1 |
| S1     | -1.8 | -29.6 | -69.6 |
| S2     | -3.6 | -31.4 | -71.7 |

*S1 – late sowing by 7 days and S2 – long-duration variety (Boomiraja, *et al.*, 2010)*

Boomiraja *et al.*, 2010 used InfoCrop model for simulating mustard yield with different increments of temperature. Under irrigated condition, the grain yield dropped steeply with rise in temperature in eastern India. In this region, yield reduction was maximum (86.6%) with 5 °C rise in temperature. Rise in temperature at same level of CO2 decreased yield reduction to 82.4 and 79.4% respectively. In north India, temperature rise by 5 °C, with no rise in CO2 reduced mustard yield by 34.7%.

Mustard crop grown in central part of the country was also vulnerable to temperature rise, where substantial yield loss was observed. Temperature rise would be most harmful for the crop in eastern region, followed by central India, where winter season temperature is comparatively higher than northern region (Table 6). Similar to irrigated crop, rainfed mustard would be most affected by temperature rise in eastern India with yield loss of 78.4% with 5 °C rise in temperature at various enhanced level of CO2. Increase in CO2 Concentration at same temperature also caused reduction in grain yield. Elevated CO2 and temperature caused more yield reduction under rain fed condition. Substantial yield loss occurred in central India with a loss of 40.2% (Fig. 4). Rainfed mustard was less vulnerable to temperature rise in northern India as compared to other two locations. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of the crop. According to Morison and Stewart, 2002 increased temperature during bolting to flowering period reduced yield of all Brassica spp.

Low temperature extremes (frost) after flowering and during pod filling will cause significant yield reductions and possible down grading. However, it is also very likely to suffer freeze injury caused by frost. Frost could induce significant pigment and water loss, structural injuries, and impaired light capture capability of photo systems at the cellular scale (Oksanen *et al.*, 2005). Furthermore, it would cause dehydrated or withered leaf blade and even canopy structure alteration. Winter rape due to large-leaf crop with high water content in the leaves, is more vulnerable to freeze injury. Winter oil seed rape growing exuberantly or with premature development has more risk of damage by frost (Gu *et al.*, 2008).

Various research studies have shown that both *B. napus* and *B. rapa* canola will imbibe water and germinate at constant temperatures of 2 °C. Sustained low temperatures for both *B. napus* and *B. rapa*, however, damage the seed embryo, which reduces germination and growth. Low temperature impairs the production of proteins required for proper germination and early seedling development through reduced metabolic processes. Acharya *et al.*, 1983 found that 4 °C or higher temperature had little effect on total percent germination in *B. napus*, however, the number of days to 50% germination increased dramatically at temperatures below 6 °C. The number of days to 50% germination in *B. napus* was only three days at 8 °C compared to nearly 13 days at 2 °C. This low temperature effect of slower and lower germination was even more pronounced with *B. rapa* canola (Fig. 5). In *B. rapa*, there was greatly reduced germination at 3 °C and 2 °C, even after 20 days, 50% emergence was not reached.

2.2.2. Moisture stress

Moisture stress is common in rain fed mustard crop in North West India during the month of February when winter rain fails. At this time mustard is in podding and seed development stage, is adversely affected by soil moisture deficit and it causes reduction in oilseed production.

The soil covered by straw mulch conserved more soil water followed by saw dust and ash over bare soil (Fig. 6). The variation in soil moisture retention was found in similar order at one month later. However the moisture content was about 2 - 3% less at this stage irrespective of the mulches applied (Awal and Sultana, 2011).

Mirzael *et al.*, 2013 reported that moisture stress(Full irrigation, stress at flowering, pod developing and seed forming stages) had significant affect on seed yield, number of seeds/pod, number pod per plant, number of branches per plant, 1000 - seed weight, plant height and
oil content of cultivars (Hyola401, Hyola308, Zarfam and PF) in Iran. Seed forming stage was the most sensitive stage, because 1000 - seed weight and oil content were decreased in this stage. The highest (3151.25 kg/ha) and lowest (2377.08 kg ha\(^{-1}\)) seed yield belonged to full irrigation and stress at flowering stage, respectively.

Gunasekara et al., 2006 reported the grain yield reduction of Brassica napus and Brassica juncea due to drought stress. Seed yield reduction occurred by low water availability during stem elongation, flowering and pod development which caused reduction of pods per plant. Supplemental irrigation applied at grain-
Figs. 6(a&b). Effect of mulches on moisture content on weight basis at 5 to 15 cm soil depth at two growth stages (29 and 59 DAS) of mustard crop (Source: Awal and Sultana, 2011)

filling stage increased the grain yield (Wang et al., 2005). Hang et al., 2008 indicated that irrigation during stem elongation, increased grain yield in non-irrigation conditions.

Pandey et al., 2001 found that water stress during flowering stage, decreased seed yield due to reduction in seeds weights. Deloche (1980) reported that drought stress at seed filling stage caused fading of seeds. Decreasing seed weight under drought stress resulted from harmful effect of drought on producing biomass (Keati and Cooper, 1998). Poma et al., 1999 also indicated in their study on effect of irrigation treatments on canola yield that all seed yield components and seed yield decreased under drought condition. The highest 1000 - seed weight was in full irrigation and Hyola 401 cultivar and the lowest seeds per pod were in stress at seed forming stage and Zarfam cultivar.

Singh et al., 2011 found that overall mean performance of Brassica progenies was comparatively higher in irrigated environment for days to 50% flowering, days to maturity, fruiting zone length, main shoot length, siliquae on main shoot, siliquae per plant, 1000 seed weight, seed yield per plant and protein content. Lowest value of drought susceptibility index (DSI) indicates the highest level of drought tolerance and vice-versa. Values of DSI (Table 8) ranged from -0.139 (07-547) to 1.316 (07-827). The genotypes 07-547, 07-515 and 07-510 had lower DSI values (< or ~0.00), thus rated as drought tolerant.

3. Management of weather extremes

Temperature and moisture stress among the weather extremes are most important which control the productivity of mustard and wheat crop in India. Low temperature stress (frost) affects mustard crop adversely when it occurs in the month of January, but on the other hand it is beneficial for wheat crop results in better tillering. High temperature stress is most detrimental for wheat crop during grain developmental phase in the month of March but it is not as important in case of timely sown mustard as the crop matures by the first week of March. Moisture stress mainly deficit of water is determinantal for both wheat and mustard crop. Therefore management of temperature and moisture stress can minimize the crop losses to a considerable extent. Some of the approaches for managing weather vagaries adopted by many research workers are presented in following subheads:

3.1. Site selection

Growers are usually aware that some spots are more prone to frost damage than others. The first step in selecting a site for a new planting is to talk with local people about what crops and varieties are appropriate for the area. Local growers and extension advisors often have a good feeling for which locations might be problematic. Typically, low spots in the local topography have colder temperatures and hence more damage.

3.2. Effect seed priming

A study evaluated the role of seed priming with inorganic salts (CaCl₂, KNO₃, KCl, plant water extracts (sorghum, moringa) and organic molecules (ascorbate, salicylate, proline) in improving the wheat performance under heat and drought stresses (Muhammad et al., 2011). Stress treatments (optimal conditions, drought stress at 50% of the field capacity, heat stress (40.0 °C) higher than the ambient temperature and both drought and heat stress) substantially reduced the wheat performance and the effects were more severe when both the plants were exposed simultaneously to both the stresses. Priming
treatments substantially improved the tissue water status, membrane stability, gas exchange and water productivity, however, priming with moringa water extract and ascorbate was better than other treatments in the respective group. Seed priming with water over night increased the number of spikes by 13.9% and seed yield by 29.4% over unprimed seed (Sharma and Kumar, 2009). This increase in yield was positively associated with chlorophyll content, canopy temperature depression and photosynthetic rate. Similar study was conducted by Hobbs, 1985.

3.3. Dates of sowing and varieties

Time of sowing is one of the most important non-monetary inputs for optimizing the growth according to prevailing agro-climatic conditions and genotypes. Adjustment in time of sowing can minimize the effect terminal heat stress in wheat. Timely sown wheat (in first fortnight of November) escapes from heat stress, caused by sudden rise in temperature in last week of March. But terminal heat stress is common in late sown wheat in North West India.

Sandhu et al. (1999) reported that planting dates affected grain yield significantly. The maximum grain yield (4456 kg ha\(^{-1}\)) was recorded when planting was done on 25\(^{th}\) October, which decreased gradually and significantly to 2132 kg ha\(^{-1}\) when planting was done on 5\(^{th}\) December. Averaged over sowing dates, PR-84 gave the highest grain yield (3835 kg ha\(^{-1}\)), which was followed by PR-85 with 3545 kg ha\(^{-1}\) grain yield. Thousand grains weight ranged from 34.8 g to 51.4 g (PR-87) (Table-VI) when planting was done on October 25\(^{th}\). As planting was delayed, gradual decrease took place in 1000-grains weight of all varieties/lines except PR-83 and PR-85 in which 1000-grains weight increased to 53 g and 46.8 g, respectively, when planting was done on 15\(^{th}\) November and then decreased till 5\(^{th}\) December. From 5\(^{th}\) December sown crop, 1000-grains weight decreased in all varieties/lines except PR-83, PR-86 and thousand grains weight ranged from 24.8 g to 46.5 g (PR-83) when sowing was done on 5\(^{th}\) December. Similar study was reported from Gurdaspur, Punjab (Sandhu et al., 1993; Samra and Singh, 1987; Mohammad et al., 2014 ). They found that crop sown on 15 October produced higher grain yield as compared to crop sown on 25 October, 4 and 14 November.

Boomeriraja et al. (2010) taken adaptation measures: (S1- late sowing by 7 days and S2 - long-duration variety) and found to prevent yield loss to certain extent in mustard crop. Yield loss would be less with adaptation measures in central and northern India in all the future scenarios (Table 6). In eastern region, adoption of adaptation measures could prevent yield loss in 2020 and 2050, while in 2080 they could not prove to be beneficial. The adaptation strategy of sowing late could be able to increase yield by 1% compared to current in northern India in 2020, while in 2050 and 2080 it decreased mustard yield loss considerably.

It is important to choose cultivars that bloom late to reduce the probability of damage due to freezing, and to select varieties that are more tolerant of freezing. For example, RH-30 variety is more tolerant to frost as compared to other mustard varieties. Yield loss was less in long variety in which maturity occurred later than that of the existing variety. Genotypes, RGN 197, PLM-2BPR-549-9, BPR-540-6 and BPR-349-9 showed tolerance to high temperature at terminal stage based on less reduction in seed yield, and medium transpiration rate (Singh et al., 2014).

Cultivars of wheat: Raj 3765, WH 1021, etc. and mustard: RH 30, RH 0749 etc. are of low water requirement/ stress tolerant can be grown in rain fed and limited irrigation areas. Rain fed cultivated wheat crop encounters water stress during later stages of growth due to dry spell leading to progressive decrease in soil moisture received by winter rains.

The rainfed wheat plant had water deficit as indicated by more negative water potential but the decrease was relatively more in cultivar WH711 over Kauz star in comparison to non stress wheat (Sharma et al., 2008). The leaves of cultivar Kauz star had higher chlorophyll content and less decrease in photosynthesis and transpiration rates under stress condition. Cultivar WH 147 maintained higher plant water status and higher

| TABLE 7 |
| --- |
| Drought susceptibility index of different characters in wheat genotypes |
| S. No. | Genotypes | Drought susceptibility index |
| | | Grains per spike | Biomass | Seed yield |
| 1. | RWP 05-09 | 1.59 | 0.58 | 0.52 |
| 2. | WH 1012 | 0.50 | 0.49 | 0.18 |
| 3. | VL 899 | 1.50 | 0.74 | 0.73 |
| 4. | VL 902 | 1.00 | 0.36 | 0.07 |
| 5. | KYPO 425 | 0.53 | 0.07 | 0.18 |
| 6. | WH 736 | 0.61 | 0.39 | 0.50 |
| 7. | AKAW 3997 | 2.27 | 0.80 | 0.83 |
| 8. | C 306 | 0.00 | 0.49 | 0.73 |

(Source: Sharma and Kumar, 2010)
TABLE 8

Classification of advanced lines of *Brassica juncea* on the basis of Drought susceptibility index (DSI)

| DSI value | Reaction         | Genotype(s)                  |
|----------|------------------|------------------------------|
| <0.0     | Drought tolerant | 07-547, 07-515 and 07-510  |
| >0.0-1.0 | Moderately tolerant | 07-501, 07-502, 07-503, 07-504, 07-505, 07-507, 07-509, 07-511, 07-512, 07-513, 07-514, 516, 07-517, 07-518, 07-520, 07-526, 07-527, 07-529, 07-531, 07-534, 07-535, 07-536, 07-537, 07-538, 07-540, 07-541, 07-542, 07-544, 07-875-1, 07-895-1 |
| >1.0-1.5 | Moderately susceptible | 07-308, 07-519, 07-521, 07-523, 07-525, 07-528, 07-539, 07-543, 07-548, 07-551, 07-552, 07-553, 07-555, 07-561, 07-606, 07-609, 07-728, 07-761, 07-763, 07-771, 07-773, 07-782, 07-788, 07-793, 07-883, 07-885, 07-895, 07-906, 07-925-1, 07-925-2, 07-885 |
| >1.5     | Susceptible       | -                            |

(Source: Singh *et al.* 2011)

rate of photosynthesis of flag leaf at anthesis than PBW 175, C 306, WH 711, WH 1024 and WH 1025 and also resulted in higher grain yield under rain fed conditions (Sharma and Kumar, 2009). Sharma and Kumar, 2010 computed the drought susceptibility index (DSI) of different characters in different wheat genotypes (Table 7; Sharma and Chakor, 1989). Drought Susceptibility Index (DSI) indicated that seed yield was determined by the biomass produced by an individual genotype. RWP 05-09, WH 1012, VL 899, VL 902, KYPO 425, WH 736, AKAW 3997 and C 306 showed tolerance in biomass and seed yield against drought. The tolerance in grains/spike was observed in WH 1012 KYPO 425, WH 736 AKAW 3997 and C 306 against moisture stress. Drought Susceptibility Index (DSI) was calculated for each mustard genotype as a criterion of drought tolerance (Table 8). The lowest value indicates the highest level of drought tolerance and vice-versa (Singh *et al*., 2011). The genotypes 07-547, 07-515 and 07-510 had lower DSI values (< or ~0.00), thus rated as drought tolerant.

3.4. *Fertilizer management*

Unhealthy trees are more susceptible to frost damage and fertilization improves plant health. However, nitrogen and phosphorus fertilization before a frost encourages growth and increases susceptibility to frost damage (Snyder and de Melo-Abreu, 2005). To enhance hardening of plants, avoid excess application of nitrogen fertilizer. However, phosphorus is also important for cell division and therefore is important for recovery of tissue after freezing. Potassium has a favorable effect on water regulation and photosynthesis in plants. An adaptation strategies such as 50% increase in recommended fertilizer (120 kg ha⁻¹) as basal as well as split dose (basal, 30 and 60 DAS) and increasing one more irrigation (1, 30, 60 DAS) did not help in improving mustard yield in future climate change scenarios (Boomiraja *et al*., 2010).

3.5. *Soil compacting*

Soil cultivation creates air spaces in the soil and it should be avoided during frost-prone periods. Air is a poor heat conductor and has a low specific heat, so soils with more and larger air spaces will tend to transfer and store less heat. If a soil is compacted and irrigated, will improve heat transfer and storage capacity. Bridley *et al*., 1965 attempted to reduce the frost damage by compacting the soil by roller in Australia.

3.6. *Irrigation*

When soils are dry, there are more air spaces, which inhibit heat transfer and storage. Therefore, in dry years, frost protection is improved by light irrigation. The goal is to maintain the soil water content near field capacity, 1 to 3 days following thorough irrigation. Wetting the soil will often make it darker, and increases absorption of solar radiation.

Irrigation by sprinkler increases long-wave radiation and sensible heat transfer to the plants relative to an unprotected crop. Over-plant sprinkler irrigation provides excellent frost protection down to near -7 °C if the application rates are sufficient and the application is uniform. Under windy conditions or when the air temperature falls so low that the application rate is inadequate to supply more heat than is lost to evaporation, the method can cause more damage than experienced by an unprotected crop. Cary, 1974 used sprinklers for frost protection under screen covering the crop field. Hang *et al*., 2008 indicated that irrigation during stem elongation, increased grain yield in non-irrigation conditions. Supplemental irrigation applied at grain-filling stage increased the grain yield (Wang *et al*., 2005).
### TABLE 9

Effect of straw mulch and irrigation on evapotranspiration, soil water depletion, biomass and grain yield of wheat

| Year       | Yield (q/ha) | Treatments                                      |  |  |
|------------|--------------|-------------------------------------------------|--|---|
|            |              | No straw mulch and no irrigation                | Straw mulch and irrigation 15 mm | No straw mulch and irrigation 30 mm | No straw mulch and irrigation 45 mm |
| 1997       | Biomass      | 3356+390                                        | 4584 + 350**                   | 4500 + 364**                           | 5556 + 493***                        |
|            | Grain        | 818 + 125                                        | 1240 + 84**                    | 1250 + 104**                           | 1384 + 156***                        |
|            | Evapotranspiration | 239.2                                              | 219.5**                       | 250.6 NSa                              | 260.8**                             |
|            | Soil water depletion | 58.1                                                | 38.4***                      | 54.5 NSa                               | 49.7***                              |
| 1998       | Biomass      | 7120 + 310                                       | 8563 + 439**                   | 9546 + 480***                           | 10970 + 570***                       |
|            | Grain        | 2061 + 199                                       | 2601 + 203**                   | 2520 + 195**                           | 2883 + 228***                       |
|            | Evapotranspiration | 369.6                                              | 355.3*                        | 349.9**                                | 338.8***                            |
|            | Soil water depletion | 91.2                                                | 76.9***                      | 71.5***                                | 60.4***                             |

(Source: Huang, et al. 2005)

- **Significance at p>0.05 level,**
- *Significance at p<0.05 level,**
- **Significance at p<0.01 level,**
- ***Significance at p<0.001, when compared to the t1 treatment.

Singh et al., 2011 found that overall mean performance of Brassica progenies was comparatively higher in irrigated environment for days to 50% flowering, days to maturity, fruiting zone length, main shoot length, siliquae on main shoot, siliquae per plant, 1000 seed weight, seed yield per plant and protein content.

#### 3.7. Mulching

Mulching has been proved to be useful in conserving moisture and increasing productivity in wheat (Chakraborty et al., 2008; Huang et al., 2005; Verma, 2004), which subsequently resulted in higher water and nitrogen uptake and their use efficiencies (Chakraborty et al., 2010). Mulch research has shown that use of surface mulch can result in storing more precipitation water in soil by reducing runoff, increasing infiltration and decreasing evaporation (Huang et al., 2005; Ji & Unger, 2001 and Smika & Unger, 1986)

Crop straw and plastic mulches are often used to warm the soil and increase protection. Clear plastic warms the soil more than black plastic and wetting the soil before applying the plastic further improves effectiveness. Fritton and Martsolf, 1981 covered soil by plastic and found that surface temperature of the soil covered with plastic was nearly 10 °C greater than that of bare soil.

Straw mulch in wheat crop increased the grain yield from 818 & 2062 (1997 and 1998) kg/ha (without mulch) to 1240 kg/ha under limited soil moisture conditions (Table 9). Evapotranspiration was reduced by straw mulch over wheat crop without mulch by reducing the soil water depletion (Huang et al., 2005). Organic mulches (straw and saw dust) provided better soil water status (Fig. 6). Mustard crop with saw dust improved plant growth in terms of biomass over in organic mulch (ash) (Fig. 8).

#### 3.8. Foliar spray of chemical

In recent past some encouraging results were obtained with post flowering foliar application of various nutrients on yield of wheat. The higher grain and straw yield of wheat by spraying 0.5 per cent KNO₃ at 50 per cent flowering stage of the crop was reported (Das and Sarkar, 1981). Wheat crop sown on 25 November sprayed with KNO₃ (1%) during anthesis produced highest grain...
yield followed by one additional irrigation during post anthesis, two foliar spray of KNO$_3$ (1%) during anthesis and recommended irrigation (Fig. 7) (Singh, 2010 and Singh et al., 2011). A study was designed to explore the role of arginine (0.0, 2.5 and 5.0 mM) in increasing the tolerance of wheat cultivar (Sids-93) to two late sowing (23/12 and 23/1) besides the normal sowing date (23/11) in Egypt (Hozayn et al., 2011). Foliar spray of 0.5 per cent KNO$_3$ at 50 per cent flowering stage or 1.0 per cent KNO$_3$ during anthesis, use of organic mulch, foliar spray of zinc, use of potassium fertilizer with waste water can alleviate the adverse impact of high temperature stress on wheat (Singh et al., 2011).

Highest grain and biological yield with normal irrigation and spraying with zinc were 62.4 and 143.0 q/ha, respectively and the lowest of 38.0 and 122.0 q/ha in the conditions of discontinuation of irrigation at flowering stage and lack of spraying zinc (Shahramlack et al., 2011). Sharma and Pannu, 2009 managed heat stress by frequent lig

3.10. **Bacterial control**

For freezing to occur, the ice formation process is mostly initiated by presence of ice nucleation active (INA) bacteria. The higher the concentration of the INA bacteria, the more likely that ice will form as it acts as a freezing nuclei (Steven et al., 1982). Bacterial ice nucleation on leaves can be detected at about -2 °C, whereas the leaves themselves, i.e., without INA bacteria, contain nuclei active only at much lower temperatures. The temperature at which injury to plants occurs is predictable on the basis of the ice nucleation activity of leaf discs, which in turn depends on the number and ice nucleation activity of their resident bacteria. After forming, it then propagates inside the plants through openings on the surface into the plant tissues. Commonly, pesticides (copper compounds) are used to kill the bacteria or competitive non-ice nucleation active (NINA) bacteria are applied to compete with and reduce concentrations of INA bacteria (Snyder and de Melo-Abreu, 2005). However, this frost protection method has not been widely used.

3.11. **Biomass residue burning/ heaters**

Heaters provide supplemental heat to help replace energy losses. Generally, heaters either raise the temperature of metal objects (e.g., stack heaters) or operate as open fires. If sufficient heat is added to the crop volume so that all of the energy losses are replaced, the temperature will not fall to damaging levels. They are not economical in low valued crops (mustard).

Biomass residues (crop straw/waste) are also used for heating the crop environment, especially under windy conditions. Straw burning in windward creates a smoke layer over the crop surface and absorbs long wave radiation released by soil; thereby protect the mustard crop from frost by raising the ambient temperature. Mee and Bartholic, 1979 found that smoke particles are usually less than 1 µm in size, reflect visible radiation but are not permeable to long wave radiation and so are effective in preventing rapid cooling of surface near ground.

3.12. **Air mixing**

Wind machine breaks up micro-scale boundary layers over plant surfaces, which improves sensible heat transfer from the air to the plants. However, wind machine is effective if inversions between 2.0 and 10 m height are
large areas in short times. Mix materials and as well as labor problems with covering 10 °C over unprotected crops. However, the method has increase the minimum temperature on the leaf surfaces by d

found that wind propeller system maintains safe a wind of more than about 2.5 m/s (8 km/h). Bates, 1972 attributes and grain yield over 0.1 H2SO4 and without 75 days after sowing significantly improved in yield adjective frost. Spray of 0.1 per cent of thiourea at 50 and under radiation frost conditions but less effective under 0 °C. Win chines are econ there is typically started when the r tem is needed each 4.0 to 5 in one large wind machine w 65 5 k wer ce at least 1.5 or greater os t ni Generally, wind direction was southerly. (Mc Martin 1974)

Distance from shelter (H*) | Years | Average |
--- | --- | --- |
| 1971 | 1972 | 1973 |
-12.5 | - | 41.5 | 33.3 | 37.4 |
-8.0 | 14.4 | 41.8 | 33.2 | 37.5 |
-4.5 | - | 43.0 | 34.0 | 38.9 |
-2.0 | 9.3 | 38.3 | 32.8 | 35.9 |
2.0 | 6.3 | 40.7 | 31.5 | 36.1 |
4.5 | 13.0 | 43.3 | 33.9 | 38.6 |
8.0 | - | 44.0 | 34.1 | 39.1 |
12.5 | 14.5 | 39.4 | 35.6 | 37.5 |

* Distance from barrier in barrier heights. Positive and negative indicate north and south sides of an east-west barrier, respectively. Prevailing wind direction was southerly. (Mc Martin et al., 1974)

at least 1.5 °C or greater on most frost nights. Generally, one large wind machine with a 65 to 75 kW power source is needed for each 4.0 to 4.5 ha. Wind machines are typically started when the air temperature reaches about 0 °C. Wind machines are not recommended when there is a wind of more than about 2.5 m/s (8 km/h). Bates, 1972 found that wind propeller system maintains safe temperature on frost nights but protection diminishes with distance from wind propeller.

3.13. Insulation

Application of foam insulation has been shown to increase the minimum temperature on the leaf surfaces by 10 °C over unprotected crops. However, the method has not been widely adopted by growers because of the cost of materials and as well as labor problems with covering large areas in short times. Mixing air and liquid materials in the right proportion to create many small bubbles is the secret to generate foam with low thermal conductivity. Siminovitch et al., 1972 covered the plants with nontoxic protein based foam material and found most effective under radiation frost conditions but less effective under adhesive frost. Spray of 0.1 per cent of thiourea at 50 and 75 days after sowing significantly improved in yield attributes and grain yield over 0.1 H2SO4 and without spray mustard crop under frosty conditions (Meena et al., 2012).

3.14. Shelter/bARRIER

Waggoner (1969) has demonstrated the importance of wind in water-stress relationships. Using wind barriers to decrease wind speed and potential evapotranspiration resulted an increase in yield and more efficient (though unchanged total) water use. Mc Martin et al., 1974 harvested spring wheat for 3 years from sample areas at regular intervals from 14 single-row shelterbelts in North Dakota. They found maximum yield at 5H. If the area occupied by the tree row was not included, the yield for the area 1H to 13H was the same as the check area. With favorable weather and absence of hot winds, the barrier influenced the yield of wheat due to modification of microclimate (Table 10). Reduction in winds in sheltered area decreased the evapotranspiration. Thereby soil/crop moisture status was improved, ultimately it contributed in grain yield. Yield data illustrate a possible trend lowest yielding positions were close to and far from the fence and highest yield at intermediate positions apparently was favorably influenced by modified microclimate of sheltered area due the barrier. Effect of barrier was observed on both sides but more beneficial effect was on the leeward side.

4. Conclusion

Based on the investigations of various research workers, it can be concluded that the adoption of cultural practices like seed priming with water and moringa water extract and ascorbate, timely sowing, mulching, additional light irrigation during post anthesis, foliar spray of 0.5 per cent KNO3 at 50 per cent flowering stage or 1.0 per cent KNO3 during anthesis, 2.5 mM of arginine, foliar spray of zinc can manage the adverse impact of terminal heat and moisture stress.

Air mixing, biomass residue burning/smoking in windward, light irrigation, spray of 0.1 per cent of thiourea and 0.1 H2SO4 at 50 and 75 days after sowing, spray of non-ice nucleation active (NINA) bacteria, avoid excess nitrogenous fertilizer and soil hoeing before frost, resistant variety, mulches and soil compaction can manage the crop losses due to frost damage.

References

Acevedo, E., Nachit, M. and Ortiz-Ferrara, G., 1991b, “Effects of heat stress on wheat and possible selection tools for use in breeding for tolerance”, In D.A Saunders, ed. Wheat for the nontraditional warm areas, 401-421, Mexico, DF, CIMMYT.

Acharya, S. N., Dueck, J. and Downey, R. K., 1983, “Selection and heritability studies on canola/rapeseed for low temperature germination”, Can. J. Plant Sci., 63, 377-384.

Aggarwal, P. K., 2008, “Impact of climate change on Indian agriculture: impacts, adaptation and mitigation”, Ind. J. Agric. Sci., 78, 911-919.

Asseng, S., Foster, I. A. N. and Turner, N. C., 2011, “The impact of temperature variability on wheat yields”, Glob. Change Biol., 17, 997-1012.
Awal, M. A. and Sultana, F., 2011, “Microclimatic Alteration and Productivity of Mustard Crop as Induced by Indigenous Mulches”, *Int. J. Agric. Res.*, 6, 819-829.

Bates, 1972, “Temperature inversion and frost protection by wind machine”, *Agric. Meteorol.*, 9, 335-346.

Boomiraja, K., Chakrabartia, B., Aggarwal, P. K., Choudharya, R. and Chandler, S., 2010, “Assessing the vulnerability of Indian mustard to climate change Agriculture”, *Ecosystems and Environ.*, 138, 265-273.

Bridley, S. F. R., Taylor, R. J. and Webber, R. T. J. 1965, “The effects of irrigation and productivity on nocturnal air temperatures in Vineyards”, *Agric. Meteorol.*, 2, 373-383.

Cary, 1974, “An energy conserving system for orchard cold protection”, *Agric. Meteorol.*, 143, 339-348.

Chakraborty, D., Garg, R. N. and Tomar, R. K., 2010, “Synthetic and organic mulching and nitrogen effect on winter wheat (Triticum aestivum L.) in a semi-arid environment”, *Agric Water Management*, 97, 738-748.

Chakraborty, D., Nagarajan, S. and Aggarwal, P., 2008, “Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment”, *Agric Water Management*, 95, 1323-1334.

Das, S. and Sarkar, A. K., 1981, “Effect of post-flowering foliar spray of potassium nitrate solution on grain filling and yield of rice and wheat”, *Indian Agric.*, 25, 267-273.

Deloche, J. C., 1980, “Environmental effect on seed development and seed polarity”, *Hort. Science*, 15, 775-779.

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., Kirilenko, A., Morton, J., Soussana, J. F., Schmidhuber, J. and Tubiolo, F. N., 2007, “Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability”, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change”, Parry ML, Canziani OF, Palutikof JP, van der Linden, P.J., Hanon, C.E. (Eds.), “Climate Change - Impacts”, *Plant Soil Environ.*, 54, 7, 313-319.

Huang, and water use efficiency and yield of winter wheat under deficit irrigation in North China”, *Plant Soil Environ.*, 54, 7, 313-319.

Gutta, M. J., Ahmad, R., Stark, J. C. and Souza, E., 2000, “End-use quality of six hard red spring wheat cultivars at different irrigation levels”, *Crop Sci.*, 40, 631-635.

Hang, H., Li, Z., Ning, T., Zhang, X., Shan, Y. and Bai, M., 2008, “Radiation use efficiency and yield of winter wheat under deficit irrigation in North China”, *Plant Soil Environ.*, 54, 7, 313-319.

Harding, S. A., Guikema, J. A. and Paulsen, G. M., 1990, “Photosynthetic decline from high temperature stress during maturation of wheat - Interaction with senescence processes”, *Plant Physiol.*, 92, 648-653.

Hobbs, P. R., 1985, “Agronomic practices and problems of wheat following cotton and rice”, In: Wheat for More Tropical Environments, R L Villereal and A. R. Klett (eds.), International Symposium, Mexico, D F: CIMMYT., 273-277.

Hozayan, M., Monem, A. and Abdel, A., 2011, “Alleviation of the potential impact of climate change on wheat productivity using arginine under irrigated Egyptian agriculture”, In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on 6-8 February, 2011, p305.

Hsiao, T. C., 1973, “Plant responses to water stress”, *Annu. Rev. Plant Physiol.*, 24, 519-570.

Huang, Y., Chen, L. and Fu, B., 2005, “The wheat yields and water use efficiency in the Loess Plateau: straw mulch and irrigation effects”, *Agric Water Management*, 72, 209-222.

IPCC, 2007, In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanon, C.E. (Eds.), “Climate Change - Impacts”, Adaptation and Vulnerability Technical Summary of Working Group II to Fourth Assessment Report of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 23-78.

Ji, S. and Unger, P. W., 2001, “Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions”, *Soil Sci. Soc. Am. J.*, 65, 442-448.

Keati, J. D. H. and Cooper, P. J. M., 1998, “Kabuli chickpea as winter – sown crop in northern Syria: moisture relations and crop productivity”, *J. Agr Sci (Cambridge)*, 100, 667-680.

KILIÇ, H. and Tacettin YAĞBASANLAR, 2010, “The Effect of Drought Stress on Grain Yield, Yield Components and some Quality Traits of Durum Wheat (Triticum turgidum ssp. durum) Cultivars”, *Notulae Botanicae Horti AgrobotaniciCluj-Napoca*, 38, 1, 164-170.
Kılıç, H., Özberk, İ. and Özbek, F., 1999, “Bazı makamlık bugünkü çeşitliinin sıkç ve kuşağa toplarınının belirlenmesi”, GAP T. Arım Kongresi 26-28 Mayis 1999 Şanlıurfa.

Kumar, A., 2005, “Rapeseed-mustard in India: current status and future prospects”, In: Winter School on Advances in Rapeseed-Mustard Research Technology for Sustainable Production of Oilsseeds, National Centre on Rapeseed-Mustard, Sewar, Bharatpur, December 15 to January 04, 2005, 278-288.

Mall, R. K., Lal, M., Bhatia, V. S., Rathore, L. S. and Singh, R., 2004, “Mitigating climate change impact on soybean productivity in India: a simulation study”, Agric. Forest Meteorol., 121, 113-125.

Miroslav Trnka, M. M. Reimund P. Rötter, Margarita Ruiz-Ramos, Kurt Christian Kersebaum, Jürgen E. Olesen, Zdeněk Žalud and Mikhail A. Semenov, 2014, “Adverse weather conditions for European wheat production will become more frequent with climate change”, Nature Climate Change, 4,637-643.

McMartin, W., Frank, A. B. and Robert, H. H., 1974, “Economics of shelterbelt influence on wheat yields in North Dakota”, J. Soil Conser., 29, 237-291.

Mee, T. R. and Bartholic, J. R., 1979, “Manmade fog. Modification of the marine, F., Abdul, W. and Dong, J., 2011, “Seed priming as an effective tool for improving wheat performance in changing climates”, In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on February 6-8, 2011, p306.

Muhammad, A. K., Sadegh, S., Esmat, F. and Mohammad, M. R., 2014, “Effect of water stress on oil yield and some characteristics of brassica napa”, Int. Res. J. App. and Basic Sci., 8, 1447-1453.

Morrison, M. J. and Stewart, D. W., 2002, “Heat stress during flowering in summer Brassica”, Crop Sci., 42, 3, 797-803.

Oksanen, E., Freiwald, V. and Prozherina, N., 2005, “Photosynthesis of birch (Betula pendula) is sensitive to springtime frost and ozone”, Can. J. For. Res., 35, 703-712.

Paknejad, F., M., Nasri, H. R., Tohidi Moghadam, Zahedi, H. and Alahmadi, M. J., 2007, “Effect of drought stress on chlorophyll fluorescence parameters, chlorophyll content and grain yield of cultivars”, J. Bio. Sci., 7, 6, 841-847.

Pandey, P. K., Maranville, J. W. and Admou, A., 2001, “Tropical wheat response to irrigation and nitrogen in a Sahelian environment - Grain yield, yield components and water use efficiency”, Europ. J. Agron., 15, 93-105.

Parry, M. L., Rosenzweig, C., Iglesias, Livermore, A. M. and Fischer, G., 2004, “Effects of climate change on global food production under SRES emission and socioeconomic scenarios”, Global Environ. Change, 14, 53-67.

Poma, I., Venezia, G. and Grstina, L., 1999, “Canola (Brassica napus L. var Oleifera D. C.) eco-physiological and agronomical aspects as affected by soil water availability”, Proceedings of the 10th International Canola Congress, Canberra, Australia, p8.

Porter, J. R. and Gawith, M., 1999, “Temperatures and the growth and development of wheat: a review”, Eur. J. Agron., 10, 23-36.

Porter, J. R. and Semenov, M. A., 2005, “Crop responses to climatic variation”, Philos. Trans. R. Soc. Lond. B Biol. Sci., 360, 2021-2035.

Prasad, P. V. V., Cruafuld, P. O. and Smmerfield, R. J., 1999, “Fruit number in relation to pollen production and in groundnut exposed to short episodes to heat stress”, Ann. Bot., 84, 381-386.

Rawson, H. M., 1992, “Plant responses to temperature under conditions of elevated CO2”, Adv. J. Agric. Univ., 40, 473-490.

Rong-hua, L. I., Pei-guo, Baum, M., Grando, S. and Ceccarelli, S., 2006, “Evaluation of chlorophyll content and fluorescence parameters as indicators of drought tolerance in barley”, Agriculture science in China, 5, 10, 751-757.

Ruiz-Ramos, M., Sánchez, E., Gallardo, C. and Minguex, M. I., 2011, “Impacts of projected maximum temperature extremes for C21 by an ensemble of regional climate models on cereal cropping systems in the Iberian Peninsula”, Nat. Hazards Earth Syst. Sci., 11, 3275-3291.

Samra, J. S. and Singh, K., 1987, “Effect of sowing dates, nitrogen levels and seed rate on growth and yield of triticale”, J. Res. Punjab Agric. Univ., 24, 536-540.

Sandhu, I. S., Hundal, S. S. and Kumar, K., 1993, “Effect of sowing dates on performance of wheat varieties under rainfed conditions of Kandi region”, J. Res. Punjab Agric. Univ., 30, 135-141.

Sandhu, I. S., Sharma, A. R. and Sur, H. S., 1999, “Yield performance and heat unit requirement of wheat (Triticum aestivum) varieties as affected by sowing dates under rainfed conditions”, Indian J. Agric. Sci., 69, 175-179.

Saseendran, S. A., Singh, K. K., Rathore, L. S., Singh, S. V. and Sinha, S. K., 2000, “Effects of climate change on rice production in the tropical humid climate of Kerala, India”, Climatic Change, 44, 495-514.

Shahramlack, Ghooshch, F. and Tohidiogaddam, H., 2011, “Effect of zinc spraying on yield and yield components of wheat under drought stress conditions”, In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on February 6-8, 2011, p307.

Sharma, K. D. and Kumar, A., 2009, “Physiological and management approaches to mitigate terminal heat stress in Wheat”, J. Agrometeorology, 11 (special issue), 57-60.

Sharma, K. D. and Kumar, A., 2009, “Physiological processes associated with grain yield of wheat under restricted soil moisture”, Indian J. Plant Physiol., 14, 55-59.

Sharma, K. D. and Kumar, A., 2010, “Genotypic variation for agro-physiological traits and their utilization as screening indices for drought tolerance in wheat”, Indian J. Genet., 70, 1, 1-5.
Sharma, K. D., Pannu, R. K., Tyagi, P. K., Chaudhry, B. D. and Singh, D. P., 2003, “Effect of moisture stress on plant water relations and yield of different wheat genotypes”, Indian J. Plant Physiol., 8, 1, 99-102.

Sharma, K. D., Sheokand, S. and Sawhney, V., 2008, “Antioxidant in wheat having stay green character under terminal stress”, J. Plant Biol., 35, 59-64.

Sharma, K. K. and Chakor, I. S., 1989, “Performance of wheat genotypes as influenced by dates of planting and mulching”, Indian J. Agron., 34, 1-3.

Siddique M. R. B., Hamid, A. and Islam, M. S., 2000, “Drought stress effects on water relations of wheat”, Bot. Bull. Acad. Sin., 41, 35-39.

Shahramlack, Ghoshch Farshad, Tohidimoghadam Hamidreza, et al., 2011, “Effect of zinc spraying on yield and yield components of wheat under drought stress conditions”, In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, on February 6-8, 2011, p307.

Siminovitch, D. B., Rheuma, L., Liyall, H. and Butler, 1972, “Foam for frost protection of crops”, Agriculture Canada Publ., 1490, p24.

Sinclair, T. R. and Jamieson, P. D., 2006, “Grain number, wheat yield, and bottling beer: An analysis”, Field Crop Res., 98, 60-67.

Singh, D., 2010, “Studies to moderate the heat stress effects on wheat (Triticum aestivum L.) productivity”, M.Sc. Thesis, Punjab Agricultural University, Ludhiana.

Singh, A., Singh, D. and Gill, B. S., 2011, “Planting time, methods, and practices to reduce the deleterious effects of high temperature on wheat”, In the Proceedings of International Conference on Preparing Agriculture for Climate Change, Punjab Agricultural University, Ludhiana, February 6-8, 2011, p338-339.

Singh, M., Rathore, S. S. and Raja, P., 2014, “Physiological and Stress Studies of Different Rapeseed-Mustard Genotypes Under Terminal Heat Stress”, Int. J. Gen. Engg. Biotech., 5, 2, 133-142.

Singh, V. V., Rai, P. K., Siddiqui, S. A., Verma V. and Yadav, R., 2011, “Genetic variability and relative drought tolerance in inter specific progenies of Brassica juncea”, Agric. Biol. J. N. Am., 2, 1, 34-41.

Smika, D. E. and Unger, P. W., 1986, “Effect of surface residues on soil water storage”, Adv. Soil Sci., 5, 111-138.

Snyder, R. L. and de Melo-Abreu, J. P., 2005, “Protection: fundamentals, practice and economics”, 17-39.

Steven, E., Lindow, Deane, Arny, C. and Christen, D. Upper, 1982, “Bacterial Ice Nucleation: A Factor in Frost Injury to Plants”, Plant Physiol., 70, 4, 1084-1089.

Stone, P., Savin, R., Wardlaw, I. and Nicolas, M., 1995, “The Influence of Recovery Temperature on the effects of a Brief Heat Shock on Wheat. I. Grain Growth”, Funct. Plant Biol., 22, 945-954.

Tashiro, T. and Wardlaw, I. F. A., 1989, “Comparison of the Effect of High Temperature on Grain Development in Wheat and Rice”, Ann. Bot.-London, 64, 59-65.

Telfer, P., Edwards, J., Bennett, D. and Kuchel, H., 2013, “Managing heat stress in wheat”, Australian Grain Technologies (AGT), Roseworthy Campus, S.A.

Tubielo, F. N., Soussana, J. F. and Howden, S. M., 2007, “Crop and pasture response to climate change” PNAS, 104, 50, 19686-19690.

Verma, M. L. and Acharya, C. L., 2004, “Soil moisture conservation, hydrothermal regime, nitrogen uptake and yield of rainfed wheat as affected by soil management practices and nitrogen levels”, J. Indian Soc. Soil Sci., 52, 69-73.

Waggoner, P. E., 1969, “Environmental manipulation for higher yields”, In J. D. Eastin et al. (ed), Physiological aspects of crop yields, Amer. SOC. Agron., Madison, Wis., 343-373.

Wang, Z., Li, S., Cecil Vera, L. and Sukhdev Malhi, S., 2005, “Effects of water deficit and supplemental irrigation on winter wheat growth, grain yield and quality, nutrient uptake, and residual mineral nitrogen in soil”, Soil Sci. Plant Analysis, 36, 11, 1405-1419.

Wardlaw, I. F. and Wrigley, C. W., 1994, “Heat tolerance in temperate cereals: an overview”, Aust. J. Plant Physiol., 21, 695-703.

Wardlaw, I. F., Sofield, I. and Cartwright, P. M., 1980, “Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperature”, Aust. J. Plant Physiol., 7, 387-400.

Wheeler, T. R., Hong, T. D., Ellis, R. H., Batt, G. R., Morrison, J. I. L. and Hadley, P., 1996b, “The duration and rate of grain growth, and harvest index, of wheat (Triticum aestivum L.) in response to temperature and carbon dioxide”, J. Exp. Bot., 47, 623-630.

Wheeler, T. R., Batt, G. R., Ellis, R. H., Morrison, J. I. L. and Hadley, P. 1996b, “Growth and yield of winter wheat (Triticum aestivum) crops in response to CO2 and temperature”, J. Agric. Sci., 127, 37-48.

Wolf, J., Evans, L. G., Semenov, M. A., Eckersten, H. and Iglesias, A., 1996, “Comparison of wheat simulation models under climate change. I. Model calibration and sensitivity analysis”, Clm. Res., 7, 253-270.

Zhao, C. Yi, Sheng, Yu and Yimam, Y., 2009 “Quantifying the impacts of soil water stress on the winter wheat growth in an arid region, Xinjiang”, J. Arid Land, 1, 1, 34-42.